Spill-overs and trade-offs for increasing livestock productivity

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Article

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Abstract

The overarching goal of the United Nations Food Systems Summit is to catalyze action for the transformations needed in food systems to accelerate the progress toward sustainable development goals (SDG). However, given the complexity of these interactions, gains in one area may determine losses in others. Using the Livestock Policy Simulation Model (LPSM), we assessed the effect of enhancing the productivity in the Ethiopian livestock sector by 2030. We show that an increase in productivity has several positive effects on GDP, employment generation, household consumption, and poverty reduction; however, these benefits might come at an environmental cost associated with a total increase in greenhouse gas emissions. Our results have important policy implications, showing that the achievement of some SDG targets could conflict with the accomplishment of others. The analysis illustrates the capacity of LPSM to integrate economic, social, and environmental dimensions while quantifying spillovers and trade-offs.

Main

Structural reforms are required in food systems to enhance their contribution to the Agenda 2030 for sustainable development (Webb et al., 2020). Indeed, the overarching goal of the United Nations Food Systems Summit 2021 (UN, 2021) is to catalyze action for the transformations needed in food systems. However, evidence highlights that benefits in one area may determine costs in others (Mehrabi et al., 2020). Thus, the design of sustainable agricultural policies requires balancing multiple goals (Barret et al., 2020) and broader assessments of the potential outcomes and their consequences (Piñeiro et al., 2020). The failure to analyze ex-ante the potential effects of policy interventions could result in the preclusion of positive synergies given the predominance of unintended negative effects.

Livestock has been acknowledged as one of the most complex subsectors of model agriculture (Msangi et al., 2014). Traditionally, livestock policy analysis has focused on assessing the behavior of the system as decision-making units operating in isolation. An advantage of this approach is that it permits the assessment of the direct effects of a policy change on a specific production system. One of the limitations is that it does not allow examination of how these changes affect the rest of the economy. This is a relevant pitfall in the context of the food systems approach, in which the interdependencies between different agents are primary features. To address this gap, the Food and Agriculture Organization (FAO) of the United Nations developed the Livestock Policy Simulation Model (LPSM).

The LPSM is a recursive dynamic open (CGE) model designed for country-level ex-ante policy analysis (Fig 1). LPSM is “recursive” as the model is solved sequentially and repeatedly, one period at a time; “dynamic” as the economy’s progression is modeled over time; “open” as the model allows for trade across borders. These characteristics allow the model to simulate the direct and indirect effects of policy change or economic shocks in the sector. This study aims to introduce the LPSM, illustrating its potential to conduct ex-ante livestock policy analysis, in support of sectoral planning processes. By employing Ethiopia as a case study, we examined the effects of increasing livestock total factor productivity (TFP).

Ethiopia is one of the countries with the largest livestock population in the world (FAO, 2021). Projections suggest that by 2050, the population will double, and GDP will triple, substantially increasing the demand for livestock products (FAO, 2019). Thus, increasing the sector’s productivity will be fundamental to ensuring that economic gains will not come at an environmental cost. To address this challenge, the government has embarked on a sectoral planning exercise to enhance the livestock sector’s sustainable transformation (Federal Democratic Republic of Ethiopia, 2016).

The results show that an increase in productivity growth by 2030 will have several positive effects on economic growth (0.7%), employment generation (0.78%), household consumption (0.82%), and poverty reduction (0.18pp); however, there might be also negative environmental effects associated with a total increase in GHG emissions (5.9%). These results have important policy implications, showing that the achievement of some SDG targets could conflict with accomplishing others. The analysis illustrates the capacity of LPSM to integrate economic, social, and environmental dimensions while quantifying spillover and trade-offs.

The Economic Structure of Ethiopia’s Livestock Sector

This section describes the economic structure of Ethiopia’s livestock sector based on information derived from the country’s social accounting matrix (SAM) for 2016. As the LPSM is livestock-specific, these statistics disaggregate livestock production to the species/product level, with crops, industry, and services comprising the remainder of total economic activity. These data provide an overview of economic functioning and the contributions of different sectors. Table 1 presents a summary of the main descriptive statistics calculated from the SAM. The value-added or GDP contribution of the agriculture sector is 36.68% (Table 1), demonstrating Ethiopia’s heavy economic reliance on the sector. In comparison, Kenya’s agricultural value-added for the same year was 26.31%, and Uganda's was 28.82% (World Bank, 2020). Of agriculture’s total value-added, livestock contributes 16.5% (6.07% of GDP), with the remainder attributable to crops. As such, the livestock sector is a small but significant component of the total value-added.

Table 1 Economic structure of the Ethiopian livestock sector

	Sectoral structure %						Sectoral factor intensity %					Sectoral demand structure %				
Commodity	VA	EMP	EXP	EXP-O	IMP	IMP-D	Unskilled	Semi-skill	Skilled	Capital	Land	Intermed	Priv Cons	Gov Cons	Inventory	Exports
Beef Cattle	1.56	1.21	3.04	0	0.02	0.41	65.3	4.3	1.6	8.3	20.4	18.5	63.8	0	0	0
Dairy Cattle	2.43	1.9	4.71	0	0	0	65	4.1	1.6	8.1	21.1	28	72	0	0	0
Sheep	0.65	0.52	1.31	33.54	0	0	67.5	4.2	1.8	8	18.5	4.1	64.2	0	-2.1	33.8
Goats	0.62	0.49	1.24	0	0	0	67.5	4.3	1.8	8	18.5	0	97.2	0	0	0
Poultry	0.32	0.25	0.61	0.02	0.01	0.76	64.6	4.3	1.7	8.5	21	22	49.9	0	0	0
Other Livestock	0.49	0.43	0.88	1.33	0	0.01	49.1	2	1.1	39.1	8.8	35.9	50.1	0	0	1.3
Meat	0.09	0.53	0.07	17.65	0	0.21	13.8	2.2	1	83.1	0	27.1	55.3	0	0	17.6
Dairy	0.03	0.46	0.05	0.03	0.1	5.21	28.9	5.9	1.9	63.3	0	9.8	90.1	0	0	0.1
Other Food	2.05	3.3	2.2	1.24	5.28	27.09	18	3.7	1.8	76.5	0	29.5	69.7	0	0	0.8
Services	42.06	41.52	20.56	7.16	11.14	7.35	16.3	6.6	16.4	60.8	0	49.3	28.6	15.4	0	6.6
Crops	30.61	24.26	59.24	6.31	5.06	5.21	64.7	4.2	1.9	8.3	20.8	10	82.9	0	0	7.1
Industry	19.09	25.13	6.09	1.11	78.38	44.68	32.8	14.1	8.9	44.2	0	32.8	12.5	0	0	0.7

VA: Sectoral share in value-added (GDP contribution); EMP: Employment Share; EXP: Export share; EXP-O: domestic sectoral supplies between exports and domestic sales; IMP: import share; IMP-D: domestic sectoral demand between exports and domestic sales output; Unskilled: low skilled labor factor intensity; Semi-skill: semi-skilled labor factor intensity; Skilled: skilled labor factor intensity; Capital: capital factor intensity; Land: land factor intensity; Intermed: intermediate sectoral demand; Priv Cons: private consumption sector demand; Gov Cons: government consumption sector demand; Inventory: inventory changes; Exports: Export sector demand.

The high level of disaggregation of Ethiopia's SAM allows for a detailed analysis of sectoral factor intensity. Factor intensity reflects the relative importance of each production factor within a sector. All production factors are represented, namely, labor (disaggregated by skill level), capital, and land. In terms of factor intensity, livestock along with crops use the highest share of labor; however, the disaggregation of employment depending on skill level indicates that the greatest proportion is unskilled. The ratio of unskilled to semi-skilled to skilled labor for cattle, sheep, goats, and poultry is approximately 65%, 4.3%, and 1.7%, respectively. Livestock operates on average at a higher capital intensity than crops (13.3% vs. 8.3%) and a slightly lower land factor intensity (18.1% vs. 20.8%). However, with crops having a larger GDP component, each factor's total economic share is significantly larger, for example, 4.8% of employed labor in livestock vs. 24.26% in crops.

Turning to the demand structure, livestock has a significantly higher intermediate use share than crops (18.03% vs. 10%). Among livestock production systems, poultry, dairy cattle, and beef cattle have larger forward linkages with other activities (>18%). In other words, these production systems have a higher multiplier effect and, as a result, promoting this production system leads to greater second-round effects. The private (or household) consumption profile varies by species, with goats (97.2%) having the highest private consumption fraction followed by dairy (90.1%), crops (82.9%), dairy cattle (70%), sheep (64.2%), and beef cattle (63.8%). Sheep and other livestock were the only animals exported. Most of this export value is in the form of live animals, followed by hides and skins (Hailemariam et al., 2009).

Baseline scenario

This section covers the model's projected macroeconomic indicators for the baseline scenario. The baseline scenario represents a business-as-usual projection to 2030 without any policy changes. Given that the intent is to build such a scenario, the baseline should maintain the economy's initial macroeconomic structure. Moreover, to facilitate the presentation and analysis, the baseline scenario assumptions are as simple and transparent as possible.

We use available information and estimates to generate a plausible picture for the country's economic development for the base year period (2016–2020). Drawing on projections from the International Monetary Fund World Economic Outlook (IMF, 2020), we impose an average GDP growth rate of 7.4% for the analysis period. In the baseline scenario, GDP growth is imposed by endogenously calibrating the TFP. In addition, we assume that government consumption, government to household transfers, and domestic and foreign government net financing grow at the same rate as GDP.

Taxes are fixed at their base-year rates, which means that they grow at the same pace as the overall economy. For the total population and working-age population (15-64 years), we use projections from the 2019 World Population Prospects of the UN Population Division (UN, 2019). Overall, average annual growth rates for the period 2021-2030 are similar across the different indicators (at an average of 7.5% per year during the period 2016-2030). GDP growth is sufficient to bring about relatively rapid employment expansion; the employment underutilization rate is reduced from 15.5% in 2016 to 12.6% in 2030. In turn, real wages grow at a rate of 2.2% per year on average.

In per-capita terms, household consumption grows at a rate of 4.3% per year, more rapidly than government consumption, and in step with private investment. Consequently, there is a significant decrease in the poverty rate from 23.3% in 2019 to 10.0% in 2030. This poverty drop is particularly significant for rural households. At the sectoral level, the GDP growth rate is close to aggregate GDP growth. For livestock, growth is lower because of slow land supply growth and low-income elasticities of demand.

Policy simulations

We simulate the effects of an exogenous 10% increase in livestock TFP between and 2021-2030. This is a rise in the level of output (meat, milk, eggs) while keeping the level of inputs (land, labor, capital) constant. We assume that the productivity level of intermediate inputs remains constant. In particular, based on FAOSTAT (2021) historical data, we assume that yields per production system will remain stable (Annex 1). As shown in Table 1, livestock production systems differ in size; thus, to conduct a meaningful comparison, we calculated the semi-elasticities of selected results with respect to changes in the value-added of the targeted production system. The results below present the effect of the shock on the livestock sector as a whole, and for each livestock production system separately, as a deviation from the business-as-usual simulation by 2030.

By 2030, the national poverty rate is reduced by 0.18 pp compared to the base scenario (Fig 2). In the species-specific scenarios, poverty is reduced by less, but at least by 0.01 pp relative to the base scenario. The scenario that yields the largest poverty reduction targets dairy cattle. This result is explained by dairy's higher value-added share compared to other production systems. As observed, the employment level increases for all production systems, particularly for beef and dairy cattle. The household consumption results closely follow the effect on poverty reduction and employment generation, reflecting the effect that an income increase, particularly among the poorest, has on livestock product demand.

Overall, we find positive macroeconomic effects (Fig 2). Therefore, indicators such as GDP and private consumption grow on average at rates higher than those recorded in the base scenario. For instance, by 2030, the level of GDP is 0.7%, and private consumption is 0.8% higher than in the base scenario. The slope of the simulations suggests that the effect varies between the medium and long term among the production systems. For example, whereas for beef cattle, the effect of the shock on GDP remains in the long term, for dairy cattle, it stabilizes, while for goats' decreases.

The effect on major macroeconomic aggregates tends to be more favorable when the production system is directly or indirectly export-oriented. Table 1 shows that beef cattle is indirectly export-oriented through the meat sector. However, dairy cattle and dairy products are not exported. In turn, given the assumption that Ethiopia is a global market price taker, an increase in export products' domestic supply has a lower price decrease effect in the domestic market.

Other macroeconomic indicators, such as investment, exports, and imports, also show a positive impact (Fig 3). However, the effect depends on which production system is shocked. A TFP increase in dairy cattle generates the largest gains in terms of private (household) consumption, which is partially explained by the fall in household food basket relative price. A TFP increase in beef cattle, in turn, has the highest effect on exports, reflecting the international trade orientation of meat production; nevertheless, sheep is the production system with the largest increase in exports, when controlling for its size (see Table 1).

Enhancing production system output increases not only the system's demand and supply but also downstream and upstream activities along the food supply chain (Fig 4). In the case of beef cattle, for example, a 10% TFP change leads by 2030 to an increase in cattle supply of 5.7% and a rise in meat output of 7.8%. In addition, increased livestock production also generates additional demand for products such as cereals and trade services, which further stimulates growth in other manufacturing and service sectors.

We found an increase in the total equivalent emissions for all production systems (Fig 5). As observed, the result of the combined effect of increasing TFP in all production systems is an increase of 5.9% in total livestock emissions by 2030. The production system with the highest increase was beef cattle, with a change of 3.5% over that of the base scenario, followed by dairy cattle with a 1.3% increase. These results are explained by the different species' emission coefficients, technological changes, the effect of the different production systems' sectoral output, and increasing productivity's economic rebound effect.

The emission coefficient for beef cattle is the largest; thus, an increase in the output leads to relatively higher emissions than other production systems. As shown in Annex 1, during the last two decades, the carcass weight per animal has remained constant, suggesting that an increase in supply will mainly occur through an increase in head numbers. Beef cattle are the most export-oriented production systems through their input-output relationship with the meat sector; thus, an increase in output does not lead to an equivalent reduction in domestic prices, generating indirect incentives to expand production further. In other words, the beef cattle results reflect the combination of a relatively large emission coefficient with a relatively large output increase.

Discussions

We employed LPSM using Ethiopia as a case study to examine the economic structure of the livestock sector, assess the development path of the sector under a business-as-usual scenario, and simulate the effect of increasing livestock total factor productivity (TFP) by 10 %. The results show that livestock contributes significantly to the value-added of agriculture (16.5%). As such, the livestock sector is a small but significant component of GDP (6.07%). Livestock has a significantly higher intermediate use profile than crop agriculture (18.03% vs. 10%), suggesting a comparatively larger multiplier effect. The business-as-usual scenario shows large gains in important welfare indicators. The employment underutilization rate is reduced from 15.5% in 2016 to 12.6% in 2030. In turn, real wages are estimated to grow at 2.2% per year and household consumption by 4.3% per year. This leads to a significant decrease in the poverty rate from 23.3% in 2019 to 10% in 2030. The policy simulation results show that while an increase in TFP growth has several positive spillover effects on economic growth (0.7%), employment generation (0.78%), household consumption (0.82%), and poverty reduction (0.18%); there are also environmental trade-offs associated with an increase in GHG emissions (5.9%). These results have important policy implications, showing that the achievement of some SDG targets could conflict with the accomplishment of others.

The analysis illustrates LPSM's capacity to integrate economic, social, and environmental dimensions while quantifying spillover and trade-offs. This analysis extends existing literature in several ways. First, to the best of our knowledge, LPSM is the only sector-specific CGE dynamic model that disaggregates the subsector to the species level; second, in comparison to similar models, LPSM can address questions concerning impacts across sectors, household categories, and employment groups. Third, since LPSM includes functional relationships between economic actors, it can assess the effect of price changes, the reallocation of labor and capital markets, and longer-run impacts. Finally, the results of the model application contrast with previous evidence, contributing to the policy debate about sustainable livestock transformation with evidence.

Together with these advantages, LPSM is limited by the quality of a country's SAM, since in many developing countries, such data on livestock are not sufficiently desegregated, collected, or reported. LPSM requires parametrization with exogenously determined elasticities, and the accuracy of these coefficients will be a determinant factor in the model's simulation accuracy. Finally, the LPSM treats technological change as exogenous. However, LPSM could be coupled with a biophysical model to capture heard and productivity dynamics, allowing the simulation of the effects of different technological innovations (see Herrero et al, 2020) options on the heard structure, output flow, and emissions.

Method

This section provides a discursive illustration of the main features of LPSM. A detailed presentation of the mathematical statement of the model is provided in Appendix A. LPSM is a dynamic economy-wide simulation model for the country-level analysis of issues relevant to livestock and crops for the analysis of medium- and long-run development policies. LPSM is a multi-purpose model in the sense that it can analyze policies in a wide range of areas, including growth, employment generation, poverty, and inequality while capturing the effects of external shocks. The starting point for the LPSM specification is Cicowiez and Acosta (2021), which draws on GEM-Core (Cicowiez and Lofgren, 2017), Lofgren et al. (2013), and Lofgren et al. (2002). LPSM has been extended and adapted to the livestock sector's peculiarities, benefitting from the literature on agricultural CGE modeling and agricultural household modeling; among others, see Keeney and Hertel (2005), Gelan and Muriithi (2012), Oladosu and Msangi (2013), and Taylor and Adelman (2003).

Figure 1 presents an overview of LPSM. Productive sectors are represented by profit-maximizing activities that operate in competitive markets, both for factors and commodities. For each simulation period, income flows circularly within the economy and between the economy and the rest of the world. Therein, arrows show the direction of payments that, except for transfers, are made in exchange for something else that flows in the opposite direction, for example, the provision of a good or service for consumption in the current period. The major building blocks are livestock activities (the entities that carry out livestock production), non-livestock activities, commodities (goods and services produced by activities and/or provided via imports), factors of production, and institutions (households, enterprises, the government, and the rest of the world). LPSM provides a relatively detailed treatment of the financing of private investment (compared to most other CGE models); thus, the private (non-government) capital account also has its box.

The production function for livestock activities in the LPSM is presented in Appendix B. The livestock production structure characterizes the substitution possibilities between range-fed and ranch-fed production. Thus, for the livestock sector, LPSM defines an extended value-added that is decomposed into a labor-capital composite and a land-feed composite. The capital-labor composite is decomposed into its components: capital and labor. The land-feed composite is decomposed into a feed composite and land. The feed aggregate is further decomposed into its different components, such as wheat, oilseeds, and other grains (depending on data availability). For non-agricultural sectors, the figure is simplified by not allowing for substitution between intermediate inputs and factors. For crops, LPSM allows for substitution between fertilizers and land. Activities can produce one or more commodities. Furthermore, each commodity can be produced by one or more activities. The total production of each good or service can be sold domestically or exported to the rest of the world.

Typically, the following institutional sectors are identified in the model: households, enterprises, government, and the rest of the world. Households obtain their income from two sources: factor income from their factor endowments and transfers from other institutions. Households spend their income to buy goods and services, save, pay direct taxes, and transfer part of their income to other institutions. The government receives tax revenue, consumes/provides goods and services, provides transfers to households, and (dis)saves. The rest of the world demands exports, supplies imports, and provides transfers/grants to domestic institutions. The model assumes that the economy is modeled as a small country, so it takes as given the world prices of its exports and imports. Furthermore, the model identifies eight types of taxes (i.e., income, activities, consumption, value-added, export, import, factor income, and factor use by activities). In addition, trade and transport margins are explicitly modeled, assuming that the services required to move a commodity from the producer to the consumer are a fixed share of the marketed commodity.

For international trade, LPSM follows the usual treatment in CGE modeling and assumes that goods and services are differentiated according to country of origin (Armington, 1969). Thus, two-way trade can be considered (i.e., the same commodity is imported and exported simultaneously). The combination of domestic and imported products is conducted at the border; that is, for a given commodity, the domestic/imported composition of consumption is the same regardless of the product destination (e.g., intermediate consumption versus final consumption). The assumption of imperfect substitution between imports and domestic purchases is implemented with the constant elasticity of substitution (CES) function. This implies that the value of a domestic product is at a constant ratio to the value of an identical imported product. On the production side, there is a symmetrical assumption that exports and sales to the domestic market are imperfect substitutes, and a constant elasticity of transformation (CET) function is used to model the imperfect transformability between exports and domestic sales.

For the labor market, we assume that unemployment is modeled through a wage curve, which establishes a negative relationship between the level of wages and the unemployment rate (see Blanchflower and Oswald, 2005). In a given simulation, labor can be perfectly or imperfectly mobile among sectors. On the other hand, once installed, capital cannot move across sectors.

LPSM can also track the evolution of greenhouse gas (GHG) emissions from different domestic uses: intermediate consumption by production activities (e.g., of energy commodities), final consumption by households, and factor employment by production activities (e.g., cattle in livestock). Specifically, in this application of LPSM-Ethiopia, we project GHG emissions from enteric fermentation and manure management linked to different animal stocks. As mentioned before, LPSM is recursive and dynamic, that is, it assumes that agents are myopic. Economic agents, such as firms and households, expect future prices to be the same as current prices. The economy grows due to the accumulation of capital, growth in the labor force, growth in the supply of natural resources, and increases in factor productivity. At the beginning of each period, sectoral capital stocks are modified based on investments from the previous period. In turn, the endowments of the other factors grow exogenously. In each period, the model differentiates between private and public investments and capital stocks.

- **Database**

The accounting structure and many of the underlying data of LPSM are derived from a social accounting matrix (SAM). Most features of a SAM for LPSM are familiar to the SAMs used for other models. However, a SAM for LPSM has some unconventional features related to (a) the livestock and crop sectors, (b) the rural economy (e.g., household production for household consumption), and (b) the explicit treatment of selected financial flows (see, for example, Round, 2003; Pyatt and Round, 1985). In this analysis, LPSM was calibrated using a modified version of the SAM for Ethiopia for years 2015/2016 (hereafter, 2016) recently published by the EU Joint Research Centre (see Mengistu et al., 2019). The SAM accounts, which determine the disaggregation of the model, divide the economy into 42 activities, 43 commodities, and six factors of production. However, to save space, all figures, and tables in the main text aggregate SAM data to 11 activities and commodities with a focus on livestock and five factors.

In addition to SAM, LPSM requires a set of elasticities for production, consumption, and trade, as well as base-year estimates for sectoral employment levels and unemployment rates. Furthermore, given that LPSM is a dynamic model, we need to project the modeled economy under the assumption of a “business as usual” or base scenario. The base scenario serves as a reference for comparing the counterfactual simulation scenarios, that is, scenarios in which one or more shocks are introduced and compared to the baseline or reference scenario. For the base, we require base-year capital stocks, a baseline projection for population and labor force growth, and a baseline projection for GDP growth.

The required (exogenous) elasticities apply to the production, trade, consumption, and labor markets. In sum, the values for elasticities are as follows: (a) the elasticities of substitution among factors are in the 0.2–0.95 range, lower for natural resource activities, such as agriculture (0.25) and mining (0.2) (Aguiar et al., 2019); (b) the wage curve unemployment elasticity is -0.1 (Blanchflower and Oswald, 2005); (c) the expenditure elasticities are in the 0.62–5.4 range (Muhammad et al., 2011); (d) trade-related elasticities are in the 0.9 and 2 range for the substitution between imports and domestic purchases and transformation between exports and domestic sales, respectively (Saudolet and de Janvry, 1995).

The parameters associated with the amount of greenhouse gas (GHG) emissions (specifically, CH_4 and N_2O) from enteric fermentation and manure management for each livestock subsector were obtained from FAOSTAT (2021). GHG emissions from enteric fermentation consist of methane gas produced in the digestive systems of ruminants and, to a lesser extent, non-ruminants. GHG emissions from manure management consist of methane and nitrous oxide gases from aerobic and anaerobic manure decomposition processes. In this application, LPSM-Ethiopia only considers livestock emissions from enteric fermentation and manure management. Hence, we did not consider CO_2 emissions related to the use of fossil fuels.

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Figures

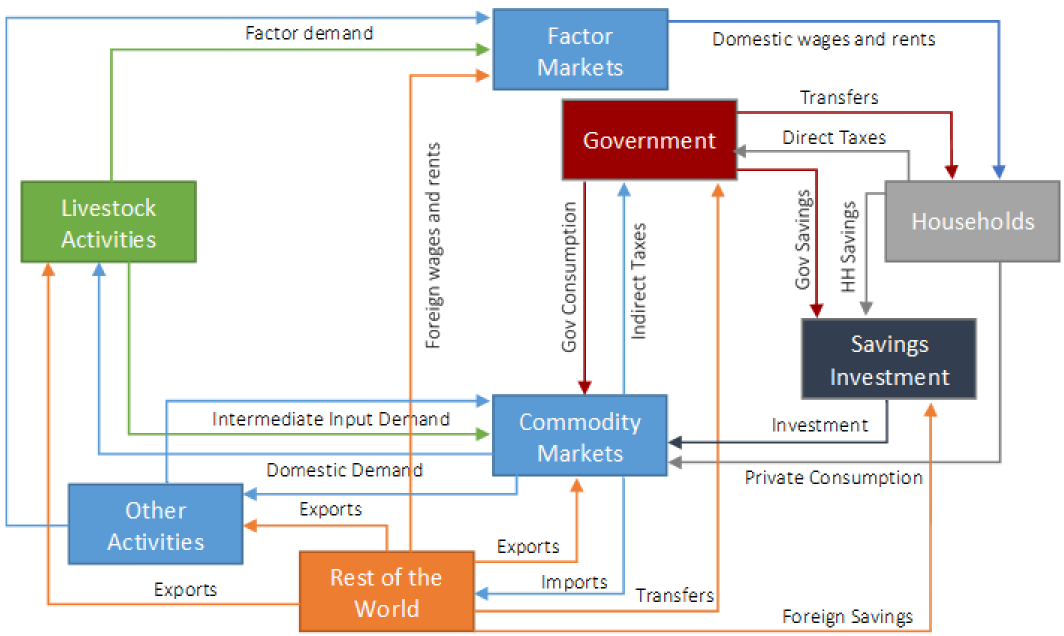

Figure 1

LPSM Structure

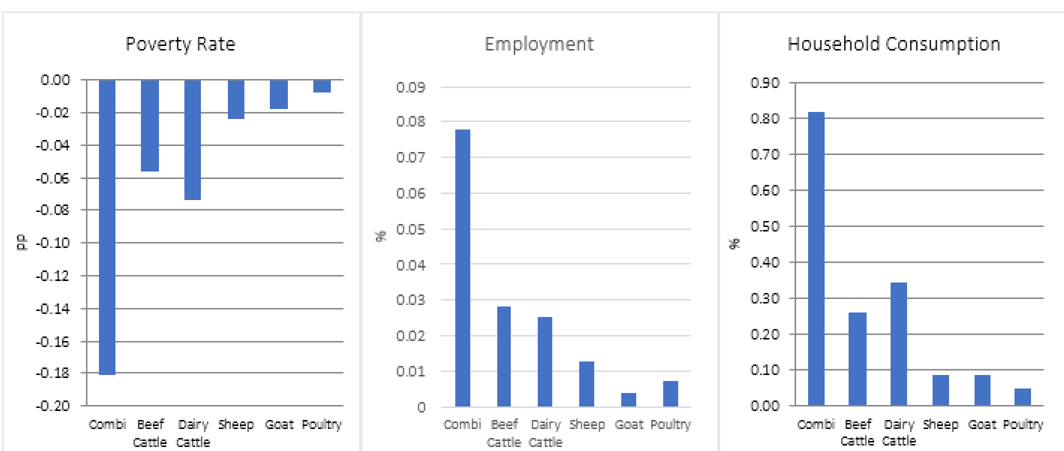

Figure 2

Poverty rate, employment, and household consumption (deviation from the base in 2030). Source: Authors' calculations using LPSM simulation results

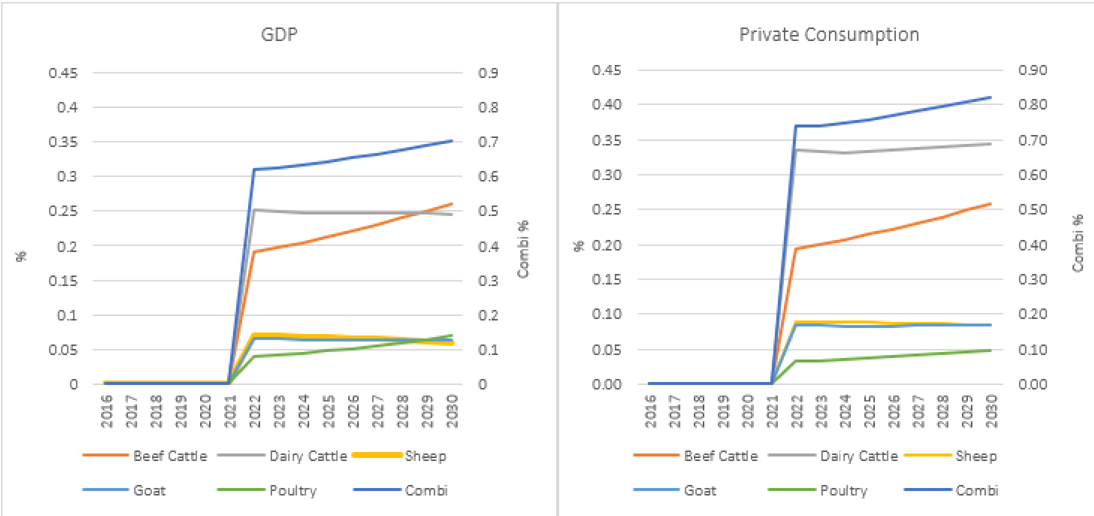

Figure 3

GDP and private consumption (% level deviation from the base in 2030). Source: Authors' calculations using LPSM simulation results

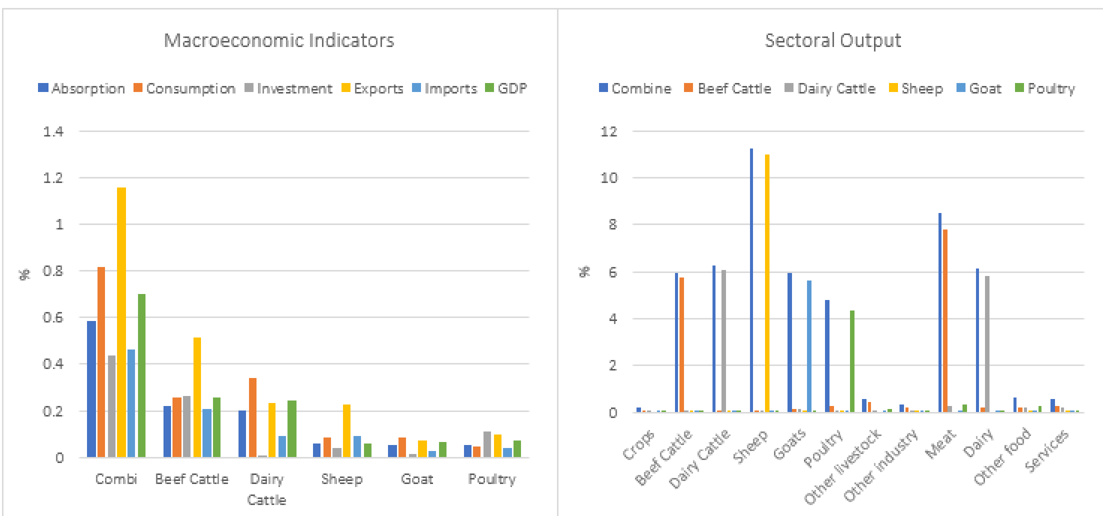

Figure 4

Macroeconomic and sectoral output indicators (% level deviation from the base in 2030)

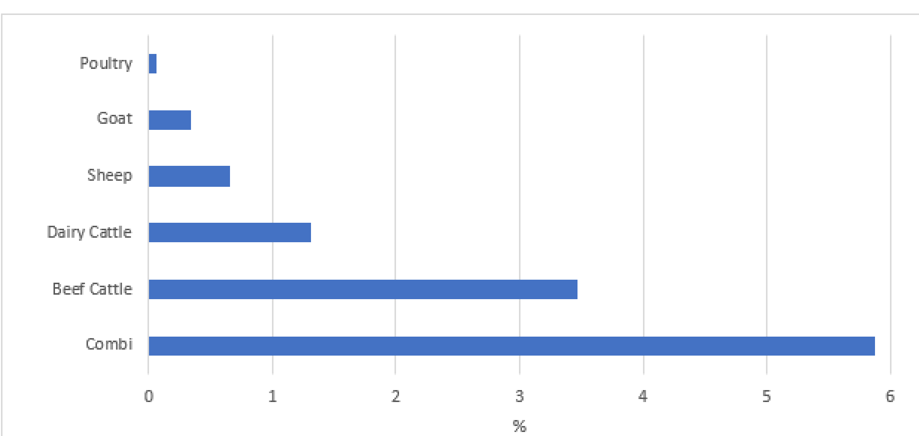

Figure 5

GHG emissions from enteric fermentation and manure (% level deviation from the base in 2030. Source: Authors' calculations using LPSM simulation results

Supplementary Files

This is a list of supplementary files associated with this preprint. Click to download.

- NatureLPSMMathematicalStatement.docx
- Annex.docx