Livestock Demand, Global Land Use, and Induced Greenhouse Gas Emissions

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Introduction

The global demand for livestock products has grown over the years and is likely continue to grow in future as well (FAO, 2011). Increasing overall livestock output has implications for environment. Typically when forest land is converted into pasture or cropland to accommodate increased livestock production, it results in higher greenhouse gas (GHG) emissions due to land clearing and reduced long term carbon sequestration. With growing concern about climate change, potential sources of GHG emissions mitigation are being identified. Lately, livestock sector has received considerable attention in this regard as the sector reportedly contributes significantly to human-induced GHG emissions.

Notably each species of livestock has a different effect on land use and environment. The production differences among the various livestock species vary in land use patterns and amount of GHG produced. Poultry for example requires less space and feeds higher in protein and energy than cattle (Gerbens-Leenes and Nonhebel, 2002). Moreover, increased ruminant production would trigger expansion of both pasture and cropland while increased non-ruminant production would be mostly limited to crop land increases[1.] Additionally, land use changes differ depending on the production systems used (i.e. feedlot beef versus grass fed beef). This is well illustrated in the difference between North and South American beef production systems where South American is predominantly a pasture based system and North American, a mixed system of pasture and intensive feeding (Opio et al., 2013). Expansion of beef production in South America would have a much different effect on land use and GHG

[1] Cropland expansion will be contingent on the productivity of land. If productivity of land increases with the intensive use of inputs (technology, capital, and labor) cropland expansion will be limited.

production than an expansion in North America.

Given the complexity and extent of land use changes from livestock production, it follows that a careful study of how the future changes in global livestock production and consumption may alter land use and associated GHG emissions is required. Despite the magnitude of the potential impacts of production changes on the environment, the literature relating to livestock-induced land use changes is sparse. The available literature generally focuses on estimating land requirements for various livestock production systems at the country level (e.g. Gerbens-Leenes and Nonhebel, 2001; Elferink and Nonhebel, 2006) or estimating emission changes which emanate from causes other than land use changes due to livestock production (e.g. Hertel et al. 2010, Tyner et al. 2010, and Keeney and Hertel 2008).

Further, estimation of emissions from land use changes induced by livestock production is a contentious issue. For example, Steinfeld et al. (2006) and Goodland and Anhang (2009) estimate about 2.4 to 2.6 billion tons Co_2 e emissions per year as a result of land use change due to livestock production. These reports, however, do not provide a detailed explanation of the methods used to obtain these estimates and appear to be more of "a back-of-the-envelope" type of calculations. Revising the previous estimates, a FAO report authored by Gerber et al. (2013) reduced the GHG emission estimates from the livestock sector. The report estimates about 7.1 billion tons of CO_2 e (CO_2 equivalent) emissions annually from the livestock sector and attribute about 0.65 billion tons Co_2 e per year (about 9.2 % of the total emissions from the sector) to the land use changes due to livestock production. However, this estimate fails to fully account the emissions from land use change associated with livestock production as it mainly accounts for land use changes in Latin America and the Caribbean regions due to expansion of soybean crops only. Given that the report does not account for land use changes in all regions of the world and for all crops, it is likely that it under estimates the emissions from land use change due to livestock production. Moreover, Gerber et al. (2013) emission estimates are based on the reference years 1996-2006, which needs to be updated to account for the livestock production after 2006. Given this gap in the literature, this work therefore focuses on land use changes in the world due to increase in livestock production between 2004 and 2022 and the associated GHG emissions from such change.

The objectives of this paper are threefold: (1) Provide a baseline projection for regional livestock output growth between 2004 and 2022 at the global scale; (2) Use the baseline projection estimates of livestock output to estimate the expected global land use changes by regions; and (3) Estimate the GHG emissions associated with those changes. Considering the global scale of this work and the number of interactions among many economic sectors and regions, a computable general equilibrium (CGE) model is used.

The model

A modified version of the standard GTAP (Global Trade Analysis Project) model, GTAP-BIO is used for the analysis. The GTAP-BIO was originally developed and used to estimate the impact of increased biofuels production on global land use and associated GHG emissions (Hertel et al., 2010, Tyner et al., 2010). Given that the standard GTAP model is fully described and discussed with underlying assumptions and equations in the book "Global Trade Analysis" (Hertel ed., 1997), the discussion in this section is focused on the features of GTAP-BIO model that are pertinent to the objectives of this study.

The GTAP-BIO explicitly models the competition among crops, livestock, and the biofuels sector in the land market. Besides modeling the land use, the model explicitly incorporates feed demand for livestock. The livestock feed demand includes not only conventional feed sources but also distillers' grains, a by-product of corn ethanol production primarily used as a livestock feed ingredient. Given that the GTAP-BIO model explicitly models land supply and the livestock feed demand in addition to retaining the general equilibrium features of the standard GTAP model, the model is very appropriate to estimate the growth of livestock demand and associated land use changes.

Figure 1 illustrates the land use module in the GTAP-BIO model. This module determines the supply of land for forest, crop, and pasture production purposes in 18 Agro-Ecological Zones (AEZs) around the world. The elasticity of transformation, ETL1 determines the transformation of land for forest, crops and pasture, while ETL2 governs allocation of crop land among different crops. ETL3 is the elasticity of transformation of pasture land for meat and milk production. These elasticities are tuned according to the changes in land cover and harvested areas by at the global scale (Taheripour and Tyner, 2013).

The nested livestock feed demand structure used in the model is shown in Figure 2. The DDGS and coarse grain are kept in the energy feed nest while oilseeds and oilseed meals constitute the protein feed nest. The energy and protein feeds make the energy-protein composite feed. This composite feed along with other sources of feed such as intermediate processed livestock products, crops, and other processed feed make up the final feed composite used for feeding livestock. Details on the elasticity values used at each nest in the feed demand tree are provided by Taheripour et al. (2011).

The experiments and data sources

In order to examine the impact of increased livestock output on global land use and resulting GHG emissions three iterations or experiments are applied using the GTAP-BIO model and

GTAP database version 7, which corresponds to the reference year 2004.

1. Experiment 1: An experiment is carried out by using the forecasted changes (Table 2) in GDP, population, capital, and skilled and unskilled labor between the years 2004 (baseline) and 2022 as exogenous shocks to the GTAP-BIO model for all GTAP regions (Table 1). The land use changes obtained from this experiment can be attributed to changes in demand for all goods and services in the regional economies including changes in livestock production.
2. Experiment 2 is used in combination with experiment 1 to determine the effect that private household demand has on land use. To isolate this, livestock demand is held constant for the private households while the other forecasted changes, GDP, population, capital, and skilled and unskilled labor are made. The difference in land use between this experiment and experiment 1 can be attributed to the effect of the private households alone on land use. The details of these experiments are presented in Appendix A.
3. Experiment 3: This experiment is similar to the second experiment, but it not only fixes the private households demand but also the intermediate demands (intermediate demand includes demands for livestock products by industries as an input in production process) for livestock products. The difference between the results of the first and this third experiment amounts to the induced land use changes as a result of change in the sum of household and intermediate demands for livestock products.

Two additional steps are followed: First, the resulting land use changes are coupled with emissions factors developed by Plevin et al. (2014) to calculate induced land use emissions due to changes in livestock outputs for the time period of 2004-2022. Plevin et al. (2014) has developed a comprehensive model, “the AEZ_EF v47”, specifically designed to estimate GHG emissions associated with land use changes. The model considers various sources and sinks of GHG emission such as the above and below-ground live biomass, dead organic matter, soil organic matter, harvested wood products, non-Co2 emissions (e.g. CH4 and N2O), and foregone sequestration in estimating the induced land use emissions (Plevin et al. 2014). Moreover, the model is designed to fit well with the GTAP-BIO model such that the regions and AEZs in the AEZ_EF v47 model exactly matches with the 19 regions and 18 AEZs in the GTAP model. This facilitates direct use of the land use change results from the GTAP model simulations into the AEZ_EF v47 model. The detailed methodology and the assumptions used in estimating the emissions from land use change are provided by Plevin et al. (2014). Second, a series of simulations with changes in the substitution parameter of the model are solved to test the sensitivity of the results.

Data Sources for the exogenous shocks in the model

The projected data for GDP, population, and capital (Table 2) mainly come from Centre d'Études Prospectives et d'Informations Internationales (CEPII) baseline database version 2.1 (Foure' et. al, 2012). The projected changes in skilled and unskilled labor between the years 2004 to 2022 (Table 2) are from the baseline projection database prepared by Chappuis and Walmsley (2011) for the GTAP model. Both the CEPII and Chappuis and Walmsley (2011) information are presented originally as country level data and therefore are aggregated into the 19 GTAP regions. The percentage change in each of the five variables between 2004 and 2022 is calculated and then used as a shock in these variables in the model thus simulating projected growth in livestock output and associated land use change.

Results

Change in livestock output[2]

Table 3 presents the GTAP-BIO simulation result on growth in global livestock outputs as a consequence of the projected regional changes in the five factors (GDP, population, capital, and skilled and unskilled labor) between the years 2004 (baseline year) and 2022 (Table 2). As expected the largest percentage increase is observed for non-ruminant production followed by ruminant and milk production (Table 3).

Table 4 shows the projected increases in livestock output for each of the 19 regions. Among these regions, China-Hong Kong (CHIHKG) and INDIA are the regions with the greatest increases in livestock output. CHIHKG has more than a 200% increase in all categories with INDIA not far behind with nearly a 200% increase. This increase is mainly driven by the large simultaneous increase in GDP and capital (Table 2). Among livestock output categories, CHIHKG has the highest growth for ruminants but INDIA has the largest increase in non- ruminants. The rest of south Asia (R_S_Asia), other east Europe and the rest of the former Soviet Union excluding Russia (Other_CEE_CIS), Middle-Eastern and North Africa (MEAS_NAfr), and Sub-Saharan Africa (S_S_AFR) are the other regions with relatively high growth in livestock outputs.

The demand for livestock output comes mainly from two sources[3]: household demand and intermediate input demand by firms that use it to produce another product. Table 5 shows the projected increase in regional household demands for the livestock outputs. INDIA, CHIHKG, and S_S_AFR are the regions with the largest increase in household demand (Table

[2] The GTAP-BIO results (except for the land use change) are presented in proportionate change form, hence the results on livestock output changes are in percentage change rather than the absolute change.

[3] Livestock output demand from the government is also another source. Given that the share of government's demand in the total demand for the livestock output is negligible, this category of demand is not considered in the analysis.

5). Demand for livestock production for INDIA and S_S_AFR are larger in percentage terms than that of CHIHKG; excluding non-ruminants for which CHIHKG has a higher percentage increase than S_S_AFR but lower than INDIA. These increases are mainly driven by extraordinary population growth in INDIA and S_S_AFR (Table 2). Other regions which are projected to have large percentage increases in demand are MEAS_NAfr, R_S_Asia, Malaysia and Indonesia (Mala_Indo), and Oth_CEE_CIS (Table 5).

Livestock output is not only used by the private households but is also used as an input into many industries. For example, raw milk, meat and eggs are used as ingredients in other value added products such as baked and processed foods. Table 6 shows the projected growth in the processed food industry demand for livestock outputs[4]. Similar to the household demand, growth in output demanded by the processed food industry is also highest in INDIA and CHIHKG regions, followed by Oth_CEE_CIS, MEAS_NAfr, and S_S_AFR.

Land use impact

Tables 7 through 9 show the impacts of livestock output growth on land use by private household, intermediate industry, and their combined demand effects. The columns associated with "A" in the tables are the results associated with Experiment 1 and represent the total change in land use by land use types i.e. forest, crops, and pasture land. These columns are repeated on all three tables, 7, 8 and 9. The columns listed under "B" in the Table 7, columns under "D" in the Table 8, and columns under "F" in the Table 9 report respectively the changes in land use while holding household demand constant (experiment 2), holding

[4] Since processed food industry is one of the largest consumer of livestock output, only the projected demand from this industry is presented in Table 6. Results for other industries are omitted here for space considerations. Further, in the table, the projected growth in demand for milk, ruminants, and non-ruminants are equal for a region which is an implication of the fixed proportion assumption in the model whereby the percentage increase in the inputs used for production is equal to the percentage increase in the outputs.

intermediate industrial demand constant, and lastly holding the combined demand (private plus intermediate) constant (experiment 3) at the baseline level. The “C”, “E”, and “G” columns in the tables isolate the predicted net land use change induced by the growth 1) in household demand for livestock output, 2) in intermediate industrial livestock demand, and 3) in the combined demand for the 2004-2022 periods.

As is evident in columns listed under “C”, “E”, and “G” of the tables, pasture area always expands, while forest land is always reduced as a result of increases in livestock demands. In Table 9, the final result of the overall change in crop land has a mixed outcome. In some regions cropland is reduced, while in others such as Canada (CAN), CHIHKG and Mala_Indo crop land increases. Globally there is a net increase in pasture of about 44.5 billion hectares, with a decrease in crop land and forest of 1.1 billion and 43.3 billion hectares respectively.

Contrastingly with the increase in demand from private households only, Table 7 indicates that crop land increases globally, which is evident in six of the regions in order of decreasing magnitude, CHIHKG, Mal_Indo, rest of South East Asia (R_SE_Asia), CAN, INDIA, and EU27. The expansion in pasture area is most notable in S_S_AFR, BRAZIL, South and Other Americas (S_o_Amer), and R_S_Asia (Table 7). In particular, the pasture expansion is largest in S_S_AFR with an increase of about 8.5 million hectares in pasture land and decreases of about 8 and 0.5 million hectares in forest and crop land cover. The expansion of pasture is small in the advanced economies such as the EU27, Canada (CAN), JAPAN, Oth_Europe, and Oceania.

In comparing the magnitude of the changes between Table 7 and 8 it is obvious that intermediate demand for livestock output constitutes a major share of the total output demand

and accounts for the major portion of the land use changes. Unlike the household demand effects, the intermediate demand induces not only conversion of forest to pasture but also conversion of crop land to pasture as there is a decrease in crop land at the global level (Table 8). Among the regions, CHIHKG emerges as the region of largest pasture expansion followed by S_S_AFR, BRAZIL, S_o_Amer, and R_S_Asia (Table 8).

Emissions due to the land use changes

The results on regional land use change obtained from the GTAP-BIO model simulations are used in the "AEZ_EF v47" model to estimate the induced land use emissions as a result of regional changes in livestock demands for livestock outputs[5]. Tables 10, 11, and 12 present the induced land use emissions due to changes in household, intermediate, and the combined demand. Results in all three tables reflect the huge contribution of deforestation to the total emissions; particularly, the conversion of forest to pasture accounts for the majority of the emissions. Conversely, the conversion of crop land to pasture reduces emissions. The regions with relatively higher emission are S_S_Afr, CHIHKG, BRAZIL, and S_o_Amer (Tables 10, 11, and 12). Mal_Indo, R_SE_Asia, and R_S_Asia are other regions with major land use emissions, which is consistent with the nature of pasture-based livestock production in these regions which are also the regions where demand for livestock is likely to be higher. At the global level with the household-level demand increase only, the induced emissions are about 10 billion tons Co_2 e (Co_2 equivalent) (Table 10). The emissions almost double to 19.8 billion tons Co_2 e with the increase in combined demand (Table 12), about 9.8 billion tons accounted to the intermediate demand (Table 11). Since these emissions are the aggregated emissions for

[5] For this purpose regional land use change results similar to the ones presented in tables 7 and 9 but disaggregated to the 18 AEZ levels of the GTAP-BIO model are used in the "AEZ_EF V47" model.

the 18 year period (2004-2022), the average annualized emission due to the increase in the combined demand is about 1.1 billion tons Co_2 e per year.

Notably, total emissions due to household demand are greater than the emissions induced by the intermediate demand (Tables 10 and 11), even though the net land use changes due to intermediate demand are greater than that of household demand (Tables 7 and 8). Since there is a net increase in global crop land associated with the increase in household demand (Table 7), a net decrease in crop land and a greater increase in pasture with the increase in intermediate demand (Table 8), the higher emissions associated with the conversion of forest to crop land due to household demand compared to that of the intermediate demand (Tables 10 and 11) led to higher total emissions for the household demand. As stated earlier, given that the 0.65 billion tons Co_2 e per year estimate by Gerber et al. (2013) might be underestimated, the estimate of 1.1 billion tons Co_2 e per year obtained from this study is very plausible.

Sensitivity analysis

As with all models of this type, the results are a function of the magnitude of the parameters. Therefore if the parameters are altered, it is expected that the results would be altered. It is in this spirit that a sensitivity analysis is undertaken. The demand for livestock products comes directly from the preferences of those purchasing it, the final consumers. To incorporate some change in consumer preferences over the time, the elasticity associated with the substitution among livestock products is relaxed by making them more elastic. This in effect amounts to an increase in price sensitivity for any individual product type. This increase in elasticity is accomplished by altering the substitution parameter (SUBPAR) in the model. The parameter SUBPAR helps determine how easily goods are substitutable in consumption. The SUBPAR values in the model are decreased by 50% for all regions compared to the baseline case. The decrease in SUBPAR increases own and cross price compensated elasticities. For example, Tables 13 and 14 show the compensated partial elasticity matrix for CHIHKG for the baseline simulation and the simulation with the reduced SUBPAR. The compensated price elasticities for the CHIHKG region increase substantially with the reduced SUBPAR.

Tables 15 and 16 present the difference in the percentage changes in the global and regional livestock outputs when SUBPAR is reduced. Compared to the baseline simulation, with the reduced parameter values, the global livestock output increased for all categories. The increased price sensitivity in consumption to both own-price and cross-price changes significantly increased the global output for non-ruminants. At the regional level, INDIA, CHIHKG, MEAS_NAfr, Oth_CEE_CIS, R_S_Asia, Russia, S_O_Amer, and BRAZIL are the regions with the largest increase in non-ruminant output compared to the baseline scenario (Table 16).

Table 17 shows the difference in land use changes with the increased price sensitivity. The “G” columns are the baseline scenario, the "H” columns are the price sensitive scenario, and the difference (H-G) is listed in “I” columns. With increased price sensitivity, “I” columns of Table 17 indicate that about 3.8 million hectares of forest are spared, while both crop land and pasture area decline by just over 3 million hectares and 767 thousand hectares respectively. Even with the reduction in crop and pasture land, livestock output is higher at the global level for the price sensitive scenario compared to the baseline (Tables 15 to 17). While most regions had a decline in deforestation under the price sensitive scenario, four regions had an increase, which include BRAZIL, C_C_Amer, MEAS_NAfr, and S_S_AFR. The regions having the most reduction in deforestation are CHIHKG, INDIA, Mal_Indo, R_SE_Asia, and Rest of South Asia (R_S_Asia). These are also the major regions with the largest decrease in the crop land area (Table 17).

Table 18 compares total emissions from the baseline simulation to the emissions of the price sensitive scenario. At the global level, the total emissions with the reduced SUBPAR is about 17.5 billion tons of Co_2 e., approximately 2.3 billion tons less (about 11% less) than the baseline simulation. The 11% drop in emissions is partly due to the decrease in deforestation and the increase in crop land being used for pasture. The regions with substantial reduction in emissions are CHIHKG, Mala_Indo, R_SE_Asia, R_S_Asia, and INDIA (Table 18). The results indicate that more price sensitivity in consumption can lead to increased non-ruminant production and a substantial reduction in the global GHG emission.

Summary and conclusions

Based on regional projections of GDP, population, capital, and skilled and unskilled labor, demand for livestock outputs are forecasted for the period between the years 2004 to 2022. Globally, the demand for non-ruminant output increases the most. Regionally, this expansion is most evident in fast growing economies such as CHIHKG and INDIA. Livestock production and consumption are primarily driven by household and intermediate (processing or industrial) sources. Intermediate demand accounts for the majority of the output changes.

Changes in land use as a result of the growth in livestock output are estimated to be large with a loss of forest amounting to over 43.3 million hectares, a reduction in crop land of about 1 million hectares, and an increase in pasture of over 44 million hectares. Given that the forests sequester more carbon than other land uses, clearing them results in significant emissions of GHG. Alternatively, changing crop land to pasture has a significant effect on reducing GHG emissions. The change in land use due to increased livestock production increase emissions by about 20 billion tons of Co_2 e between 2004 and 2022 or about an average of 1.1 billion tons annually, which is about 15.5% of the total emissions (7.1 billion tons of Co_2 e) from livestock sector as estimated by Gerber et al.(2013) and about 2.2% of the total human induced GHG emissions (49 billion tons of Co_2 e) as estimated by the Intergovernmental Panel on Climate Change for the year 2004 (IPCC, 2007).

Even though the intermediate demand changes account for the majority of the land use changes from livestock production, their share in total emissions from land use changes is slightly smaller than the share of the private household demand. This is due primarily to the expansion of crop land associated with private demand changes which leads to higher emissions. This result is important given the fact that any intervention with an aim of reducing land use emissions from livestock production can achieve higher emission reduction by targeting the private household demand rather than intermediate demand. When consumer response to price changes are made more elastic i.e. more sensitive to price changes and willing to substitute more readily among livestock products, a reduction in the deforestation and GHG emissions occur.

The results from this study indicate that there is a potential for significant reduction in GHG emissions from livestock sector through policy interventions that target the consumption pattern of the private households. For this purpose, the intervention should encourage increased substitution among livestock products leading to increased consumption of non-ruminant products. Policies that promote consumption of non-ruminant products can be helpful in this regard.

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Table 1: Countries included in the GTAP-BIO regions

GTAP-BIO regions	Description of the regions	Corresponding countries
USA	United States	Usa
EU27	European Union 27	aut, bel, bgr, cyp, cze, deu, dnk, esp, est, fin, fra, gbr, grc, hun, irl, ita, ltu, lux, lva, mlt, nld, pol, prt, rom, svk, svn, swe
BRAZIL	Brazil	Bra
CAN	Canada	Can
JAPAN	Japan	Jpn
CHIHKG	China and Hong Kong	chn, hkg
INDIA	India	Ind
C_C_Amer	Central and Caribbean Americas	mex, xna, xca, xfa, xcb
S_o_Amer	South and Other Americas	col, per, ven, xap, arg, chl, ury, xsm
E_Asia	East Asia	kor, twn, xea
Mala_Indo	Malaysia and Indonesia	ind, mys
R_SE_Asia	Rest of South East Asia	phl, sgp, tha, vnm, xse
R_S_Asia	Rest of South Asia	bgd, lka, xsa
Russia	Russian Federation	Rus
Oth_CEE_CIS	Other East Europe and Rest of Former Soviet Union	xer, alb, hrv, xsu, tur
R_Europe	Rest of European Countries	che, xef
MEAS_NAfr	Middle Eastern and North Africa	xme,mar, tun, xnf
S_S_AFR	Sub Saharan Africa	Bwa, zaf, xsc, mwi, moz, tza, zmb, zwe, xsd, mdg, uga, xss
Oceania	Oceania countries	aus, nzl, xoc

Table 2: Projected growth (in percentage) in GDP, population, capital, and skilled and unskilled labor (2004-2022)

GTAP-BIO regions	GDP	Population	Capital	Skilled Labor	Unskilled Labor
USA	34.49	16.38	38.24	33.04	6.26
EU27	27.3	4.84	24.55	36.94	-13.56
BRAZIL	89.05	15.80	71.89	76.14	18.89
CAN	44.78	18.17	42.18	33.78	12.45
JAPAN	25.65	-1.76	10.59	26.62	-23.15
CHIHKG	312.68	7.08	319.00	79.36	4.19
INDIA	247.85	26.14	211.37	112.64	32.26
C_C_Amer	77.59	25.85	65.14	105.18	25.83
S_o_Amer	111.81	22.98	85.07	94.56	23.53
E_Asia	105.72	7.96	95.90	67.14	-1.60
Mala_Indo	129.3	20.4	106.39	114.25	22.62
R_SE_Asia	137.00	22.34	120.90	100.87	17.64
R_S_Asia	155.04	29.35	131.10	147.88	45.86
Russia	111.93	-2.76	44.30	22.57	-15.15
Oth_CEE_CIS	154.67	-0.02	71.04	27.13	-10.68
R_Europe	35.78	11.52	35.41	33.97	-5.44
MEAS_NAfr	108.47	31.71	99.06	113.78	17.07
S_S_AFR	143.00	54.08	95.65	160.34	59.46
Oceania	4.41	31.15	48.82	44.40	23.63

Source: GDP, Population and Capital changes from CEPII baseline version 2.1(Foure et. al, 2012). The data for skilled and unskilled labor are obtained from the baseline projection database prepared by Chappuis and Walmsly (2011)

Table 3: Projected growth (in percentage) in the global livestock output (2004-2022)

Livestock output	Percentage change
Milk	63.62
Ruminant*	83.96
Non-ruminant**	110.73

*Ruminant includes live ruminant animals such as cattle, buffalo, sheep, goats etc.
** Non-ruminant includes swine, poultry including eggs etc.

Table 4: Projected growth (in percentage) in the regional livestock output (2004-2022)

GTAP-BIO regions	Raw Milk	Ruminant	Non ruminant
USA	31.90	32.60	34.60
EU27	23.20	26.60	26.20
BRAZIL	70.20	73.30	77.00
CAN	48.30	61.00	61.60
JAPAN	21.60	18.50	18.90
CHIHKG	292.70	323.60	216.00
INDIA	188.30	170.90	208.30
C_C_Amer	67.20	46.80	65.80
S_o_Amer	88.80	84.70	86.70
E_Asia	58.20	52.70	58.30
Mala_Indo	97.10	68.60	135.90
R_SE_Asia	119.40	69.20	78.10
R_S_Asia	119.80	125.60	132.80
Russia	80.80	79.20	81.30
Oth_CEE_CIS	106.40	115.60	110.70
Oth_Europe	31.90	32.80	37.60
MEAS_NAfr	110.70	107.20	106.60
S_S_AFR	174.20	153.20	162.90
Oceania	60.70	70.40	78.60

Table 5: Projected growth (in percentage) in the regional household livestock demand (2004-2022)

GTAP-BIO regions	Milk	Ruminant	Non ruminant
USA	27.40	27.10	28.30
EU27	17.50	17.90	18.60
BRAZIL	62.30	62.10	63.40
CAN	41.10	40.50	41.00
JAPAN	16.60	18.00	20.60
CHIHKG	166.80	162.10	177.90
INDIA	175.10	183.80	194.10
C_C_Amer	53.00	48.70	54.40
S_o_Amer	89.90	79.90	88.30
E_Asia	40.40	44.50	53.00
Mala_Indo	93.70	102.30	132.30
R_SE_Asia	72.30	80.50	86.80
R_S_Asia	118.00	124.90	127.80
Russia	78.50	92.50	82.00
Oth_CEE_CIS	94.70	101.80	102.40
Oth_Europe	35.30	35.30	40.30
MEAS_NAfr	108.90	108.10	109.00
S_S_AFR	192.50	182.00	175.00
Oceania	63.40	62.90	67.80

Table 6: Projected growth (in percentage) in the food industry demand for livestock outputs (2004-2022)

GTAP-BIO regions	Milk	Ruminant	Non ruminant
USA	35.56	35.56	35.56
EU27	26.17	26.17	26.17
BRAZIL	71.19	71.19	71.19
CAN	40.16	40.16	40.16
JAPAN	20.60	20.60	20.60
CHIHKG	156.00	156.00	156.00
INDIA	174.67	174.67	174.67
C_C_Amer	72.96	72.96	72.96
S_o_Amer	80.23	80.23	80.23
E_Asia	55.27	55.27	55.27
Mala_Indo	83.14	83.14	83.14
R_SE_Asia	25.24	25.24	25.24
R_S_Asia	65.47	65.47	65.47
Russia	89.69	89.69	89.69
Oth_CEE_CIS	137.59	137.59	137.59
Oth_Europe	23.48	23.48	23.48
MEAS_NAfr	114.19	114.19	114.19
S_S_AFR	106.06	106.06	106.06
Oceania	60.21	60.21	60.21

Table 7: Projected change in land use (in hectare) induced by the change in household demand for livestock outputs (2004-2022)

GTAP-BIO Regions	Land use change with growth in all sectors (A)			Land use change with household demand for livestock fixed at the baseline level (B)			Land use change due to increase in household demand for livestock (C = A-B)		
	Forest	Cropland	Pasture	Forest	Cropland	Pasture	Forest	Cropland	Pasture
USA	291,008	(10,304)*	(280,720)	472,160	10,752	(482,864)	(181,152)	(21,056)	202,144
EU27	186,976	(88,264)	(98,676)	246,144	(94,104)	(152,044)	(59,168)	5,840	53,368
BRAZIL	4,909,472	(333,844)	(4,575,760)	7,517,648	(55,916)	(7,461,680)	(2,608,176)	(277,928)	2,885,920
CAN	73,904	(4,520)	(69,398)	134,984	(26,820)	(108,138)	(61,080)	22,300	38,740
JAPAN	44,128	(36,179)	(7,952)	49,134	(35,372)	(13,768)	(5,006)	(807)	5,815
CHIHKG	9,482,352	(6,177,248)	(3,304,960)	12,334,512	(8,730,400)	(3,603,968)	(2,852,160)	2,553,152	299,008
INDIA	668,762	(755,568)	86,836	1,066,094	(776,992)	(289,070)	(397,332)	21,424	375,906
C_C_Amer	162,808	(27,524)	(135,312)	201,968	(21,208)	(180,752)	(39,160)	(6,316)	45,440
S_o_Amer	2,506,504	(307,036)	(2,199,440)	4,456,112	(158,636)	(4,297,440)	(1,949,608)	(148,400)	2,098,000
E_Asia	49,760	(40,546)	(9,192)	138,410	(37,916)	(100,480)	(88,650)	(2,630)	91,288
Mala_Indo	745,968	(564,832)	(181,121)	1,153,288	(783,408)	(369,879)	(407,320)	218,576	188,758
R_SE_Asia	839,672	(687,292)	(152,376)	1,202,032	(800,868)	(401,153)	(362,360)	113,576	248,777
R_S_Asia	118,168	(244,816)	126,648	457,176	849,760	(1,306,944)	(339,009)	(1,094,576)	1,433,592
Russia	437,216	(200,216)	(237,040)	847,488	(182,040)	(665,544)	(410,272)	(18,176)	428,504
Oth_CEE_CIS	266,000	(219,112)	(46,880)	430,432	(144,912)	(285,472)	(164,432)	(74,200)	238,592
Oth_Europe	4,278	(1,160)	(3,125)	6,624	(327)	(6,295)	(2,346)	(833)	3,170
MEAS_NAfr	12,204	(75,756)	63,568	20,380	(24,324)	3,984	(8,175)	(51,432)	59,584
S_S_AFR	12,063,280	(9,281,232)	(2,782,080)	20,199,776	(8,845,456)	(11,354,240)	(8,136,496)	(435,776)	8,572,160
Oceania	48,745	(35,708)	(12,960)	67,005	(22,232)	(44,640)	(18,260)	(13,476)	31,680
World	32,911,205	(19,091,156)	(13,819,941)	51,001,367	(19,880,418)	(31,120,386)	(18,090,162)	789,262	17,300,445

*Values in parenthesis are the negative changes

Table 8: Projected change in land use (in hectare) induced by change in the intermediate demand for livestock outputs (2004-2022)

GTAP-BIO Regions	Land use change with growth in all sectors (A)			Land use change with intermediate demand for livestock fixed at the baseline level (D)			Land use change due to increase in intermediate demand for livestock (E = A-D)		
	Forest	Cropland	Pasture	Forest	Cropland	Pasture	Forest	Cropland	Pasture
USA	291,008	(10,304)*	(280,720)	389,872	(5,328)	(384,512)	(98,864)	(4,976)	103,792
EU27	186,976	(88,264)	(98,676)	249,488	(74,936)	(174,520)	(62,512)	(13,328)	75,844
BRAZIL	4,909,472	(333,844)	(4,575,760)	6,505,296	(181,312)	(6,324,128)	(1,595,824)	(152,532)	1,748,368
CAN	73,904	(4,520)	(69,398)	126,200	(23,428)	(102,772)	(52,296)	18,908	33,374
JAPAN	44,128	(36,179)	(7,952)	46,762	(35,126)	(11,640)	(2,634)	(1,053)	3,687
CHIHKG	9,482,352	(6,177,248)	(3,304,960)	25,433,632	(6,064,616)	(19,368,992)	(15,951,280)	(112,632)	16,064,032
INDIA	668,762	(755,568)	86,836	950,162	(658,960)	(291,196)	(281,400)	(96,608)	378,032
C_C_Amer	162,808	(27,524)	(135,312)	290,004	(11,352)	(278,704)	(127,196)	(16,172)	143,392
S_o_Amer	2,506,504	(307,036)	(2,199,440)	4,029,008	(183,424)	(3,845,648)	(1,522,504)	(123,612)	1,646,208
E_Asia	49,760	(40,546)	(9,192)	97,242	(35,594)	(61,624)	(47,482)	(4,952)	52,432
Mala_Indo	745,968	(564,832)	(181,121)	768,192	(441,896)	(326,300)	(22,224)	(122,936)	145,179
R_SE_Asia	839,672	(687,292)	(152,376)	1,165,224	(541,860)	(623,412)	(325,552)	(145,432)	471,036
R_S_Asia	118,168	(244,816)	126,648	203,097	243,420	(446,544)	(84,929)	(488,236)	573,192
Russia	437,216	(200,216)	(237,040)	493,008	(197,048)	(296,000)	(55,792)	(3,168)	58,960
Oth_CEE_CIS	266,000	(219,112)	(46,880)	345,140	(144,472)	(200,640)	(79,140)	(74,640)	153,760
Oth_Europe	4,278	(1,160)	(3,125)	5,300	(704)	(4,615)	(1,022)	(456)	1,489
MEAS_NAfr	12,204	(75,756)	63,568	17,083	(46,480)	29,408	(4,879)	(29,276)	34,160
S_S_AFR	12,063,280	(9,281,232)	(2,782,080)	16,998,064	(8,809,792)	(8,188,608)	(4,934,784)	(471,440)	5,406,528
Oceania	48,745	(35,708)	(12,960)	68,983	11,700	(80,736)	(20,238)	(47,408)	67,776
World	32,911,205	(19,091,156)	(13,819,941)	58,181,756	(17,201,207)	(40,981,182)	(25,270,551)	(1,889,949)	27,161,242

*Values in parenthesis are the negative changes

Table 9: Projected change in land use (in hectare) induced by change in the combined demand (household plus intermediate) for livestock outputs (2004-2022)

GTAP-BIO Regions	Land use change with growth in all sectors (A)			Land use change with private and intermediate demand for livestock fixed at the baseline level (F)			Land use change due to increase in sum of private and intermediate demand for livestock (G = A-F)		
	Forest	Cropland	Pasture	Forest	Cropland	Pasture	Forest	Cropland	Pasture
USA	291,008	(10,304)*	(280,720)	571,024	15,728	(586,656)	(280,016)	(26,032)	305,936
EU27	186,976	(88,264)	(98,676)	308,656	(80,776)	(227,888)	(121,680)	(7,488)	129,212
BRAZIL	4,909,472	(333,844)	(4,575,760)	9,113,472	96,616	(9,210,048)	(4,204,000)	(430,460)	4,634,288
CAN	73,904	(4,520)	(69,398)	187,280	(45,728)	(141,512)	(113,376)	41,208	72,114
JAPAN	44,128	(36,179)	(7,952)	51,768	(34,318)	(17,455)	(7,640)	(1,861)	9,503
CHIHKG	9,482,352	(6,177,248)	(3,304,960)	28,285,792	(8,617,768)	(19,668,000)	(18,803,440)	2,440,520	16,363,040
INDIA	668,762	(755,568)	86,836	1,347,494	(680,384)	(667,102)	(678,732)	(75,184)	753,938
C_C_Amer	162,808	(27,524)	(135,312)	329,164	(5,036)	(324,144)	(166,356)	(22,488)	188,832
S_o_Amer	2,506,504	(307,036)	(2,199,440)	5,978,616	(35,024)	(5,943,648)	(3,472,112)	(272,012)	3,744,208
E_Asia	49,760	(40,546)	(9,192)	185,892	(32,964)	(152,912)	(136,132)	(7,582)	143,720
Mala_Indo	745,968	(564,832)	(181,121)	1,175,512	(660,472)	(515,058)	(429,544)	95,640	333,937
R_SE_Asia	839,672	(687,292)	(152,376)	1,527,584	(655,436)	(872,188)	(687,912)	(31,856)	719,812
R_S_Asia	118,168	(244,816)	126,648	542,105	1,337,996	(1,880,136)	(423,938)	(1,582,812)	2,006,784
Russia	437,216	(200,216)	(237,040)	903,280	(178,872)	(724,504)	(466,064)	(21,344)	487,464
Oth_CEE_CIS	266,000	(219,112)	(46,880)	509,572	(70,272)	(439,232)	(243,572)	(148,840)	392,352
Oth_Europe	4,278	(1,160)	(3,125)	7,646	129	(7,784)	(3,368)	(1,289)	4,659
MEAS_NAfr	12,204	(75,756)	63,568	25,258	4,952	(30,176)	(13,054)	(80,708)	93,744
S_S_AFR	12,063,280	(9,281,232)	(2,782,080)	25,134,560	(8,374,016)	(16,760,768)	(13,071,280)	(907,216)	13,978,688
Oceania	48,745	(35,708)	(12,960)	87,243	25,176	(112,416)	(38,498)	(60,884)	99,456
World	32,911,205	(19,091,156)	(13,819,941)	76,271,918	(17,990,469)	(58,281,627)	(43,360,713)	(1,100,688)	44,461,687

*Values in parenthesis are the negative changes

Table 10: Total induced emission (in 1000 tons Co_2 e) from land use changes due to changes in household demand for livestock output

GTAP-BIO Regions	Land Conversion Sequences[6]								Total
	F-to-C	P-to-C	CP-to-C	C-to-F	C-to-P	C-to-CP	P-to-F	F-to-P	
USA	11,524	0	0	0	-2,534	-48,509	0	41,183	1,663
EU27	2,585	0	0	0	-22	0	0	11,150	13,714
BRAZIL	0	0	0	0	-49,940	-102,117	0	1,804,984	1,652,928
CAN	11,405	0	0	0	-152	0	0	10,347	21,600
JAPAN	412	0	0	0	-393	0	0	931	950
CHIHKG	1,467,582	6,331	0	0	0	0	0	74,432	1,548,345
INDIA	96,506	0	0	0	-8,182	0	0	136,876	225,201
C_C_Amer	0	0	0	0	-1,533	0	0	21,827	20,295
S_o_Amer	256	0	0	0	-33,949	0	0	1,020,114	986,421
E_Asia	404	0	0	0	-280	0	0	9,717	9,841
Mala_Indo	444,061	0	0	0	-3,500	0	0	146,716	587,278
R_SE_Asia	94,663	0	0	0	-6	0	0	152,009	246,666
R_S_Asia	177,043	0	0	0	-61,217	0	0	60,530	176,356
Russia	17,026	0	0	0	-6,372	0	0	38,848	49,501
Oth_CEE_CIS	1,661	0	0	0	-5,657	0	0	31,172	27,176
Oth_Europe	0	0	0	0	-167	0	0	303	136
MEAS_Nafr	0	0	0	0	-3,884	0	0	3,112	-772
S_S_Afr	343,949	0	0	0	-72,024	0	0	4,097,118	4,369,043
Oceania	2,719	0	0	0	-895	0	0	5,948	7,771
World	2,671,798	6,331	0	0	-250,707	-150,626	0	7,667,318	9,944,113.43

[6] F = forest, C = cropland, P = pasture, and CP = cropland- pasture (land that can alternate between crop cultivation and pasture).

Table 11: Total induced emission (in 1000 tons Co_2 e) from land use changes due to changes in intermediate demand for livestock output

GTAP-BIO Regions	Land Conversion Sequences[7]								Total
	F-to-C	P-to-C	CP-to-C	C-to-F	C-to-P	C-to-CP	P-to-F	F-to-P	
USA	8,192	0	0	0	-1,240	-17,806	0	21,429	10,575
EU27	-2,181	0	0	0	-1,106	0	0	14,005	10,717
BRAZIL	0	0	0	0	-27,611	-60,945	0	1,102,322	1,013,766
CAN	9,642	0	0	0	-124	0	0	8,947	18,464
JAPAN	92	0	0	0	-309	0	0	538	322
CHIHKG	315,839	-6,331	0	0	-33,138	0	0	4,824,257	5,100,628
INDIA	1,835	0	0	0	-8,286	0	0	141,041	134,590
C_C_Amer	0	0	0	0	-3,932	0	0	70,750	66,818
S_o_Amer	-92	0	0	0	-29,268	0	0	795,055	765,695
E_Asia	-188	0	0	0	-357	0	0	5,117	4,573
Mala_Indo	-188,931	0	0	0	-5,928	0	0	103,668	-91,190
R_SE_Asia	-76,725	0	0	0	-11,463	0	0	254,869	166,680
R_S_Asia	2,913	0	0	0	-22,604	0	0	43,123	23,432
Russia	2,215	0	0	0	-910	0	0	5,308	6,613
Oth_CEE_CIS	-1,661	0	0	0	-6,262	0	0	16,399	8,476
Oth_Europe	0	0	0	0	-93	0	0	135	42
MEAS_Nafr	0	0	0	0	-2,180	0	0	1,860	-320
S_S_Afr	38,345	0	0	0	-41,384	0	0	2,581,601	2,578,562
Oceania	-545	0	0	0	-2,298	0	0	9,264	6,422
World	108,751	-6,331	0	0	-198,494	-78,751	0	9,999,689	9,824,864

[7] F = forest, C = cropland, P = pasture, and CP = cropland- pasture (land that can alternate between crop cultivation and pasture).

Table 12: Total induced emission (in 1000 tons CO_2 e) from land use changes due to changes in the combined demand (household plus intermediate) for livestock output

GTAP-BIO Regions	Land Conversion Sequences[8]								Total
	F-to-C	P-to-C	CP-to-C	C-to-F	C-to-P	C-to-CP	P-to-F	F-to-P	
USA	19,716	0	0	0	-3,774	-66,315	0	62,612	12,239
EU27	404	0	0	0	-1,128	0	0	25,155	24,431
BRAZIL	0	0	0	0	-77,551	-163,062	0	2,907,306	2,666,693
CAN	21,047	0	0	0	-276	0	0	19,294	40,064
JAPAN	505	0	0	0	-702	0	0	1,469	1,272
CHIHKG	1,783,421	0	0	0	-33,138	0	0	4,898,689	6,648,973
INDIA	98,341	0	0	0	-16,468	0	0	277,917	359,791
C_C_Amer	0	0	0	0	-5,465	0	0	92,577	87,112
S_o_Amer	164	0	0	0	-63,217	0	0	1,815,169	1,752,116
E_Asia	216	0	0	0	-637	0	0	14,834	14,414
Mala_Indo	255,131	0	0	0	-9,428	0	0	250,385	496,087
R_SE_Asia	17,938	0	0	0	-11,469	0	0	406,877	413,346
R_S_Asia	179,956	0	0	0	-83,821	0	0	103,653	199,788
Russia	19,241	0	0	0	-7,282	0	0	44,155	56,114
Oth_CEE_CIS	0	0	0	0	-11,919	0	0	47,571	35,653
Oth_Europe	1	0	0	0	-260	0	0	437	177
MEAS_Nafr	0	0	0	0	-6,064	0	0	4,972	-1,092
S_S_Afr	382,294	0	0	0	-113,408	0	0	6,678,720	6,947,606
Oceania	2,174	0	0	0	-3,193	0	0	15,212	14,193
World	2,781,398	0	0	0	-437,208	-229,377	0	17,688,554	19,768,978

[8] F = forest, C = cropland, P = pasture, and CP = cropland- pasture (land that can alternate between crop cultivation and pasture).

Table 13: Compensated elasticities in CHIHKG for the baseline scenario

Livestock outputs	Milk	Ruminant	Non ruminant
Milk	-0.2130	0.0001	0.0001
Ruminants	0.0001	-0.2537	0.0002
Non ruminants	0.0001	0.0002	-0.2075

Table 14: Compensated elasticities in CHIHKG with the reduced SUBPAR

Livestock outputs	Dairy animals	Ruminant	Non ruminant
Dairy animals	-0.6098	0.0012	0.0602
Ruminants	0.0005	-0.6286	0.0616
Non ruminants	0.0005	0.0012	-0.5498

Table 15: Percentage point difference in the global livestock output growth with the reduced SUBPAR compared to the baseline simulation

Livestock outputs	Percentage point difference in growth compared to baseline simulation
Milk	3.40
Ruminant	2.75
Non-ruminant	7.98

Table 16: Percentage point difference in the regional livestock output growth with the reduced SUBPAR compared to the baseline simulation

GTAP-BIO regions	Milk	Ruminant	Non ruminant
USA	0.10	0.40	0.40
EU27	0.80	0.40	0.80
BRAZIL	12.80	9.70	10.00
CAN	1.70	1.00	1.40
JAPAN	1.40	1.50	1.10
CHIHKG	-0.70	-0.60	15.00
INDIA	7.70	-0.90	29.70
C_C_Amer	0.80	0.20	2.20
S_o_Amer	10.20	8.30	10.30
E_Asia	5.80	4.30	4.70
Mala_Indo	-0.10	-0.60	1.10
R_SE_Asia	3.60	-2.20	1.90
R_S_Asia	-0.80	-1.60	12.20
Russia	8.20	15.80	11.70
Oth_CEE_CIS	12.60	9.40	12.30
Oth_Europe	1.10	0.20	1.40
MEAS_NAfr	11.30	11.80	14.40
S_S_AFR	-2.20	1.80	4.10
Oceania	3.30	1.60	2.40

Table 17: Impact of higher substitution in consumption on the land use change (in hectare)

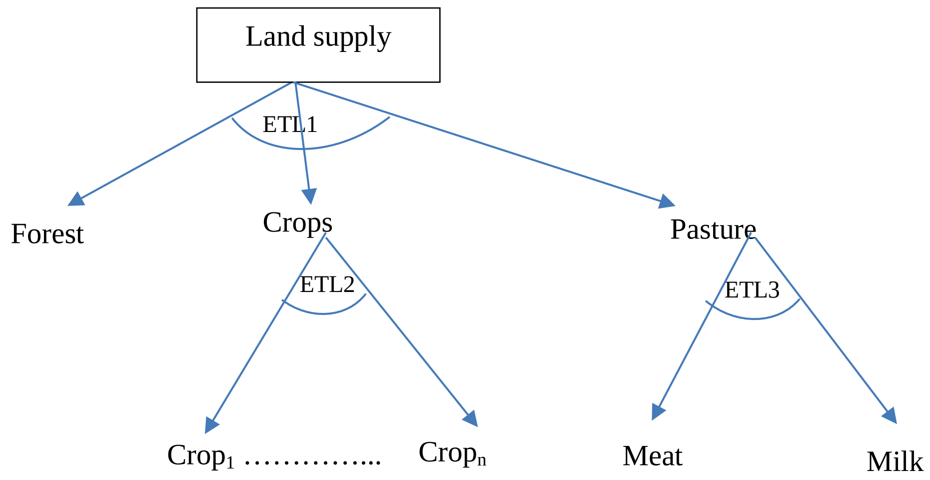
GTAP-BIO Regions	Land use change due to change in the aggregate demand for livestock output in the baseline scenario (G)			Land use change due to change in the aggregate demand for livestock with the reduced SUBPAR (H)			Difference in land use change due to reduced SUBPAR (I = H - G)		
	Forest	Cropland	Pasture	Forest	Cropland	Pasture	Forest	Cropland	Pasture
USA	(280,016)	(26,032)	305,936	(256,992)	(48,096)	305,104	23,024	(22,064)	(832)
EU27	(121,680)	(7,488)	129,212	(114,896)	(20,176)	135,004	6,784	(12,688)	5,792
BRAZIL	(4,204,000)	(430,460)	4,634,288	(4,568,416)	(527,912)	5,096,464	(364,416)	(97,452)	462,176
CAN	(113,376)	41,208	72,114	(107,440)	32,292	75,206	5,936	(8,916)	3,092
JAPAN	(7,640)	(1,861)	9,503	(7,618)	(2,860)	10,475	22	(999)	973
CHIHKG	(18,803,440)	2,440,520	16,363,040	(15,675,056)	674,496	15,000,576	3,128,384	(1,766,024)	(1,362,464)
INDIA	(678,732)	(75,184)	753,938	(481,876)	(271,136)	753,042	196,856	(195,952)	(896)
C_C_Amer	(166,356)	(22,488)	188,832	(172,464)	(21,672)	194,184	(6,108)	816	5,352
S_o_Amer	(3,472,112)	(272,012)	3,744,208	(3,421,528)	(325,448)	3,746,944	50,584	(53,436)	2,736
E_Asia	(136,132)	(7,582)	143,720	(126,620)	(14,378)	140,992	9,512	(6,796)	(2,728)
Mala_Indo	(429,544)	95,640	333,937	(102,092)	(196,864)	298,957	327,452	(292,504)	(34,980)
R_SE_Asia	(687,912)	(31,856)	719,812	(489,032)	(184,228)	673,275	198,880	(152,372)	(46,537)
R_S_Asia	(423,938)	(1,582,812)	2,006,784	(98,976)	(1,295,420)	1,394,360	324,962	287,392	(612,424)
Russia	(466,064)	(21,344)	487,464	(389,280)	(82,136)	471,360	76,784	(60,792)	(16,104)
Oth_CEE_CIS	(243,572)	(148,840)	392,352	(205,360)	(197,128)	402,688	38,212	(48,288)	10,336
Oth_Europe	(3,368)	(1,289)	4,659	(3,316)	(1,515)	4,840	52	(226)	181
MEAS_NAfr	(13,054)	(80,708)	93,744	(13,435)	(100,072)	113,520	(381)	(19,364)	19,776
S_S_AFR	(13,071,280)	(907,216)	13,978,688	(13,245,584)	(1,524,080)	14,769,792	(174,304)	(616,864)	791,104
Oceania	(38,498)	(60,884)	99,456	(34,076)	(73,100)	107,136	4,422	(12,216)	7,680
World	(43,360,713)	(1,100,688)	44,461,687	(39,514,057)	(4,179,433)	43,693,919	3,846,657	(3,078,745)	(767,767)

Table 18: Impact on induced land emission (in 1000 tons Co_2 e) with the reduced SUBPAR

GTAP-BIO Regions	Land Conversion Sequences[9]								Emissions with the new SUBPAR (A)	Emissions in the baseline simulation (B)	Difference in emissions (A-B)
	F-to-C	P-to-C	CP-to-C	C-to-F	C-to-P	C-to-CP	P-to-F	F-to-P			
USA	14,074	0	0	0	-4,322	-74,787	0	59,772	-5,263	12,239	-17,502
EU27	88	0	0	0	-2,813	0	0	23,886	21,161	24,431	-3,270
BRAZIL	0	0	0	0	-95,183	-187,099	0	3,158,970	2,876,688	2,666,693	209,995
CAN	17,645	0	0	0	-324	0	0	19,757	37,079	40,064	-2,986
JAPAN	345	0	0	0	-879	0	0	1,528	994	1,272	-278
CHIHKG	768,930	0	0	0	-38,790	0	0	4,494,995	5,225,136	6,648,973	-1,423,837
INDIA	26,252	0	0	0	-28,145	0	0	226,234	224,342	359,791	-135,449
C_C_Amer	0	0	0	0	-5,179	0	0	95,967	90,789	87,112	3,677
S_o_Amer	3	0	0	0	-75,799	0	0	1,789,402	1,713,605	1,752,116	-38,510
E_Asia	114	0	0	0	-1,191	0	0	13,351	12,273	14,414	-2,141
Mala_Indo	0	0	0	0	-47,713	0	0	86,104	38,390	496,087	-457,697
R_SE_Asia	484	0	0	0	-37,947	0	0	298,009	260,546	413,346	-152,800
R_S_Asia	9,134	0	0	0	-67,321	0	0	46,576	-11,611	199,788	-211,400
Russia	8,194	0	0	0	-9,383	0	0	39,032	37,844	56,114	-18,270
Oth_CEE_CIS	0	0	0	0	-17,162	0	0	40,151	22,989	35,653	-12,664
Oth_Europe	0	0	0	-12	-303	0	0	434	119	177	-59
MEAS_Nafr	0	0	0	0	-7,369	0	0	5,125	-2,244	-1,092	-1,153
S_S_Afr	122,084	0	0	0	-137,012	0	0	6,958,418	6,943,490	6,947,606	-4,115
Oceania	32	0	0	0	-3,690	0	0	14,887	11,230	14,193	-2,963
World	967,380	0	0	-12	-580,524	-261,885	0	17,372,597	17,497,556	19,768,978	-2,271,422

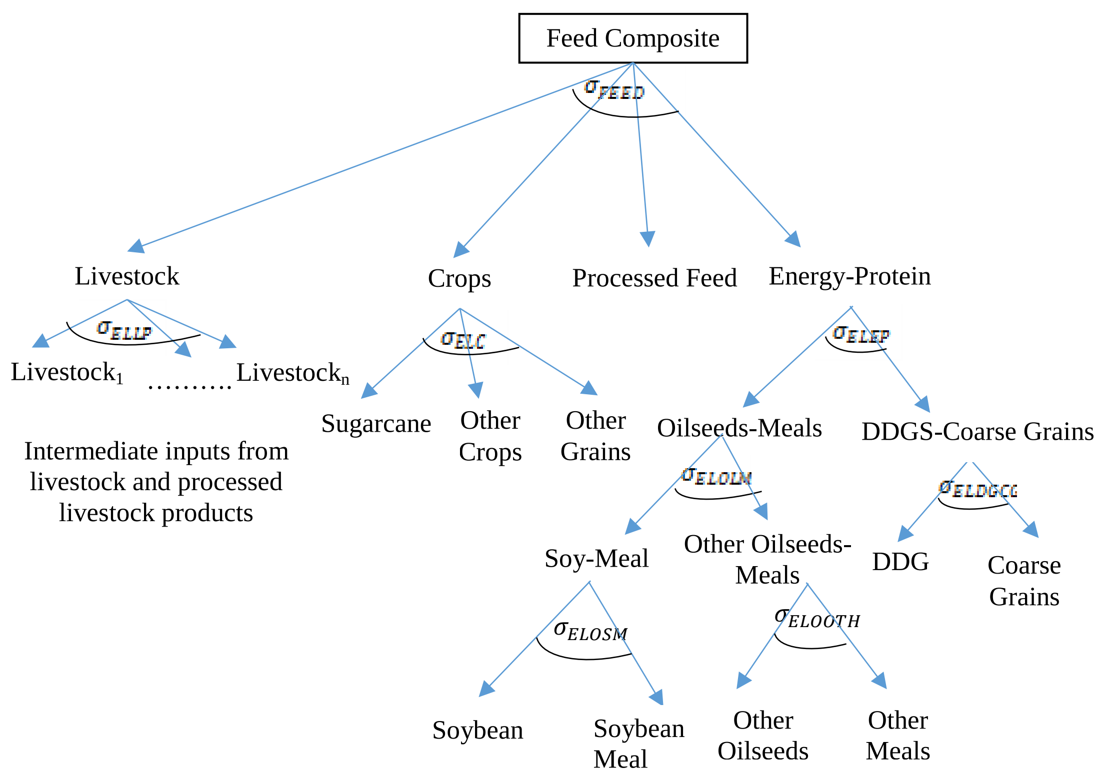
[9] F = forest, C = cropland, P = pasture, and CP = cropland pasture.

Figure 1: Land supply in the GTAP BIO model



(Source: GTAP-BIO model)

Figure 2: Feed demand structure for livestock industry in the GTAP-BIO model



(Source: Taheripour et al., 2011 and GTAP-BIO model)

Appendix A: Experiments used in the simulation

Experiment 1: Simulation without fixing demand for livestock output

Exogenous shocks to GDP, population, capital, and skilled and unskilled labor

shock qgdp(REG) = file shcks.har header "QGDP";

shock pop = file shcks.har header "POPU";

shock qo("Capital", REG) = file shcks.har header "CAPI";

shock qo("sklab", REG) = file shcks.har header "SLAB"; shock

qo("Unsklab", REG) = file shcks.har header "ULAB";

The "shcks.har" file contained data on projected growth in GDP, population, capital, and skilled and unskilled labor as outlined in Table 2.

Model Closure: In order to achieve, the state growth in GDP following swap is implemented.

Swap afreg(REG) = qgdp(REG);

This swap makes factor augmenting technology (*afreg*) for each region in the model endogenous and hence the model mathematically solves for the growth in *afreg* until the GDP target is attained.

Experiment 2: Simulation with demand for household demand for the livestock output fixed at the baseline level

This simulation is performed in order to isolate the impact of household demand on land use change. In addition to the shocks and swap mentioned in experiment 1, following swaps are implemented to fix household demand for livestock output at the baseline levels.

swap qp("Dairy_Farms" , REG) = consslack("Dairy_Farms" , REG);

swap qp("Ruminant" , REG) = consslack("Ruminant" , REG);

swap qp("NonRuminant" , REG) = consslack("NonRuminant" , REG);

swap qp("Proc_Dairy" , REG) = consslack("Proc_Dairy" , REG); swap

qp("Proc_Rum" , REG) = consslack("Proc_Rum" , REG);

swap qp("Proc_NonRum" , REG) = consslack("Proc_NonRum" , REG);

Experiment 3: Simulation with the combined demand (household plus intermediate) for the livestock output fixed at baseline level

In order to fix intermediate demand in addition to the household demand for livestock output, following swaps are added in addition to the swaps and shocks in simulation 2a.

swap qf("Dairy_Farms" , ALL_INDS,REG) = afall("Dairy_Farms", ALL_INDS,REG);

swap qf("Ruminant",ALL_INDS,REG) = afall("Ruminant" ,ALL_INDS,REG);

swap qf("NonRuminant" , ALL_INDS,REG) = afall("NonRuminant", ALL_INDS,REG);

swap qf("Proc_Dairy" , ALL_INDS,REG) = afall("Proc_Dairy" , ALL_INDS,REG); swap

qf("Proc_Rum",ALL_INDS,REG) = afall("Proc_Rum",ALL_INDS,REG);

swap qf("Proc_NonRum", ALL_INDS,REG) = afall("Proc_NonRum", ALL_INDS,REG);

swap txs("Dairy_Farms",REG,REG) = qxs("Dairy_Farms",REG,REG);

swap txs("Ruminant",REG,REG) = qxs("Ruminant",REG,REG);

swap txs("NonRuminant",REG,REG) = qxs("NonRuminant",REG,REG); swap

txs("Proc_NonRum",REG,REG) = qxs("Proc_NonRum",REG,REG); swap

txs("Proc_Rum",REG,REG) = qxs("Proc_Rum",REG,REG);

swap txs("Proc_Dairy",REG,REG) = qxs("Proc_Dairy",REG,REG);

swap qgm("Proc_Rum",REG)=tgm("Proc_Rum",REG);

swap qpm("Proc_Rum",REG)=tpm("Proc_Rum",REG);

swap qgm("Proc_NonRum",REG)=tgm("Proc_NonRum",REG);

swap qpm("Proc_NonRum",REG)=tpm("Proc_NonRum",REG);

swap qgm("Proc_Dairy",REG)=tgm("Proc_Dairy",REG);

swap qpm("Proc_Dairy",REG)=tpm("Proc_Dairy",REG);

Appendix B: SUBPAR used in the simulations

1) SUBPAR used in the baseline simulations

GTAP-BIO regions	Dairy animals	Ruminant	Non ruminant	Dairy products	Ruminant products	Non-ruminant products
USA	0.30	0.30	0.30	0.30	0.30	0.30
EU27	0.44	0.49	0.47	0.41	0.42	0.44
BRAZIL	0.77	0.77	0.77	0.77	0.77	0.77
CAN	0.40	0.39	0.40	0.40	0.40	0.40
JAPAN	0.35	0.35	0.35	0.35	0.35	0.35
CHIHKG	0.79	0.75	0.78	0.49	0.74	0.77
INDIA	0.82	0.82	0.82	0.82	0.82	0.82
C_C_Amer	0.76	0.73	0.73	0.74	0.76	0.77
S_o_Amer	0.79	0.76	0.78	0.77	0.77	0.78
E_Asia	0.61	0.64	0.65	0.61	0.61	0.61
Mala_Indo	0.81	0.78	0.73	0.76	0.73	0.75
R_SE_Asia	0.87	0.81	0.79	0.75	0.78	0.80
R_S_Asia	0.84	0.84	0.84	0.83	0.83	0.83
Russia	0.76	0.72	0.76	0.76	0.76	0.76
Oth_CEE_CIS	0.77	0.77	0.77	0.77	0.77	0.77
Oth_Europe	0.24	0.24	0.24	0.24	0.24	0.24
MEAS_NAfr	0.75	0.74	0.74	0.75	0.76	0.74
S_S_AFR	0.82	0.81	0.81	0.78	0.78	0.80
Oceania	0.42	0.40	0.41	0.42	0.44	0.42

2) SUBPAR used in the sensitivity simulations

GTAP-BIO regions	Dairy animals	Ruminant	Non ruminant	Dairy products	Ruminant products	Non-ruminant products
USA	0.15	0.15	0.15	0.15	0.15	0.15
EU27	0.22	0.25	0.23	0.21	0.21	0.22
BRAZIL	0.38	0.38	0.38	0.38	0.38	0.38
CAN	0.20	0.20	0.20	0.20	0.20	0.20
JAPAN	0.17	0.17	0.17	0.17	0.17	0.17
CHIHKG	0.39	0.37	0.39	0.25	0.37	0.38
INDIA	0.41	0.41	0.41	0.41	0.41	0.41
C_C_Amer	0.38	0.36	0.37	0.37	0.38	0.38
S_o_Amer	0.39	0.38	0.39	0.38	0.39	0.39
E_Asia	0.30	0.32	0.33	0.30	0.30	0.31
Mala_Indo	0.40	0.39	0.36	0.38	0.36	0.38
R_SE_Asia	0.43	0.40	0.40	0.38	0.39	0.40
R_S_Asia	0.42	0.42	0.42	0.42	0.42	0.42
Russia	0.38	0.36	0.38	0.38	0.38	0.38
Oth_CEE_CIS	0.39	0.38	0.39	0.39	0.39	0.39
Oth_Europe	0.12	0.12	0.12	0.12	0.12	0.12
MEAS_NAfr	0.38	0.37	0.37	0.38	0.38	0.37
S_S_AFR	0.41	0.41	0.40	0.39	0.39	0.40
Oceania	0.21	0.20	0.20	0.21	0.22	0.21