Why a global carbon policy could have a dramatic impact on the pattern of the worldwide livestock production

By

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Introduction

Developing and transitional economies generate a substantial share of greenhouse gas emissions and recently overtook developed country emissions to become the source of the majority of observed anthropogenic emissions. Compared to developed countries, a disproportionate share of developing country emissions comes from agriculture and forestry activities. Similarly, significant low cost greenhouse gas abatement potential is estimated to be available in these sectors in developing countries. These considerations have clearly affected domestic and international climate change management policy proposals. For instance, recent U.S. greenhouse cap-and-trade proposals permit the use of large quantities of international abatement for containing the cost of achieving domestic emissions reduction objectives; and, international discussions strive for developing and transitional country abatement participation in order to achieve more aggressive climate objectives and to manage overall costs.

Developing countries understandably see opportunities for potential new revenue as suppliers of low-cost abatement. Livestock is one sector that could potentially contribute abatement, with livestock sectors responsible for over 35 percent of direct global non-CO_2 GHG emissions, not to mention having a significant role in deforestation carbon emissions. While abatement of direct GHG emissions associated with livestock production is not expected to be the largest sectoral abatement strategy, as a globalized food producing and competing land using sector, livestock GHG abatement is likely to have global implications. The size and distribution of which would be of interest to farmers, development planners, the private sector, multinationals, and non-governmental organizations. To date, there is a dearth of analysis on the impacts of climate policy on the global livestock industry. While there are livestock specific emissions and mitigation cost and supply estimates (e.g., USEPA, 2006a, 2006b; IPCC, 2007; Golub et al., 2009), there is a lack of analysis of the potential structural implications for the global industry as a whole.

This paper analyzes why global production might change, and then using illustrative climate policies, estimates and analyzes industry-wide changes within and across regions. We also analyze these changes in the context of the debate on "food miles". The next section discusses why a GHG abatement incentive might be perceived differently across regions and then considers actual regional livestock emissions and production differences. We then present a global economic modeling framework and conduct analysis in order to evaluate the potential structural implications for the global livestock industry.

Valuing livestock emissions

With the enforcement of new environmental regulations, governments, civil society and the private sector become concerned about the impact of these policies on the relationship between production and climate change. This is also true for the food sector, which accounts for 15% of global emissions (World Bank, 2008). While it is commonsensical to expect that GHG taxation or payment can help to achieve the desired level of emissions, the effect of a tax or payment will vary across countries and sectors. To further investigate this issue we concentrate on the impact of GHG taxation in the most greenhouse gas intensive food production systems – namely livestock commodities.

In this analysis we use the GTAP version 6 non-CO_2 greenhouse gas emissions database developed by USEPA and Purdue University's Global Trade Analysis Project[1], designed particularly for use in global economic models. This highly disaggregated information about emissions improves the modeling of emitting activities and emissions abatement strategies.

We aggregate the non-CO_2 greenhouse gas emissions data set to 19 regions and 29 sectors, wherein 15 sectors represent food categories. According to Rose and Lee (2009), one-quarter of global agriculture-related non-CO_2 emissions are generated by the ruminants sector.

How might a GHG tax be felt by livestock sectors? Hertel et al. (2009) develop the components that affect the realized power of a tax. Considering a tax associated with GHG emissions stemming from the use of inputs, the change in the ad valorem tax rate on input i in production of commodity j in region r depends on the change in the ordinary, ad valorem, tax, Δto_{ijr}, the change in the specific tax, $\Delta \tau_{ijr}$, and the change in the market price of the input in question: ΔPM_{ir}:

$$\Delta t_{ijr} = \Delta to_{ijr} + [\varphi_{ijr} / PM_{ir}] \cdot [\Delta \tau_{ijr} - (\tau_{ijr} / PM_{ir}) \cdot \Delta PM_{ir}]$$

1 See Rose and Lee (2009)

Assume for the time being that the ordinary tax does not change and the input is in perfectly elastic supply, so the price does not change. Then the change in the ad valorem tax depends on the change in the specific tax on the associated emissions, adjusted for the emissions intensity of the input, φ_{ijr}. The latter is total emissions from use of the input in production divided by the amount of input used. Dividing by the price of the input, PM_{ir}, is the emissions intensity in tonnes of emissions per dollar of input purchased, valued at market prices. Thus, the economic impact of an emissions tax will depend not only on the size of the tax, but also on the emissions intensity. The larger the intensity, the greater the impact of a given $/tonne tax.

Cross sectoral comparison

As shown above, when a carbon tax is imposed on a sector, the first-order determinant of its impact on that sector vs. another is the GHG emissions intensity, measured as MKgCO2e/$ output (MKgCO2e = Metric kilograms of carbon dioxide equivalent). Therefore, we list in Table 1 the emissions intensities for a range of sectors in the economy (A more disaggregated version of emissions intensities by sector and gas is available in the Appendix Table 1). As can be seen from Table 1, ruminant meat production has the highest intensity across all sectors, followed by coal and dairy farm production. Accordingly, we will focus here on ruminant meat production, with some discussion also of dairy and other meat production for the sake of contrast.

Table 1. Global emissions intensities by sector and gas (MKgCO2e/$)

Sector	Total	CO_2	N_2O	CH_4	FGAS
Ruminant	14.254	0.132	3.661	10.461	0
Coal	4.371	0.603	0.001	3.767	0
Dairy_Farms	3.165	0.099	0.987	2.079	0
Gas	2.516	1.18	0.004	1.332	0
Air_transp	2.042	1.97	0.064	0.008	0
Other_Agri	2.007	0.191	1.217	0.598	0
Manufactures	1.787	1.697	0.031	0.024	0.035
NonRuminant	1.691	0.155	1.067	0.469	0
Other_transp	1.407	1.19	0.032	0.186	0
Oil	1.247	0.618	0.001	0.627	0
Water_transp	1.155	1.125	0.024	0.005	0
Forestry	0.21	0.208	0.001	0.002	0
Other_Food	0.124	0.123	0.001	0	0
Services	0.098	0.061	0.003	0.03	0.004

Source: GTAP version 6 database

Emissions per dollar of livestock output can vary greatly across countries. Therefore, it is useful to decompose emissions intensity to understand the differences. Emissions intensity can differ due to differences in emissions per animal, or due to differences in the value of output per animal. The latter can differ due to differences in the value per unit physical output and physical output per animal:

$$\text{Value per animal}(\$/\text{animal}) = \text{value per unit output}(\$/\text{kg}) \times \text{output per animal}(\text{kg/animal})$$

Value per unit output is simply the regional market price. Output per animal is a recognized factor in GHG emissions inventory methods (IPCC, 2006), as well as the focus of some livestock GHG abatement technologies that seek to improve output per animal and thereby reduce emissions per unit output (e.g., USEPA, 2006b).

Physical emissions intensities

Estimates of GHG emissions per animal, based on GTAP output values and FAO livestock numbers for 2001 are reported in Table 2. To be able to aggregate the EPA raw emissions categories for heterogeneous animal types, we establish conversion factors, with cows being the common factor (1 cow = 1 animal unit). For instance, in the United States we find that approximately 8 goats generate the same amount of GHG emissions as 1 dairy cow, so goats are given a weight of 1/8th. The emissions intensities for animals vary across countries based on breed of cattle, feed rations and feed volume and more. India shows the lowest emissions rate at 0.8 MTCO2e/animal, and the EU shows the highest emissions intensity at 2.9 MTCO2e/animal.

It is useful to compare the aggregate estimates in Table 2 (based on national data) to other sources. For example, the US Environmental Protection Agency estimates that an adult cow in the U.S. produces 80-110 Kg of methane per year[2], which is the main non-CO_2 emission from ruminant livestock (recall Table 1). Compared to CO_2, methane has 21 times more power to warm the atmosphere[3] (global warming potential). Thus, if converted to CO_2 equivalent emissions, this yields 1.68-2.31 MTCO2e/animal of methane emissions. As we can see from Table 2, our GTAP based estimates for physical emissions intensities in the US (2.1 MTCO$_2$e/animal) are comfortably within this range.

Output value for livestock

Output value per animal is calculated by dividing the value of annual output at market prices in the GTAP version 6 data base by the FAO livestock numbers for 2001. These values are presented in the second block of columns in Table 2. Here we see much greater variation across countries than for the physical emissions intensities. Indeed, focusing on the dairy farm column, we seek annual output flows ranging from $26/animal

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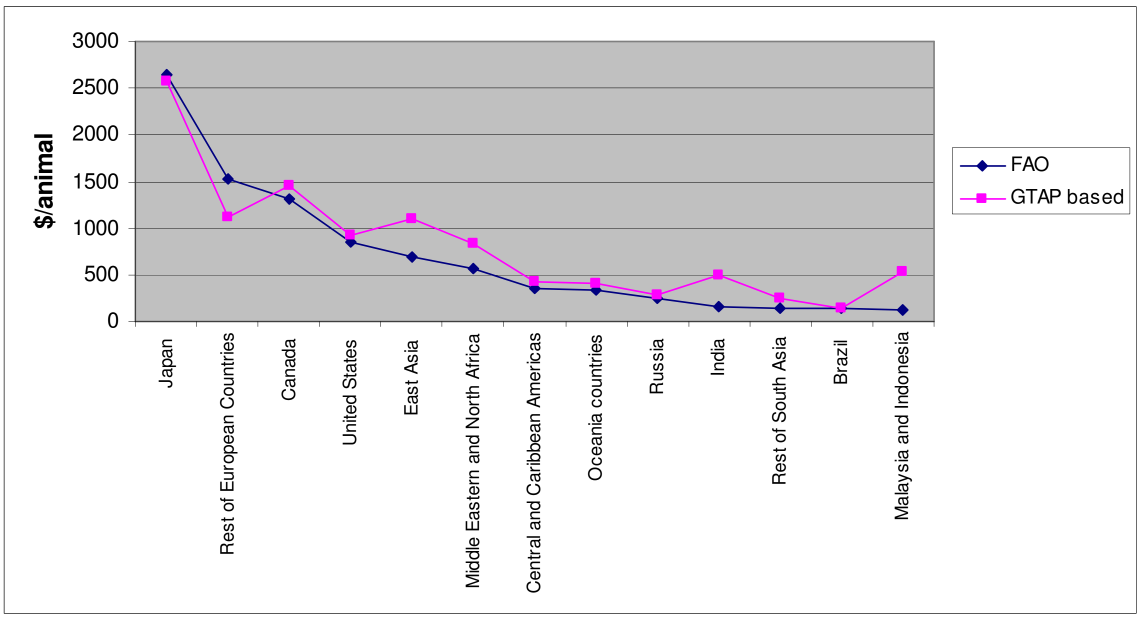
[2] http://www.epa.gov/rlep/faq.html#1
[3] http://www.epa.gov/methane/scientific.html

in Sub Sahara Africa to roughly $3,000/animal in Canada and Japan, and even higher in some of the residual regions. This naturally raises a question of measurement error. To what extent is this due to inconsistencies between the GTAP data base (which gives the value flow) and the FAO data base which provides the estimates of animal numbers? To answer this, we turn to Figure 1, which plots our GTAP-based estimates against those calculated based on FAO data on value of output by livestock industry, where available. As can be seen from the figure, the two show strong agreement. And where there are differences between the two, these do not seriously alter the ranking of intensities across regions.

Figure 1. FAO and GTAP based dairy values generated per animal, ($/animal)



Decomposition of emissions intensity

Having generated the two components of the emissions intensity per dollar of output, we are in a position to assess the relative contribution of each factor. Since the emissions intensity per dollar of output is simply the product of the two factors, it is useful to present these in log-linear form (Appendix - Table 2) to determine the effect of each factor on the total outcome:

$$\text{Emissions intensity(MTCO2e/animal)} \times \frac{1}{\text{Value of animal(\$/animal)}} = \text{Emissions intensity(MTCO2e/\$)}$$

or

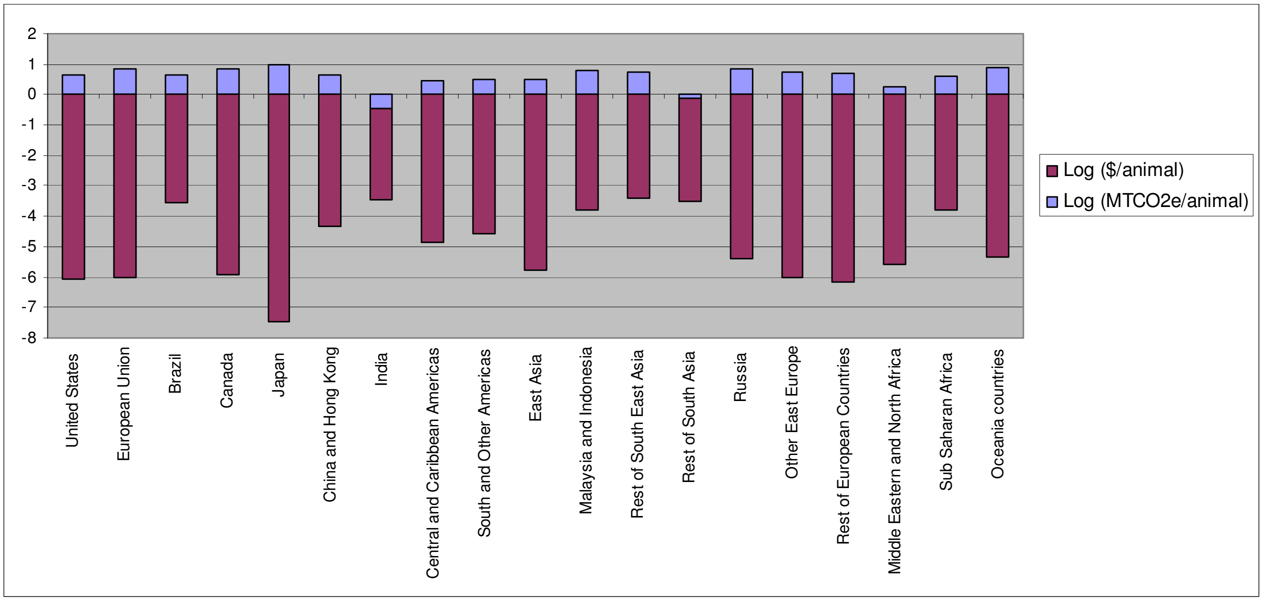
$$Log\,[\text{Em. intens.(MTCO2e/animal)}] + Log\,[\text{Value of animal(\$/animal)}]^{-1} = Log\,[\text{Em. intens.(MTCO2e/\$)}]$$

Table 2. Disaggregation of emissions intensities per dollar of output

Regions	Emissions intensity (MTCO$_2$e/animal)			Value of animals ($/animal)			Emissions intensity (MTCO$_2$e/$)		
	Dairy_Farms	Ruminant	NonRuminant	Dairy_Farms	Ruminant	NonRuminant	Dairy_Farms	Ruminant	NonRuminant
United States	2.1	1.9	3.3	920	436	2102	0.0023	0.0044	0.0016
European Union	2.9	2.3	2.9	1134	404	2408	0.0025	0.0058	0.0012
Brazil	1.8	1.9	2.4	140	34	507	0.0127	0.0547	0.0048
Canada	2.6	2.3	3.0	1451	372	3122	0.0018	0.0061	0.0010
Japan	2.7	2.6	2.7	2579	1743	2923	0.0010	0.0015	0.0009
China and Hong Kong	2.4	1.9	3.9	586	77	1997	0.0041	0.0243	0.0019
India	0.8	0.6	1.0	502	21	953	0.0017	0.0309	0.0011
Central and Caribbean Americas	1.5	1.6	2.2	434	126	2591	0.0034	0.0125	0.0008
South and Other Americas	2.1	1.7	2.4	489	96	981	0.0043	0.0174	0.0025
East Asia	1.9	1.6	6.7	1093	316	6202	0.0018	0.0051	0.0011
Malaysia and Indonesia	2.3	2.2	4.3	530	45	1478	0.0043	0.0494	0.0029
Rest of South East Asia	1.5	2.1	3.4	153	30	1476	0.0101	0.0688	0.0023
Rest of South Asia	1.2	0.9	3.0	255	30	739	0.0047	0.0301	0.0040
Russia	2.3	2.3	2.9	276	221	1668	0.0085	0.0105	0.0017
Other East Europe	2.3	2.1	3.2	803	418	7201	0.0028	0.0050	0.0004
Rest of European Countries	2.3	2.0	4.6	1127	468	10103	0.0020	0.0042	0.0005
Middle Eastern and North Africa	1.8	1.3	4.4	831	262	2790	0.0022	0.0049	0.0016
Sub Saharan Africa	1.2	1.8	3.4	26	44	489	0.0464	0.0413	0.0069
Oceania countries	2.3	2.4	2.5	413	211	1147	0.0055	0.0114	0.0021

Source: FAO and GTAP version 6 database

Figure 2. Contribution of two factors to emissions intensities per dollar of output



This decomposition is plotted in Figure 2 and shows that the effect of differences in the *value of output per animal* strongly dominates the contribution of the *physical emissions intensity*, in determining overall differences in emissions per $ of output. In summary, *the bulk of the variation in emissions intensities per dollar of output is due to differences in the value of output per animal produced by each animal in different regions.* More specifically, the lower the generated value of annual output per animal, the higher is the emissions intensity per dollar of output. Therefore, we expect that a global CO_2 tax will have larger negative effect on livestock output of countries with higher emissions intensities per dollar of output.

Analysis

We develop four GHG taxation scenarios to analyze the impact of a global carbon policy on the pattern of the worldwide livestock industry:

1. A global GHG tax of $27.3/MTCO2e (equivalent to $100/MTCe) on ruminants (scenario **RUMCO2TAX**). The highest emissions intensity is in the ruminants sector. Therefore, we choose ruminants for our main analysis.
2. A global GHG tax of $27.3/MTCO2e (equivalent to $100/MTCe) on non-ruminants (scenario **NRUMCO2TAX**).
3. A global GHG tax of $27.3/MTCO2e (equivalent to $100/MTCe) on dairy farms (scenario **DAFCO2TAX**).
4. A global GHG tax of $27.3/MTCO2e (equivalent to $100/MTCe) on all three livestock sectors, i.e. ruminants, non-ruminants, and dairy farms (scenario **LIVCO2TAX**).

Besides the carbon taxation scenarios, we develop two additional experiments to analyze the impact of changes in ruminant production and trade on both production and transportation emissions ("food miles debate"):

1. **EURUMINANTS** - Impose taxes on private consumption of both domestically produced and imported ruminants to shift domestic purchases in EU by some arbitrary number ($10 million in this case), and decrease import sourced consumption of ruminants in the region by the same amount.
2. **CHNRUMINANTS** - Impose taxes on private consumption of both domestically produced and imported ruminants to shift domestic purchases in China and Honk Kong by some arbitrary number ($10 million in this case), and decrease import sourced consumption of ruminants in the region by the same amount.

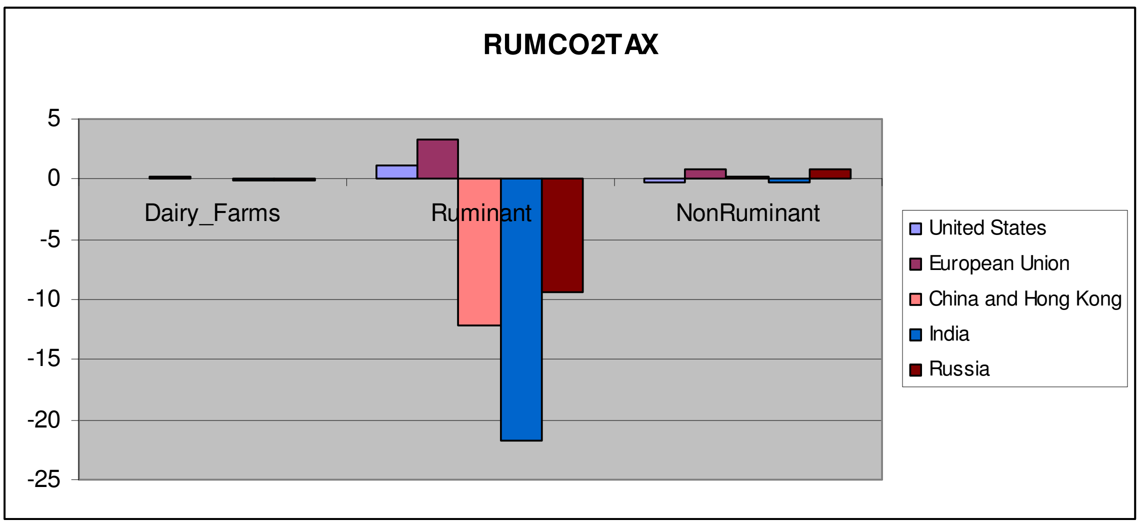
The results of additional scenarios are summarized in the Appendix.

Results

Scenario - RUMCO2TAX

Under **RUMCO2TAX**, the global CO_2 tax on ruminants reduced its output mainly in regions with higher emissions intensities (Figure 3). The largest decrease occurs in Rest of South East Asia region, which has the highest emissions intensity for ruminants per dollar of output (69.8 MKgCO2e/$) across all regions (Appendix - Table 3a). There is also reduction in the output of energy commodities in most regions, as anticipated.

Figure 3. Change in regional output, percent change



More detailed changes in the production as well as in the consumption of ruminants (scenario **RUMCO2TAX**) are presented in Table 4. As already mentioned, the highest reduction takes place in the ruminants sector in Rest of South East Asia (-42.3%) followed by Brazil (-28.5%) and Malaysia and Indonesia (-26.5%). This is due to high emission intestines per dollar of output in these regions: Rest of South East Asia (69.75 MKgCO2e/$), Brazil (54.05 MKgCO2e/$), and Malaysia-Indonesia (49.7 MKgCO2e/$).

Table 4. Change in ruminant production and consumption, percent change

Regions	Production of ruminants (qo)	Consumption of ruminants imported (qpm)	Consumption of ruminants domestic (qpd)
United States	1.1	-14.2	-5.5
European Union	3.4	-6.8	-4.5
Brazil	-28.5	272.5	-21.9
Canada	-1.6	-1.9	-11.0
Japan	6.9	-29.7	-1.5
China and Hong Kong	-12.1	61.9	-17.7
India	-21.7	75.8	-17.5
Central and Caribbean Americas	-8.2	28.4	-8.9
South and Other Americas	-7.7	25.0	-10.7
East Asia	2.6	-26.0	0.3
Malaysia and Indonesia	-26.5	233.0	-19.1
Rest of South East Asia	-42.9	391.4	-33.9
Rest of South Asia	-16.5	104.5	-11.6
Russia	-9.3	21.5	-6.6
Other East Europe	-2.4	-8.2	-2.9
Rest of European Countries	5.8	-15.8	-1.3
Middle Eastern and North Africa	-1.9	-3.6	-4.1
Sub Saharan Africa	-17.6	62.6	-14.9
Oceania countries	-1.1	0.6	-9.0

There are also changes in bilateral trade pattern due to a global CO_2 tax on ruminants. Table 4a in the Appendix reports changes in exports and imports of ruminants. We find that countries with higher emissions intensities per dollar of output reduce their exports of ruminants, while the ones with lower emissions intensities, such as the United States and European Union, increase their exports (and decrease their imports) to other countries and regions. Change in bilateral trade flows for all products combined is shown in Table 4b in the Appendix.

To further study the impacts of a global CO_2 tax on livestock we concentrate on changes in emissions, which are illustrated in Table 5. Under **RUMCO2TAX,** carbon dioxide, nitrous oxide and methane emissions decline globally, while F-gas emissions increase. There is also decrease in world emissions by -526,378,906 MTCO2e. The effect of this shock is negative in most regions, i.e. there is decline in overall emissions in almost every region with the least reduction occurring in Rest of European Countries. Such outcome can be explained by relatively low emissions intensity in the ruminants sector (3.91 MKgCO2e/$) in this region. Interestingly enough emissions increase in Japan, which is due to the lowest emissions intensity per dollar of output (1.47 MKgCO2e/$) in the ruminants sector across all regions.

Table 5. Change in emissions (MTCO2e)

Regions	RUMCO2TAX				
	CO_2	N_2O	CH_4	FGAS	Total
United States	337,121	-7,234,270	-9,938,062	-27,272	-16,862,484
European Union	227,715	-2,696,582	-3,095,354	-40,669	-5,604,890
Brazil	-1,334,188	-30,011,784	-82,463,409	49,359	-113,760,025
Canada	-25,166	-588,680	-1,504,009	-5,758	-2,123,614
Japan	245,665	248,848	25,320	-9,153	510,680
China and Hong Kong	-1,643,576	-11,598,234	-40,880,268	109,234	-54,012,844
India	-891,407	-2030254	-49,735,168	6,756	-52,650,074
Central and Caribbean Americas	-182,510	-1,734,371	-7,987,205	989	-9,903,096
South and Other Americas	64,021	-9,603,609	-19,148,676	5,542	-28,682,722
East Asia	-37,704	-183,911	-339529	-2,848	-563,992
Malaysia and Indonesia	-89,482	-2339097	-8,218,026	-262	-10,646,869
Rest of South East Asia	-170,165	-7,856,150	-24,350,304	501	-32,376,118
Rest of South Asia	-140928	-4451595	-16154060	247	-20,746,336
Russia	-1,491,558	-1,181,868	-3,541,779	2,773	-6,212,433
Other East Europe	-2,454,157	-1,632,608	-4,315,645	-7,057	-8,409,468
Rest of European Countries	-6,682	-48,906	-11,469	-4,234	-71,292
Middle Eastern and North Africa	-651,756	-2,072,429	-3,034,033	-3,763	-5,761,981
Sub Saharan Africa	1,791,661	-46,101,723	-105,498,627	82,537	-149,726,151
Oceania countries	-573,799	-1,538,966	-6,649,477	-12,942	-8,775,185
Total	-7,026,896	-132,656,189	-386,839,783	143,979	**-526,378,906**

In most countries emissions decrease, some much more than others, yet we also see some increases. Overall, this is due to varying emissions intensities in different countries and changes in output, affected by growing market prices of livestock globally.

The change in bilateral trade pattern both directly and indirectly affects the use of transport (domestic and international), and, therefore, emissions from transportation.

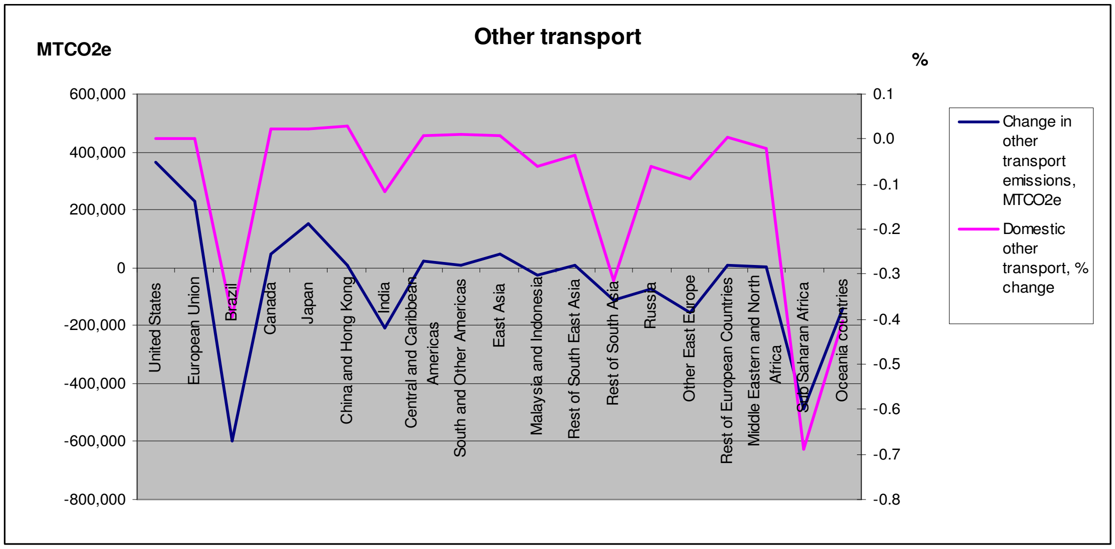
As illustrated in Table 6, emissions associated with transport decrease under **RUMCO2TAX**.

Table 6. Change in transportation emissions (MTCO2e)

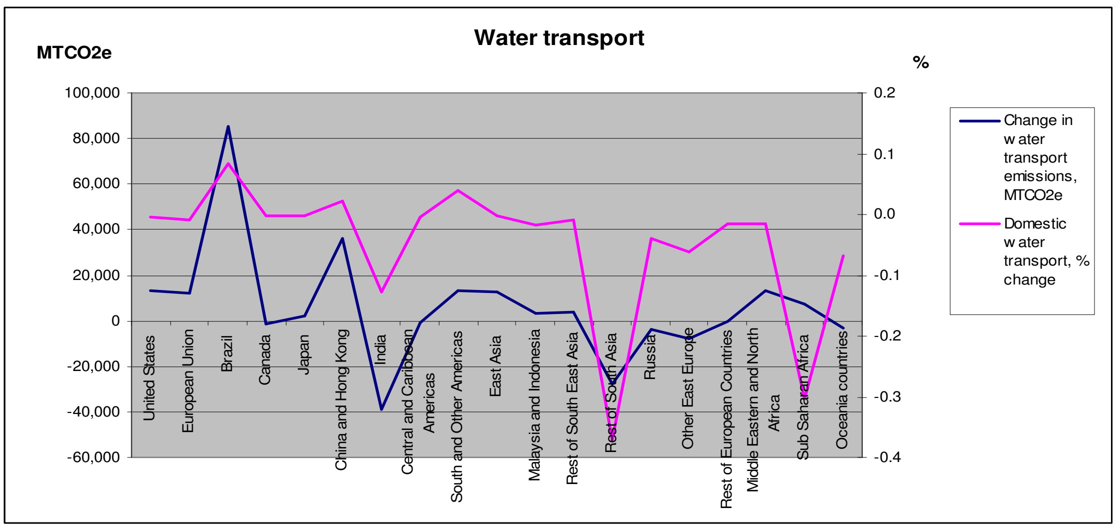
Regions	RUMCO2TAX			
	Other	Water	Air	Total
United States	365,690	13,198	449,071	827,959
European Union	228,578	12,044	-3,953	236,669
Brazil	-598,726	85,224	-31,188	-544,690
Canada	48,571	-1,461	2,384	49,494
Japan	151,478	2,196	-218	153,456
China and Hong Kong	10,318	36,127	44,160	90,605
India	-207,933	-39,068	-9,831	-256,832
Central and Caribbean Americas	22,080	-757	7,811	29,134
South and Other Americas	7,180	13,403	49,098	69,681
East Asia	45,032	12,882	5,468	63,382
Malaysia and Indonesia	-25,280	3,574	-796	-22,502
Rest of South East Asia	7,150	3,986	17,607	28,743
Rest of South Asia	-111,239	-27,924	37,107	-102,056
Russia	-74,570	-3,531	-7,125	-85,226
Other East Europe	-154,673	-8,079	7,891	-154,861
Rest of European Countries	7,407	-452	816	7,771
Middle Eastern and North Africa	3,108	13,299	12,114	28,521
Sub Saharan Africa	-485,322	7,423	29,224	-448,675
Oceania countries	-139,660	-3,110	24,610	-118,160
Total	-900,811	118,973	634,250	**-147,588**

The analysis reveals that the changes in transport emissions are associated mainly with changes in domestic transport use. This is due to the trade pattern of ruminants, i.e. ruminants are traded more locally than internationally. Thus, the effect of a global CO_2 tax on ruminants will be more significant on local transportation, which, in this case, is the main driving force for changes in transportation emissions (Figure 4a-c). For illustration purposes we depict percent change in domestic transportation for different transport modes on the secondary vertical axis in Figure 4a-c.

Figure 4a-c. Change in transportation emissions



(a)



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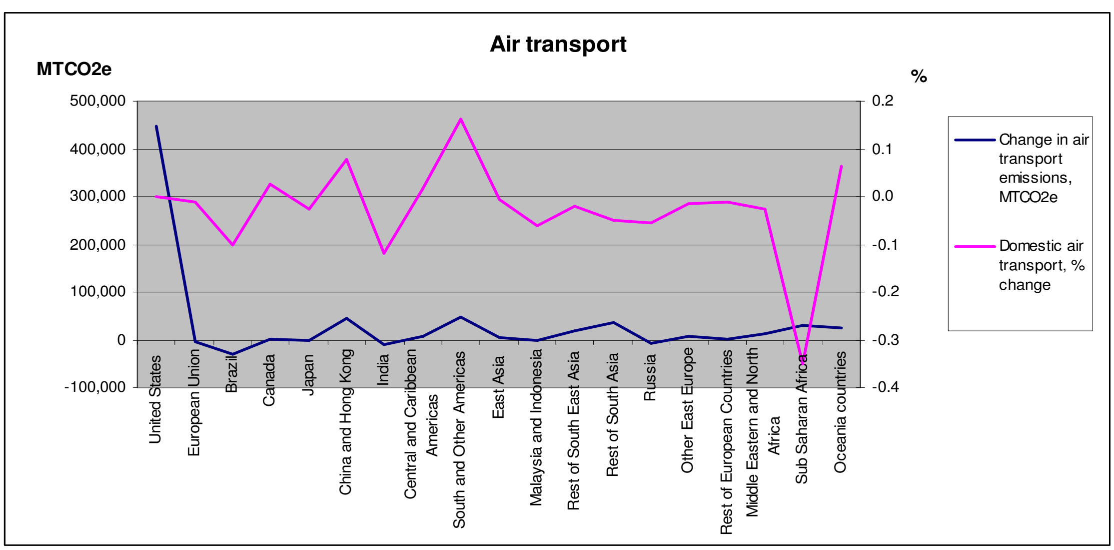


(c)

From Table 7 we see that wealthier countries tend to have lower emissions intensities due primarily to higher output per animal and higher value per unit output, which implies a higher abatement cost and explains the relatively small reduction in their emissions.

Table 7. Emissions intensities (MKgCO2e/$) and changes in global emissions (MTCO2e and percent)

Regions	Emissions intensity, MKgCO2e/$					Change in emissions	
	Ruminants	Rum. Prod.	Other trans.	Water trans.	Air trans.	MTCO2e	Percent
United States	4.45	0.08	0.04	1.66	0.85	-16,862,484	-0.24
European Union	5.74	0.07	0.05	0.91	1.17	-5,604,890	-0.12
Brazil	54.05	0.04	0.04	3.68	3.63	-113,760,025	-14.50
Canada	6.06	0.02	0.02	1.36	0.79	-2,123,614	-0.31
Japan	1.47	0.01	0.03	0.57	0.35	510,680	0.05
China and Hong Kong	24.63	0.17	0.07	1.06	1.78	-54,012,844	-1.24
India	31.04	0.22	0.09	1.83	1.89	-52,650,074	-3.50
Central and Caribbean Americas	12.75	0.03	0.02	1.54	1	-9,903,096	-1.18
South and Other Americas	17.91	0.04	0.02	1.97	0.98	-28,682,722	-3.06
East Asia	5.15	0.03	0.07	1.78	1.69	-563,992	-0.07
Malaysia and Indonesia	49.72	0.08	0.03	5.05	2.56	-10,646,869	-1.64
Rest of South East Asia	69.75	0.14	0.08	1.97	1.43	-32,376,118	-4.70
Rest of South Asia	30.32	0.07	0.03	1.7	1.13	-20,746,336	-5.07
Russia	10.44	0.17	0.13	6.75	3.4	-6,212,433	-0.33
Other East Europe	4.95	0.09	0.08	2.85	0.83	-8,409,468	-0.54
Rest of European Countries	3.91	0.03	0.03	0.62	0.35	-71,292	-0.06
Middle Eastern and North Africa	5.28	0.12	0.14	2.52	2.38	-5,761,981	-0.29
Sub Saharan Africa	41.82	0.02	0.01	2.66	2.19	149,726,151	-10.84
Oceania countries	11.42	0.06	0.07	1.28	0.54	-8,775,185	-1.40
Total						**-526,378,906**	**-1.63**

Scenarios – EURUMINANTS and CHNRUMINANTS

Given the variations in emissions intensities, it is useful also to analyze the impact of changes in livestock production and trade on emissions. In this context we develop two additional scenarios, which impose a tax on private consumption of both domestically and import sourced ruminants first in a developed region such as the European Union (Scenario **EURUMINANTS**), and then in a developing region such as China and Honk

Kong (Scenario **CHNRUMINANTS**). In particular, we increase the consumption of domestically produced ruminants and decrease the imported consumption by the same amount, without changing total consumption of ruminants in a particular region. We further test whether global emissions decrease because of reduced production in regions with higher emissions intensities or lower international transport activity. This has been known as "food miles debate", and is extensively analyzed in Avetisyan et. al (2010). They focus on emissions-trade tradeoff and test whether the substitution of domestic for imported ruminant products decreases consumption related direct and indirect GHG emissions. Avetisyan et al. conclude that increased consumption of domestically sourced ruminant products reduces global emissions mainly due to increased production in regions with relatively lower emissions intensities in the ruminant products sector and not because of lower transport requirements.

In scenario **EURUMINANTS**, we impose a tax on private consumption of ruminants in the European Union, which increases its domestically produced consumption by 10 US$ million, while reducing the import sourced consumption by the same amount. Similar to **RUMCO2TAX** global emissions decrease. We see from Table 8 that both total (-12,969 MTCO2e) and transportation (-1,183 MTCO2e) emissions decrease but the contribution of transportation emissions to global pollution abatement is almost 10 times less than that of production. As Avetisyan et al. state, the substitution of domestic for imported food decreases global GHG emissions mainly due to changes in production patterns and not because of lower transport requirements.

Table 8. Change in total and transportation emissions (MTCO2e)

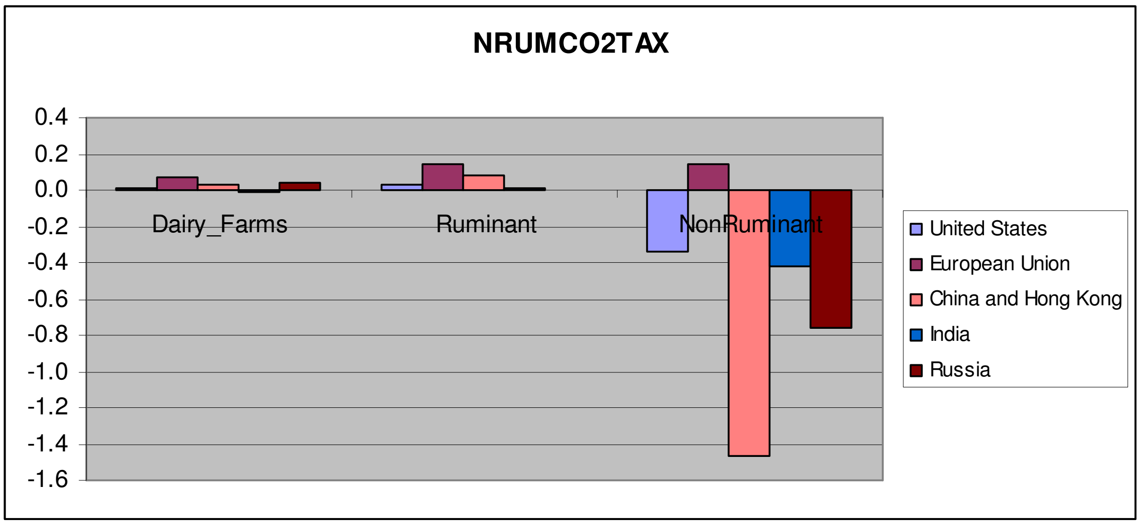
Regions	RUMCO2TAX		EURUMINANTS		CHNRUMINANTS	
	Total emissions	Transport emissions	Total emissions	Transport emissions	Total emissions	Transport emissions
United States	-16,862,484	827,959	-3,174	8	-1,880	153
European Union	-5,604,890	236,669	27,588	-726	-4,406	0
Brazil	-113,760,025	-544,690	-1,428	1	-1,106	-11
Canada	-2,123,614	49,494	-359	-78	-802	3
Japan	510,680	153,456	-145	-8	-305	-27
China and Hong Kong	-54,012,844	90,605	-4,596	24	238,870	-292
India	-52,650,074	-256,832	-840	-4	187	1
Central and Caribbean Americas	-9,903,096	29,134	-333	0	-449	-12
South and Other Americas	-28,682,722	69,681	-2,719	0	-4,190	-1
East Asia	-563,992	63,382	-253	-137	-542	-61
Malaysia and Indonesia	-10,646,869	-22,502	-297	-10	-569	-14
Rest of South East Asia	-32,376,118	28,743	-903	-89	-1,176	-60
Rest of South Asia	-20,746,336	-102,056	-223	0	-128	-5
Russia	-6,212,433	-85,226	-239	-130	-116	-35
Other East Europe	-8,409,468	-154,861	-512	-129	-434	-109
Rest of European Countries	-71,292	7,771	-220	-14	-41	-4
Middle Eastern and North Africa	-5,761,981	28,521	-2,150	34	-800	-7
Sub Saharan Africa	-149,726,151	-448,675	-5,566	4	-3,410	3
Oceania countries	-8,775,185	-118,160	-16,600	70	-65,122	258
Total	**-526,378,906**	**-147,588**	**-12,969**	**-1,183**	**153,580**	**-219**

In scenario **CHNRUMINANTS** we impose a similar tax on private consumption of ruminants in China and Honk Kong. We find that despite the decrease in transport emissions (-219 MTCO2e), total emissions rise by 153,580 MTCO2e. This due to increasing domestically sourced consumption in a region with relatively higher emissions intensities. Emissions intensity in the ruminants sector in China and Honk Kong is 24.63 MKgCO2e/$, whereas in the European Union it is only 5.74 MKgCO2e/$. Therefore, the results are very different compared to those in **RUMCO2TAX** and **EURUMINANTS**. We conclude that due to variations in emissions intensities in the ruminants sector across countries it is better to use a global GHG tax on ruminants instead of taxing private consumption in individual regions (leading to different results) to achieve reduction in global emissions.

Scenario - NRUMCO2TAX

As expected, the output of non-ruminants decreases in almost all regions under scenario **NRUMCO2TAX**. The largest reduction happens in Brazil, which has relatively high emissions intensity (4.74 MKgCO2e/$). China's non-ruminants sector is also relatively emission intensive (1.96 MKgCO2e/$), thus the largest output reduction across five regions in Figure 5 occurs in China (also Appendix – Table 3b).

Figure 5. Change in regional output (NRUMCO2TAX), percent change



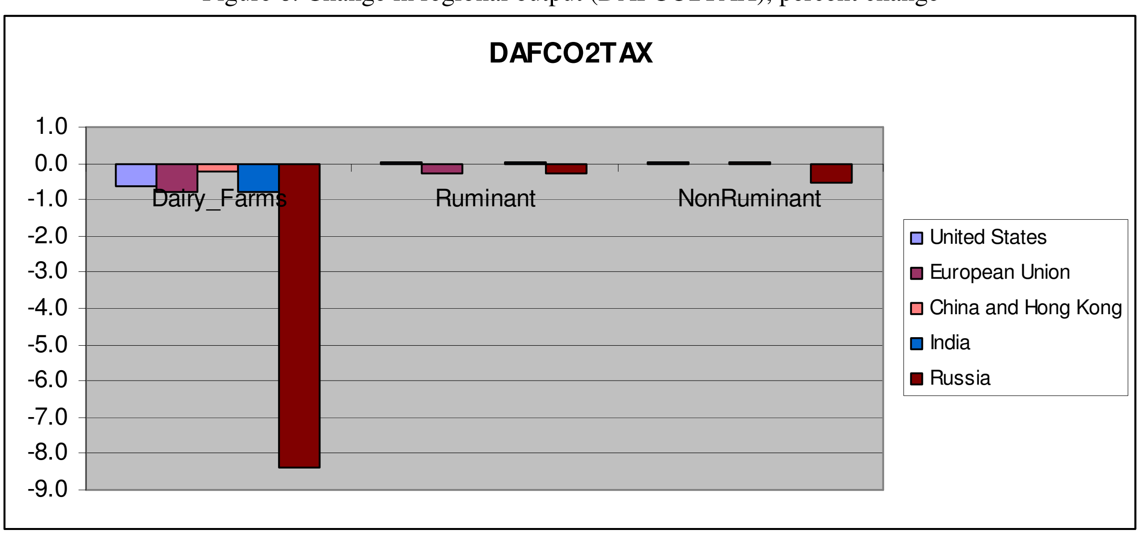
Since non-ruminants are less emissions intensive, the same CO_2 tax on this sector (**NRUMCO2TAX**) yields less reduction in global emissions (-123,909,775 MTCO2e) compared to that in scenario **RUMCO2TAX** (-526,378,906 MTCO2e). The highest reduction, related more to nitrogen oxide emissions, i.e. fertilizer use, takes place in China and Hong Kong region (-30,368,105 MTCO2e), while the least pollution abatement occurs in Rest of European Countries (-60,536 MTCO2e). It follows almost the same pattern as the change in output, as expected (Appendix – Table 5a). The United States and European Union have similar emissions intensities in non-ruminants sector, and, therefore, experience similar reductions in emissions.

It is interesting that under **NRUMCO2TAX** the only region that experiences reduction in transportation emissions is Brazil (Appendix – Table 6a). This is mostly because of relatively high emissions intensity (4.74 MKgCO2e/$) for non-ruminants in that country, where its output faces the highest reduction (-7.8%) across other regions. Consequently, Brazil decreases its production and exports of non-ruminants, and, therefore, generates less pollution in the transportation sector. The United States, European Union and China have comparable emissions intensities per dollar of non-ruminant output, and, thus, have similar changes in transportation emissions.

Scenario - DAFCO2TAX

A global CO_2 tax on dairy farms negatively affects its output in the majority of regions. We can see that in Figure 6 the output of dairy farms is reduced in all five regions and the largest reduction takes place in Russia (-8.38%). Again, the reason is the relatively high emissions intensity in its dairy farms sector. The results are also summarized in Table 3c in the Appendix.

Figure 6. Change in regional output (DAFCO2TAX), percent change



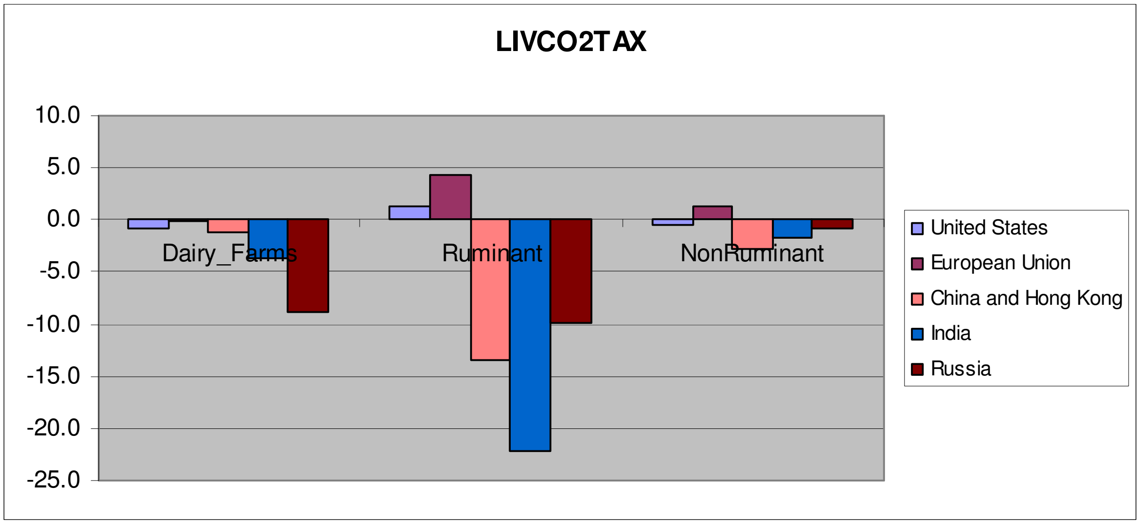
Scenario **DAFCO2TAX** generates very small reduction in global emissions compared to all other scenarios (-64,751,907 MTCO2e). There are two main reasons for such outcome. First, dairy farms (similar to non-ruminants) are less emissions intensive than ruminants. Second, the bilateral trade pattern of dairy cattle is very different, i.e. its export levels are very small (184 million US$) compared to that of ruminants (9,032 million US$) and non-ruminants (15,517 million US$). From Table 5b in the Appendix we see that the highest reduction in emissions occurs in European Union (-12,088,757 MTCO2e) and Other East Europe (-10,553,330 MTCO2e), which have the largest exports of dairy farms across all regions (47 million US$) and (49 million US$), respectively.

Similar to **RUMCO2TAX**, the domestic transportation component is the main factor affecting transportation emissions under scenario **DAFCO2TAX**. The bilateral trade volumes of dairy cattle (184 million US$) are even lower than that of ruminants (9032 million US$), and, therefore, mainly the local transport is being affected. We can see from Table 6b in the Appendix that the highest reduction in transportation emissions occurs in Other Eastern Europe region (-279,226 MTCO2e), which is represented by the Commonwealth of Independent States (CIS), where bilateral trade is based mostly on ground transportation (other transport in our model).

Scenario - LIVCO2TAX

The changes in the ruminants sector under scenario **LIVCO2TAX** are similar to those happening in scenario **RUMCO2TAX** (Figure 7). Again, the largest percentage output reduction (-42.7%) happens in Rest of South East Asia region, which has the highest emissions rate for ruminants per dollar of output (69.8 MKgCO2e/$) across all regions. Due to higher emissions intensity in ruminants the effect of the CO_2 tax is more significant in the ruminants sector (Appendix – Table 3d). There is significant increase in the output of forestry due to substitution effect, i.e. land available for livestock is now used to expand the forest area.

Figure 7. Change in regional output (LIVCO2TAX), percent change



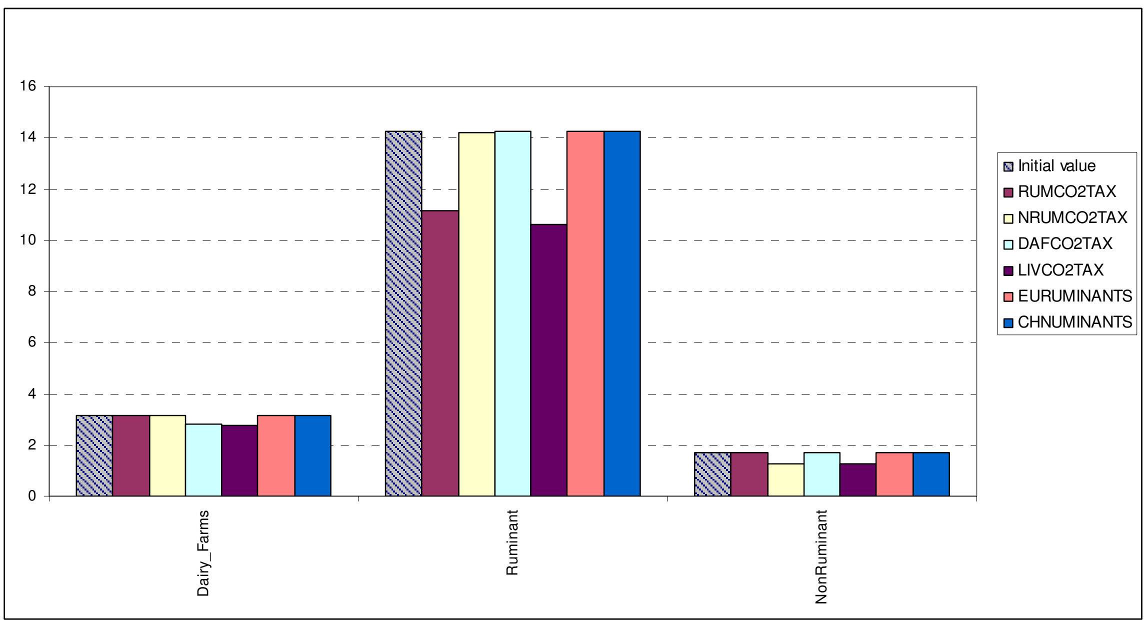
Under scenario **LIVCO2TAX**, there is global decrease in all types of emissions, while the total reduction (-789,669,373 MTCO2e) is almost 1.5 times more than in **RUMCO2TAX**. Similar to the previous two cases, all regions experience reduction in emissions. The smallest abatement happens in Rest of European Countries region, which is due to lower emissions intensity in its ruminants sector (Appendix – Table 5c).

A global CO_2 tax on all three livestock sectors (**LIVCO2TAX**) decreases transportation emissions globally and in most regions (Appendix – Table 6c). The largest increase is in the United States and in the European Union, which have lower emissions intensities and are able to produce more livestock and become net exporters, while the largest reduction happens in Sub Saharan Africa followed by Brazil. The latter is due to highest emissions intensities in non-ruminant (6.93 MKgCO2e /$^{\text{Sub Saharan Africa}}$ and 4.74

MKgCO2e /$[Brazil]) and dairy farm (46.5 MKgCO2e /$[Sub Saharan Africa] and 12.56 MKgCO2e /$[Brazil]) sectors, and the relatively high emissions rate for ruminants (41.82 MKgCO2e /$[Sub Saharan Africa] and 54.05 MKgCO2e /$[Brazil]) in Sub Saharan Africa and Brazil.

The changes in output and emissions levels also affect the emissions intensities under each scenario. Figure 8 illustrates changes in emissions intensities in three livestock sectors. A more detailed picture of changes in emissions intensities associated with each scenario is summarized in Table 7 in the Appendix.

Figure 8. Change in livestock emissions intensities under each scenario, MKgCO2e/$

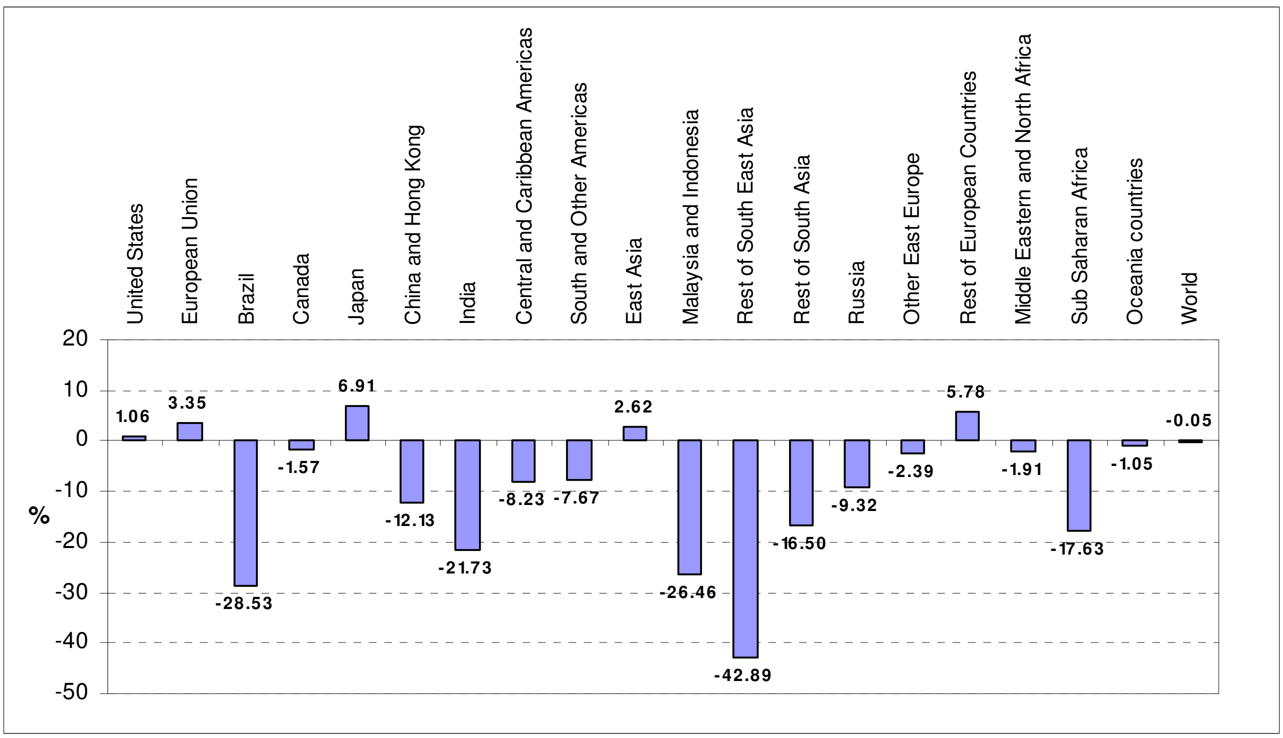


Conclusions

As expected, countries with higher emissions intensities experience the largest reduction in emissions under scenario **RUMCO2TAX**. This is also true for the additional three scenarios. As we have previously seen, Japan has the lowest emissions intensity per dollar of output, which gives the country an advantage to increase the output of ruminants and ruminant products and, thus, generate more emissions.

Recall that the high variation of emissions intensities per dollar of output is due to differences in the value produced per animal in different regions. Since the lower value generated per animal translates into higher emissions intensity per dollar of output, the negative effect of a global CO_2 tax is larger in countries with higher emissions intensities per dollar of output. This is also illustrated in Figure 9.

Figure 9. Change in the output of ruminant products (RUMCO2TAX), percent change



Since livestock is traded more locally than internationally, the emissions from transportation are being affected largely by changes in the use of domestic transport.

Due to variations in livestock emissions intensities across regions taxing private consumption in individual regions to achieve global emissions reduction can lead to different results compared to that of a global GHG tax on livestock.

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Appendix

Table 1. Global emissions intensities by sector and gas (MKgCO2e/$)

Sector	CO_2	N_2O	CH_4	FGAS
Paddy_Rice	0.109	0.990	6.409	0
Wheat	0.225	1.393	0.017	0
CrGrains	0.232	1.989	0.021	0
Oilseeds	0.173	1.636	0.015	0
Sugar_Crop	0.150	1.498	0.020	0
OthAgri	0.196	1.047	0.017	0
Forestry	0.208	0.001	0.002	0
Dairy_Farms	0.099	0.987	2.079	0
Ruminant	0.132	3.661	10.461	0
NonRuminant	0.155	1.067	0.469	0
Proc_Dairy	0.073	0.001	0	0
Proc_Rum	0.064	0	0	0
Proc_NonRum	0.048	0	0	0
vol	0.122	0.001	0	0
Bev_Sug	0.099	0.001	0	0
Proc_Rice	0.123	0.001	0	0
Ofd	0.093	0.001	0	0
OthPrimSect	0.399	0.002	0.001	0
Coal	0.603	0.001	3.767	0
Oil	0.618	0.001	0.627	0
Gas	1.180	0.004	1.332	0
Oil_Pcts	0.877	0.042	0.211	0
Electricity	8.366	0.018	0.002	0.027
En_Int_Ind	0.342	0.032	0.002	0.042
Other_transp	1.190	0.032	0.186	0
Water_transp	1.125	0.024	0.005	0
Air_transp	1.970	0.064	0.008	0
Oth_Ind_Se	0.065	0	0	0.005
NTrdServices	0.048	0.010	0.139	0

Table 2. Log-linear disaggregation of emissions intensities per dollar of output

Regions	Log [Emissions intensity ($MTCO_2e$/animal)]			Log [Value of animals ($/animal)]			Log [Emissions intensity ($MTCO_2e$/$)]		
	Dairy_Farms	Ruminant	NonRuminant	Dairy_Farms	Ruminant	NonRuminant	Dairy_Farms	Ruminant	NonRuminant
United States	0.740	0.663	1.198	-6.824	-6.078	-7.651	-6.084	-5.415	-6.452
European Union	1.062	0.844	1.055	-7.034	-6.000	-7.787	-5.972	-5.156	-6.731
Brazil	0.578	0.631	0.889	-4.944	-3.536	-6.228	-4.366	-2.905	-5.339
Canada	0.940	0.822	1.088	-7.280	-5.919	-8.046	-6.340	-5.096	-6.958
Japan	0.978	0.973	0.986	-7.855	-7.464	-7.980	-6.877	-6.491	-6.994
China and Hong Kong	0.884	0.629	1.352	-6.374	-4.347	-7.599	-5.490	-3.718	-6.247
India	-0.183	-0.447	0.005	-6.219	-3.029	-6.860	-6.402	-3.475	-6.855
Central and Caribbean Americas	0.380	0.456	0.778	-6.073	-4.838	-7.860	-5.694	-4.383	-7.081
South and Other Americas	0.742	0.516	0.896	-6.193	-4.569	-6.889	-5.451	-4.054	-5.993
East Asia	0.651	0.484	1.904	-6.996	-5.755	-8.733	-6.345	-5.270	-6.828
Malaysia and Indonesia	0.824	0.794	1.457	-6.274	-3.801	-7.298	-5.449	-3.008	-5.842
Rest of South East Asia	0.431	0.740	1.217	-5.028	-3.417	-7.297	-4.597	-2.677	-6.080
Rest of South Asia	0.184	-0.118	1.087	-5.540	-3.387	-6.605	-5.356	-3.505	-5.518
Russia	0.846	0.847	1.053	-5.619	-5.399	-7.419	-4.773	-4.552	-6.366
Other East Europe	0.815	0.729	1.155	-6.689	-6.037	-8.882	-5.874	-5.308	-7.726
Rest of European Countries	0.835	0.685	1.521	-7.027	-6.149	-9.221	-6.193	-5.463	-7.700
Middle Eastern and North Africa	0.599	0.253	1.470	-6.723	-5.570	-7.934	-6.124	-5.317	-6.464
Sub Saharan Africa	0.200	0.596	1.212	-3.270	-3.782	-6.193	-3.070	-3.186	-4.980
Oceania countries	0.829	0.882	0.897	-6.024	-5.352	-7.045	-5.195	-4.470	-6.148

Table 3a. Scenario RUMCO2TAX - Change in regional output, percent change

Sector	RUMCO2TAX				
	USA	EU	CHIHKG	INDIA	RUSSIA
Paddy_Rice	0.58	2.86	-0.14	-1.18	0.16
Wheat	-0.22	0.09	-0.36	-0.59	-0.50
CrGrains	0.67	0.45	-0.18	-0.95	-0.78
Oilseeds	-0.42	-0.32	-0.10	-1.89	-0.20
Sugar_Crop	0.02	0.07	-0.28	-0.18	-0.30
OthAgri	-0.30	-0.35	0.04	-2.02	-0.32
Forestry	-0.19	-0.45	-0.17	-0.12	-0.42
Dairy_Farms	0.01	0.21	0.07	-0.05	-0.13
Ruminant	1.06	3.35	-12.13	-21.73	-9.32
NonRuminant	-0.31	0.83	0.28	-0.21	0.79
Proc_Dairy	0.00	-0.01	0.69	-0.11	-0.24
Proc_Rum	0.23	3.20	-10.09	43.71	-11.93
Proc_NonRum	-0.62	1.24	2.27	5.69	2.77
vol	0.17	0.25	-0.28	-2.28	-0.44
Bev_Sug	0.02	0.07	0.00	-0.17	-0.10
Proc_Rice	0.16	0.02	-0.02	-0.45	-0.13
Ofd	0.03	0.20	-0.09	-0.48	-0.16
OthPrimSect	-0.07	-0.07	0.06	0.11	-0.08
Coal	-0.03	-0.06	0.10	0.03	-0.07
Oil	-0.10	-0.10	0.17	0.11	-0.07
Gas	-0.10	-0.18	0.39	0.05	0.10
Oil_Pcts	0.00	0.00	0.07	-0.07	-0.08
Electricity	-0.01	-0.02	0.03	-0.07	-0.10
En_Int_Ind	-0.12	-0.16	0.35	0.21	0.01
Other_transp	-0.01	-0.02	0.14	-0.09	-0.05
Water_transp	-0.03	-0.04	0.24	-0.06	-0.03
Air_transp	-0.03	-0.07	0.41	-0.01	-0.03
Oth_Ind_Se	0.01	-0.02	-0.10	0.06	0.03
NTrdServices	0.02	0.00	0.16	0.19	0.04

Table 3b. Scenario NRUMCO2TAX - Change in regional output, percent change

Sector	NRUMCO2TAX				
	USA	EU	CHIHKG	INDIA	RUSSIA
Paddy_Rice	0.08	-0.05	0.23	0.01	-0.03
Wheat	0.19	0.42	0.71	0.02	0.30
CrGrains	0.12	0.78	0.14	0.02	0.29
Oilseeds	0.10	0.05	0.55	0.01	0.02
Sugar_Crop	0.01	0.03	0.01	-0.01	0.05
OthAgri	0.01	0.02	-0.01	0.02	0.07
Forestry	-0.02	-0.05	0.06	-0.01	0.01
Dairy_Farms	0.01	0.07	0.04	-0.02	0.05
Ruminant	0.03	0.14	0.09	0.01	0.00
NonRuminant	-0.34	0.14	-1.46	-0.42	-0.76
Proc_Dairy	0.01	0.02	0.17	-0.02	0.12
Proc_Rum	0.02	0.16	0.12	0.66	0.13
Proc_NonRum	0.00	0.27	-2.71	0.17	-0.06
vol	0.23	0.06	-0.05	-0.01	0.06
Bev_Sug	0.01	0.00	-0.12	-0.01	-0.02
Proc_Rice	0.08	0.04	-0.10	-0.01	-0.04
Ofd	0.12	0.17	0.11	0.01	-0.03
OthPrimSect	-0.02	0.00	0.04	0.00	0.02
Coal	-0.01	-0.02	0.01	0.01	-0.02
Oil	-0.03	-0.02	0.11	0.00	-0.01
Gas	-0.04	-0.09	0.25	0.02	0.06
Oil_Pcts	-0.03	-0.03	0.08	0.02	-0.02
Electricity	0.00	-0.02	0.14	0.03	-0.05
En_Int_Ind	-0.05	-0.03	0.21	0.01	0.08
Other_transp	0.00	0.01	0.13	0.01	0.03
Water_transp	0.00	0.02	0.17	0.01	0.04
Air_transp	-0.01	0.00	0.26	0.01	0.01
Oth_Ind_Se	0.00	0.00	0.09	0.01	0.00
NTrdServices	0.01	0.01	0.19	0.03	0.02

Table 3c. Scenario DAFCO2TAX - Change in regional output, percent change

Sector	DAFCO2TAX				
	USA	EU	CHIHKG	INDIA	RUSSIA
Paddy_Rice	-0.08	-0.27	0.00	0.01	0.04
Wheat	0.03	-0.09	0.02	0.02	-0.42
CrGrains	0.05	0.05	0.01	0.00	-0.63
Oilseeds	0.05	0.07	0.05	-0.02	0.08
Sugar_Crop	0.00	0.00	0.00	-0.02	-0.19
OthAgri	-0.02	-0.06	0.00	-0.01	-0.19
Forestry	-0.02	-0.06	-0.04	0.01	0.12
Dairy_Farms	-0.65	-0.78	-0.20	-0.78	-8.38
Ruminant	0.05	-0.28	-0.04	0.03	-0.27
NonRuminant	0.04	-0.03	0.01	-0.03	-0.55
Proc_Dairy	-0.39	0.20	2.32	-0.28	-5.57
Proc_Rum	0.03	-0.08	0.02	0.45	-0.33
Proc_NonRum	0.07	0.01	0.10	-7.20	-1.05
vol	0.00	-0.01	-0.04	0.05	-0.34
Bev_Sug	0.00	-0.01	0.00	-0.01	-0.08
Proc_Rice	-0.03	-0.04	-0.01	0.00	-0.11
Ofd	0.00	0.01	0.01	0.08	-0.24
OthPrimSect	-0.02	-0.02	-0.01	-0.02	0.06
Coal	-0.01	-0.02	-0.02	-0.01	-0.02
Oil	-0.03	-0.03	-0.02	-0.02	0.01
Gas	-0.05	-0.18	0.00	0.00	0.10
Oil_Pcts	-0.01	-0.01	-0.01	0.00	-0.02
Electricity	0.00	-0.01	0.00	0.00	-0.04
En_Int_Ind	-0.03	-0.06	0.00	0.03	0.35
Other_transp	-0.01	0.00	0.00	-0.01	-0.02
Water_transp	-0.01	-0.01	-0.01	-0.01	0.06
Air_transp	-0.01	-0.01	-0.02	-0.01	0.06
Oth_Ind_Se	0.00	0.00	0.00	0.03	0.00
NTrdServices	0.01	0.01	0.01	0.09	0.10

Table 3d. Scenario LIVCO2TAX - Change in regional output, percent change

Sector	LIVCO2TAX				
	USA	EU	CHIHKG	INDIA	RUSSIA
Paddy_Rice	0.61	16.66	-1.42	-2.90	2.67
Wheat	-2.60	3.36	-1.66	-1.84	-0.69
CrGrains	0.45	2.89	-0.67	-2.06	-1.10
Oilseeds	0.66	8.50	-0.79	-3.77	4.64
Sugar_Crop	-0.15	0.31	-0.50	-1.32	-0.49
OthAgri	-0.11	4.60	-1.00	-4.49	0.32
Forestry	17.88	2.09	101.62	30.40	5.63
Dairy_Farms	-0.87	-0.11	-1.14	-3.64	-8.82
Ruminant	1.35	4.33	-13.44	-22.13	-9.82
NonRuminant	-0.42	1.27	-2.86	-1.79	-0.83
Proc_Dairy	-0.52	0.55	1.51	-2.59	-6.11
Proc_Rum	0.35	3.66	-11.87	48.57	-12.44
Proc_NonRum	-0.46	1.55	-2.86	-6.62	0.98
vol	0.04	0.82	-3.12	-7.18	0.30
Bev_Sug	-0.14	0.19	-1.45	-1.34	-0.16
Proc_Rice	2.82	2.09	-0.90	-1.15	1.20
Ofd	0.25	0.76	-2.14	-3.00	0.01
OthPrimSect	-0.14	-0.17	-0.43	-0.45	-0.10
Coal	-0.10	-0.24	0.55	0.02	-0.22
Oil	-0.24	-0.21	0.24	0.04	-0.13
Gas	-0.06	-0.34	0.71	-0.13	0.24
Oil_Pcts	-0.03	-0.01	0.49	-0.51	-0.14
Electricity	-0.02	-0.09	0.35	0.07	-0.27
En_Int_Ind	-0.18	-0.39	1.04	-0.13	0.25
Other_transp	0.01	-0.04	0.04	-0.59	-0.06
Water_transp	-0.08	-0.32	-0.01	-0.64	0.01
Air_transp	-0.09	-0.21	0.01	-0.60	-0.18
Oth_Ind_Se	0.00	-0.09	-0.46	-0.25	0.13
NTrdServices	0.02	-0.03	-0.37	-0.14	-0.07

Table 4a. Change in bilateral trade flows of ruminants, US$ million

Regions	**United States**	**European Union**	**Brazil**	**Canada**	**Japan**	**China and Hong Kong**	**India**	**Central and Caribbean Americas**	**South and Other Americas**	**East Asia**	**Malaysia and Indonesia**	**Rest of South East Asia**	**Rest of South Asia**	**Russia**	**Other East Europe**	**Rest of European Countries**	**Middle Eastern and North Africa**	**Sub Saharan Africa**	**Oceania countries**	**Total**
United States	0	85	5	33	33	20	2	127	14	6	1	7	0	0	0	0	41	24	9	407
European Union	47	687	11	0	8	78	51	12	10	6	4	10	8	4	23	6	96	46	7	1114
Brazil	-4	-8	0	0	-15	0	-1	0	-6	-3	0	0	0	0	-1	0	0	0	0	-38
Canada	292	1	1	0	1	4	0	12	0	1	0	0	0	0	0	0	0	0	1	313
Japan	11	18	0	0	0	9	3	0	0	0	1	8	0	0	0	0	0	0	1	51
China and Hong Kong	-1	-37	0	0	-26	0	-37	0	0	-26	0	0	-2	0	-1	-1	-3	0	0	-134
India	-3	-6	0	0	-1	-1	0	0	0	-1	0	0	0	0	0	-2	-1	0	0	-15
Cent. and Carib. Americas	-140	-3	0	-1	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	-143
South and Oth. Americas	-16	-39	13	0	0	1	2	-2	-1	0	0	0	0	0	-1	0	-3	3	0	-43
East Asia	0	1	0	0	3	17	10	0	0	12	0	1	0	0	0	0	0	0	0	44
Malaysia and Indonesia	-1	-2	0	0	0	0	0	0	0	0	0	-1	0	0	0	0	-2	0	0	-6
Rest of South East Asia	-1	-3	0	0	0	0	0	0	0	0	-3	-19	-1	0	0	0	-1	0	0	-28
Rest of South Asia	-1	-1	0	0	0	0	-1	0	0	0	0	0	0	0	0	0	-1	0	0	-4
Russia	-1	-2	0	0	0	1	0	0	0	0	0	1	0	0	-5	0	0	1	0	-5
Other East Europe	2	13	3	0	1	24	32	1	2	1	1	8	1	9	1	0	30	7	1	137
Rest of European Country	1	10	0	0	0	0	9	0	0	0	0	0	0	0	0	0	0	0	0	20
Mid. East & North Africa	1	33	4	0	1	9	23	1	3	2	2	15	25	1	0	0	55	11	1	187
Sub Saharan Africa	-10	-51	0	-1	-3	-5	-2	-1	-1	-4	-1	-1	0	-1	0	-1	-10	31	-1	-62
Oceania countries	-22	-225	0	-1	-17	931	308	3	5	36	151	336	29	0	-8	0	-15	85	4	1600
Total	154	471	37	30	-15	1088	399	154	26	30	156	365	60	13	8	2	186	208	23	3395

Table 4b. Change in bilateral trade flows in all products combined, US$ million

Regions	United States	European Union	Brazil	Canada	Japan	China and Hong Kong	India	Central and Caribbean Americas	South and Other Americas	East Asia	Malaysia and Indonesia	Rest of South East Asia	Rest of South Asia	Russia	Other East Europe	Rest of European Countries	Middle Eastern and North Africa	Sub Saharan Africa	Oceania countries	Total
United States	0	-21	-452	152	137	-143	-36	92	-229	11	-22	-61	-5	14	-50	0	29	-68	24	-628
European Union	3	2748	-549	37	94	-202	-71	-4	-258	2	-22	-34	-36	68	-227	32	53	-108	50	1576
Brazil	789	-59	0	56	-49	-64	18	155	252	62	30	-11	5	-177	2	26	-484	19	19	589
Canada	295	2	-26	0	1	-5	-1	-3	-21	-3	-2	2	3	2	-3	0	-1	-12	28	256
Japan	-236	-114	-93	-7	0	-373	-21	-34	-59	-143	-60	-118	-19	-5	-17	-7	-48	-87	-9	-1450
China and Hong Kong	780	682	-40	78	472	116	-33	47	-29	146	43	108	-6	24	4	31	89	-54	60	2518
India	129	197	-9	13	21	21	0	8	0	14	59	84	-1	2	3	7	111	70	8	737
Cent. and Carib. Americas	236	75	-30	28	19	-3	-7	19	-39	5	1	3	-1	-2	-1	6	4	-5	4	312
South and Oth. Americas	160	102	58	-7	9	14	5	45	40	21	5	9	-2	5	5	10	25	47	5	556
East Asia	134	121	-68	19	77	-162	-4	13	-44	29	7	16	-20	3	-9	4	6	-73	14	63
Malaysia and Indonesia	79	117	-16	9	71	-20	-7	5	-9	26	7	36	-6	1	0	3	28	99	13	436
Rest of South East Asia	150	213	-23	15	150	-34	-4	8	-10	59	37	26	-10	3	-1	6	39	25	20	669
Rest of South Asia	131	126	-1	8	10	10	5	4	-1	8	0	5	0	-2	-1	5	-15	-7	3	288
Russia	17	8	-11	1	10	-45	-3	-1	-3	1	0	2	0	0	106	7	5	-5	1	90
Other East Europe	48	224	-6	6	12	11	30	4	-1	3	3	10	0	105	-89	6	37	-3	5	405
Rest of European Country	4	85	-32	2	5	-17	4	1	-14	1	-1	-2	-4	0	-8	9	-6	-19	3	11
Mid. East & North Africa	23	176	-49	5	-13	-29	-6	2	-8	-28	-1	-3	10	1	-6	4	117	-24	2	173
Sub Saharan Africa	312	738	-16	21	113	58	67	21	7	49	24	33	13	12	23	26	48	8	22	1579
Oceania countries	-271	-446	-8	-25	-405	940	304	-25	5	-72	156	325	30	-9	-14	-10	4	201	-3	677
Total	2783	4974	-1371	411	734	73	240	357	-421	191	264	430	-49	45	-283	165	41	4	269	8857

Table 5a. Scenario NRUMCO2TAX - Change in emissions (MTCO2e)

Regions	NRUMCO2TAX				
	CO_2	N_2O	CH_4	FGAS	Total
United States	-631,349	-7,479,153	-6,303,417	-19,106	-14,433,024
European Union	-964,353	-4,134,898	-11,385,081	-7,257	-16,491,589
Brazil	-218,067	-5,606,686	-8,023,581	9,264	-13,839,069
Canada	-15,505	-41,822	-399,227	-2,401	-458,955
Japan	83,495	-1,614,963	-160,396	-3,082	-1,694,946
China and Hong Kong	-2,405,178	-23,384,003	-4,662,974	84,049	-30,368,105
India	302,450	-737,950	-1,130,747	629	-1,565,618
Central and Caribbean Americas	-16,000	-596,329	-460,068	-597	-1,072,995
South and Other Americas	48,605	-2,452,400	-1,406,012	14	-3,809,793
East Asia	18,835	-2,243,617	-434,901	1,135	-2,658,547
Malaysia and Indonesia	147,299	-4,117,019	-280,871	1,123	-4,249,468
Rest of South East Asia	-94,371	-6,005,513	-2,409,482	1,843	-8,507,523
Rest of South Asia	55,957	-1,964,666	-315,465	124	-2,224,050
Russia	-465,608	-1,431,965	-744,060	6,829	-2,634,804
Other East Europe	-600,085	-961,387	-1,235,191	-2,395	-2,799,058
Rest of European Countries	-15,194	-12,128	-32,198	-1,016	-60,536
Middle Eastern and North Africa	201,027	-4,137,766	-273,790	630	-4,209,899
Sub Saharan Africa	452,469	-9,945,597	-2,853,552	12,722	-12,333,957
Oceania countries	-4,428	-258,985	-229,601	-4,824	-497,838
Total	-4,119,999	-77,126,846	-42,740,616	77,683	-123,909,775

Table 5b. Scenario DAFCO2TAX - Change in emissions (MTCO2e)

Regions	DAFCO2TAX				
	CO_2	N_2O	CH_4	FGAS	Total
United States	-130,814	-2,263,592	-5,253,349	-6,629	-7,654,385
European Union	-252,741	-6,124,280	-5,692,340	-19,394	-12,088,757
Brazil	-152,049	-1,261,671	-2,108,949	-471	-3,523,139
Canada	-8,733	-124,297	-246,447	-514	-379,992
Japan	96,491	-124,251	-232,711	-1,517	-261,987
China and Hong Kong	-6,653	-265,484	-754,201	786	-1,025,552
India	7,654	-700,504	-1,783,310	1,490	-2,474,669
Central and Caribbean Americas	-45,949	-209,557	-970,384	111	-1,225,780
South and Other Americas	-60,193	-1,474,179	-1,654,413	174	-3,188,611
East Asia	-4,547	-24,281	-110,139	-297	-139,263
Malaysia and Indonesia	19,983	12,865	-67,774	-219	-35,145
Rest of South East Asia	1,045	-41,730	-162,603	296	-202,992
Rest of South Asia	33,701	-706,632	-979,156	250	-1,651,836
Russia	-544,095	-2,042,725	-3,364,520	34,244	-5,917,097
Other East Europe	-3,787,852	-2,035,194	-4,710,384	-19,901	-10,553,330
Rest of European Countries	-20,865	-166,192	-181,511	-968	-369,535
Middle Eastern and North Africa	-64,525	-837,474	-553,606	909	-1,454,695
Sub Saharan Africa	414,409	-4,435,875	-5,638,558	18,327	-9,641,697
Oceania countries	-79,501	-1,151,971	-1,737,911	5,940	-2,963,443
Total	-4,585,234	-23,977,022	-36,202,263	12,616	-64,751,907

Table 5c. Scenario LIVCO2TAX - Change in emissions (MTCO2e)

Regions	LIVCO2TAX				
	CO_2	N_2O	CH_4	FGAS	Total
United States	1,628,931	-7,058,362	-22,884,977	-359,138	-28,673,546
European Union	792,557	-4,750,743	-18,852,064	-327,315	-23,137,566
Brazil	-1,989,934	-37,234,550	-95,296,127	18,242	-134,502,365
Canada	210,767	1,421,060	-2,831,880	-103,111	-1,303,164
Japan	570,850	-1,369,673	-639,974	-112,468	-1,551,265
China and Hong Kong	5,536,946	-30,624,149	-66,752,846	28,047	-91,812,004
India	-1,892,092	-3,017,588	-62,839,775	-49,774	-67,799,232
Central and Caribbean Americas	-985,289	-2,931,425	-12,245,403	-17,709	-16,179,827
South and Other Americas	1,023,087	-21,585,859	-36,616,867	43,556	-57,136,086
East Asia	-899,218	-2,562,620	-2,075,713	-32,513	-5,570,064
Malaysia and Indonesia	-789,587	-6,619,730	-11,990,425	-1,121	-19,400,864
Rest of South East Asia	-467,730	-13,342,377	-30,076,208	-9,974	-43,896,290
Rest of South Asia	-4,563	-6,313,769	-18,741,148	472	-25,059,010
Russia	-3,487,350	-4,243,802	-8,157,684	-38,324	-15,927,159
Other East Europe	-7,233,099	-3,362,691	-10,950,202	-62,606	-21,608,599
Rest of European Countries	-14,435	-60,832	-201,217	-26,347	-302,830
Middle Eastern and North Africa	-1,141,467	-6,253,335	-4,475,622	-22,070	-11,892,494
Sub Saharan Africa	-1,446,116	-66,389,801	-140,917,160	85,323	-208,667,755
Oceania countries	-540,428	-2,951,861	-11,729,870	-27,071	-15,249,229
Total	-11,128,168	-219,252,106	-558,275,146	-1,013,903	**-789,669,373**

Table 6a. Scenario NRUMO2TAX - Change in transportation emissions (MTCO2e)

Regions	**NRUMCO2TAX**			
	Other	**Water**	**Air**	**Total**
United States	197,673	10,896	155,036	363,605
European Union	171,101	42,931	29,371	243,403
Brazil	-33,912	17,866	4,257	-11,789
Canada	23,099	1,016	2,093	26,208
Japan	38,986	2,743	1,269	42,998
China and Hong Kong	326,798	78,348	47,931	453,077
India	37,103	8,025	2,628	47,756
Central and Caribbean Americas	13,947	527	1,935	16,409
South and Other Americas	39,365	3,410	7,373	50,148
East Asia	23,206	9,243	6,890	39,339
Malaysia and Indonesia	26,746	7,930	9,137	43,813
Rest of South East Asia	40,231	8,360	22,122	70,713
Rest of South Asia	15,516	5,402	8,336	29,254
Russia	71,185	11,353	10,095	92,633
Other East Europe	26,548	2,444	3,003	31,995
Rest of European Countries	3,810	1,353	984	6,147
Middle Eastern and North Africa	50,780	19,990	17,268	88,038
Sub Saharan Africa	33,052	8,489	21,898	63,439
Oceania countries	24,867	507	4,839	30,213
Total	1,130,101	240,832	356,464	1,727,397

Table 6b. Scenario DAFCO2TAX - Change in transportation emissions (MTCO2e)

Regions	DAFCO2TAX			
	Other	Water	Air	Total
United States	105,699	3,517	122,967	232,183
European Union	79,742	11,455	15,379	106,576
Brazil	-16,706	4,931	505	-11,270
Canada	12,012	-165	-58	11,789
Japan	40,522	-545	-1,061	38,916
China and Hong Kong	5,333	-397	-1,342	3,594
India	-6,458	-1,037	-433	-7,928
Central and Caribbean Americas	6,964	-511	892	7,345
South and Other Americas	2,810	1,268	4,951	9,029
East Asia	11,138	2,352	-3,212	10,278
Malaysia and Indonesia	10,322	943	-1,654	9,611
Rest of South East Asia	2,574	144	-974	1,744
Rest of South Asia	-6,040	-1,406	5,050	-2,396
Russia	-62,895	4,612	10,959	-47,324
Other East Europe	-295,799	-3,182	19,755	-279,226
Rest of European Countries	3,157	-94	627	3,690
Middle Eastern and North Africa	10,863	4,857	9,814	25,534
Sub Saharan Africa	-39,136	4,416	14,330	-20,390
Oceania countries	-21,618	1,914	53,385	33,681
Total	-157,515	33,072	249,880	125,437

Table 6c. Scenario LIVCO2TAX - Change in transportation emissions (MTCO2e)

Regions	LIVCO2TAX			
	Other	Water	Air	Total
United States	1,232,745	29,661	1,037,972	2,300,378
European Union	671,176	-220,673	-58,099	392,404
Brazil	-1,309,656	167,084	-77,212	-1,219,784
Canada	403,510	15,414	-39,546	379,378
Japan	358,502	-20,768	-5,809	331,925
China and Hong Kong	335,841	17,336	10,850	364,027
India	-550,372	-119,955	-38,025	-708,352
Central and Caribbean Americas	-112,295	-4,968	-29,062	-146,325
South and Other Americas	-746,959	151,773	211,462	-383,724
East Asia	37,727	-25,127	-7,096	5,504
Malaysia and Indonesia	-102,775	-29,584	-80,822	-213,181
Rest of South East Asia	50,243	-7,499	24,997	67,741
Rest of South Asia	-68,229	-15,505	11,399	-72,335
Russia	2,110	17,764	-34,172	-14,298
Other East Europe	-670,699	-21,265	11,015	-680,949
Rest of European Countries	24,100	-12,866	1,979	13,213
Middle Eastern and North Africa	-25,034	-12,530	-11,232	-48,796
Sub Saharan Africa	-1,365,305	-12,989	-5,427	-1,383,721
Oceania countries	-79,375	-350	123,047	43,322
Total	-1,914,744	-105,048	1,046,218	**-973,574**

Table 7. Global emissions intensities by sector under each scenario (MKgCO2e/$)

Sector	Initial value	Scenario					
		RUMCO2TAX	NRUMCO2TAX	DAFCO2TAX	LIVCO2TAX	EURUMINANTS	CHNRUMINANTS
Paddy_Rice	7.508	7.515	7.507	7.512	6.726	7.508	7.508
Wheat	1.636	1.632	1.638	1.636	1.625	1.636	1.636
CrGrains	2.241	2.239	2.24	2.241	2.22	2.241	2.241
Oilseeds	1.825	1.828	1.826	1.824	1.77	1.825	1.825
Sugar_Crop	1.669	1.665	1.669	1.669	1.631	1.669	1.669
OthAgri	1.26	1.262	1.26	1.26	1.241	1.26	1.26
Forestry	0.21	0.211	0.21	0.21	0.239	0.21	0.21
Dairy_Farms	3.165	3.17	3.163	2.811	2.74	3.165	3.165
Ruminant	14.254	11.135	14.208	14.251	10.637	14.254	14.254
NonRuminant	1.691	1.675	1.27	1.691	1.26	1.691	1.691
Proc_Dairy	0.073	0.073	0.073	0.072	0.072	0.073	0.073
Proc_Rum	0.065	0.06	0.064	0.064	0.06	0.065	0.065
Proc_NonRum	0.048	0.048	0.048	0.048	0.048	0.048	0.048
vol	0.123	0.123	0.123	0.123	0.122	0.123	0.123
Bev_Sug	0.1	0.1	0.1	0.1	0.1	0.1	0.1
Proc_Rice	0.124	0.123	0.124	0.124	0.121	0.124	0.124
Ofd	0.093	0.093	0.093	0.093	0.093	0.093	0.093
OthPrimSect	0.402	0.403	0.403	0.403	0.408	0.402	0.402
Coal	4.371	4.373	4.372	4.372	4.425	4.371	4.371
Oil	1.247	1.248	1.247	1.247	1.263	1.247	1.247
Gas	2.516	2.513	2.516	2.516	2.538	2.516	2.516
Oil_Pcts	1.13	1.13	1.13	1.13	1.144	1.13	1.13
Electricity	8.413	8.41	8.416	8.411	8.509	8.413	8.413
En_Int_Ind	0.418	0.418	0.418	0.418	0.423	0.418	0.418
Other_transp	1.407	1.407	1.408	1.407	1.422	1.407	1.407
Water_transp	1.155	1.155	1.155	1.155	1.168	1.155	1.155
Air_transp	2.042	2.043	2.043	2.043	2.068	2.042	2.042
Oth_Ind_Se	0.071	0.071	0.071	0.071	0.071	0.071	0.071
NTrdServices	0.197	0.197	0.197	0.197	0.199	0.197	0.197