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Research Paper

Potentials and perspectives of food self-sufficiency in urban areas—a case study from Leipzig

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Abstract

Regionalization of food systems is a potential strategy to support environmental, economic and social sustainability. However, local preconditions need to be considered to assess the feasibility of such a transformation process. To better understand the potentials and perspectives of food self-sufficiency in urban and peri-urban areas, we determined the food self-sufficiency level (SSL) of a German metropolitan region, i.e., the percentage of the food demand that could be potentially provided on existing agricultural land. Main input parameters were actual food demand, agricultural productivity and its temporal variability and land availability. Furthermore, we considered changes in diet, food losses and land management. Based on current diets and agricultural productivity, the administrative region of Leipzig achieved a mean SSL of 94%, ranging from 77 to 116%. Additionally, an area of 26,932 ha, representing 12% of the regionally available agricultural land, was needed for commodities that are not cultivated regionally. Changes in food demand due to a diet shift to a more plant-based diet and reduced food losses would increase the SSL by 29 and 17%, respectively. A shift to organic agriculture would decrease the SSL by 34% due to lower crop yields compared with conventional production. However, a combination of organic agriculture with less food loss and a more plant-based diet would lead to a mean SSL of 95% (75–115%). Our results indicate the feasibility of food system regionalization in the study area under current and potential near future conditions. Addressing a combination of multiple dimensions, for example plant-based and healthier diets combined with reduced food loss and organic farming, is the most favorable approach to increase food self-sufficiency in urban and peri-urban areas and simultaneously provide synergies with social and environmental objectives.

Introduction

In light of climate change, environmental degradation and rising food demands, achieving productive, resilient and sustainable food production is a major challenge humankind faces today (Bailey *et al.*, 2015). Regionalization of food systems and increasing food self-sufficiency is discussed as a possible way to better address this issue (Doernberg *et al.*, 2016), as well as current and future food security particularly in light of ongoing urbanization (Zasada, 2011; Sali *et al.*, 2014). Regional food systems are often characterized by personal relationships between the various stages of short food supply chains, for example farmer shops, within a specific geographic region (Schönhart *et al.*, 2009) or within a radius of 100 km around big cities (Kremer and DeLiberty, 2011). It has been argued that shorter food supply chains potentially reduce greenhouse gas (GHG) emissions due to fewer food miles, i.e., the distance between food production and food consumption (European Commission, 2013; Augére-Granier, 2016), and food losses (Teitscheid, 2012; Schipanski *et al.*, 2016). Regional agricultural activities can support and strengthen regional economic structures, because local services and suppliers and money flow are supported (European Commission, 2013; Kurtz *et al.*, 2020). Additionally, the close link between production and consumption can help to increase consumers' awareness of the social, economic and environmental impacts of food choices (Schönhart *et al.*, 2009) and lead to a higher transparency of production processes (Doernberg *et al.*, 2016). In contrast, a purely regional system might be less resilient, as trade with other regions can compensate for local food supply shocks, e.g., production losses after extreme weather events (Kinnunen *et al.*, 2020). Additionally, higher land demands due to inefficient and unproductive land uses could reduce the sustainability of regional food systems (Schlich and Fleissner, 2005; Brown *et al.*, 2014).

Today, only around one-quarter of the population could be nourished regionally under the current patterns of food production and consumption (Kriewald *et al.*, 2019; Kinnunen *et al.*,

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2020). Compared to the global scale, metropolitan regions in Europe show higher self-sufficiency potentials (Cardoso *et al*., 2017; Zasada *et al*., 2019). Hamburg, for example, could reach full self-sufficiency within a 100 km-radius (Joseph *et al*., 2019).

Major control factors of food self-sufficiency in urban and rural areas are (i) food demand, (ii) agricultural productivity and (iii) availability of agricultural land (Peters *et al*., 2007). The total food demand (i) can be determined by actual diet, food losses and waste along the supply chain (Birney *et al*., 2017). Hence, diet shifts toward less area intensive food as well as food waste and food loss reduction are possible ways to reduce area demands. Globally, animal products such as meat and dairy products are a major component of diets accounting for about 35% of the total daily food intake (German average, BMEL, 2020d) and is still increasing (Godfray *et al*., 2018). Due to their high area demands, the production of meat and dairy products are among the main contributors to global warming, and can lead to the degradation of ecosystems and loss of biodiversity as well as depletion of fresh-water sources (Cassidy *et al*., 2013; Muller *et al*., 2017; Godfray *et al*., 2018). Additionally, high consumption of meat can negatively affect peoples' health, for example increase cancer, diabetes and stroke risks (Röös *et al*., 2016; Wolk, 2017; Godfray *et al*., 2018). In summary, a diet shift to more plant-based food could provide environmental and human health benefits simultaneously (EAT-Lancet-Commission, 2019). Further aspects of total food demand are food waste and losses. Around one-third or 1.3 billion tons of agricultural products are lost annually along the global value chains (Gustavsson *et al*., 2011), and halving these losses is a major international (SDG 12.3) and national objective (BMEL, 2020a).

Agricultural productivity (ii) mainly depends on agricultural practices. For example, yields of organic agriculture are often 5–40% lower compared to conventional agriculture, depending on crop type, region and individual factors (Mäder *et al*., 2002; Seufert *et al*., 2012). However, additional environmental benefits are associated with organic agriculture, including reduced pesticide use and nitrogen losses and increased soil quality and biodiversity (Mäder *et al*., 2002; Muller *et al*., 2017). In Germany, the number of organic farms and the area of organic agriculture—currently around 10%—are steadily increasing (BMEL, 2020c).

In urban and peri-urban areas, availability of agricultural land (iii) is limited due to competing spatial demands for industry, infrastructure, housing and other non-agricultural land use (Russo and Cirella, 2019; Torquati *et al*., 2020). Additional land competition arises from for the production of non-food purposes on agricultural land such as bioenergy, fibers or other biomaterials. For example, the production of crops for bioenergy and biomaterials such as rapeseed and maize increased around 2.5-fold in the last 20 years (FNR, 2020a). In total, about 82% of the German agricultural area is used for food or feed production (FNR, 2020a).

In this paper, we examined the food self-sufficiency level (SSL) of the administrative region Leipzig ('Direktionsbezirk Leipzig') in Central Germany. We linked average food demand, regional population numbers and crop yield data to estimate the area demand in relation to the regionally available agricultural area. We analyzed the SSL under current food demand (baseline diet), a diet shift toward a more plant-based diet, reduced food losses and each scenario with conventional or organic production. We combined these scenarios, as they could potentially address multiple sustainability targets (Muller *et al*., 2017). The results yield important insights into the feasibility of food system regionalization and provide an important baseline to investigate ecological and socio-economic impacts associated with food system regionalization.

Methods and data

Area definition and population data

The administrative region of Leipzig, comprising Leipzig, the district ('Landkreis') of Leipzig and the district Northern Saxony, was selected as study region, because it represents a typical region in Germany, comprising a large city and a less densely populated peri-urban area. The total human population in 2018 was 1,043,293 (DESTATIS, 2020b). The agricultural area in 2019 was 228,551 ha including cropland, grassland and land for permanent cultures (Statistisches Landesamt des Freistaates Sachsen, 2019, Supplementary Table 1). We assumed 100% availability of agricultural land for food production.

Due to high GHG emissions, conversion of permanent grassland into cropland is prohibited in Germany (UBA, 2019). Therefore, these agricultural areas were only used to satisfy demands for animal feed. In scenarios with lower demand for animal commodities, the remaining grassland was considered to be taken out of production (Supplementary Tables 2 and 3).

Demand data

To calculate total commodity demand, average national food demand per capita data of 2017 were used (BMEL, 2020d; Supplementary Table 4). Processed commodities were converted to primary commodity equivalents using standardized factors (Supplementary Table 4). Data do not reflect actual food intake but market availability of food. To account for food losses, standard factors for different commodity groups during post-harvest handling and storage and further processing were applied (Gustavsson *et al*., 2011; Supplementary Tables 6 and 7). On-field losses are excluded in the yield data (DESTATIS, 2018a). All commodities accounting for 99% of total demand (in kg/capita) were included. The remaining 1% was excluded to reduce data input and to avoid uncertainties resulting from less important commodities. Demand values were then scaled up to 100% to approximate total demand.

Furthermore, the dietary composition recommended by the EAT-Lancet Commission including food group-specific quantities was used and commodities were grouped into the EAT Lancet categories (EAT-Lancet-Comission, 2019). We assumed that every commodity within one food group is eaten in equal amounts. As above, oil plants and sugar were converted to primary commodity equivalents, food-processing factors were applied to calculate the quantity of needed raw products and food loss factors were applied (Supplementary Table 5). Furthermore, losses related to post-harvest handling, storage, processing, retail and consumption were added (Supplementary Table 7), because demand data of EAT Lancet refer to actual food intake.

Yield data

Conventional and organic yield data for each commodity were extracted for the years 2012 to 2018 from various sources (BMEL, 2019; FAO, 2019; Statistisches Landesamt Sachsen, 2019; DESTATIS, 2020a; Statistisches Landesamt Sachsen-Anhalt, 2020).

The data taken from DESTATIS were classified as conventional yield, because about 90% were conventional and only 10% organic yield data (UBA, 2020). Most data sources provided aggregated area, but farm level data of test farms ('Testbetriebsnetzdaten') were used for organic yields partially (Supplementary Table 8, BMEL, 2019). The highest available data resolution and closest association to the study area was chosen in the following order: Leipzig city, the district of Leipzig and the district of Northern Saxony; state level data for Saxony; Saxony-Anhalt, Brandenburg and Thuringia; German and global data for imported commodities. The selected yields were used for the entire study region, i.e., homogeneous soil fertility and suitability was assumed. For commodities that were summarized in a product group to match demand data, area weighted mean yields over all commodities belonging to the same category were calculated for each year. To account for the variability in yield data, a sample size of at least three replicates per year for the data extracted from farm level data and a minimum of 5 years for the calculation of mean, standard deviation, minimum and maximum values for all data was assumed to be adequate. Yield data with lower sample sizes were reviewed and handled manually (Supplementary Table 9). In the case of extreme variability in the data, single values were excluded from the analysis. For crops with multiple cultivation methods (open field/under cover), the dominant cultivation technique was used (Supplementary Table 10). To account for multiple cropping per year of vegetables on the same field, vegetable yields were increased by the factors 1.02 and 1.20 for conventional and organic production, respectively (Goy, 2009; Hübbers, 2017).

The calculation of areas needed for the production of livestock commodities was based on animal feed intake and feed yields of the corresponding production type (Woitowitz, 2007; Meier *et al.*, 2014; Hönle, Meier and Christen, 2017; Treu *et al.*, 2017; DESTATIS, 2019; Supplementary Table 9). Most of the livestock data referred to carcass weight, thus, unless more specific information was available, this assumption was made for all data sources. Fish was assumed to be produced in 100% aquaculture. In addition to literature data, a calculation for trout in France was conducted and included in the analysis (FAO, 2011; Supplementary Table 11).

Analysis

To calculate the area demand for each commodity A_C, per capita demand of the single commodity C_C was divided by the respective yield Y_C (Equation 1). The single commodity area demand was then summed up over all commodities for a total area demand per capita and multiplied by the number of inhabitants (I) in the study area to calculate the total area demand of all inhabitants A_T (Equation 2). Following Zasada *et al.* (2019), the available agricultural area A_{AV} was subsequently divided by the total area demand and multiplied with 100 to calculate the SSL in percent (Equation 3). An SSL value of 100% means that a region could potentially be self-sufficient. An SSL of more than 100% indicates that the region could achieve a food surplus (more food available than needed), whereas an SSL below 100% reveals that food would need to be imported to meet the demand. The SSL was only calculated for commodities that can be produced regionally (regional commodities). Non-regional commodity (non-regional commodities) yields such as coffee were only available for conventional production and the corresponding non-regional area demand was computed.

To account for variability in production data, yields were sampled from a normal distribution based on the mean and the standard deviation (S.D.) of the underlying data. Sampled yields were bounded to the minimum and maximum yields observed in the data. This procedure was repeated 1000 times and mean values and their variation were extracted:

$$A_C[\mathrm{ha}] = \frac{C_C[\mathrm{kg}]}{Y_C[\mathrm{kg\,ha^{-1}}]} \tag{1}$$

where A_C is the area demand of single commodity, C_C is the per capita demand of single commodity and Y_C is the yield of single commodity

$$A_T[\mathrm{ha}] = \sum\nolimits_C^A [\mathrm{ha}] \times I \tag{2}$$

where A_T is the total area demand of all inhabitants, A_C is the area demand of single commodity and I is the number of inhabitants:

$$\mathrm{SSL}[\%] = \frac{A_{AV}[\mathrm{ha}]}{A_T[\mathrm{ha}]} \times 100 \tag{3}$$

where SSL is the self-sufficiency level, A_{AV} is the available agricultural area and A_T is the total area demand of all inhabitants.

The analysis was conducted with R Studio (Version 1.2.1335).

Scenarios

Three demand scenarios were developed and combined with conventional or organic yields, respectively. For the *baseline diet scenarios*, current food demand was used. The *baseline diet scenario with conventional yields* is assumed to be closest to the current situation in Germany. For the calculation of the *diet shift scenarios*, the diet composition published by the EAT Lancet Commission was used. Compared to the current food demand, this diet contains halved meat and dairy consumption and increased vegetables (about 50% more) and legumes proportions (about threefold). For the *food loss scenarios*, German average per capita food demand data with halved food loss at the retail and consumption levels were used, ranging between 5 and 25% loss depending on the commodity group. In the *combined scenario*, the diet composition published by the EAT Lancet Commission was computed with halved food loss at the retail and consumption levels and organic yield data. All data that support the findings of this study, as well as related codes for data preparation and analyses, are openly available here: https://doi.org/10.5281/zenodo.5575201.

Results

Proportion of food and area demand

The German average food demand was dominated by milk (29%) as well as roots and tubers (27%), with sugar beet as the main contributor to the latter group, whereas the EAT Lancet Commission diet showed the highest percentage in fruits and vegetables (31%) (Fig. 1). The milk, meat and roots and tubers categories showed much smaller proportions of demand in the EAT Lancet diet compared to the German average food demand with a reduction of 61, 67 and 37%, respectively.

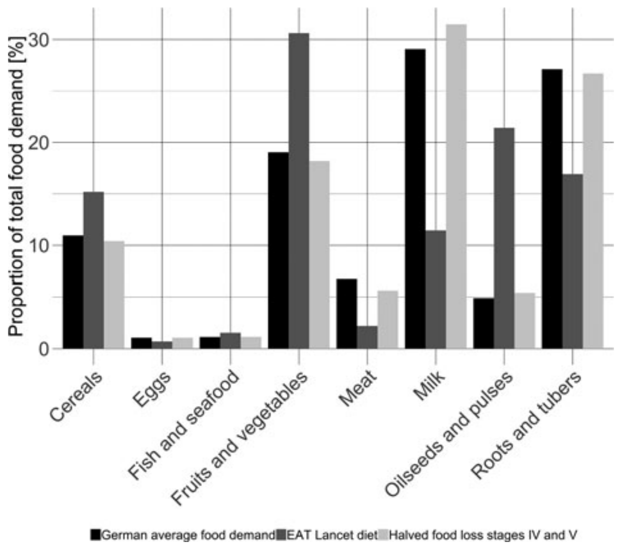

Fig. 1. Food group-specific proportion of food demand. German average food demand (black), the diet published by the EAT Lancet Commission (dark gray) and German average food demand with halved food loss on retail and consumption level (light gray) are considered (Supplementary Table 7). The EAT Lancet Commission published a diet composition including reduced animal commodities and increased legumes, vegetables and nut proportions. The food categories include regional and non-regional commodities. Food groups were categorized according to FAO food loss categories.

In the *baseline diet scenarios* and in contrast to the food demand meat and milk dominated the area demand with a proportion of more than 50%, whereas roots and tubers had a small share of the total area demand (about 2.6%). The *diet shift scenarios* showed an increasing proportion of area demand in oilseeds and pulses, followed by fruits and vegetables, and cereals, whereas the proportion of meat and milk was around 64–72% lower. The *food loss scenario* showed the similar relations as the baseline scenario. Organic production led to a smaller area share of fruits and vegetables. In contrast, organic meat, cereals and eggs had a much larger impact on the area demand. For the other food groups, the share of area demand was similar between conventional and organic agriculture. The *combined scenario* food-group-specific proportions of area demand were similar to the results of the *diet shift scenario* with organic yields. For cereals and fruits and vegetables, the proportional area demands were slightly lower, whereas they were marginally higher for oilseeds/pulses (Fig. 2).

Area demand and SSL

In the *baseline diet scenario* with conventional yields, the area demand in the administrative region Leipzig per capita was 0.23 ha. For all inhabitants the area demand summed up to 243,325 ha, which resulted in a mean SSL of 94% (range = 77–116%) (Fig. 3; Supplementary Table 12). The low SSL of the city of Leipzig (7%, range = 5–8%) was compensated by a high SSL of Northern Saxony (271%, range = 221–331%) and the district Leipzig (160%, range = 130–194%). Besides the area that was needed regionally, 26,932 ha were needed elsewhere to grow non-regional commodities, corresponding to 12% of the regionally available agricultural land.

The SSLs of the *diet shift scenario* and the *food loss scenario*, each with conventional yields, were 29 and 17% higher, respectively, than the *baseline diet scenario*. The cultivation of non-regional commodities elsewhere would take up an additional 10% of the regionally available land for both scenarios.

When the scenarios were coupled with organic yields the SSLs decreased by around one-third because the respective area demands increased due to the lower yields in organic agriculture. However, if organic yields were combined with a diet shift and reduced food losses, a mean SSL of nearly 95% could be achieved.

Discussion

Food demand, agricultural production and land availability have strong impacts on the SSL of a region. The combination of dietary changes toward less animal product consumption with reduced food waste and organic production was able to provide an SSL of nearly 100%. Therefore, regional self-sufficiency depends on both consumption and production habits, which will be discussed in the following sections.

Food demand

Based on average food demand and conventional agricultural production, 94% of the required regional commodities in the administrative region Leipzig could be produced. The associated per capita area demand of 0.23 ha of agricultural area is comparable to studies for other European cities such as Rotterdam and Milan, with per capita area demands of 0.17 and 0.21 ha, respectively (Zasada *et al.*, 2019). The SSL of these cities is about three-quarters lower due to the coastal or alpine location and the accompanying deficit of available agricultural land (Zasada *et al.*, 2019). Calculations for New York State showed higher land requirements of 0.3–0.5 ha per person including current meat consumption (Peters *et al.*, 2007).

For the inhabitants of the administrative region Leipzig, the additional non-regional agricultural area demand sums up to ~27,000 ha assuming average yields for coffee, tropical fruits, etc., adding 12% of the local area. Shifting land requirements to other countries can lead to reduced land access for the local population in the remote production area and therefore raises the question of justice in the global food system (IAASTD, 2009). A reduction of the area demand would therefore be favorable to increase land availability regionally and in the Global South.

Our results show that reducing meat, milk, egg and fish consumption and increasing the consumption of vegetables, fruits and legumes would lead increase the SSL to 122%. Our calculations confirm the strong impact of the consumption of animal products on agricultural area demand (Foley *et al.*, 2011; Knapp and van der Heijden, 2018; Gerten *et al.*, 2020).

The EAT Lancet Commission (2019) stated that the choice of food is the strongest lever to optimize human health and environmental sustainability. Nevertheless, it has to be considered that on a global scale, considerable fractions of agricultural land are solely suitable for pastures (Ramankutty *et al.*, 2008; Röös *et al.*, 2016), and thus unsuitable for crop production in the case of reduced meat consumption.

In Germany, 1 and 5% of the citizens follow a vegan and vegetarian diet, respectively (BMEL, 2020b). In recent years, these proportions are increasing, especially among younger citizens (BMEL, 2020b). Increasing awareness of environmental costs and negative health consequences of diets rich in animal products leads to higher willingness to reduce meat consumption (Nelson *et al.*, 2016; Laroche *et al.*, 2020). In turn, this trend reduces the

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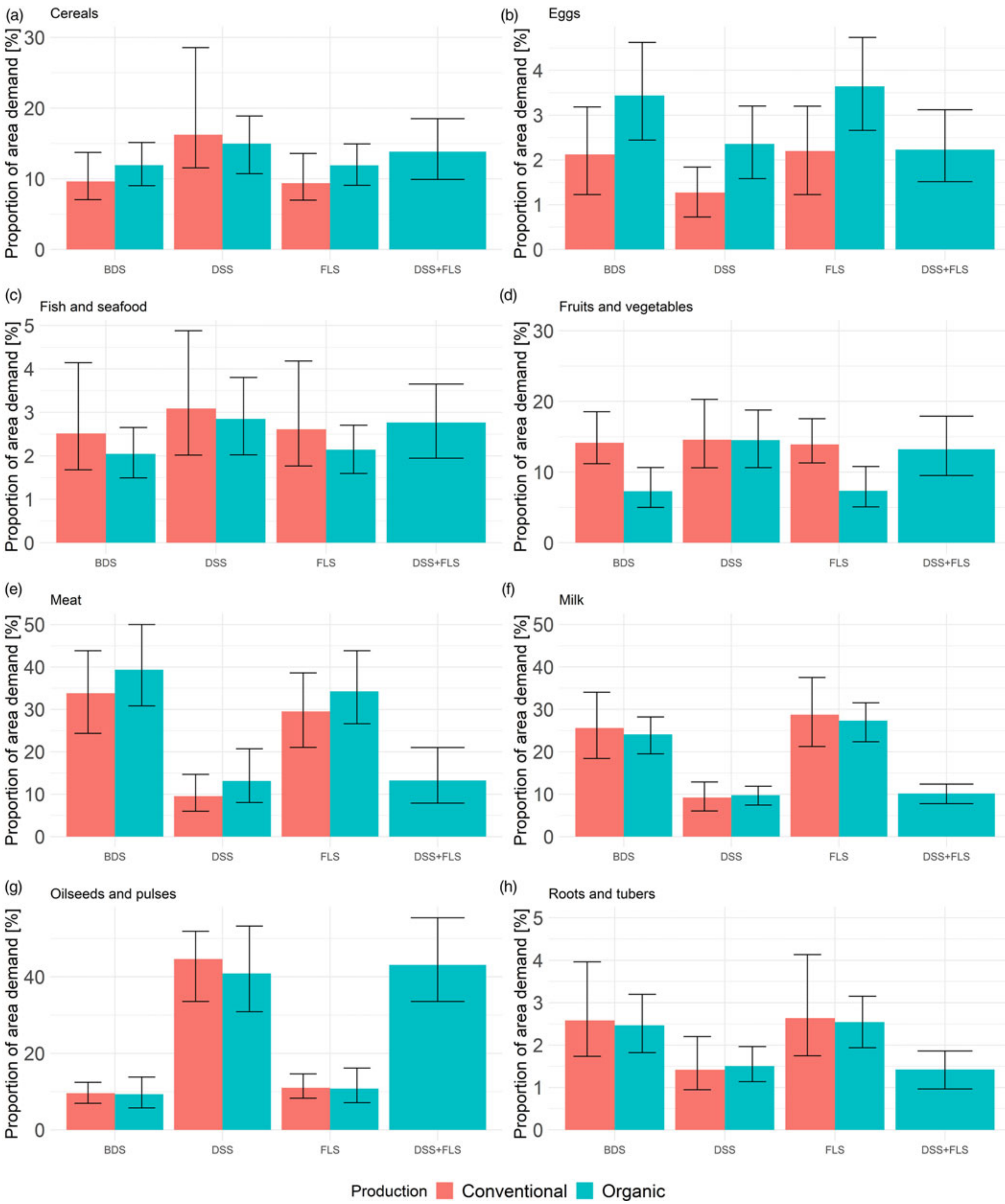

Fig. 2. Food group-specific proportion of area demand. Error bars show the minimum and maximum proportions of agricultural area demand per food group. Red indicates conventional production data and blue indicates organic production. The baseline diet scenarios (BDS) calculate the area demand based on German average demand data and either conventional or organic yields for all commodities. The diet shift scenarios (DSS) use a diet composition including reduced animal commodities and increased legumes, vegetables and nut proportions with conventional or organic production data. The food loss scenarios (FLS) include halved food loss on retail and consumption level and conventional or organic production data. The combined scenario (DSS + FLS) combines organic production with the EAT Lancet diet used in the diet shift scenario and halved food loss at the retail and consumption levels. Food groups were categorized according to FAO food loss categories.

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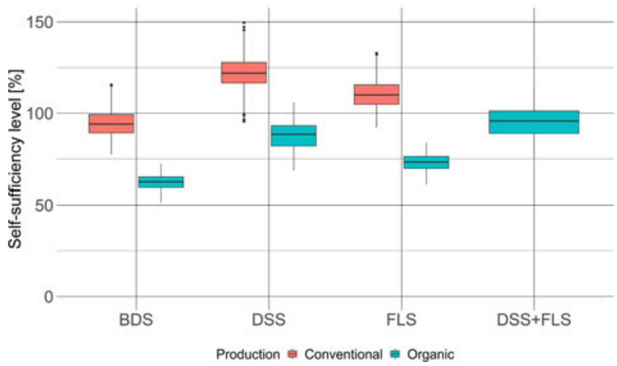

Fig. 3. SSLs for all scenarios (Supplementary Table 12) including both conventional (red) or organic production (blue). The BDS calculate the SSL based on German average demand data. The DSS use a diet composition including reduced animal commodities and increased legumes, vegetables and nut proportions. The food loss scenarios (FLS) compute demand values with halved food loss on food loss at the retail and consumption levels. The combined scenario (DSS + FLS) combines organic production with the EAT Lancet diet used in the Diet shift scenario and halved food loss at the retail and consumption levels.

area demand of food production and increases the sustainability of food systems and human health.

In addition to diet, the one-third of primary food production, which is lost or wasted (Gustavsson *et al.*, 2011), has a strong effect on food demand (Birney *et al.*, 2017). Halving losses at the household level, as well as at retailing and food-service-level would reduce the area demand in the study area by around 16%. Similar studies from Europe and the USA estimated that even 25–31% of the agricultural area could be saved if all food losses would be eliminated along the entire supply chain (Birney *et al.*, 2017; Zasada *et al.*, 2019).

Agricultural production

Agricultural production is another important factor influencing the SSL. With a complete shift to organically grown crops and livestock, the SSL of all scenarios would decrease by 28 to 34%, as organic yields in the study area were substantially lower than conventional yields, reaching an SSL of maximally 88% when combining reduced animal product consumption or reduced food losses with organic yields.

However, yield differences between conventional and organic agriculture are discussed controversially. Although there is some agreement that organic yields are generally lower (de Ponti *et al.*, 2012; Wilbois and Schmidt, 2019), actual crop yield differences are crop and context dependent (de Ponti *et al.*, 2012; Seufert *et al.*, 2012; Ponisio *et al.*, 2015). Moreover, agricultural practices such as crop rotation and multi-cropping can reduce the yield differences substantially (Ponisio *et al.*, 2015).

Assessing yield differences only offers limited insights into the performance of different production systems. Although conventional agriculture mainly focuses on yields, organic agriculture accepts lower yields to simultaneously conserve biodiversity and reduce resource input, like mineral fertilizers, concentrates, as well as pesticides and herbicides (Gomiero *et al.*, 2008; Muller *et al.*, 2017; Wilbois and Schmidt, 2019). Furthermore, conventional agriculture requires 10–70% more energy per unit of land (Gomiero *et al.*, 2008) and can lead to higher loss of biodiversity, N-surpluses, as well as lower soil fertility and water quality than in organic agriculture (Bengtsson *et al.*, 2005; Leifeld and Fuhrer, 2010; Muller *et al.*, 2017; Seufert and Ramankutty, 2017). Although organic production reduces GHG emissions locally due to decreased inputs and higher soil carbon sequestration, higher area demands due to lower yields might lead to higher emissions on the large scale (Smith *et al.*, 2019).

Taking this into account and given that only 1.2% of the global agricultural land is cultivated organically, a comprehensive evaluation of the potential of organic agriculture is not yet possible (McIntyre, 2009; Carlisle and Miles, 2013; Wilbois and Schmidt, 2019). In most European and North American countries, organic agriculture is the fastest growing food sector (Seufert and Ramankutty, 2017). The German government aims at reaching 20% organic production by 2030 (Bundesregierung, 2018). Reaching this goal in the study region, would lead to an SSL of around 88%.

Combining organic production with changes in consumption to a more plant-based diet and with lower food losses would open the opportunity to simultaneously reach a high SSL of 95% and to provide other benefits, such as protecting ecosystem services and biodiversity (Benton *et al.*, 2021). Accordingly, comprehensive approaches addressing multiple dimensions of sustainability are most promising, because an adequate food supply with low environmental impacts will only be achievable in a socio-environmentally well adapted food system (West *et al.*, 2014; Muller *et al.*, 2017).

Land availability

Land availability for food production is another important determinant of regional SSL. Currently, 82% of agricultural area in Germany is used for food production. If only this area would be included in the analyses, SSL would be substantially lower (Supplementary Fig. 1). As the remaining agricultural land is mainly used for bioenergy (FNR, 2020b), it needs to be evaluated whether increasing the proportion of agricultural land for food production would be reasonable from a sustainability perspective. Moreover, ongoing urbanization leads to more demand for settlement and transport areas increasing land competition. Another pressure on land availability originates from land degradation and land loss. Around 16–40% of the world's terrestrial surface is affected by soil degradation (Tscharntke *et al.*, 2012). Germany alone has lost over 6500 km^2 of agricultural land in the last 15 years (DESTATIS, 2018b) due to soil sealing, erosion and compaction (Wunder *et al.*, 2018).

Around 20,339–35,518 ha of the agricultural land would not be needed to supply the regional area demand if food losses would be halved or less animal products would be consumed. This area surplus could, for example, be used to supply food for the global market, meet the increasing demand for bio-based energy and materials, as well as to foster biodiversity conservation and the provision of multiple ecosystem services (Galzki *et al.*, 2015; Cardoso *et al.*, 2017; Kurtz *et al.*, 2020).

Regionalization

The scenarios presented here demonstrate that the study region could reach high levels of food self-sufficiency and a regionalization of food production would be largely possible. However, besides the feasibility, impacts on sustainability, resilience and personal freedom have to be evaluated to determine which level of regionalization would be desirable from multiple perspectives.

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In general, the effects of regionalization on the sustainability of the food system are highly debated. For example, reduced transport distances and value chains might reduce GHG emissions (Mundler and Rumpus, 2012; Kriewald *et al.*, 2019), although transport emissions only contribute to 15% of the total GHG emissions (European Commission, 2013; Majewski *et al.*, 2020). In contrast, more intensive agricultural systems as a result of increased regional food demand could increase GHG emissions due to the higher use of pesticides or greenhouse cultivation (Coley *et al.*, 2009). Moreover, regional production systems might lead to smaller producing units, which are both economically and ecologically less efficient (Schlich and Fleissner, 2005). Additionally, not all crops are equally suitable for regional cultivation (Peters *et al.*, 2012). At the same time, regionalization can enhance the local economy by creating jobs in agriculture and food production, for example (Augére-Granier, 2016). Social benefits arise from better knowledge about food production, reconnection of humans and nature, as well as of producers and consumers (Seyfang, 2006; Bagdonis *et al.*, 2009). This could also foster dietary changes (Brown and Miller, 2008). Also the resilience of regional food systems is controversially discussed. On the one hand, a lower dependency on globalized and specialized supply chains can reduce the vulnerability to global shocks such as the COVID-19 crisis (FAO, 2020; Garnett *et al.*, 2020; Kinnunen *et al.*, 2020). On the other hand, supportive trade structures can compensate for production losses in the face of local shocks (Marchand *et al.*, 2016; Kinnunen *et al.*, 2020). However, establishing diversified, locally adapted and decentralized food production within a region can reduce the vulnerability to local shocks (Schreiber *et al.*, 2020).

Assumption and limitations

This study includes three major limitations. First, the consumption data are based on Germany-wide averages, because no regional specifications are available yet. Second, as the EAT Lancet Commission and the food loss categories by the FAO only distinguish food groups, differences in individual commodities could not be reflected in the diet-shift scenarios and regarding food losses. Third, yield data were collected from a variety of sources. Region-specific yields were not available for all crops and we had to rely on conversion factors for some organic commodities. Moreover, homogenous crop yields across the study area were used, implying homogenous soil fertility and suitability to grow all crops considered in this study. However, the sampling approach with consideration of yields from different years partially accounts for these uncertainties.

Conclusions and outlook

Our study underlines that regionalization of the food system in the administrative region Leipzig would be largely feasible. In particular, diet shifts and reduced food losses would reduce the area demand and therefore provide opportunities to use parts of the agricultural land for the production of bio-based energy and materials, as well as to foster biodiversity conservation and the provision of multiple ecosystem services. Moreover, these changes would also allow to nearly reach full self-sufficiency with lower yielding but potentially more environmentally friendly production practices, such as organic agriculture. The combination of diet shifts, reduced food losses and organic agriculture is promising to provide synergies.

The approach developed in this study is broadly applicable, contributing to achieve a more comprehensive understanding of the feasibility of regionalization across different environmental and socio-economic contexts.

Further studies could examine the implications of food system regionalization on sustainability and resilience. Moreover, the identified potentials have to be compared to current land use and complemented by information on actual supply chains. Follow-up investigations will contribute to identify pathways toward more regional and sustainable food systems.

Supplementary material. The supplementary material for this article can be found at https://doi.org/10.1017/S174217052100048X

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Conflict of interest. The authors declare none.

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