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ORIGINAL PAPER

# The market impacts of shortening feed supply chains in Europe

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**Abstract**

Recently, consumers' awareness regarding food production has increased, leading to a growing focus on shorter food supply chains and regional or local food systems. In the livestock sector, these developments are closely related to a regionalization of feed production. At the same time, a low self-sufficiency rate in protein feed is being reported for many European countries. In this paper, we analyze market impacts resulting from a complete switch to regionally produced feed in the European livestock sector. We simulate a shortening of feed supply chains in European livestock production using a large-scale agricultural sector model. Livestock production was restricted to feed that can be produced within the same EU member state. Our work represents a first step towards a simulation of regional or local food systems. The results reveal large increases in the prices of livestock products in Europe due to the shortening of feed supply chains. This is a result of a significant increase in livestock production costs. The ability to supply livestock products with regionally produced feed in the EU would be improved through a reduced consumption of livestock products.

**Keywords** Regional feed supply · Agricultural sector model

## 1 Introduction

Shorter food supply chains and regional or local food systems have recently been getting more attention (Augère-Granier 2016; Kneafsey et al. 2013). Although local food production currently remains a niche market (Augère-Granier 2016), socioeconomic issues related to food production and distribution have become more important to consumers (Weatherell et al. 2003), and their interest in local food has steadily increased over the past decades (Feldmann and Hamm 2015).

Several EU member states have developed frameworks to support short supply chains in food production (Kneafsey et al. 2013). Furthermore, since the 2013 reform of the European Common Agricultural Policy, short supply chains and local markets have become an explicit element of the EU rural development policy (EU 2013; Augère-Granier 2016).

In this paper, we focus on feed supply chains in Europe. There is some evidence that some European consumers prefer livestock products raised with local feed (Wägeli and Hamm 2012; Wägeli et al., 2016). In addition, regionally produced feed is an important factor for a growing organic livestock sector for which a further increase in demand can be expected (Früh et al. 2015). A regionalization trend in feed markets is also recognized by large feed companies (Byrne 2017) and some companies already use regional production as a marketing tool, including the utilization of regionally produced animal feed.

A large amount of oilseeds and meals is, however, currently being imported into Europe providing proteins to the European livestock industry. A low self-sufficiency rate in protein feed is reported for many European countries, particularly in Western Europe (Watson et al. 2017; Früh et al. 2015; Bues et al. 2013; Erb et al. 2012). This situation has caused some concerns at the EU level. A 2011 report of the committee on agriculture and rural development of the European Parliament (Häusling 2011, p.11) sees an "alarming

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dependency of the Union on the imports of protein crops", due to major risks for the livestock sector and environmental concerns.

The ban of meat and bone meal as animal feed after the Bovine Spongiform Encephalopathy (BSE) crisis in 2001 and the history of international trade agreements, are two major reasons for the current situation. Apart from this, a high competitiveness of cereals in European agriculture due to higher and more stable yields has led to low production levels of protein rich crops (Häusling 2011; Bues et al. 2013; Watson et al. 2017).

Several different questions related to the described situation have been analyzed in the scientific literature. Some articles focus on the environmental effects of regionally produced feed: Hörtenhuber et al. (2011) for example, analyzed the potential of selected regionally produced protein-rich feed in Austrian dairy production to reduce greenhouse gas (GHG) emissions by comparing emissions from imported feedstuff to regionally produced feedstuff. Sasu-Boakye et al. (2014) compared regionally produced protein feed in Sweden to imported feed in terms of land use effects and GHG emissions. Röös et al. (2016) investigated a scenario in which livestock would only eat 'ecological leftovers', that is, grass from pasture and by-products unfit for human consumption, showing a significant reduction in environmental impact.

Other studies have focused on the market effects of disruptions in protein feed imports to Europe: Henseler et al. (2013), Kalaitzandonakes et al. (2014), and Philippidis (2010) estimated the market effects of different trade disruption scenarios in protein feed markets caused by an asynchronous approval of genetically modified soy varieties between EU and non-EU countries. They calculated the impacts of shocks for the EU agricultural sector for potential cases where one or more main trading partners would drop out.

The aim of this paper is to assess market impacts resulting from a complete switch to regionally produced feed in the European livestock sector. To this end, we applied a global agricultural sector model and estimated the impacts of scenarios where livestock production is only sourced from feed produced within the same EU member state. The study contributes to the literature assessing developments of regional food systems, with a quantified analysis of the shortening of the European feed supply chain. Furthermore, this research also responds to interests in focusing policies and strategies on local feed sourcing among practitioners throughout the niche food initiative cases and stakeholder meetings of the TRANSMANGO project, which is the focus of this special section (Grivins et al.; Moragues Faus et al.; Cerrado-Serra et al.; Galli et al.; Hebinck and Oostindie, this issue).

Future feed demand will depend on livestock production developments, which in turn depend on future meat and milk demands. To take this into account, we assessed a shortening of the European feed supply chains against different background assumptions regarding the development of human diets in Europe and their reliance on animal-sourced proteins. We focused on the shortening of feed supply chains and its consequences on European animal product supply, consumption, and price levels. This is clearly related to the question of European food self-sufficiency. We, however, did not analyze more general self-sufficiency here, since food for human consumption (crops and livestock products) can still be imported by Europe in our scenarios.

## 2 Methodology

### 2.1 Agricultural sector model

For our analysis, we applied the Global Biosphere Management model (GLOBIOM) (Havlík et al. 2011, 2014). GLOBIOM is a global recursive dynamic bottom-up partial equilibrium model integrating the agricultural, bioenergy, and forestry sectors. It is a linear programming model with a spatial equilibrium approach (Takayama and Judge 1971). An agricultural and forest market equilibrium is computed, based on a welfare maximizing objective function subject to resource, technology, demand, and policy constraints. More details about the general structure of the model can be found in the Supplementary Appendix (SI), Section 1.

The livestock sector in GLOBIOM represents eight different animal groups: bovine dairy and meat herds, sheep and goat dairy and meat herds, poultry broilers, poultry laying hens, backyard poultry, and pigs. Monogastrics are split into industrial and smallholder and for ruminants, four production systems are defined: grassland based, mixed, urban, and other. The first two systems are further differentiated by agro-ecological zones (arid/semi-arid, humid/sub-humid, and temperate/tropical highlands).

As outputs, different kinds of meat and milk, as well as eggs are depicted. The livestock production system parameterization relies on the dataset of Herrero et al. (2013). Animal numbers, production, and feed demand were harmonized for the model base year using the Food and Agriculture Organization Corporate Statistical Database (FAOSTAT). Leontief production functions were determined for each species, production system, and region.

Feed rations consist of grass, stover, feed crops, and other feedstuffs, such as animal meal. Feed crops are further differentiated to match with crops represented in GLOBIOM. However, only explicitly represented crops (barley, dry beans, cassava, chickpeas, corn, cotton, groundnut, millet, palm oil, potato, rapeseed, rice, soybean, sorghum, sugarcane, sunflower, sweet potato, wheat) are modelled endogenously in feed rations. Some crops which might be of special interest for this work (peas, broad beans, lupins) are exogenously represented due to their small share in overall feed quantities in the base year '(see also discussion in Section 4)'. Exogenously implemented feed crops were considered in the calculation of initial feed balances but fixed at base year levels. The additional feed demand for livestock production exceeding the base year production levels throughout a scenario run has to be fully provided by endogenously modelled crops.

The production of ruminants is modelled in a spatially explicit set-up in GLOBIOM. The resolution of the GLOBIOM model for this paper corresponds to a 2° × 2° latitude-longitude grid, disaggregated by three agro-ecological zones and country boundaries. The production of monogastrics is represented at the national level because it is not linked to a specific spatial feature in the model, such as grasslands.

Roughage production is represented in a spatially explicit way in the model and demand and supply of grass match at the regional level. But in Europe, large amounts of concentrate feed are imported or at least transported over long distances to regions with high density in livestock production.

To enable the implementation of regionalized feed supply chains, imported animal feed has to be replaced by other inputs that can be grown within the region of production. In the standard version of GLOBIOM, production functions assume fixed input-output relations and thus, substitution between feedstuff is only possible by switching between production systems, but not within a given production system. Thus, only a limited space of substitution options was given and for the implementation of regionalized feed supply chains, these options had to be extended.

To this end, we modified the livestock module to enable more substitution options and to allow for the complete elimination of certain crops from the feed rations. The original crop-specific feed demand in livestock production was transformed into energy and protein requirements that have to be fulfilled as a minimum requirement for the production of a certain livestock unit. The originally compiled feed rations were considered optimal at the calibration year since they are based on observed data, thus implicitly reflecting all costs and constraints connected to the production process (Howitt 1995). Consequently, any deviation from the original feed rations is assumed to be connected to extra costs, which are depicted by a linearized quadratic cost function in the model. More details about the feed module and the substitution relations can be found in the SI, Section 1.

Given the fact that we only ran scenarios on the regionalization of feed supply chains in Europe, we left the livestock module in the rest of the world in its original form, since computation time increases exponentially with the number of regions where the new feed substitution mechanism is implemented. This may have given Europe an economic advantage in terms of livestock production. However, the same approach was applied in all scenarios to ensure the internal consistency of the analysis.

## 2.2 Scenario design

For the analysis, we first ran a baseline scenario to capture the main drivers and trends impacting the agricultural sector until 2050. This scenario was run without any restriction on regionalized feed and served as a benchmark to measure the impacts of an implementation of regionalized feed supply chains until 2050. In a second step, we ran an alternative scenario with implemented regional feed supply chains, which was then compared to the benchmark (i.e., baseline) scenario.

For the baseline assumptions, we applied the Shared Socioeconomic Pathway "Middle of the road" (SSP2) that is often considered a business-as-usual scenario (O'Neill et al., 2014; Fricko et al. 2017). Trends were additionally adjusted to align with historical developments and recent structural breaks in European livestock markets (more information on baseline assumptions and developments can be found in the SI, Section 2).

Since we expected that the future development of the European consumption of livestock products would have a strong influence on the results, we tested the implementation of regional feed supply chains additionally against two modified baseline scenarios with varying assumptions on the development of European diets.

SSP2 served as standard baseline scenario (henceforth 'MED'). In addition, we defined one baseline with 20% lower consumption levels for animal products in Europe (henceforth 'LOW') and one with 20% higher levels (henceforth 'HIGH') with all other assumptions remaining the same as in MED.[1]

In the alternative regionalization scenarios, we simulated an implementation of regional feed supply chains in the EU28, which is the only difference from the respective benchmark scenario. To this end, the model was constrained so that all feedstuff had to be sourced from the same region as where livestock production was taking place. Since forage is considered a regionally produced, non-tradable product, the new regulation mainly affected the composition of concentrate feed. The regionalization was implemented stepwise. In 2020, the requirement is that 50% of the feed has to be produced regionally, in 2030 the share is increases to 75% and in 2040 and 2050 all feedstuff has to be produced regionally. These assumptions reflect a rather extreme scenario which serves as an example of testing the solution space and market impacts of a regionalization of feed supply chains.

We defined regionally produced feed as feed that is produced in the same EU member state as where the livestock production takes place. The national level is a relatively broad definition of regional production (Kneafsey et al. 2013), which reflects data availability issues. Although ruminant production in the model is implemented at a high spatial

[1] The changes in consumption levels refer to the exogenously implemented trends of demand only.

resolution (200 $km^2$ x AEZ x country borders), data on the production of monogastric animals are only available at the national level. A mixed definition of regionally produced feed would lead to a biased analysis and results would be difficult to interpret.

Note that the only change between a baseline scenario and an alternative with regional feed supply chains is that feed needs to be produced regionally (i.e., in the same EU member state). Consumers can still buy imported products from other countries. In the following, we refer to the three different benchmarking baseline scenarios (with global feed supply chains) as LOW_bench, MED_bench and HIGH_bench, while the respective scenarios with implemented regional feed supply chains are referred to as LOW_regio, MED_regio and HIGH_regio.

## 3 Results

The introduction of regionalized feed supply chains causes additional costs for European livestock producers. Producers partly have to switch from cheap imported feedstuff to more expensive regionally produced feed crops, and they have to bear the costs of adjustment in supply chains and feed rations.

Due to higher production costs, livestock production in Europe declines compared to production in the benchmark scenarios in 2050 (Fig. 1). The strongest impact can be observed in the scenario with an assumed high increase of meat and milk consumption ('HIGH'). Instead of increasing by 34% as in the benchmark scenario, meat production increases by only 19% until 2050, which reflects an 11% decrease of 2050 production levels. A slightly stronger impact (−16%) can be observed for the milk market.

Furthermore, higher production costs lead to higher commodity prices and lower consumption levels of meat (displayed as an aggregate of beef, sheep and goat, pork, and poultry meat) and dairy products (i.e., cow, sheep, and goat milk). While in the 'LOW' scenario, the impact on consumption is relatively small (meat consumption declines by 2% and milk consumption by 3%), it is stronger when a higher demand for livestock products is assumed in the benchmark scenarios (meat consumption declines by 4% ['MED'] and 6% ['HIGH'], and milk consumption by 6% ['MED'] and 8% ['HIGH']).

With a relatively price-inelastic food demand in Europe (Muhammad et al. 2011), impacts on demand quantities for milk and meat are low compared to impacts on prices. Prices increase by up to 26% for meat and 22% for milk due to the implementation of regional feed supply chains. In general, effects are stronger for the higher demand levels for livestock products than they are in the benchmark scenarios.

Lower production levels are partly compensated for by trade effects (Fig. 2). In the strongest scenario ('HIGH'), the EU28 turns into a net importer of milk and meat products. In the other two scenarios, the EU considerably reduces meat and milk exports, but remains in a net-export position. Thus, the ability of the EU28 to produce all consumed livestock products with regionally produced feedstuff depends on the consumption level for livestock products and on the price consumers are willing to pay.

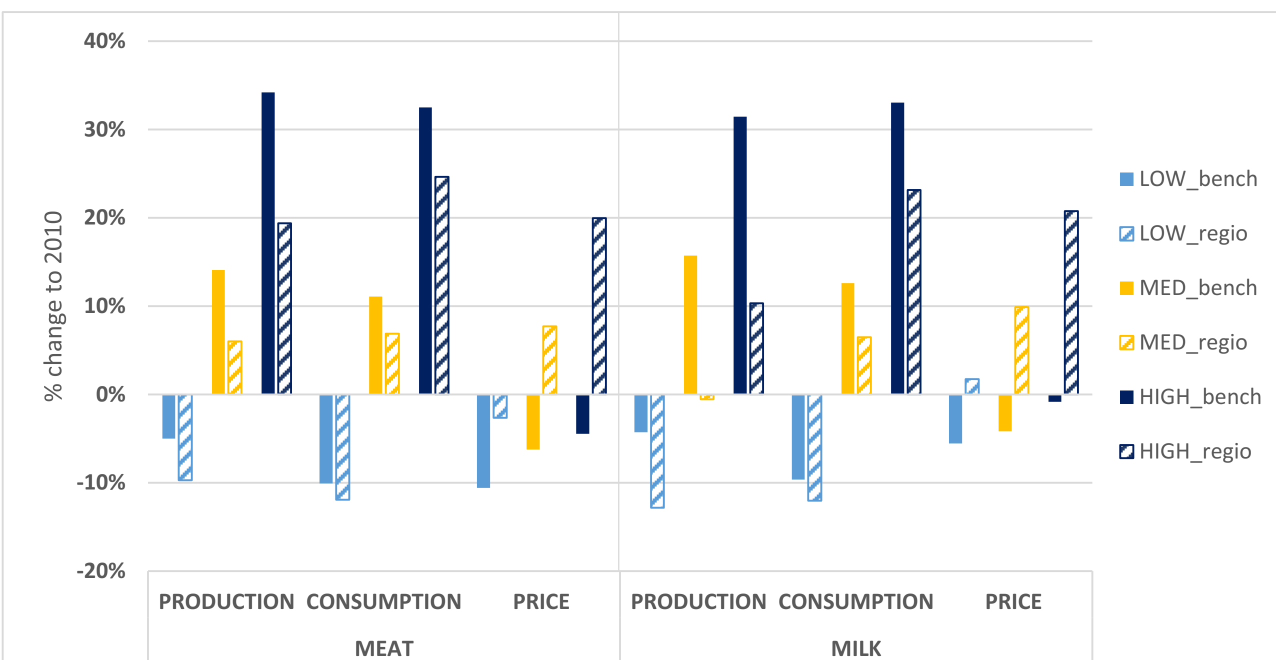


**Fig. 1** Development of meat and milk in the EU28 in 2050 – production, consumption, and prices in relation to 2010 levels for benchmark scenarios (LOW_bench, MED_bench, HIGH_bench), as well as respective scenarios with regionalized feed supply chains (LOW_regio, MED_regio, HIGH_regio)

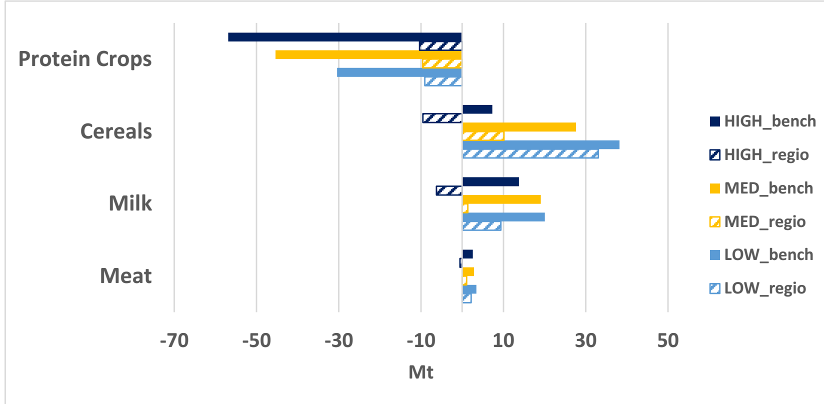


**Fig. 2** EU28 net-trade positions (negative values = net-imports, positive values = net-exports) of meat, milk, cereals and protein crops in 2050

For protein crops,[2] the EU28 remains in a net-import position in all scenarios with an implementation of regional feed supply chains in 2050, however, to a much lower extent than in respective scenarios with global supply chains. The remaining protein crop imports are used for other purposes than feeding livestock.

Additionally, the implementation of regional feed supply chains causes higher net-imports of cereals in the EU in 2050. In the 'HIGH' scenario, the EU turns from a net-exporter into a net-importer, while in the other two scenario a net-export position is kept, but at considerably lower levels. While fewer protein crops are imported into the EU because of the omitted demand from the livestock sector, cereal net-imports are increased because some cereal production is replaced by higher protein crop production within the EU28 countries.

Crop production patterns in Europe are significantly impacted due to the implementation of regional feed supply chains. The significant extension of European protein crop production (mainly rapeseed, sunflower, and soybean) in all scenarios and the reduced cereal production can be observed in Fig. 3. However, overall, the demand for feedstuff from both categories (cereals and protein crops) declines due to the reduced livestock production in the scenarios with regionalized feed supply chains.

The effects of regionalized feed supply chains differ substantially between Western and Eastern European countries (Fig. 4), because Eastern Europe is almost self-sufficient in protein crop production in the base year of the scenarios. Due to the implementation of regional feed supply chains, livestock production in Eastern Europe gains in competitiveness compared to Western Europe, where a much higher share of formerly imported protein crops has to be replaced by domestic production, leading to a larger cost increase. Consequently, a significant switch of area formerly used for cereal production towards the production of protein crops can be observed in Western Europe, while no strong changes in land use patterns appear in Eastern Europe.

[2] The term "protein crops" refers to oilseeds (including meals and cake) and dry beans. The latter is the only pulse of relevance in European agriculture that is endogenously depicted in GLOBIOM.

While both milk and meat production is decreasing for all scenarios in Western Europe, meat production increases in Eastern Europe. In the 'MED' and 'HIGH' scenarios milk production decreases slightly in Eastern Europe because meat production becomes more profitable than milk production.

## 4 Discussion

The results of our analysis revealed strong impacts on prices for livestock products in the EU28 due to the implementation of regional feed supply chains. This is a result of a significant increase in livestock production costs, as producers have to switch from imported cheaper feedstuff to more expensive regional products. Furthermore, higher costs would also be expected due to the reorganization of long and complex feed supply chains (Martin 2015), the need to supplement minerals to preserve the nutrient balance of feed rations (Olson and Hale 2001), or the special pretreatment of feedstuff, for example, to reduce anti-nutritive factors (Soetan and Oyewole 2009; Bell 1993).

The introduction of regional feed supply chains in our scenarios can be interpreted as being enforced by the government, since it was simulated as a strict constraint applied to the entire European livestock sector. This certainly would reflect a rather extreme policy scenario, which is not likely to happen in reality. For example, the resulting trade distortions and the favoring of domestic feed producers could generate some disputes at the WTO level. Alternatively, it can be interpreted as a shift in consumer preferences (reflecting, for example, an upscaling of niche initiatives aiming at shortening food supply chains). However, it currently also seems unlikely that a large-scale shift of preferences would happen without policy intervention, despite some evidence that consumers are willing to pay a premium for locally produced food (Feldmann and Hamm 2015). Nevertheless, the high import rates of feed (mostly related to protein crops, Häusling 2011) and the advantages and disadvantages of local food (Schmitt et al. 2017; Brunori et al. 2016; Edwards-Jones 2010) are under frequent discussion. This paper contributes to that

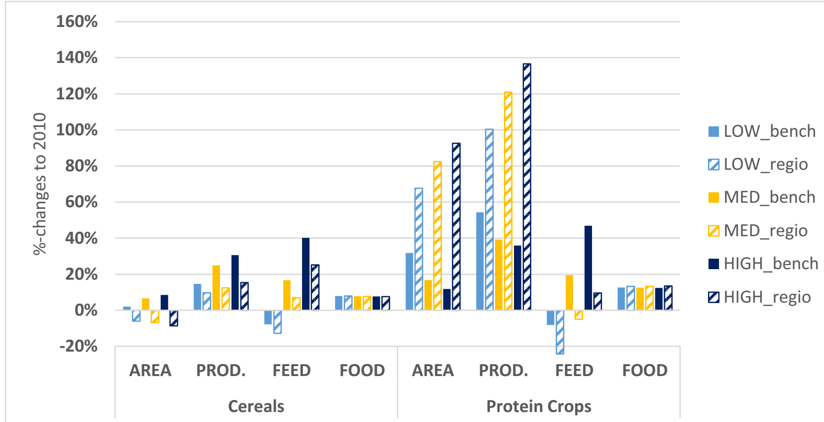


**Fig. 3** EU28 cereals and protein crops – development of area, production, feed demand, and food demand until 2050 in relation to 2010 levels

discussion by showing the trade-offs and quantifying the impacts on land use, production, consumption, prices and trade.

In our analysis, however, we did not restrict total food consumption to regionally produced food. We only restricted feed use in Europe to regionally produced crops. While in the 'LOW' and 'MED' scenarios, the EU28 would reduce the net exports for livestock products, in the 'HIGH' scenario, at least for dairy products, a clear net import position was reached. This obviously counteracts the idea of a regionalization of livestock production and it shows that there is only limited potential to fully substitute for imported feeds within the EU.

Due to a relatively price-inelastic food demand in Europe (Muhammad et al. 2011), strong changes in production costs translate into strong price changes and comparatively small changes in consumption levels. The results, however, also depend on the representation of trade within the model. Increasing marginal trade costs were assumed when trade quantities were extended. Thus, prices increased with major shifts in imports, which prevented the model from substituting all domestically produced livestock products with imports from other regions.

Despite the relatively inelastic demand for food, we observed a reduced consumption of livestock products in our scenarios with regional feed supply chains in comparison to

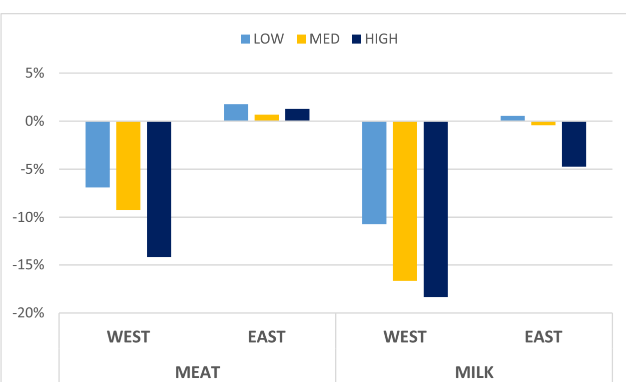


**Fig. 4** Meat and milk production in Eastern Europe (Estonia, Latvia, Lithuania, Bulgaria, Croatia, Czech Republic, Hungary, Poland, Romania, Slovakia, and Slovenia) compared with Western Europe

the benchmark scenarios with global feed supply chains. However, we did not observe a significant increase in crop demand for human consumption, which might be expected as a compensation for the reduced calories consumed from livestock products (Schösler et al. 2012). This is owed to the fact that the demand system in our model incorporates own-price elasticities of demand, while cross-price effects are only indirectly incorporated via the price changes at the production side. With a direct consideration of cross-price effects at the demand side, we would likely see stronger substitution effects. These effects, however, were not crucial for our analysis, since we focused on regional feed supply chains and food imports were not restricted in our scenarios.

Due to data availability, we restricted feed production to the national level, even though that is quite a large scale for most member states. Based on a literature review, Kneafsey et al. (2013) found that the geographical size that is often used to refer to 'local food systems', is an area that typically has a radius of about 20 to 100 km. To emphasize the difference to the local scale, we used the term regional feed supply chains.

An implementation of feed supply chains at a smaller scale than the national level would constrain production even more and stronger effects would be expected. Furthermore, if the goal would be to exclusively consume regionally or locally produced food (not only imposing requirements for feed), production would be even more constrained and additional problems would likely appear. A weakness of short supply chains, for example, is that local demand cannot always be met by local producers (Kneafsey et al. 2013). However, this kind of analysis is beyond the scope of our paper.

In our scenarios we mainly focused on oilseeds to provide the required proteins for livestock production in the EU28, even in the scenarios with regional feed supply chains. This is because currently oilseed meals, cakes and seeds are dominating the protein supply in European livestock production. Other crops such as peas, lupins and faba beans account only for a very small share in feed rations, despite their high protein content (FAOstat, Voisin et al. 2014). The reason for the current situation is mainly the relatively low profitability of these legumes compared to other

European field crops (de Visser et al. 2014, Voisin et al. 2014). However, in a policy context as described for our analysis, where feed use in Europe is restricted to exclusively regionally produced crops, legumes could gain competitiveness, due to their very high protein production levels per hectare (Pilorgé and Muel 2016) or positive effects on subsequent cereal crop yields in crop rotation systems. In addition, the production of legumes may have fertilizer saving effects and thus potentially reduce production costs (Reckling et al. 2014). Since we did not include these effects in our analysis, we may have overestimated the costs of an implementation of regional feed supply chains and respectively the sectoral impacts.

Finally, we neither considered attempts to reduce the amount of proteins used in feed diets, such as in precision feeding (Martin 2014) nor alternative protein sources, such as insects or algae, which may play an important role in livestock production in the future (Sánchez-Muros et al. 2014; Yaakob et al. 2014).

## 5 Conclusions

In this paper, we aimed to assess the market impacts of a drastic regionalization scenario, as advanced by many stakeholders in the TRANSMANGO project.

We conclude that an implementation of regional feed supply chains in the EU would cause significant impacts for agricultural markets. Costs of livestock production and thus prices for livestock products would be expected to increase substantially. The ability to produce livestock products exclusively with regional feed depends on the European demand for livestock products. With a strong future increase of demand for meat and milk, the EU might increase imports of livestock products due to the implementation of regional feed supply chains, which would counteract the idea of regional production. On the contrary, a reduced consumption of livestock products would expand the option room for a regionalization of livestock production with less pronounced impacts on meat and milk prices.

Moreover, crop production patterns would have to change considerably to facilitate regional feed supply chains, mainly in Western Europe, where the share of protein crops would have to be increased substantially. In Eastern European countries, less pronounced impacts are expected due to higher regional rates of self-sufficiency for protein crops.

While shortening feed supply chains may have positive environmental effects (as suggested by e.g. Hörtenhuber et al. 2011, Sasu-Boakye et al. 2014, Watson et al. 2017), our results show that meat and milk prices may substantially increase. The socio-economic implications of such price rises are ambivalent. On the one hand, higher meat prices will incentivize consumers to eat less meat and change their consumption patterns. But higher meat prices will result in lower welfare outcomes for low-income consumers who do not or cannot change their consumption practices. Such trade-offs confirm the conclusion of Brunori et al. (2016) that sustainability assessments of localization strategies are complex and that one should be careful if attempting to equate local food with sustainable food.

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## Compliance with ethical standards

**Conflict of interest** The authors declare that they have no conflict of interest



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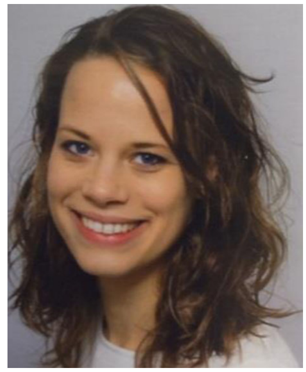

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