Core Model Proposal #312: Livestock Trade with Regional Markets

Product: Global Change Analysis Model (GCAM)

Institution: Joint Global Change Research Institute (JGCRI)

Authors: Xin Zhao and Marshall Wise

Reviewers: Stephanie Waldhoff, Page Kyle, and Kanishka Narayan

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Related sector: Agriculture, Land, Trade

Type of development: Data and Queries

Purpose: The purpose of this proposal is to enable inter-regional trade responses for livestock sectors (i.e., beef, dairy, pork, poultry, and sheep & goat) in GCAM. In particular, we make necessary changes in the GCAM data system to incorporate the regional livestock markets: (1) we remove the existing framework of fixed (exogenous) net trade flows for livestock sectors, (2) we incorporate the logit-based Armington gross trade modeling framework with regional markets for livestock sectors in a way consistent with existing crop trade framework, and (3) we calibrate trade parameters (regional and international logit parameters) based on literature information for both crops and livestock and investigate the impacts.

Contents

1. Introduction

The world total meat export was around 20 million tons (Mt) in 2010, as indicated by GCAM base data, and the international trade flows of livestock products are currently fixed at initial values in GCAM (v5.2). However, this world total meat export was about 34 Mt in 2018 (OECD/FAO, 2019), considerably higher than the value in GCAM. Even though the difference was partly because GCAM only includes net trade flows, the trade volume of livestock products has been growing significantly in the past decade, at around 3% per year globally, with high regional variations. Livestock sectors play unique roles in integrated assessments of the global future, given its interconnections with land, water, energy, and agriculture (crops) systems. Improving the trade modeling of livestock sectors will undoubtedly enhance our understanding of future economic and environmental consequences of biophysical shocks. Thus, the objective of this proposal is to enable livestock trade in GCAM by connecting regional livestock markets with the logit-based Armington approach (Zhao et al., 2022).

2. Livestock trade modeling

2.1. The current structure in GCAM 5.2

There are six livestock sectors in GCAM, including beef, dairy, pork, poultry, sheep & goat, and other meat & fish. Besides other meat & fish, net trade flows are included for all other livestock sectors but exogenously fixed at initial levels. In particular, net trade flows for these livestock sectors were used and modeled as a residual sector in market equilibrium. That is, net export ("Exports_Meat") was modeled as an exogenous livestock product demander, net import was modeled as an exogenous supplier (see Fig. 1), and markets were cleared with the consideration of these exogenously fixed values. Also, other meat & fish is not modeled in detail as production technologies and trade flows are not specified, but its consumption is assumed to grow in total livestock product consumption with a fixed share.

In addition, the regional crop market was introduced into GCAM 5.2 following a logit-based Armington framework with gross trade modeling, in which regional consumers could distinguish domestically produced products and imported products and treat them as imperfect substitutes with different prices. And producers in each region would supply to an international market ("traded crops") for competitions, and these supplies are aggregated with a relative cost logit function to be supplied to importing regions (imported crops). As a result, this framework could generate regional prices and gross trade flows.

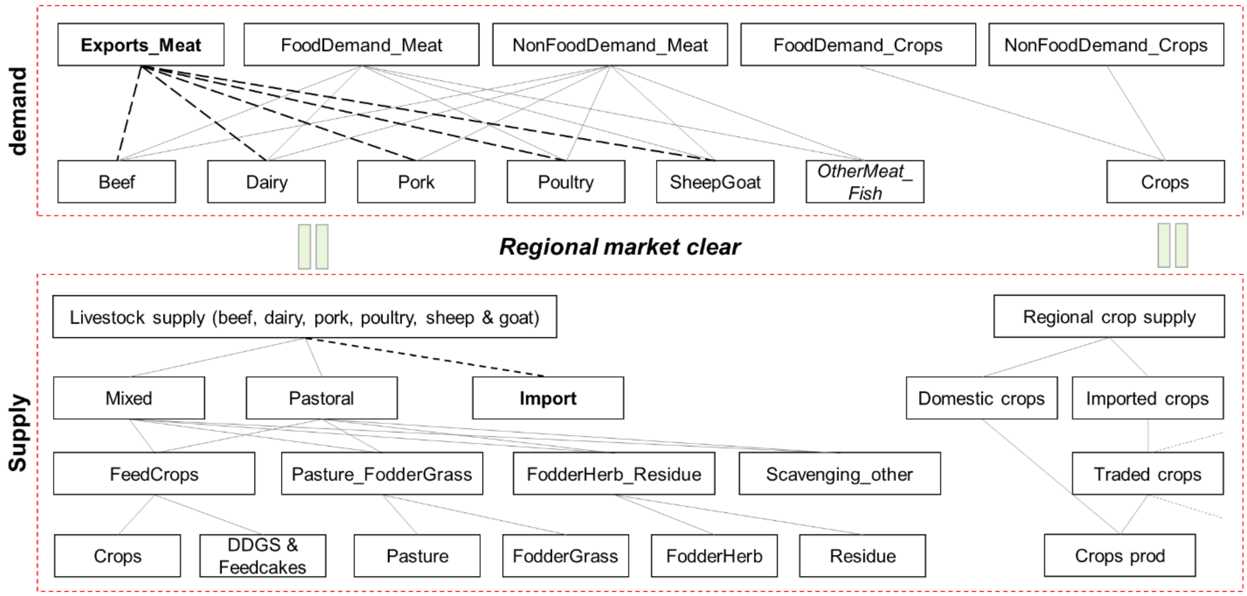

Fig. 1 Regional supply and demand for livestock products and crops in GCAM 5.2.For market clearing, the source of demand for livestock products includes food demand, nonfood demand, and export. In contrast, the source of demand for crops may consist of food demand, nonfood demand, FeedCrops, and regional biomass oil. **Modifications for livestock trade**

In this proposal, we suggest leveraging the existing trade modeling framework for crops to improve livestock trade modeling in GCAM. In other words, we will remove the current fixed trade modeling structure and introduce the logit-based Armington trade approach for livestock sectors in a way consistent with the existing trade structure of crops (see **Fig. 2** for the new framework). Trade for other meat & fish is not included in this update since we do not have quality data, while data (e.g., bilateral trade flows) are available for other livestock sectors. Note that two trade parameters would be required for each sector in the new framework, international logit ($\boldsymbol{\theta}_{\boldsymbol{intl.}}$) and regional logit ($\boldsymbol{\theta}_{\boldsymbol{reg.}}$), for governing the flexibility of substitutions across sources of production, respectively, for foreign–foreign and domestic–foreign. We rely on Armington trade elasticity reported in the literature (Aguiar et al., 2019; Hertel et al., 2007) to calibrate the logit parameters (see Table 1) since the import demand elasticity implied by the logit function and the constant elasticity of substitution (CES) function used in original Armington approach are similar. Currently, we are using -3 (regional) and -6 (international) for logit trade parameters for crops in the core model. The parameters implied by the literature are relatively more plausible since they were econometrically estimated based on historical data. But we also test -3 (regional) and -6 (international), which are smaller than the literature estimates for all livestock sectors, to investigate the parameter sensitivity.

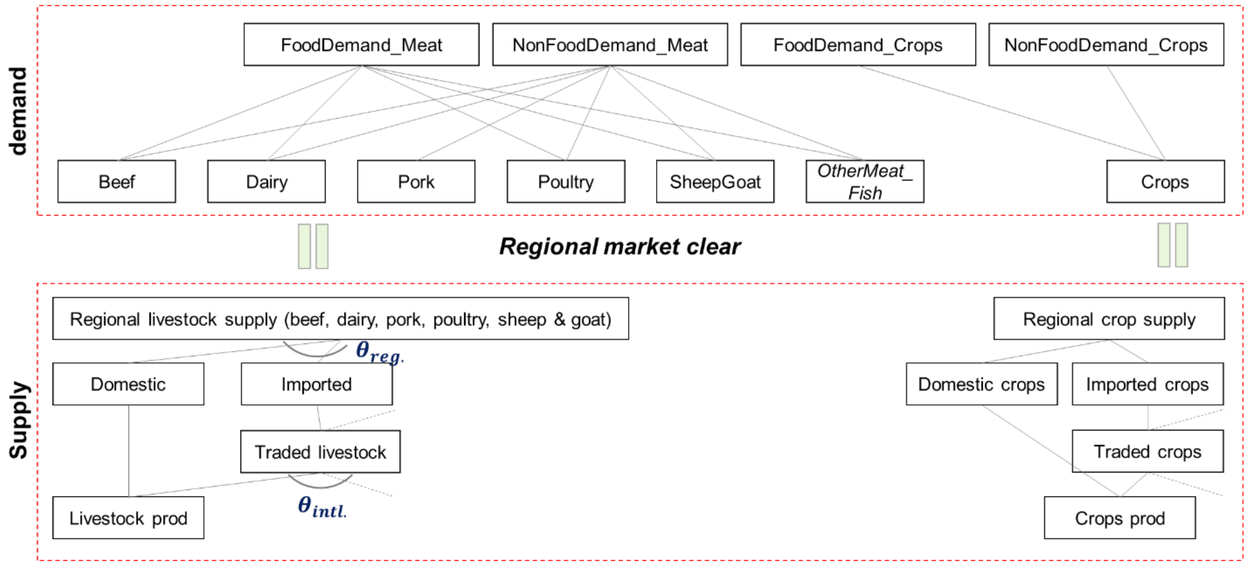

Fig. 2 Modified livestock trade modeling in GCAM. International logit ($\boldsymbol{\theta}_{intl.}$) and regional logit ($\boldsymbol{\theta}_{reg.}$) parameters are required for the logit-based Armington trade modeling framework.

Table 1 Logit trade parameters implied by trade elasticities in literature (Aguiar et al., 2019).

Sector	Regional	International
Beef	-3.9	-7.7
Dairy	-3.7	-7.3
Pork	-4.4	-8.8
Poultry	-4.4	-8.8
Sheep & Goat	-3.9	-7.7

3. Changes in GCAM data system for livestock trade modeling

Modifications made for updating livestock trade modeling in GCAM are documented in Table 2. Note that we could either create separate new CSV and R files dedicated to livestock trade or incorporate necessary changes into existing files of crop trade. We choose the latter since the existing codes are directly usable for livestock sectors, and it has fewer files for building the data system. A set of livestock sectors, including all the five livestock sectors by default, are added in constants.R to allow choosing sectors, we want the updates (with corresponding parameter file changes). These changes have been pushed to the working branch, xz/feature/livestock-trade (cloned from Master after base year update).

Table 2 GCAM data system modifications

Files	Changes made
A_agRegionalSector.csv	Add livestock sectors and logit trade parameters.
A_agRegionalSubsector.csv	
A_agRegionalTechnology.csv	
A_agTradedSector.csv	
A_agTradedSubsector.csv	
A_agTradedTechnology.csv	
A_an_subsector.csv	Remove fixed livestock trade items and, where needed, add "regional" for livestock products.
A_demand_supplysector.csv	
A_demand_subsector.csv	
A_demand_technology.csv	
constants.R	Add the set for livestock sectors (aglu.TRADED_MEATS).
zchunk_LB1091.ag_GrossTrade.R	Include livestock sectors (aglu.TRADED_MEATS) into the existing structure for generating required trade data.
zchunk_L240.ag_trade.R	
zchunk_L202.an_input.R	Remove fixed livestock trade flows if in aglu.TRADED_MEATS
zchunk_L203.demand_input.R	

4. Impacts of the updates

The experiments for studying the impacts of the livestock trade modeling updates are described in **Table 3**. The scenarios with livestock trade responses are compared with the original GCAM reference of fixed livestock trade.

Table 3 Experimental design

Experiment	Description
Fixed_antrade	The reference scenario from GCAM core before the livestock trade updates. Livestock trade (net) flows are fixed at initial values. This is also the reference scenario in comparison.
Arm_antrade_3_6	The scenario with the updates of livestock trade. Logit parameters of -3 (regional) and -6 (international) are used. This is a sensitivity run.
Arm_antrade_anpara	With the updates of livestock trade but using calibrated trade parameters. This is the default scenario for the updates.

The updates had a significant impact on livestock trade (**Fig. 3** presents the world-level results). Note that initial values are different because gross trade is modeled in the updates while only net trade was included previously. The results indicate that after enabling trade responses, the world total trade volume would reach the peak (about doubled the initial value) around the mid-century.

Land use sectors (beef, dairy, and sheep &goat) are more sensitive to trade parameter changes. Higher parameters (anpara vs 3_6) generally lead to higher trade volume due to the more flexible trade responses, with small exceptions for sheep & goat, though.

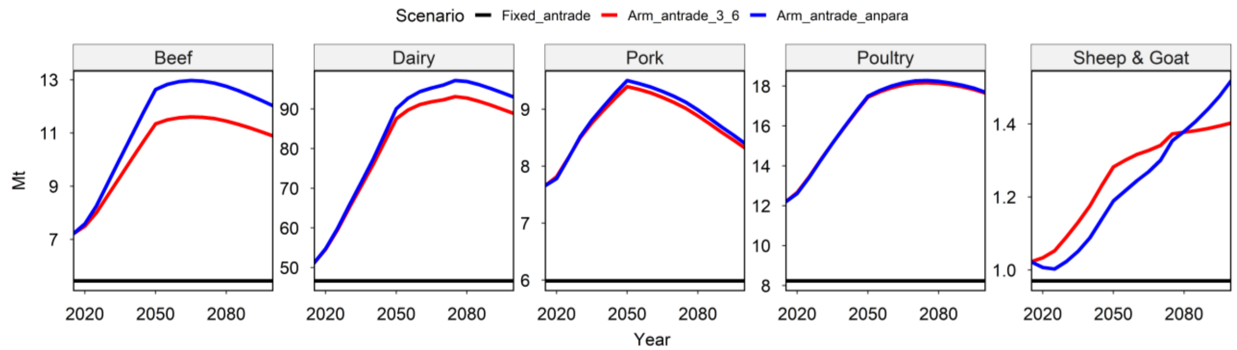

Fig. 3 World total livestock trade volume

The total trade volume of livestock products is about 5-10% of the world production/consumption over time. However, the trade modeling updates had marginal impacts on world-level livestock production, regardless of parameters (increased slightly for all livestock sectors, **Fig. 4**). That is, enabling livestock trade will mainly have a reallocation effect on regional livestock production. More importantly, this reallocation effect driven by the exploitation of comparative advantage through livestock trade expansion encourages higher productivity in worldwide livestock production. **Figs. 5 – 7** present a comparison of the major feed inputs in livestock production across scenarios. Given that the total production increased slightly, the feed consumption mostly decreased due to enabling livestock trade, particularly for beef and dairy, and to a lesser extent for pork and poultry (likely because of relatively smaller regional differences in their productivity). Furthermore, with higher trade parameters (in absolute values) in the default scenario (and thus more pronounced trade responses), the world-level livestock productivity is also higher (not significantly, though), implied by less amount of feed inputs in production.

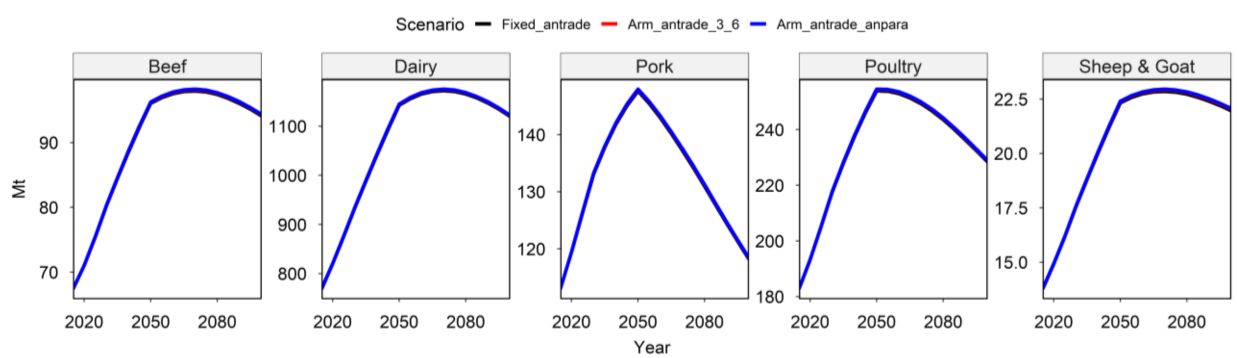

Fig. 4 World total livestock production

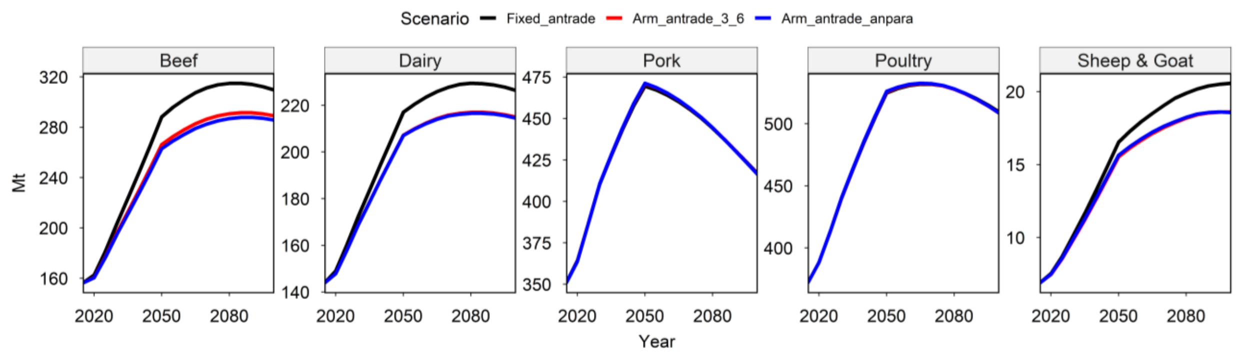

Fig. 5 World total feed crops input for livestock production

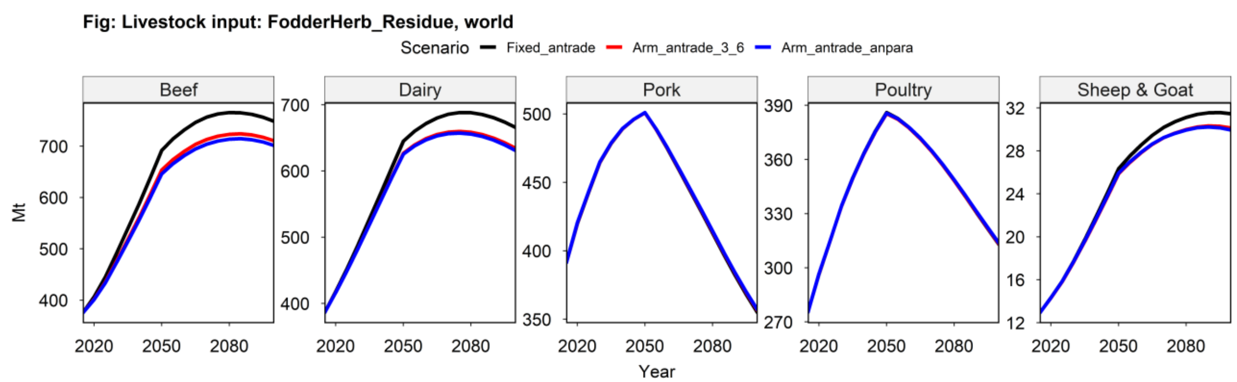

Fig. 6 World total FodderHerb_Residue input for livestock production

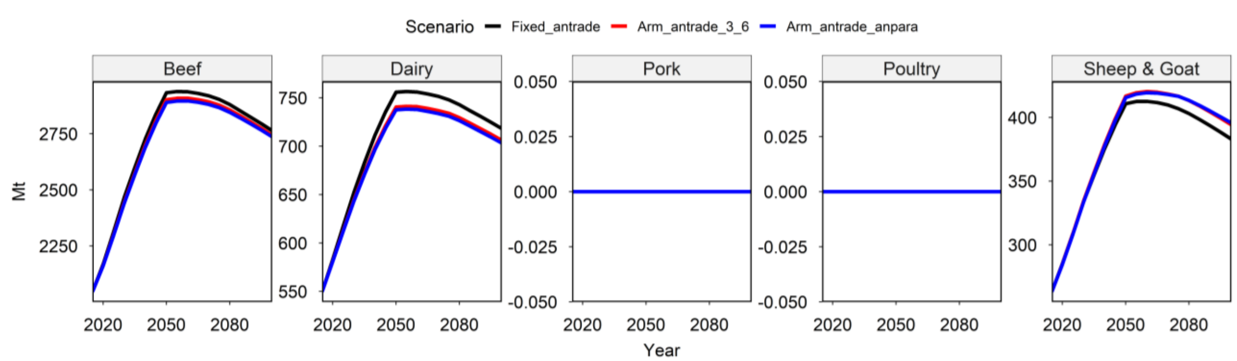

Fig. 7 World total Pasture_FodderGrass input for livestock production

Driven by the higher livestock productivity globally, the use of feed crops and pasture in livestock production decreased, so the land demand for crops and pasture also reduced. Thus, there was effectively more land available so that less forest and natural land would be converted. Note that biomass land would also increase. The decrease in cropland was mainly driven by the decline in harvested areas of crops with increasing use for feeds, e.g., grains, fodder, oil crops (cakes), and to a lesser extent in wheat and rice (Southeast Asia feed).

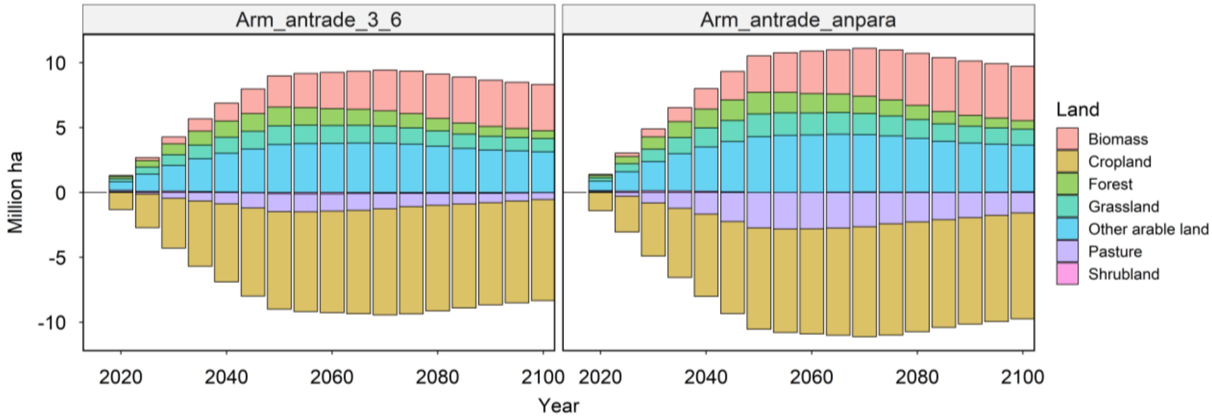

Fig. 8 World total land cover change, relative to the reference scenario

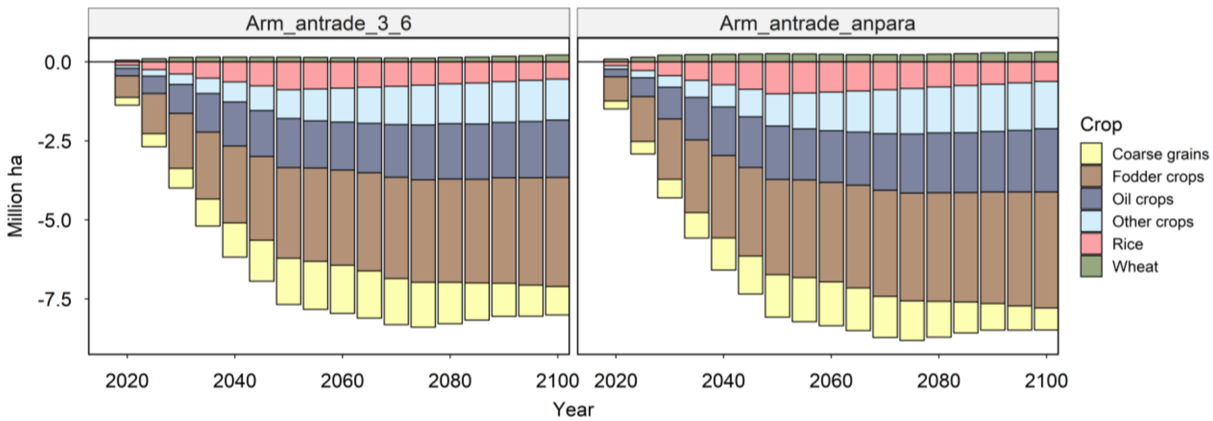

Fig. 9 World total harvested area change, relative to the reference scenario

Next, let us take a look at the impacts on regional results, which are considerably heterogeneous given the different roles of regions in livestock trade. We focus on comparing the default scenario (Arm_antrade_anpara) with the reference scenario since the results from the sensitivity scenario are similar to the default scenario with relatively weak responses, though.

Figs. 10 – 12 present regional changes in livestock production, export, and import, respectively, in the default scenario relative to the reference. With the reallocation impacts, some regions would produce and export more (e.g., Australia, Brazil, and the USA), and some would import more and produce less (e.g., Africa regions, Southeast Asia, the Middle East, and Canada). There are also some differences across livestock sectors. But generally, these responses are consistent with expectations. The regional reallocation of production also leads to changes in regional land use and crop harvested area (**Fig. 13** and **Fig. 14**). There are very different impacts on regional land use and harvested area results because regions have different livestock trade responses and different livestock technologies and mix of feed sources. For example, livestock production in Australia is more pasture-intensive, so increases in Australian production and export encouraged major expansions in the pasture area. In contrast, livestock production in India is relatively more crop feed-intensive, so the decrease in production due to higher imports led to decreases in cropland, mainly fodder crops. Most other regions have mixed uses of pasture and feed crops in livestock production, so there were changes in both pasture and cropland. And the regional change could offset each other so that the world level results could mask regional variations.

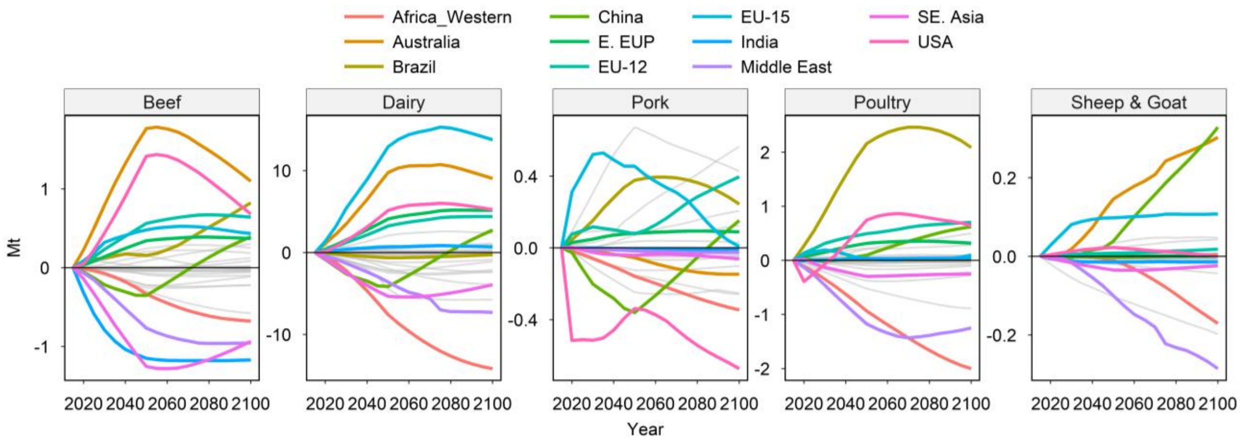

Fig. 10 Regional production change in the default scenario, relative to reference

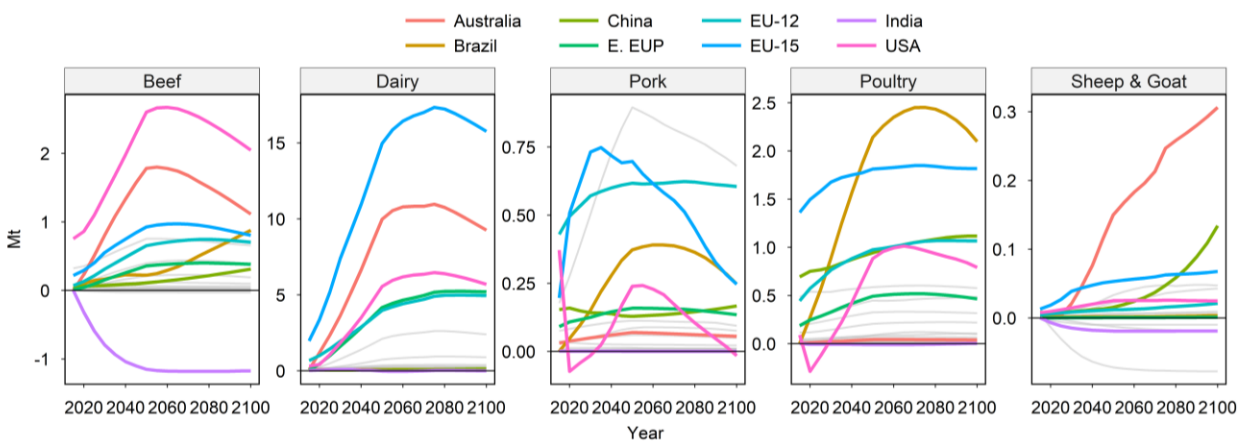

Fig. 11 Regional export change in the default scenario, relative to reference

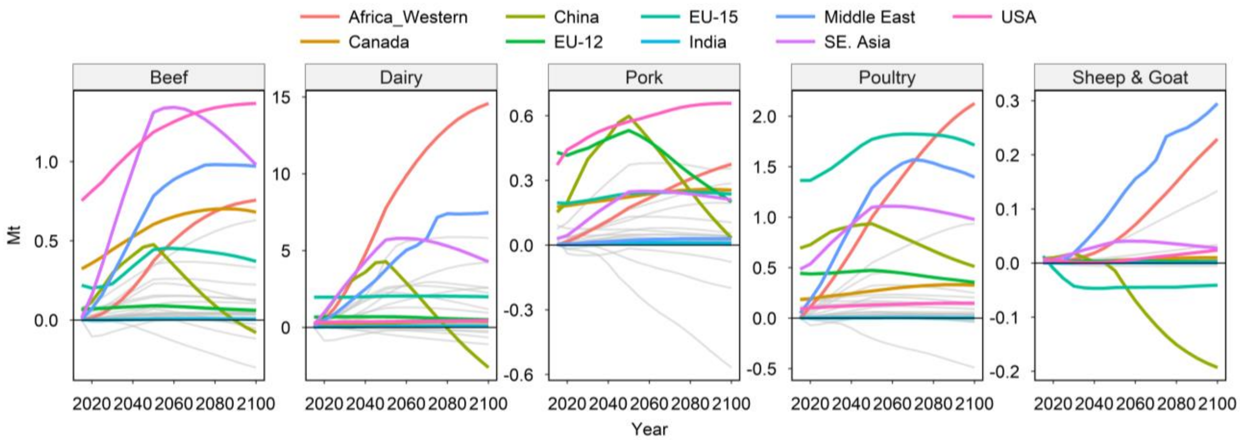

Fig. 12 Regional import change in the default scenario, relative to reference

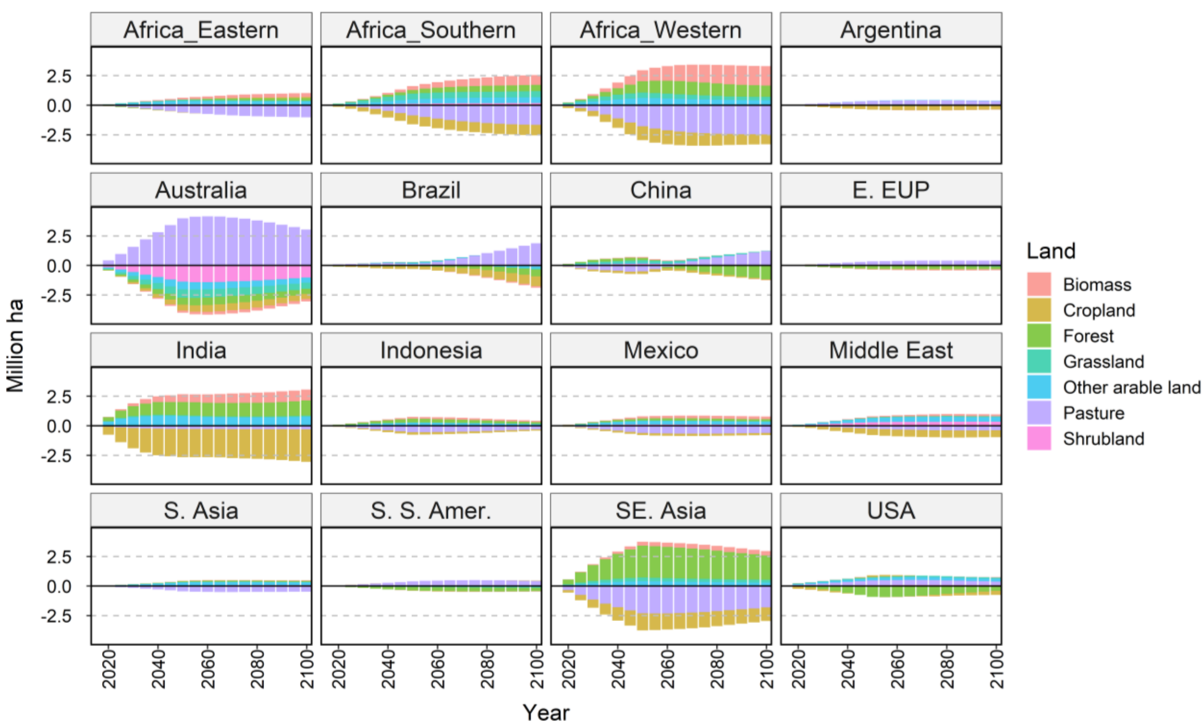

Fig. 13 Regional land use changes in the default scenario relative to the reference. The top 16 regions by pasture change are presented.

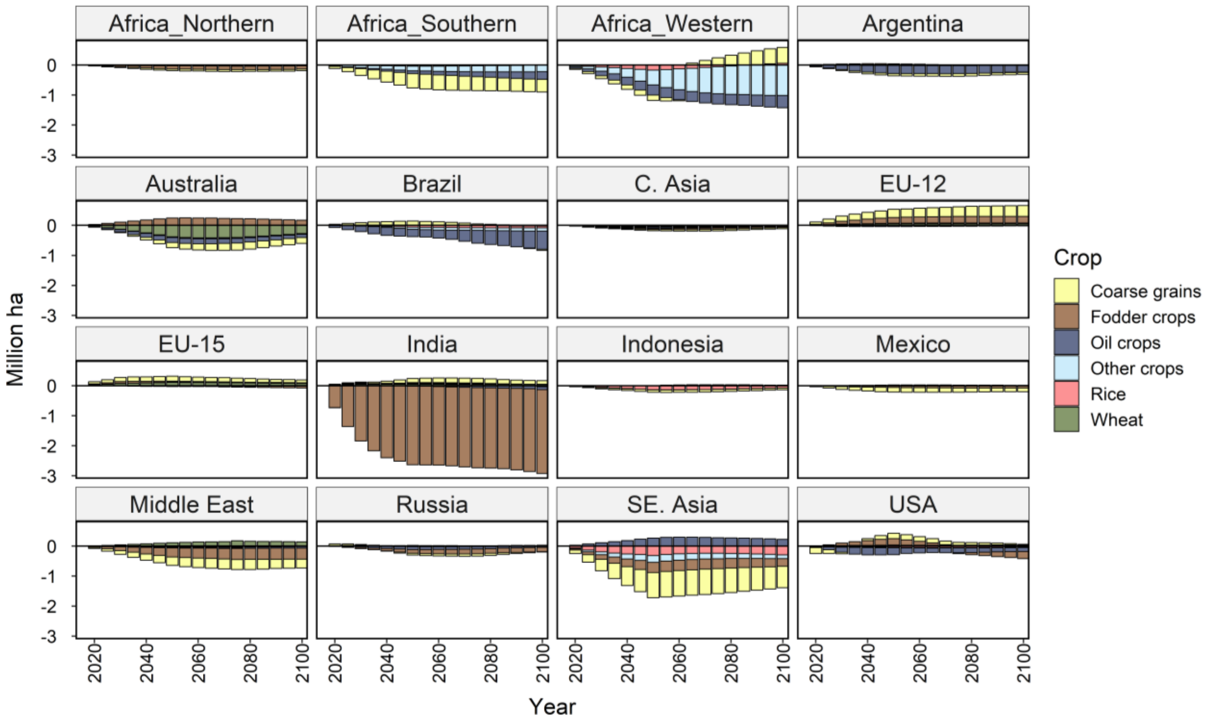

Fig. 14 Regional harvested area changes in the default scenario relative to the reference. The top 16 regions by cropland change are presented.

The following figures present regional producer (**Figs. 15-16**) or consumer price (**Figs. 17-18**) changes due to the livestock updates for livestock (**Figs. 15 &17**) or crop (**Figs. 16 & 18**) sectors.

- The impacts on crop prices were mostly in a range of +-5%, either for producer or consumer prices.
- There are generally higher impacts on beef, dairy, and sheep &goat, while the impacts on pork and poultry were relatively small.
- Most regional producer changes can be explained by regional changes in trade responses.
    - Meat importing (exporting) regions will have lower (higher) crop prices.
- However, there could be relatively larger changes in consumer prices for livestock products.
    - Regions with higher shares of import are more vulnerable to international price changes.
    - Also, note that there was inconsistency in the comparison of livestock consumer prices since net trade was updated to gross trade.

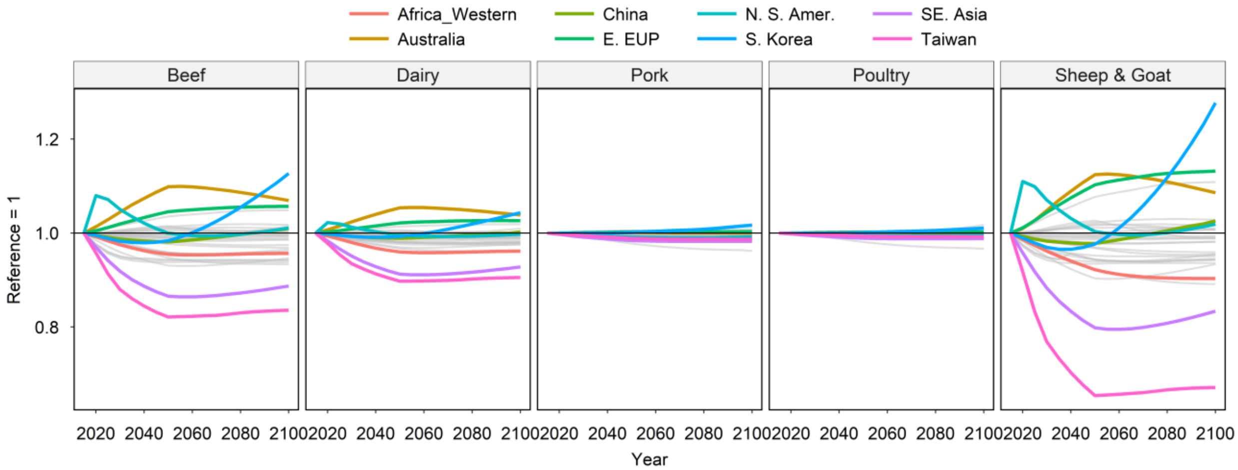

Fig. 15 Regional producer price changes for livestock products in the default scenario, relative to the reference

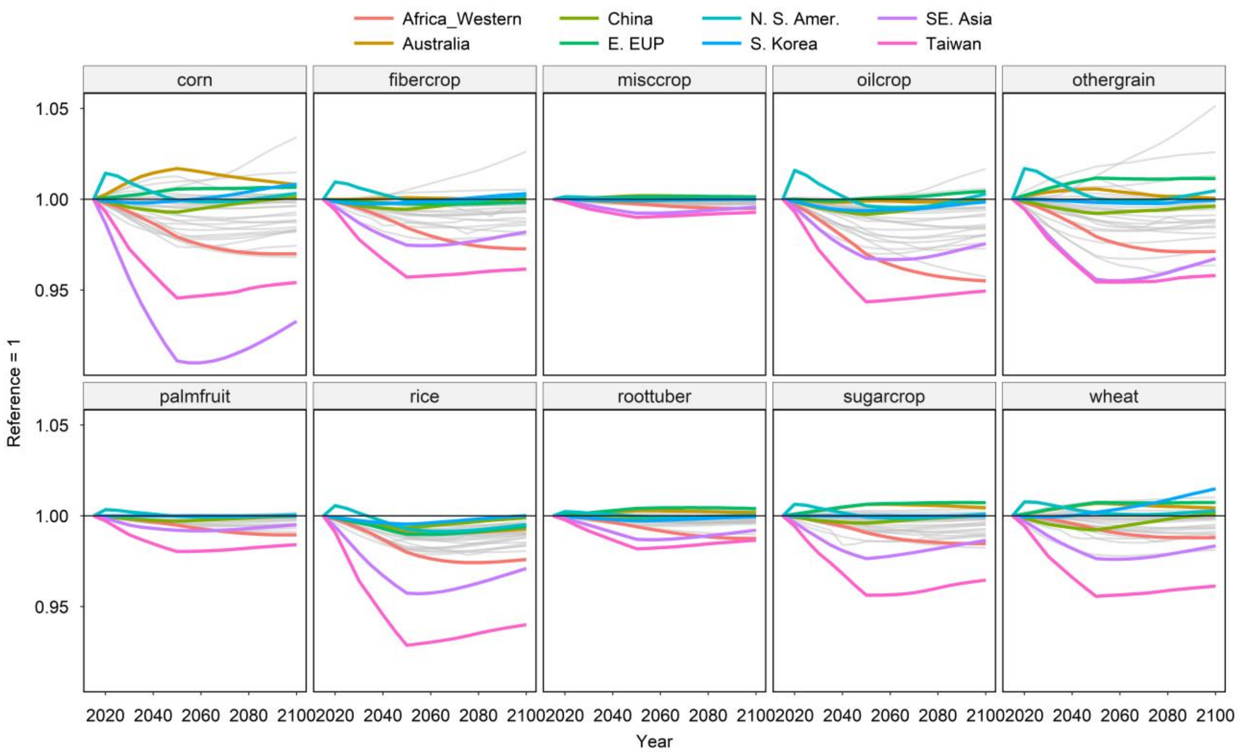

Fig. 16 Regional producer price changes for crops in the default scenario, relative to the reference

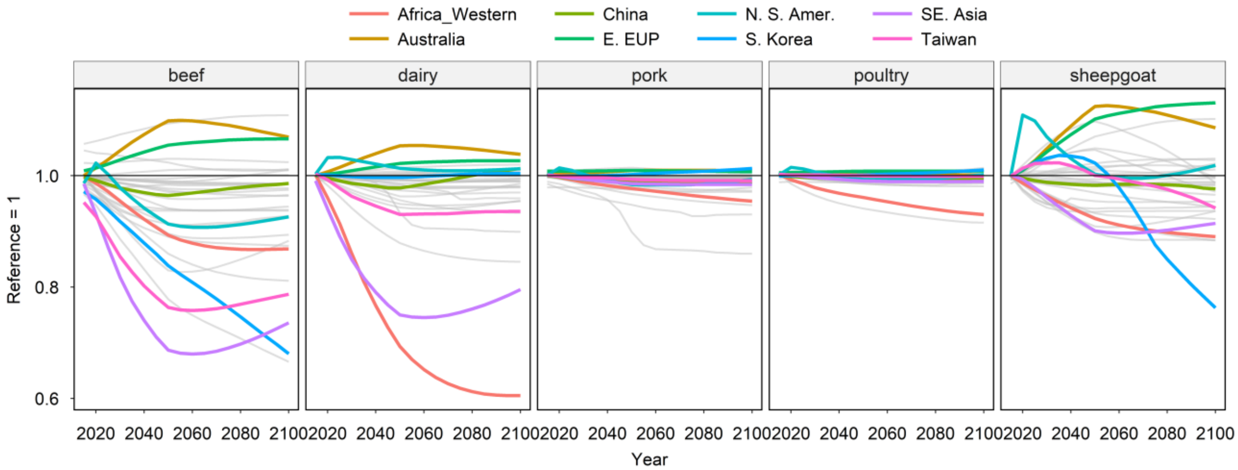

Fig. 17 Regional consumer price changes for livestock products in the default scenario, relative to producer prices in reference

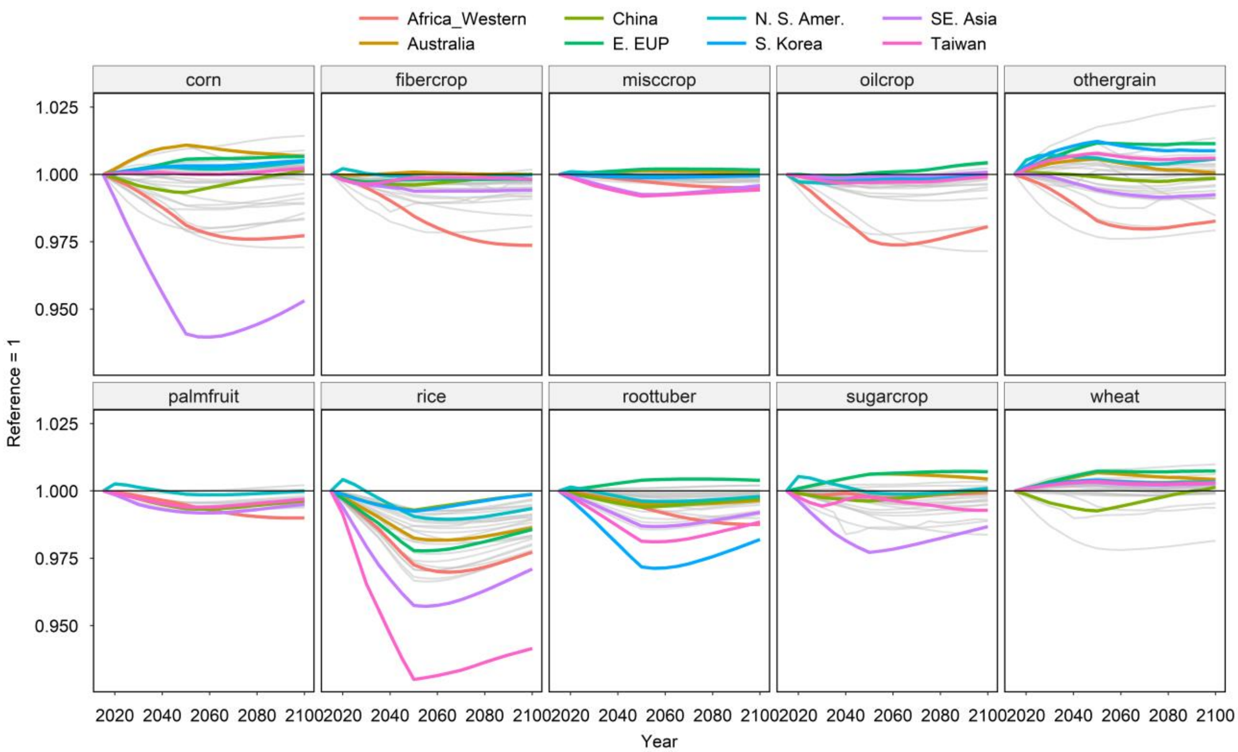

Fig. 18 Regional consumer price changes for crops in the default scenario, relative to the reference

5. Shared policy assumption (SPA) GCAM validation runs

5.1. Overview of the global results

Here we show the high-level results from the SPA runs (SSP & RCP2.6) in the following figures. Note that the comparison is made between results from the default scenario of this proposal (*livetrade*) and the latest core model update from bugfix. In general, the impact of enabling livestock trade on the world level climate results, e.g., forcing, temperature, and carbon concentration, was small (**Figs. 19-21**). Allowing livestock trade improved global livestock productivity and thus lowered the associated land use and emissions (**Figs. 23-24**). The effort (carbon price) of achieving RCP 2.6 becomes smaller given the more flexible livestock trade (**Fig. 22**). Also, due to the improved global average productivity, the water and land use for producing livestock products would be lower as well (**Fig. 25-27**). Also, SSP3 & 4 would be more sensitive to livestock trade given the higher global livestock consumption. Globally, with livestock trade, there will be slightly more livestock product consumption (**Fig. 28**). The impact on the global harvested area of corn or oil crops was also mostly small at the world level (**Figs. 29-30**).

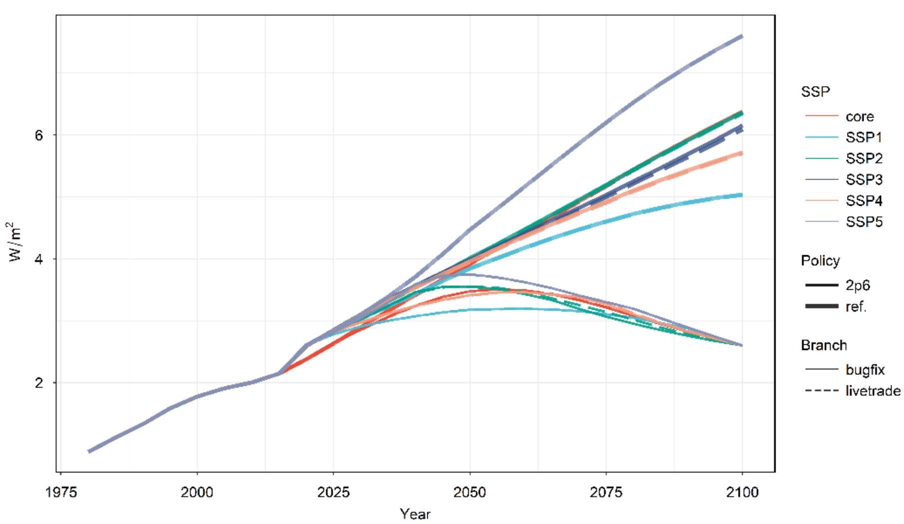

Fig. 19 Total forcing across SPA scenarios. Note that SSP3-RCP2p6 does not solve in GCAM.

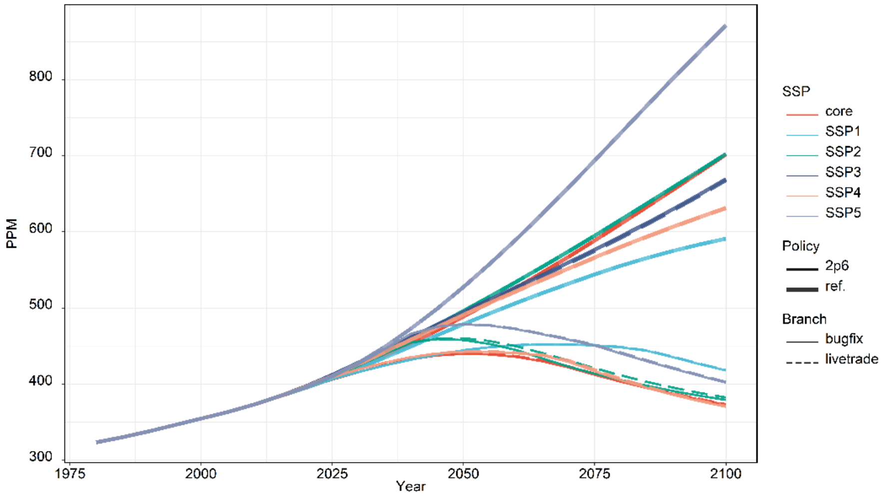

Fig. 20 CO2 concentration across SPA scenarios

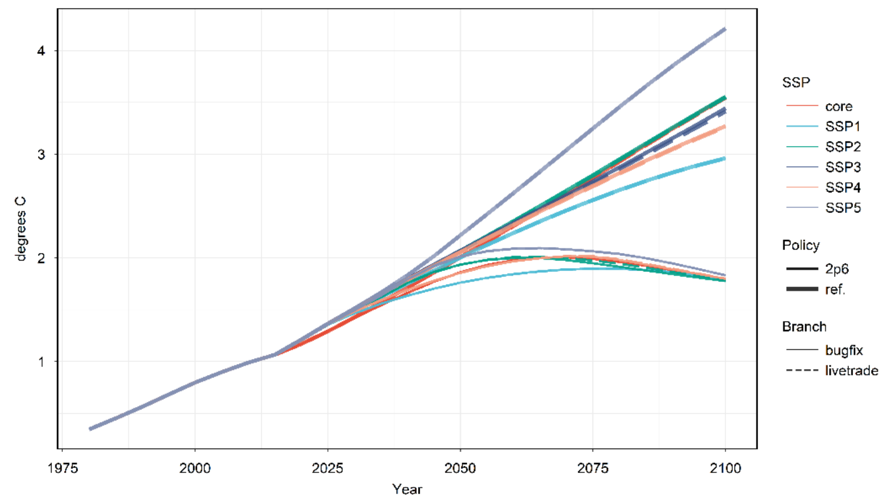

Fig. 21 Global mean temperature across SPA scenarios

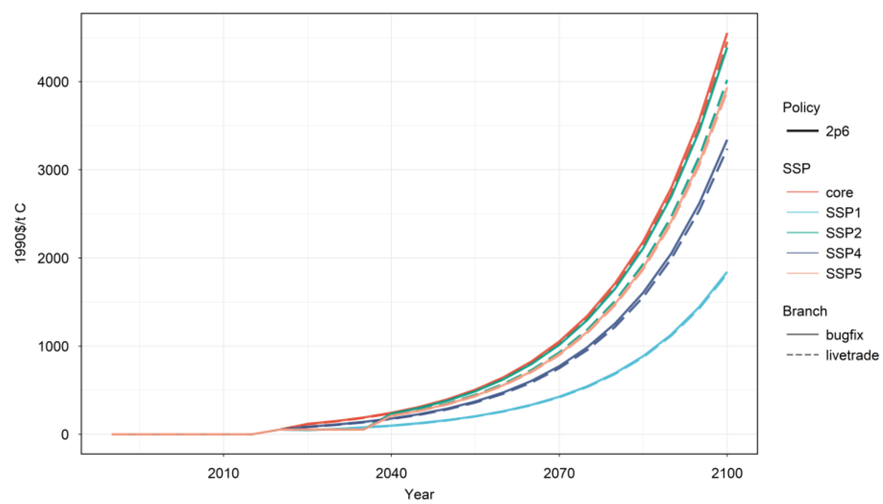

Fig. 22 CO2 price across RCP scenarios

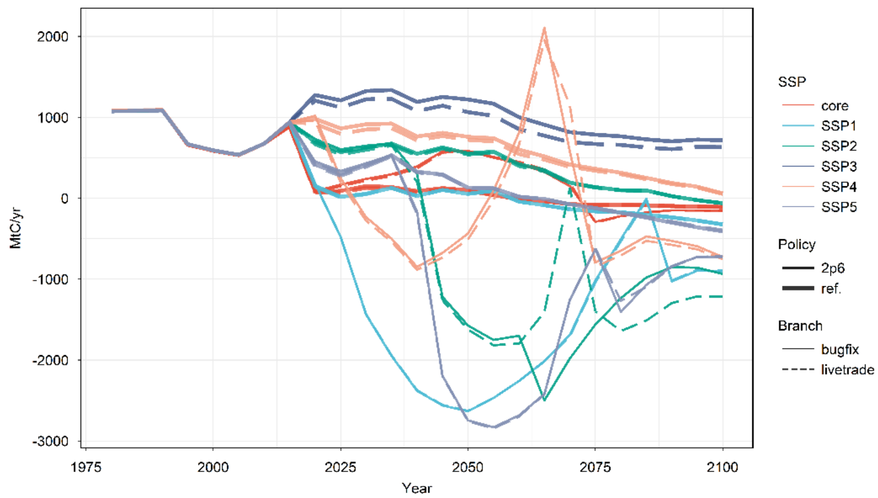

Fig. 23 Annual LUC carbon emissions across SPA scenarios

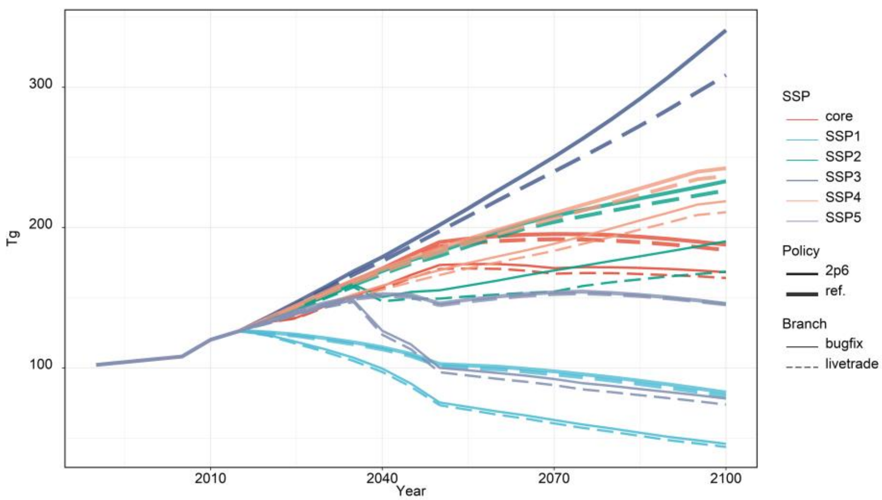

Fig. 24 CH4 emissions from livestock sectors across SPA scenarios

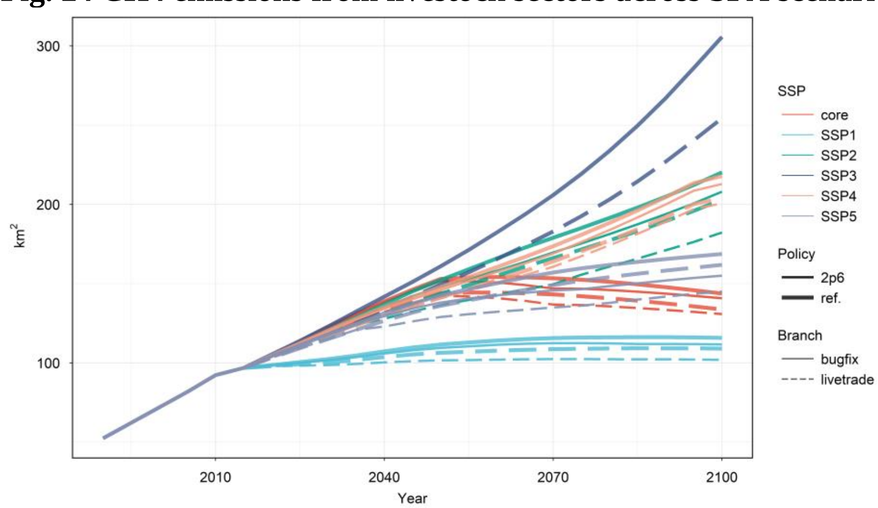

Fig. 25 Water withdrawal from livestock sectors across SPA scenarios

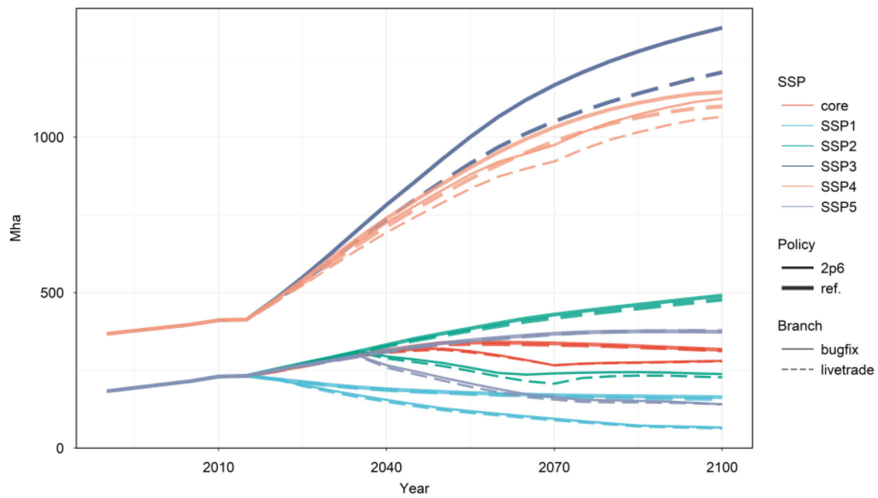

Fig. 26 Pasture area change across SPA scenarios

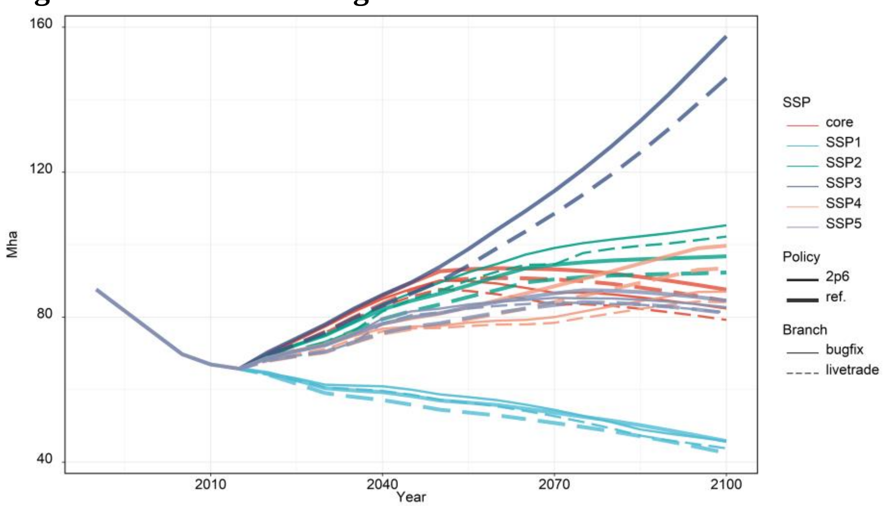

Fig. 27 Fodder crop area change across SPA scenarios

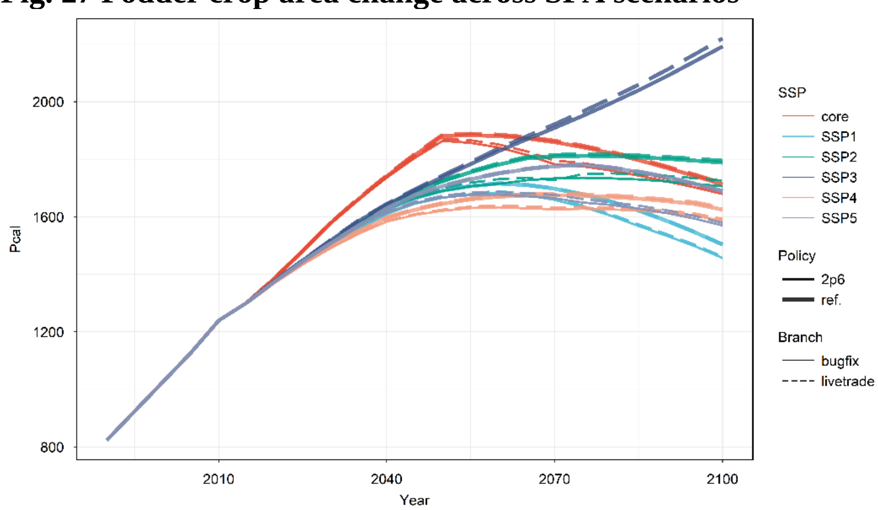

Fig. 28 World livestock product consumption across SPA scenarios

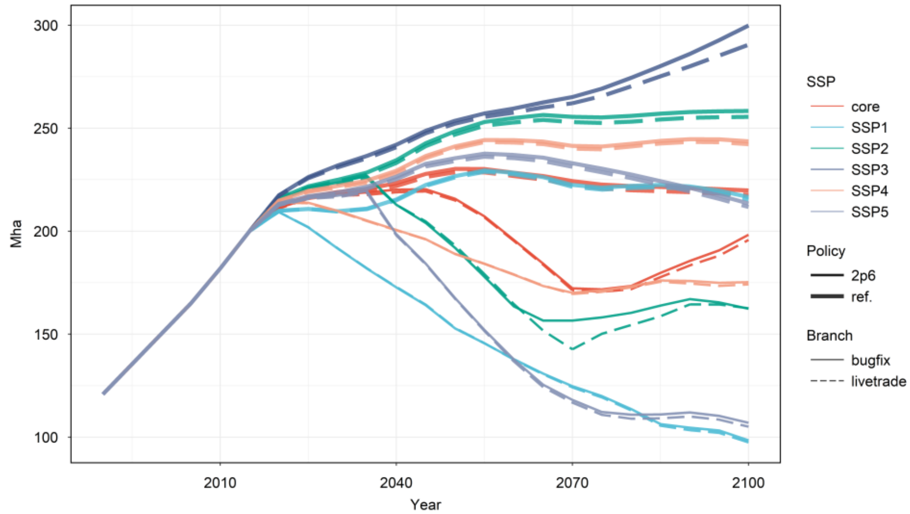

Fig. 29 World oil crop area across SPA scenarios

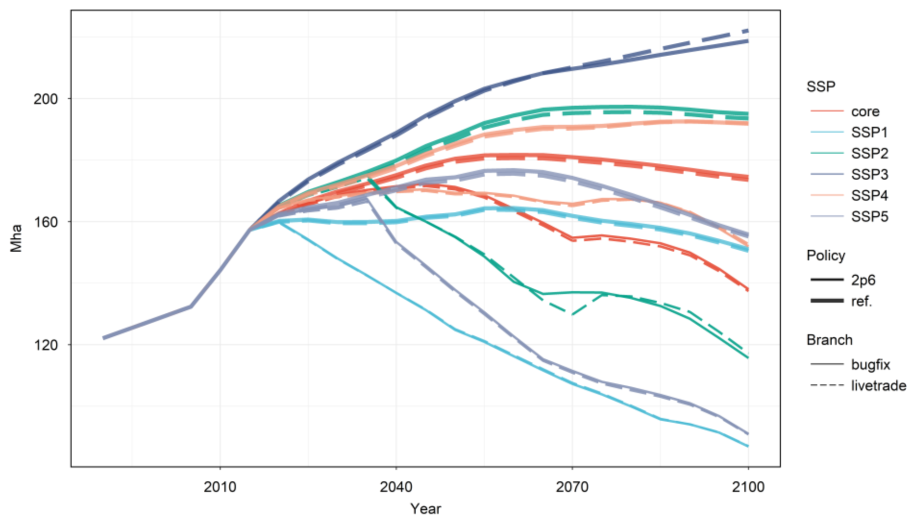

Fig. 30 World corn area across SPA scenarios

5.2.More detailed sector- and region-level results from SPA validation

The impact of allowing livestock trade on world total livestock production was small (**Fig. 31**), while there were major changes in the trade volume of livestock products at the world scale (**Fig. 32**). In most scenarios, there would be more livestock trade, except beef and sheep & goat under SSP1 (e.g., low population growth). Also, there will be generally less world production but more trade with climate policy (2p6). Allowing trade of livestock made global adaptation easier. The world crop production and trade across SPA runs are presented in **Figs. 33 and 34**. There were relatively higher impacts on the trade of corn and oil crops than other crops given the higher use in feedstuff. Generally, the impacts of the updates on crops were relatively small. Furthermore, regional results of the impacts from the update on the SSP4 were provided in **Figs. 35 - 37** for production, import, and export, respectively. These regional impacts on SSP4 have a similar pattern to those from GCAM core (**Figs. 10 - 12**), though there were changes in trade assumptions (more restricted) for low-income regions for SSP4.

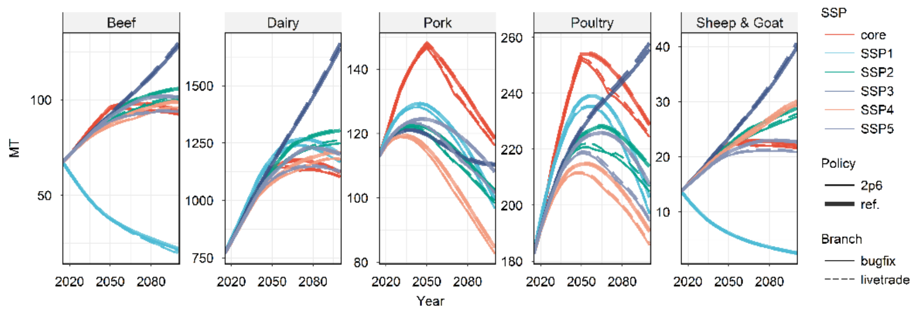

Fig. 31 World production for livestock sectors

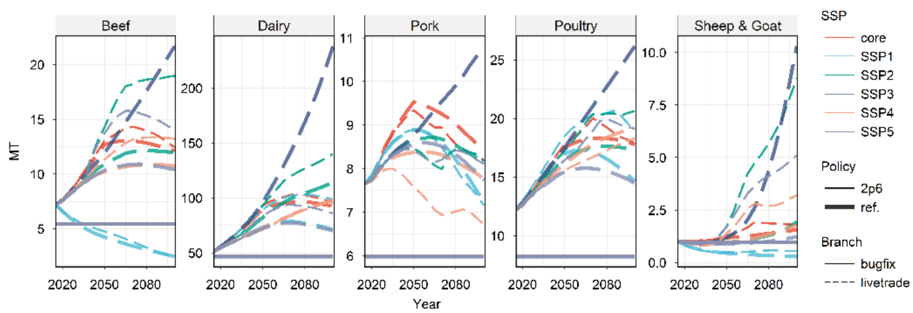

Fig. 32 World trade volume for livestock sectors

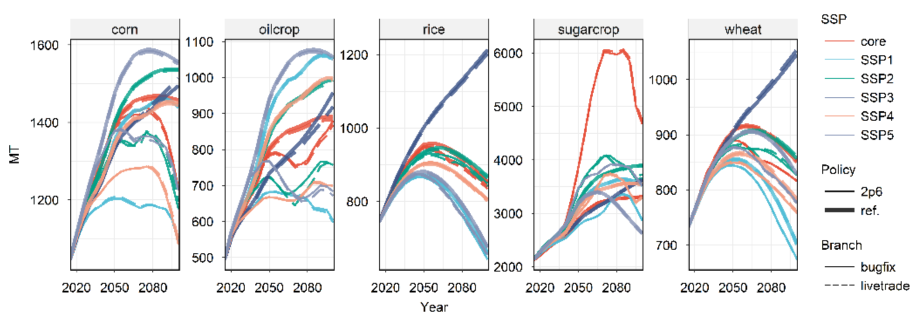

Fig. 33 World production for major crops

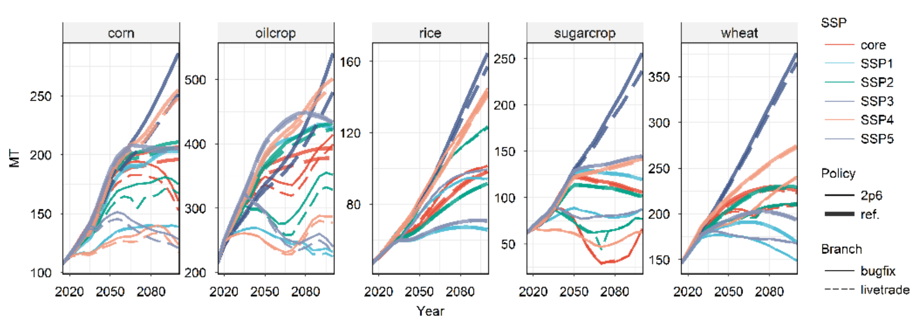

Fig. 34 World trade volume for major crops

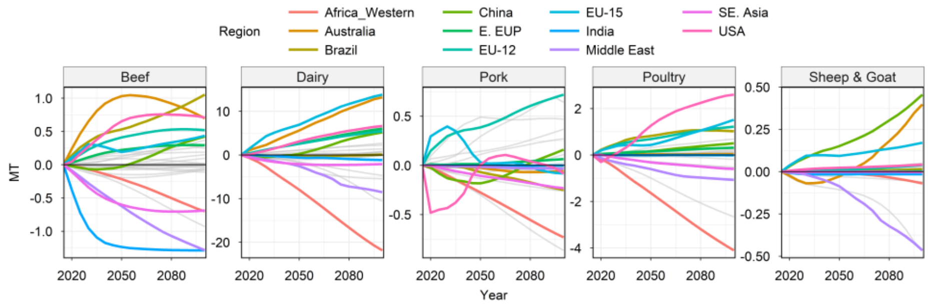

Fig. 35 Impacts on regional production of livestock products under SSP4 (ref.), livetrade relative to bugfix

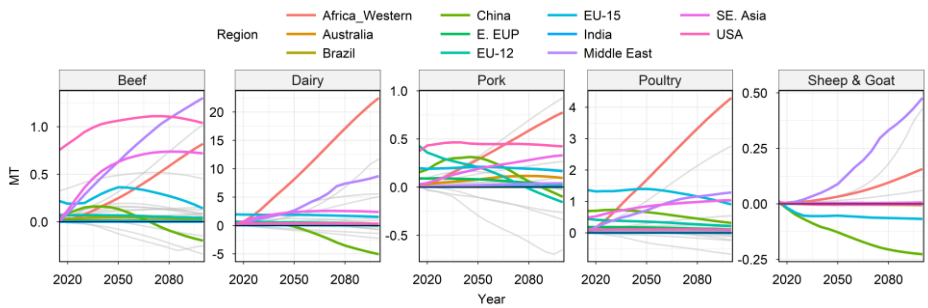

Fig. 36 Impacts on regional production of livestock import under SSP4 (ref.), livetrade relative to bugfix

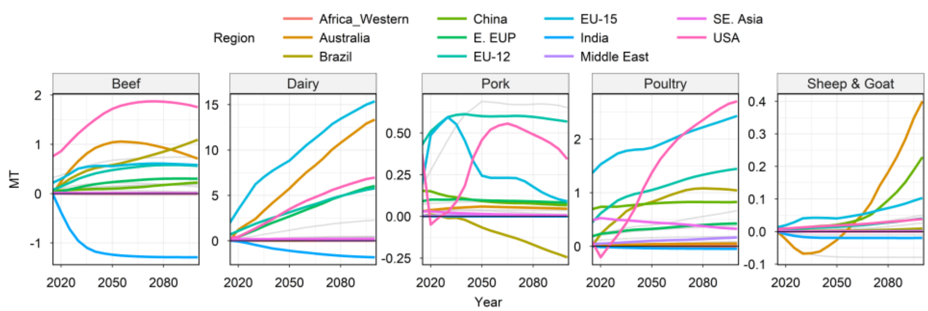

Fig. 37 Impacts on regional production of livestock export under SSP4 (ref.), livetrade relative to bugfix

6. Summary and discussion

The main impacts of the livestock trade modeling updates were on the regional supply and trade of livestock products. The reallocation of production led to mostly higher livestock productivity, and, thus, fewer inputs use in livestock production. Less pasture and feed crops used in livestock production increased land availability, and therefore there were more crops supplied to food, which in turn led to slightly lower prices and higher crop consumption globally. Also, the water uses in livestock production also decreased globally by 10 km^3 or 7% (mainly dairy, which accounted for 7 km^3 of the change). Note that the current demand system did not allow substitutions between meat and crop, and there might be more change with a higher magnitude on crops if the substitution were allowed.

Due to enabling livestock trade, there might be impacts on land and crops for bioenergy production globally. These changes are small, though, e.g., + 2.6 Mt or +1.2% from palm oil and 0.4 EJ or+0.4% from biomass while -1.3 Mt or -0.3% from oil crops, -1.7 Mt or – 0.4% from corn, and -3.9 Mt or -0.3% from sugar crops, in 2100 in the default scenario relative to the reference scenario. Thus, the change in DDGS & oil cake use in feeds was also negligible, and the impacts of the updates on other energy sectors are small. Furthermore, the land use change emissions would be generally lower (with regional variations) with the livestock trade updates as there was less cropland expansion.

Overall, the impacts of the livestock trade modeling updates are in line with expectations. These updates significantly improve the modeling responses and the projection of agriculture and land use future. With improved livestock trade responses, the model can now be used to study more advanced livestock related issues, e.g., impacts from diet transition (Laroche et al., 2020), closing yield gaps in livestock production (Ferreira-Filho and Stocco, 2019), land use and emission consequences (Mbow et al., 2017), and implications from future market integration (Yarlagadda et al., 2023).

Other related issues (*resolved already in later CMPs*):

1. The naming convention of Root & Tuber is not consistent as "root_tuber" is used in trade-related files while "RootTuber" is used in other places.
2. Biomass expansion has an important impact on the reference results. Ghost shares may be too high for some developing regions. And we may consider postponing the introduction of biomass to 2025 since the current assumption of 2020 expansion is no longer valid.
3. Trade parameters for crop trade are -3 (regional) and -6 (international). Calibrating these parameters based on literature information and distinguishing them across crops could likely improve the trade responses for crops.

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