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Land Consumption of Current Diets Compared to the Planetary Health Diet—How many People can our Land Feed?

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Abstract: The way people in many countries eat today is disconnected to the resources and land locally available. In Europe, for instance, too much meat is eaten, but often cannot be fed by local resources. The percentage of non-local and non-seasonal food is tremendous, exploiting other regions and their water reservoirs. Current diets harm eco systems and people's health. (Re-)regionalising food systems and aligning diets to planetary boundaries could be one way to reconnect people to the food they eat. Before demanding the (re-)regionalisation of food, it should be analysed whether current consumption patterns can be met at all with the regionally available agricultural land. We looked at the region Hesse in Central Germany, calculated and compared land consumption of current diets with the consumption as recommended by the Planetary Health Diet. Our focus is on livestock because land consumption to produce meat, dairy and eggs is relatively high. Our results show that the region is far from being able to feed the current livestock population, that it does not have the land to support the livestock needed to meet current consumption patterns, but that it could support a smaller livestock population according to the Planetary Health Diet, especially if farmers adopt crop rotation systems and extensive husbandry.

Keywords: self-sufficiency degree; planetary health diet; land consumption; food sovereignty; livestock; consumption

1. Introduction

Food production accounts for about one-third of total greenhouse gas emissions caused by human activity [1]. Of which approximately 20% are due to food transport alone [2]. Globally, one out of three people is overweight or obese, whereas one out of nine people is under- or malnourished [3]. Consequently, both, agriculture and consumption behaviour must be rethought.

Short food supply chains have been shown to have a positive impact on health [4] (e.g., ancient varieties and landraces, often being more nutritious, are typically more cultivated and sought in short food supply chain) [5], climate (e.g., preserving agrobiodiversity) and the local economy (e.g., regional value creation) [6]. Not only since COVID-19 and the Russian attack on Ukrainian, two events that have unequivocally shown the risks of dependency on global supply chains [7,8], many scientists, politicians and civilians agree that food systems need to become more resource- and climate friendly, but also more regional, not least to be able to guarantee national (food) sovereignty [9–11].

Following the lead of the global peasant movement *La Via Campesina*, actors of nongovernmental organizations, academia, and the peasant community are striving for food sovereignty in their communities and regions [12]. Key factors in food sovereignty include prioritizing local agricultural production; access of peasants and landless people to land, water, seeds and credit; the right of farmers and peasants to produce food and the right of consumers to be able to decide what they consume, how and by whom it is produced; the right of countries to protect themselves from too low priced agricultural and food imports; the right to impose taxes on excessively cheap imports if they commit themselves in favour of a sustainable farm production; the recognition of women farmers' rights, playing a major role in agricultural production and in food, among others [13].

The main goal of food sovereignty is to bring people's nutrition back to the forefront, rather than neo-liberal policies and international trade [13]. Thus, the demand is to transform the current food system from industrialization back to peasantry farming. The current industrialised food system can be traced back to a few historical events: the first (1870-1930s) and second (1950-1970s) food regimes as well as the Green Revolution (after the Second World War until late 1970s), but also the industrialization of agriculture as well as trade liberalisation played there part of producing and advertising cheap food, such as corn, rice, and wheat, but also the mass-production of animal products to fuel cheap labour and strengthen the hegemonic role of the US and capitalism per se [12,14,15].

Besides the negative impact on people's health, increasing hunger, dependence on agricultural imports as well as the overall level of poverty, the Green Revolution and agro-industrialization had significant negative impacts on our climate and biodiversity [12,13,16]. For instance, while the production of corn per acre increased ~2.4 times from 1945 to 1970, fuel inputs rose ~3.1. As early as 1973, scholars discovered that 80 gallons (897 litre per 1 ha) of gasoline are consumed per one acre of corn produced. Such examples showcase, why greenhouse gas emissions from food production are so high today [1].

This in mind and to (re-)gain food sovereignty, in many parts of the world, food policy councils and other food activists, such as the movements transition town, the slow food movement etc. have been established [17–19], all aiming at gaining back food sovereignty and shortening food supply chains.

When following the approach to shorten food chains, a first step ought to be assessing the level of self-sufficiency and then act upon the results [20–24]. To assess the level of self-sufficiency, we need to know which plants grow on local fields and how much of those would be necessary to feed the local population. How much livestock is kept? Can the local land feed them? How many animals would be necessary to satisfy the hunger for regional animal products (meat, dairy and eggs) in the context of current consumption patterns? In anticipation of the results, we can state that the analysed region currently cannot feed itself. Moreover, the cropping pattern of local farmers is not very diverse and not in line with the call of *La Via Campesina*.

It is therefore interesting to analyse how the self-sufficiency degree (SSD) would adjust if the total population of the considered regions within the state of Hesse followed the Planetary Health Diet (PHD) published by the EAT-Lancet Commission in 2019 [10], and, additionally, all farmers pursued crop rotation systems and only extensive husbandry, two important steps to transform the current food system from industrialization back to peasantry farming. Extensive animal husbandry means feeding livestock only with grass land, lucerne and leftovers not consumed by human beings. Could we then reach a self-sufficiency degree of 100% for our diet?

A variety of studies have explored our global food system and its impact on the environment, climate as well as health, focusing on global data [25–29]. Although these studies are extremely important for understanding the interconnections of our global food system and the impacts on humanity, wildlife and plants, it is also essential to look at smaller areas, but in detail [30]. To be able to calculate and process details, local conditions must be considered, such as current local supply and demand, types of agriculture (e.g., grass land vs. arable land), soil conditions etc. Even though, our approach focuses on a small area, the state of Hesse in Germany, we propose that our findings, especially the approximate square metres required by the average local people due to their diet, can be generalized at least to a wide range of European regions, probably most areas of the Global North. Particularly, because the way of eating and consuming in Central Germany is similar to many other regions.

The main argument against local food, short supply chains and the use of sustainable agriculture is that yields are too low and not every region can produce the quantity and quality of food that local people need. Low yields are also not a viable solution, the argument goes, because population growth, income growth and changing diets are predicted to increase demand for agricultural products by 60-120% by 2050 (from a base year of 2005) [30,31]. However, if independence from global food supply chains and thus national food sovereignty is the goal, individual regions should feed themselves according to the arable and pasture land available to them.

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With this study, we want to contribute to the debate on localizing food systems and getting back food sovereignty by calculating different self-sufficiency degrees and demonstrating land consumption according to current consumption patterns, Planetary Health Diet recommendations as well as peasantry farming practices. Therefore, we look at six different regions within the state of Hesse incl. overall Hesse and four scenarios. The first two scenarios consider current consumption patterns and are based on current cultivation statistics as well as current numbers of livestock (following called *current*) and calculate the necessary livestock to meet the current consumption patterns—self-sufficiency degree of 100% (following called *SSD 100%*). The second two calculations are based on the consumption recommendations of the Planetary Health Diet and, thus, analyse the livestock necessary for the adapted consumption patterns (following called *PHD*), but also change the type of cultivation towards a seven-year crop rotation system and extensive husbandry (following called *extensive husbandry*).

2. The Method and Concept of the Study

In order to calculate the different self-sufficiency degrees, a detailed framework has been established.

2.1. The Regions under Consideration

We looked specifically at the German state of Hesse to calculate the self-sufficiency degrees and analysed overall Hesse (1), the three governmental districts: Darmstadt (2), Gießen (3), Kassel (4) as well as two smaller regions in more detail—the metropolitan area Frankfurt/Main including all bordering counties (5), and the rather rural county Marburg-Biedenkopf (6) (Figure 1) [31].

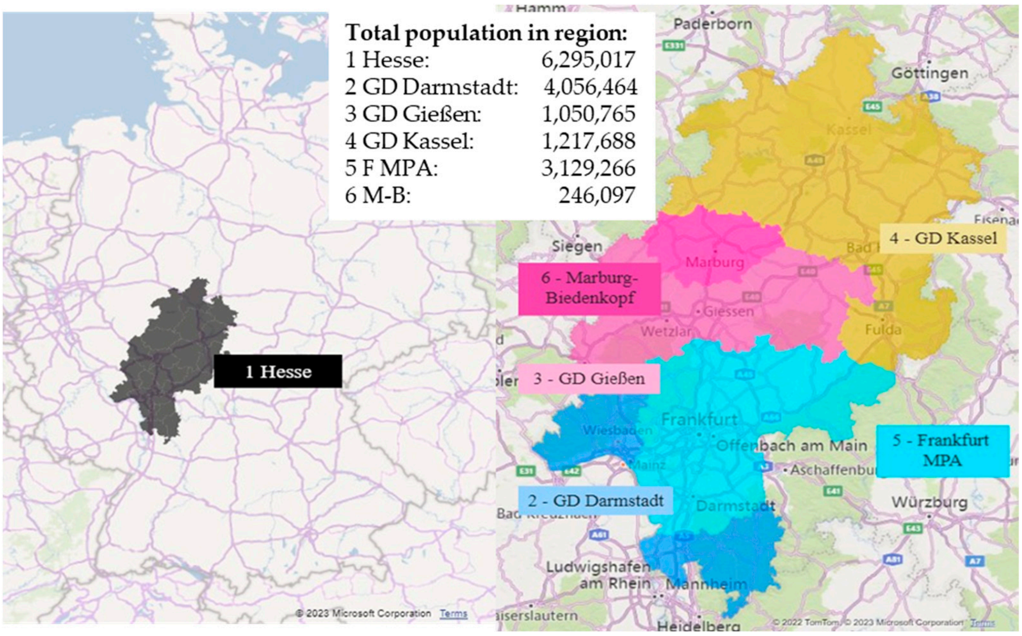

Figure 1. *Location of the Analyzed Regions and their Total Population.* Region 1 is overall Hesse, regions 2-4 are the governmental districts (GD) Darmstadt (2), Gießen (3) and Kassel (4), region 5 is the Frankfurt metropolitan area (F MPA), consisting of the city of Frankfurt/Main as well as bordering counties, region 6 is a more rural area, the county of Marburg-Biedenkopf (M-B), about 80 km north of Frankfurt.

2.2. The Selected Food Groups

We selected and adapted the food groups used for the Planetary Health Diet and combined them with the current consumption patterns as well as consumption recommended by the Planetary Health Diet per capita (Table 1). As the Planetary Health Diet calculates with 2,500 kcal per person per day, we adapted this figure to 2,150 kcal (86%), the calculated median across the age groups of the hessian population and the respective quantities required.

Table 1. *Consumption in kg/capita p.a.* In the first column left, the different food groups based on the Planetary Health Diet are displayed. In the second column the current consumption based on statistical data is shown. The third column shows the recommendation of the PHD annualised and in kg. The fourth column downscales this recommendation to a daily intake of 2,150 kcal/capita, the calculated Hessian median [10,32–36].

Food group	Current consumption[1]	Consumption recommended by PHD 2,500 kcal	Consumption recommended by PHD 2,150 kcal
Cereals	85.4	84.7	72.8
Legumes	0.9	27.4	23.5
Potatoes	71.7	18.3	15.7
Vegetables	98.6	109.5	94.2
Fruits	66.5	73.0	62.8
Plant-Oil	14.5	18.9	16.3
Nuts	5.0	18.3	15.7
Sugar	33.6	11.3	9.7
Milk, equiv. diary	409.6	91.3	78.5
Eggs (pcs.)	239.0	75.3	64.8
Red meat	42.0	5.1	4.4
White meat	13.1	10.6	9.1
Fish	14.1	10.2	8.8

[1] all data per capita per year and in kg (except eggs).

Nuts and fish are hardly cultivated in Hesse and thus, are not included. There is no exact statistic on fruits, however, the region cultivates mainly strawberries, cherries and apples. Local apples are mainly used for producing juice and cider. As these products are highly seasonal, we decided to not include them. The yields per hectare based on the German Federal Statistical Office [37], and crops can be found in Tables A1 and A2 (a, b), the extrapolated consumption per region in kg and ha in Table A3 (a, b). Yields may vary heavily, depending on the type of soil, the quality of seeds used as well as weather conditions.

2.3. Animal Production Rates

Regarding animal products, to calculate the actual self-sufficiency degree, we used averaged conventional production rates, like average milk yield per animal group (9,358 kg/cow/year; average slaughter weight: 230 kg per cattle, 21 kg per sheep, 11 kg per goat, 98 kg per pig, chicken lying performance: 288 eggs/chicken/year, slaughter weight per poultry: 2 kg for broiler chicken, 5.2 kg per goose, 10 kg per turkey, 2.2 kg per duck).

The herd factors (how many animals need to be kept to maintain the herd at a constant level) and the slaughter rate (how many animals "occupy" a pen space per year before they are slaughtered) can be found in Table A4. These factors are important in calculating how much feed is eaten in total per year and not per animal. For extensive husbandry, some of these figures are adapted, such as eggs (180 instead of 288) (cf., Table A4).

2.4. Land Consumption due to Animal Feed

To calculate how much fodder the region can provide for which number and type of animals (permanent grass land and arable land), we had to define exemplary fodder rations based on given

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literature and expert interviews [38–42] (cf., Table S2 [1]). Our fodder rations consider regional cultivation practices, such as high rations of maize silage and cereals and lower rations of legumes and lucernes. By talking to farmers, we are aware that these rations vary greatly depending on the farm and region and that it is actually impossible to obtain realistic data based on a few feeding examples (each farmer has his/her own feeding practices). However, this step was necessary in order not to make the calculation model too complicated and chaotic.[2]

2.5. Plants for Energy Production

We drew on statistics provided by the state of Hesse regarding arable land (ha and cultivated crops), grass land, permanent crops, types and number of animals, which can be found in Table S3 [43].

The statistics indicate crops per ha, not yield per region. The statistics do not reveal what crops are used for human consumption, fodder or energy production. Still, we can say that about 95% of grown legumes are for feeding [44], as are—in total—triticale, lucerne, corn-cob mix and maize silage (about 20% of the total crop land). We estimated that in Hesse, roughly at least about 2.1% of wheat, 9% of silage maize, 1.84% of sugar beets, 0.4% of potatoes, 7.2% of rape seeds and 1% of legumes are used for energy production or industry [45,46]. Table A5 shows the results. Table S4 the calculation base. These percentages were subtracted from the total amount per food group and were not considered for further calculations.

2.6. Further Assumptions

We are aware that approx. 30% of the total production of wheat and 55% of rape seeds do not enter the market for human consumption, e.g., there are remaining shares after threshing, milling and oil pressing processes and can be fed to animals as protein-rich cake or meal. Knowing that the regions do not have large processing plants, like oil mills, grain mills, threshing crop processing or sugar factories, we still pretended that all harvests are processed and consumed here by humans and animals to be able to calculate the local self-sufficiency degrees. We excluded any kind of food waste, although we are aware of the extent and problematic nature of this loss.

2.7. The Calculated Scenarios: Current, SSD 100%, PHD, Extensive Husbandry:

Based on all this data, we were able to calculate these four scenarios, focusing on livestock before calculating what is left for the plant-based share of the diet:

- *Current* livestock: The necessary feed requirements in ha for current livestock (cf., Table S5) in the different regions and the self-sufficiency degree for red meat, white meat, eggs and milk/dairy products.
- *SSD 100%* livestock: The number of livestock incl. herd factor/stable place necessary to cover our current consumption patterns (100% self-sufficiency degree of animal products).
- *PHD* livestock: The number of livestock incl. herd factor/stable place necessary to cover the recommended consumption level by the PHD (100% self-sufficiency degree of animal products).
- PHD and *extensive husbandry*—livestock incl. seven-year crop rotation system: The self-sufficiency degree of plants and animal products, in the utopian case that all farmers used a seven-year crop rotation system and kept animals only extensively instead of intensively as it is mainly practiced today.

Further we calculated the self-sufficiency degree of plants for human consumption (cereals (without triticale), sugar, potatoes, oil from rape seeds, legumes and vegetables) based on the current consumption patterns as well as PHD recommendations (cf., Table S6). We did focus on oil from rape

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[1] Supplementary information (SI) is published here: Preprints.org

[2] Readers can download our tables and adapt them accordingly.

seeds as they only play a minor role in local farming practices. For each scenario we calculated roughly the necessary land consumption of grass land and crop land, in total and per capita.

3. Status Quo: Low Self-Sufficiency Degrees - What must Change?

Before presenting the results in detail, here is a brief overview of the region.

3.1. Overview of the State of Hesse

Hesse is a state in Central Germany with almost 6.3 million inhabitants, 298 inhabitants per km², 302.53 billion Euro GDP (in 2021) and an unemployment rate of 4.9% (in 2022) [47]. In total, 15,128 farms exist in this state, thereof, 688 farms with less than 5 hectares per farm and 536 farms with more than 200 ha [48]. Most farms in this state have between 50 and 99 ha (3,853 farms). Only 4,241 of all farms work full-time as farmers. 10,221 farms keep livestock, mainly cattle (6,429 farms and 406,304 cattle, thereof, about one third are dairy cows) and pigs (2,407 farms keep 543,934 pigs). 2,108 farms work organically and 1,674 of these keep livestock (63,006 livestock units) [48,49].

3.2. Arable Farming

In total, in the state of Hesse 764,705 ha are used for agriculture (36% of the total area). Of these, 61% are used for crop land, 38% is grass land and 1% are permanent crops, like fruit as well as nut trees and bushes.

On 8,285 ha, farmers cultivate vegetables, thereof, almost 32 ha are covered; on nearly 1,000 ha strawberries are cultivated [50,51].

The shares of crop land into main crops incl. organic are displayed in Table A1 for each region. The overall share of organic farmland in ha is, depending on the region, between 10-21%; the share of organic vs. conventional farms varies between 14-20%. The state's goal is to raise the area of organic farming to 25% by 2025 (cf., Table S3) [52]. The area of organic farming per crop varies heavily with total cereals, for region 1, Hesse, being 8%, thereof, wheat, spelt, Einkorn and corn maize/corn-cob mix: each 6%, rye and triticale: each 16%, barley: 4%, oat: 27% and other cereals like Emmer, millet, buckwheat and sorghum: 42%; further, silage maize: 3%, sugar beets: 2%, potatoes: 11%, rape seeds: 0%, and legumes: 35%. The data shows that main crop cultures, such as cereals and maize, have a rather low share of organically produced crops, whereas niche products, such as Emmer, oat and buckwheat, on the other hand, have a rather high organic share.

3.3. Current Production and Consumption of Animal Products

Currently, about 580,000 grazing animals including close to 35,000 horses exist in region 1 as well as about 544,000 fattening pigs, close to 33,000 breeding sows, 1.1 million broilers and other poultry as well as nearly 1.5 million laying hens (cf., Table 5).

The self-sufficiency degree of animal products varies quite heavily per region and product (cf., Figure 2). The current production of animal products is highest in region 4. Region 5 has the highest number of inhabitants and the lowest shares of agriculture and, therefore, a low self-sufficiency degree of animal products. Region 3 and region 6, which is part of region 3, are cattle and dairy cow intensive, but still cannot cover the local demand. White meat and eggs respectively are only produced considerably in region 4.

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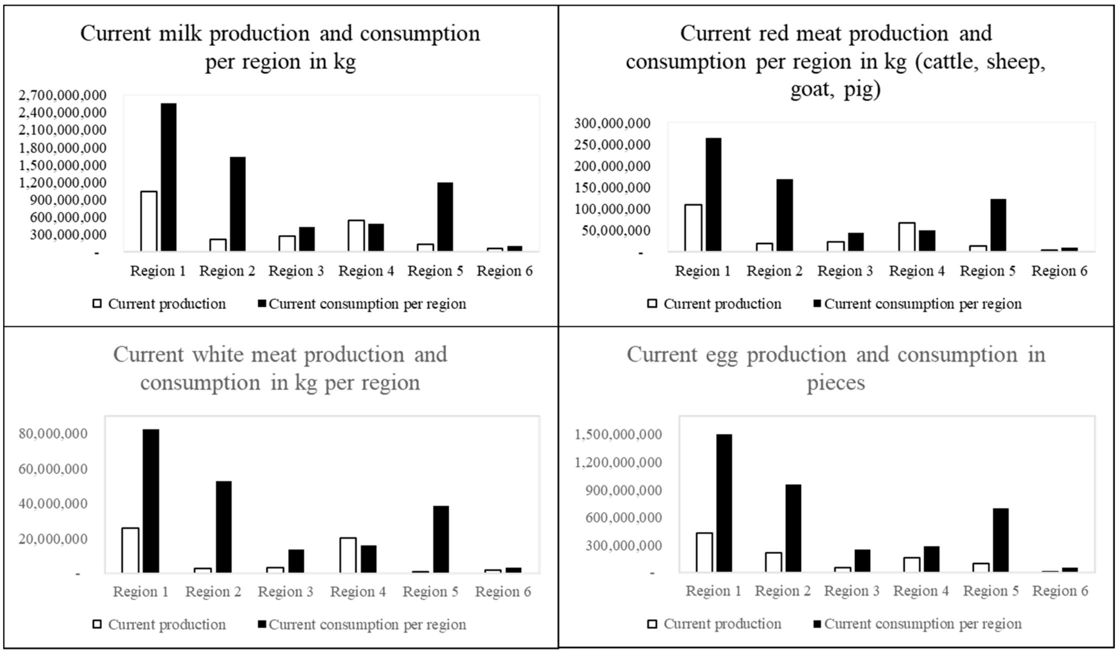

Figure 2. *Current Animal Product Consumption by Region 1 to 6.* Region 4 is an animal producing region, with producing more milk, red and white meat than consumed. For all other areas than region 4 and food types, consumption exceeds production.

3.4. Calculated Number of Animals for Current Consumption and Consumption according to PHD Recommendations

The next step of the analyses was to calculate the necessary number of animals to cover the current consumption of animal products per region (*SSD 100%,* cf., Table S9), to cover the recommended consumption after PHD (*PHD,* cf., Table S10) as well as to cover the recommended consumption after PHD with extensive animal husbandry and thus lower/slower output per animal (*extensive husbandry,* cf., Table S11). Figure 3 shows the results for region 1, Hesse total, Figure A1 shows all regions. The herd/stable place factors from Table A4 are always included. The calculation of the livestock necessary for the different diets can be found in Table S12. In Hesse, for example, many more animals would be needed to meet local demand. If all inhabitants were to eat as recommended by the Planetary Health Diet, farmers would have to keep far fewer livestock than is currently the case. If everyone in the region ate the diet recommended by the PHD and livestock were kept extensively, the number of animals would increase, but only slightly. The results of the other regions look similar. Only in region 5, the most populated one, the difference between current and necessary livestock (*PHD*) is less extreme. For poultry kept to produce meat, the differences are also less severe, because the PHD recommendations are quite high.

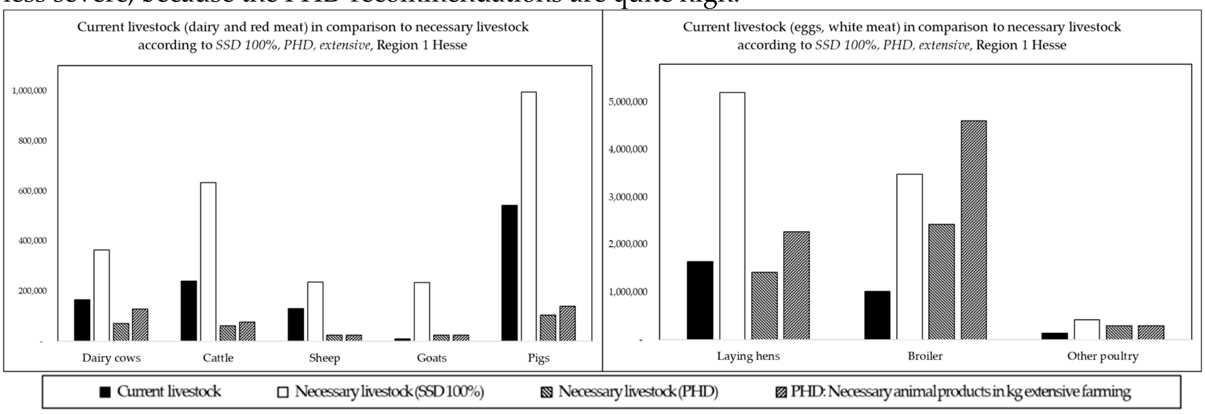

Figure 3. *Current Livestock in Comparison with Necessary Livestock.* The number of livestock needed for SSD 100% exceeds the number of livestock currently kept (current), whereas the number of livestock

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needed for PHD would be much lower. If all animals were kept extensively, the numbers would slightly increase to PHD.

3.5. Calculation of Required Feed Quantities and Land Consumption for Livestock

The following step arising directly from Figures 2 and 3 is to determine the amount of feed required for the respective livestock scenarios *current*, *SSD 100%*, *PHD* (scenario *extensive husbandry* is highlighted at a later section).

Based on our fodder examples and yields (mainly from 2021 [37]), we calculated that the livestock currently kept within the different regions 1 to 6 would use between 62% (region 3) and 80% (region 4) of the available grass land and about 34% (region 5) and 75% (region 4) of the available crop land if the total amount of fodder was produced locally (cf., Figure 4). Considering a SSD of 100%, the necessary amount of feeding would exceed the regions' resources up to 409% (region 5) for grass land, and 256% (region 5) for crop land. On the other hand, based on the PHD consumption recommendations, the regions would only need 14% (region 4) and 65% (region 5) of grass land and 14% (region 4) and 47% (region 2) of crop land, clearly indicating that extensive husbandry would be possible.

The main argument for keeping cattle (incl. dairy cows) is that ruminants are capable of processing for humans non-edible grass, clover grass and lucerne into valuable protein, although they emit due to their digestive processes a high share of methane [25]. In relation to the forage examples, grass land does not seem to be used optimally as of the 294,288 ha available grass land in region 1, only 208,985 ha are used in our calculation (Figure 4, left bars). Apart from potentially underestimated feed rations in our forage examples, within these regions, it can be observed that many animals have to stay in the barn because direct grazing is not possible, too much effort or simply difficult due to weather conditions. In addition, the proportion of concentrated feed is quite high in comparison to pasture forage for dairy cows and cattle, so that milk and meat yields are high. Looking at regional grazing practices, hardly any hybrid grazing is practised, as also shown by the number of goats and sheep in the total livestock (0.4% goats, 1% sheep). In scenario *SSD 100%*, most regions would not have enough grass land to feed all animals (necessary amount for region 1: 482,996 ha), different than for scenario *PHD.* If all people were to eat according to the PHD recommendations, there would be enough grazing land for all the animals that would then be needed (80,647 ha grass land).

The cultivation of lucerne, clover grass and legumes (status quo: mainly field beans and field peas for feeding livestock) on crop land is good for soil fertility, as nitrogen is bound, and a good source of protein for animals, not only cattle and dairy cows, but also pigs and poultry [53,54]. Especially organic farmers cultivating according to perennial crop rotation have clover grass silage and legumes in stock for their animals in winter [42,44]. According to statistics, the overall amount of lucerne and clover grass is only 1.14% of the total cultivated area in Hesse (cf., Table S7) [37]. The quantities grown are far too small to feed the current local livestock (available for region 1: 5,300 ha lucerne and clover grass; 13,277 ha legumes). No region grows nearly enough of these protein crops as needed for the current (region 1: 33,823 ha lucerne/clover grass; 58,312 ha legumes), let alone the necessary (region 1: 74,067 ha lucerne/clover grass; 120,601 ha legumes) livestock. Not even the PHD livestock could be satisfied by the current amount of lucerne (region 1: 14,447 ha) and legumes (region 1: 21,522 ha). The low number of protein crops suggests that most animals are fed with imported products, e.g., with soybeans from Brazil.

Maize silage is a very important forage crop for cattle and dairy cows as it can be used to increase the milk yield of dairy cows, among other things. It is produced only in areas where it grows well. The amount of maize silage excluding usage for energy production in Hesse is about 40,000 ha. Although we adjusted our forage examples to the statistically grown amount of maize, the maize currently used to feed livestock amounts to 21,510 ha (region 1). Thus, we suspect that the share of maize for energy production is even higher than assumed. The amount of maize silage would not be enough for *SSD 100%* in regions 1 (necessary: 51,272 ha), 2 (necessary: 32,796 ha, available: 10,636 ha) and 5 (necessary: 24,049, available: 8,330 ha). Cereals are grown enough for the *current* livestock in all regions. It would be also enough for *SSD 100%* in regions 1 (necessary: 191,130 ha, available: 286,368 ha), 3 (necessary: 32,530 ha, available: 71,947 ha), 4 (necessary: 40,662 ha, available: 126,916 ha) and 6 (necessary: 7,433 ha, available: 19,595 ha). The highest share in feeding is at the expense of pig farming.

Oil seed crops are also fed to animals, especially cattle, however, a certain amount only after pressing oil as the remaining share is high in proteins. As we do not know the currently fed shares of complete oil seeds and oil press cakes, we calculated the share of oil seeds (rape and sunflower seeds) with whole seeds. For all regions, the current amount of grown oil seeds is enough to feed current livestock, but not enough to feed the necessary livestock (except region 4). For PHD consumption, current crops would be sufficient. Tables S2, S9 and S10 show the respective arable crops divided according to animal groups and aggregated according to the calculated necessary number of animals per diet (*current* livestock feed, *SSD 100%* livestock feed, *PHD* livestock feed).

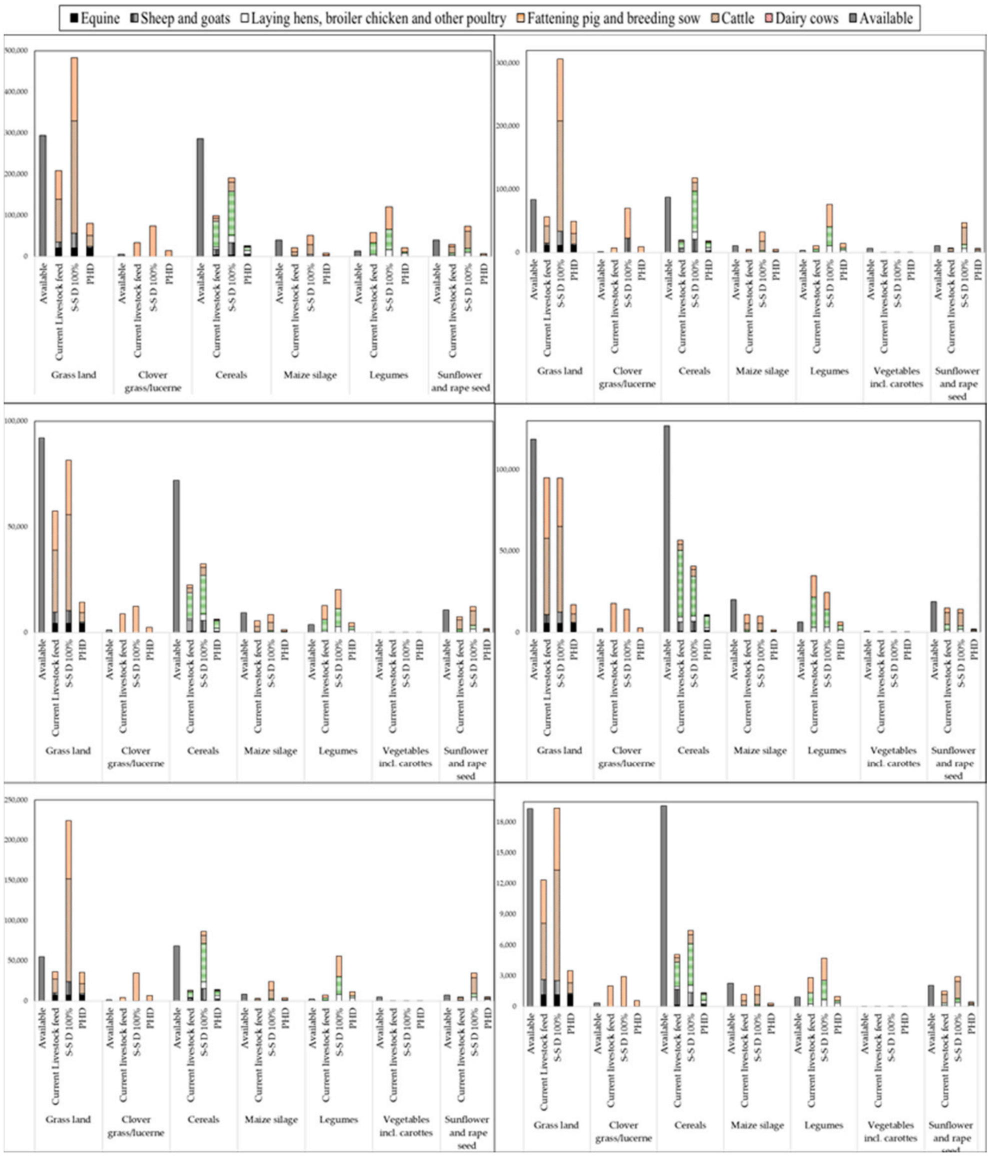

Figure 4. *Land Consumption of Current Livestock in Comparison to Necessary Livestock, Regions 1 to 6.* Each chart (regions 1-6, from top left: region 1 to bottom right: region 6) shows the available amount of grass land and arable land (left bar), the amount, current livestock needs for fodder (second left bar), the amount of fodder necessary to feed the necessary livestock for SSD 100% (third left bar) and the amount of fodder necessary, if all people consumed based on the PHD recommendations (right bar). The bars are composed of the needs of the individual animal groups and are shown stacked (cf., Tables S2, S9-S11).

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3.6. Direct Human Consumption - Self-Sufficiency Degree (SSD 100% and PHD)

The necessary current consumption of plants amounts to 226,522 ha for region 1 and slightly decreases for the PHD (region 1: 225,090 ha). Considering only plants currently grown for human consumption (wheat, spelt, Einkorn, rye, barley, oat, other cereals, sugar beets, potatoes, oilseeds, legumes—of these, considering only 5% of the total amount, as 95% are grown for animal feeding, and vegetables), the available ha adds up to 328,829 ha (region 1). Table A6 shows the available ha currently grown and the calculated self-sufficiency degrees for the current consumption as well as a diet based on the PHD. The overall self-sufficiency degree (available ha in relation to necessary ha for a plant-based diet) regarding current consumption patterns is between 75% (region 2) and 324% (region 4) and between 76% (region 2) and 326% (region 4) in regard to PHD recommendations. For single crops, the picture looks different, though. The cultivation of cereals is sufficient in all regions, namely, between 158% (region 2) and 748% (region 4); sugar beets (considering that 5 kg of sugar beets are necessary to produce one kilo of sugar) are cultivated more than currently needed in regions 1 (137%), 2 (115%), 4 (264%) and 5 (130%), but not in regions 3 (74%) and 6 (66%). The PHD recommends to eat only one third of current sugar intake, thus, for PHD consumption, the amount of cultivated sugar beets would be more than enough for all regions (region 6: 219%, region 4: 883%).

Potatoes reach a SSD between 22% (region 6) and 56% (region 2) and would increase to 83% (region 6) and 212% (region 2) based on PHD. Oil seeds (considering that 2.3 kg of seeds are necessary to produce 1 kg of oil) currently reaches a SSD of 17% (region 5) and 109% (region 4). The numbers would increase with PHD-intake to 25% (region 5) or 159% (region 4). The share of cultivated legumes, not precisely for livestock, currently can only cover between 4% (regions 2 and 5) to 24% (region 4), but regarding PHD recommendations, the share would decrease to 0.4% (regions 2 and 5) or 2.6% (region 4). Vegetables account to 3.7% (regions 3 and 6) or 43% (region 2), with a slight increase up to 4.3% (regions 3 and 6) and 50% (region 2) regarding PHD.

It can be summarised that, although the land for a local (plant-based) diet is available, the currently cultivated type of the respective arable crops is not sufficient to provide the population with a varied and healthy diet. The figures vividly illustrate how regional farmers' cropping plans do not adapt to regional needs, but to existing livestock, the global market, subsidies, as well as arable crops that are less labour-intensive. The insignificant share of other cereals (about 0.5% of total cereal production in all regions), such as summer cereals, millet, sorghum and non-cereals like buckwheat or amaranth, all of which are important for a healthy, balanced and varied diet, supports this statement.

3.7. Land Consumption due to Consumption Patterns—Total and per Capita

As stated above and displayed in Figure 4, grass land is currently underutilized (region 3: 62%, region 4: 80%). For *SSD 100%*, only in region 3 (89%), 4 (80%) and 6 (100%) enough grass land is available to feed the necessary livestock (cf., Table S8). Grass land would be much underutilized in case of *PHD:* 14% for region 4, 65% for region 5.

In other terms, each inhabitant needs approx. 767 m² of grass land (slight deviations per region due to the different numbers of equine included in the calculation for grass land), but available are between 185 m²/capita (region 5) and 974 m²/capita. The unequal distribution does not balance out for the whole of Hesse, ashere, each inhabitant has 467 m²/capita instead of the necessary 767 m²/capita. Regarding PHD recommendations, this share decreases to approx. 128 m². In this case, no region would live beyond its means.

By combining the necessary share of crop land for the plant-based diet as well as the necessary share of crop land to feed livestock, we can visualize if and how much the regions live beyond their means. Based on resources necessary to feed current livestock plus the share of current plant-based consumption shares, crop land is only sufficient for regions 3 (96% necessary in comparison to existing crop land), 4 (97%) and 6 (84%). In case of *SSD 100%*, only region 4 (82%) has enough crop land to feed livestock and humans directly. Region 1 (overall Hesse) exceeds its crop land resources by 81%. Regarding *PHD*, most regions, but 2 (154%) and 5 (148%), could supply themselves (region 3: 56%, region 4: 37%, region 6: 50%). Most importantly, if all Hessian inhabitant consumed as the

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PHD recommends, the resources would be enough (74%). Each inhabitant had 648 m² crop land, but would only need 482 m².

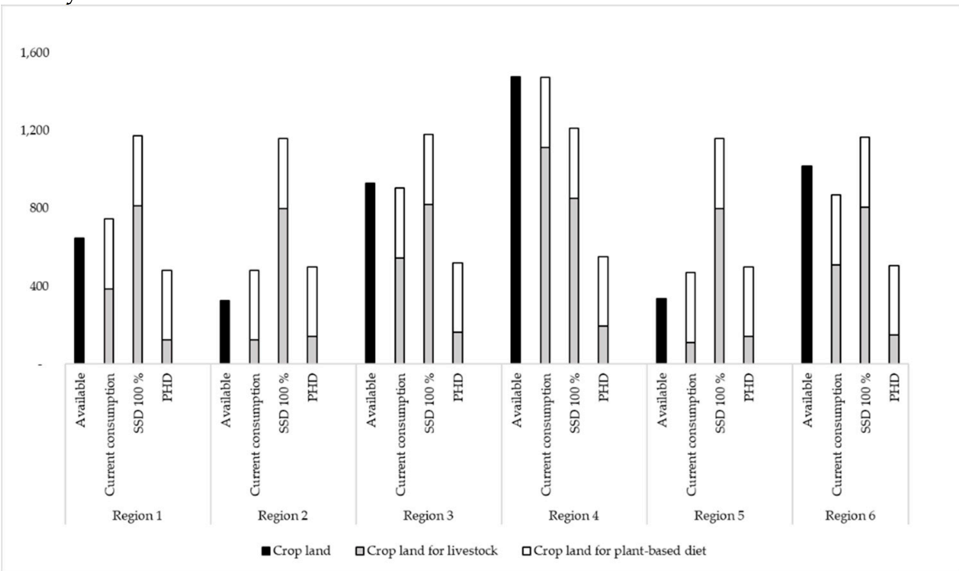

Figure 5. Available Crop Land in Comparison to Necessary Crop Land for Plant-based Diet plus Necessary Crop Land to Feed Livestock in m2 per capita, regions 1-6. The left bar shows the available crop land; the second bar displays the crop land necessary to cover the share of the plant-based diet plus feeding for current livestock; the third bar shows the crop land necessary to cover local consumption patterns completely, the fourth bar illustrates the crop land necessary to cover consumption as recommended by PHD.

Considering that, mathematically, each of us has only 2,000 m² of crop land for ones total consumption, including bread, rice, potatoes, fruit, vegetables, oil, sugar, nuts etc., but also drinks, like juice, beer, wine etc., animal products (meat, dairy, eggs), cotton, linen etc. for our clothes, tobacco for smokers, bio-gas or bio-diesel and renewable raw materials for industry [55], the usage of the nearly 1,200 m² (*SSD 100%*) of crop land could be considered as a non-balanced share. In accordance with [56], we conclude that our diet needs to be adapted to a diet consisting of less animal products. The change in behaviour towards the PHD seems to be imperative if the regions do not want to continue to "live too large".

3.8. Self-Sufficiency Degree on base on the Planetary Health Diet—Animal Products

Taking into consideration the amount of animal products based on the PHD and 2,150 kcal per day per person, the amount of animals could be decreased from currently 0.33 animals/capita for red meat to approx. 0.03 animals/capita and from approx. 0.62 poultry/capita to 0.43 poultry/capita (*SSD 100%* in comparison to *PHD*, incl. herd factors/stable places). In other terms, currently, one dairy cow can satisfy the demand of 17 people, but could feed nearly 90, if the overall consumption decreased as recommended by the PHD. The effect is event bigger for cattle: whereas today, nearly 10 people eat one cow per year, one cow could feed 103 people considering PHD consumption (sheep: 27 people vs. 256, goats: 27 vs. 258), pigs (6 vs. 60). For laying hens, the shares would more than triple (1.2 people *SSD 100%* vs. 4.4 people *PHD*). For white meat (broiler chickens and other poultry) the differences are less significant as the PHD “allows” quite high numbers of white meat per year: whereas, to date, the demand of 1.8 people can be satisfied by 1 broiler chicken pen place, it could be 2.6 people (*PHD*) as well as nearly 22 people per other poultry instead of currently 15 people. Figure 6 aims at illustrating this difference.

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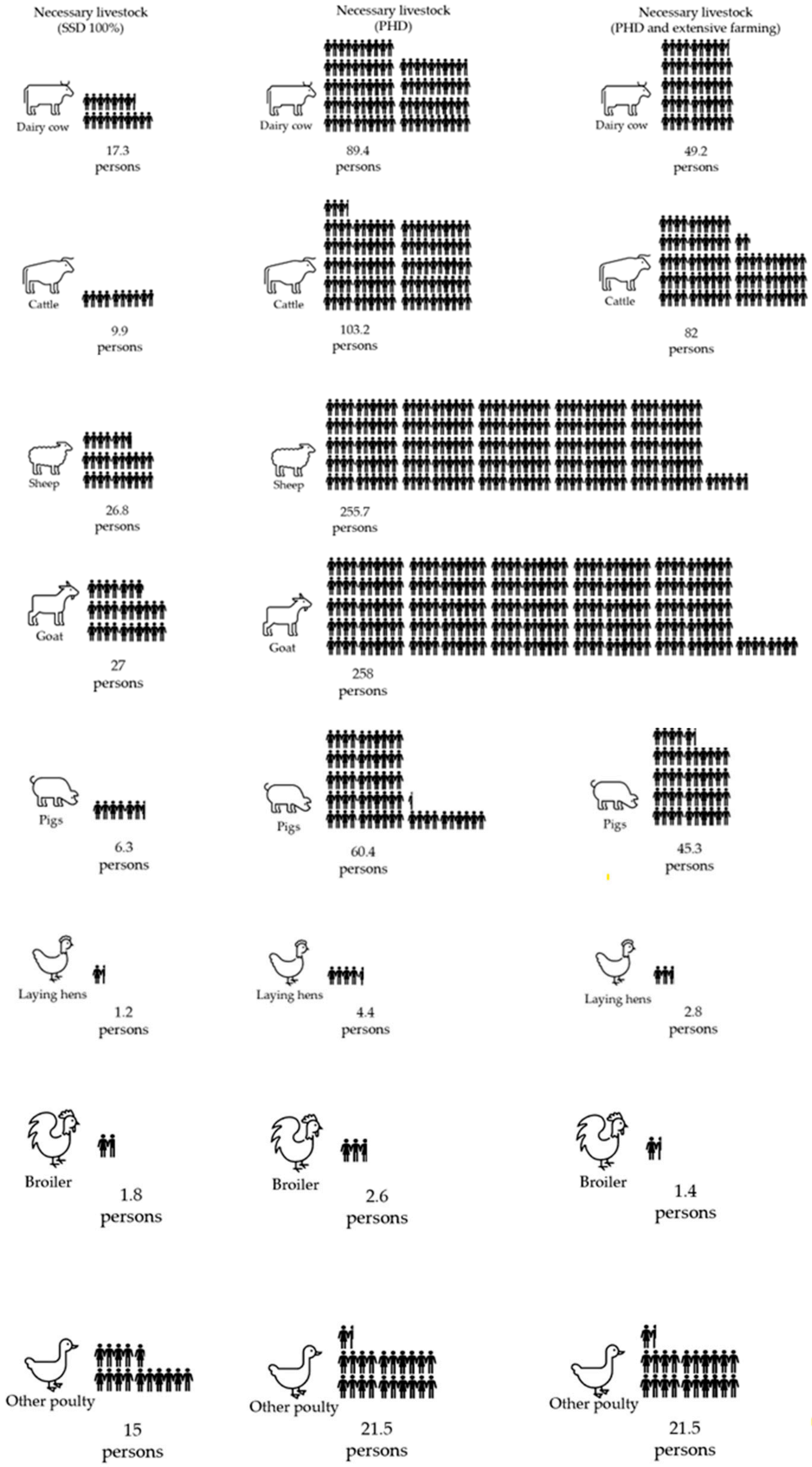

Figure 6. Number of Persons one Animal can Feed (Meat, Dairy, Eggs) Depending on Livestock SSD 100%, Livestock PHD and Livestock Extensive. For instance, currently, one cow covers the annual dairy consumption of 17.3 persons, but could cover nearly 90 persons if all consumed as recommended by the PHD. If livestock was kept extensively, milk performance decreased, thus, one cow could "only" cover consumption of about 50 persons, etc. There are no differences for goats, sheep and other poultry between PHD and extensive.

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Our data shows that not much would be achieved if only the diet changed, but not the farmers' cultivation plans. When looking at the individual crops, then, in the case of *PHD*, above all, grass land would not be used efficiently, while the plant-based diet of humans would not become more variable. Rather, more grass land and crops could theoretically be exported or burned. While the spread of the Planetary Health Diet would make a positive contribution to a more sustainable per capita-consumption in ha, a more regional diet would be relatively one-sided; moreover, the share of crop land required for the production of meat, dairy, and eggs would continue to compete with direct human food (plants), as animals would continue to get a large share of cereals and other arable crops edible by humans. A certain degree of independence from global food chains as well as development towards food sovereignty is possible in and for Hesse, but only if the consumption of animal products is drastically reduced. The related question is whether it would even be possible to move (back) towards peasantry farming, and thus agroecological practices, as demanded by *La Via Campesina* and other organisations.

3.9. What Changed if… Self-Sufficiency Degree on base of the Planetary Health Diet plus Crop Rotation and Extensive Animal Husbandry

To this point, we could show, what we cannot do (feed ourselves a varied/diverse diet) as well as the impact of livestock the regions currently keep, should keep for a SSD of 100% as well as if all ate based on the PHD. In Europe alone, the assumed soil loss is around 970 million tonnes per year due to erosion. Because of this as well as the reasons mentioned above that speak for (re-)localising and greening food chains, a sensible step could be to shift agricultural practices to a more sustainable way. But what exactly would change and is there enough land available for extensive livestock farming? To calculate this scenario, we chose a different, more utopian way. We elaborated a seven-year crop rotation system based on expert input [42] and literature [57,58]. The crop rotation system consists of two years clover grass and lucerne, followed by one year of high-yielding plants, such as winter wheat, sunflower or rape seed. Year four consists of potatoes, oat or medium- to low-yielding vegetables. The fifth year is for grain legumes, such as soya, sweet lupines, chickpeas or lentils, followed in year six by high- to medium-yielding plants such as sugar beets, sunflower/rape seeds, vegetables, winter wheat and green or silage maize. The seventh year closes the rotation crop system with a low-yielding cereal, namely oat, barley or rye. It must be stated that we did not include the different soil types and qualities, which are more or less suitable for the cultivation of individual arable crops, nor food waste.

Following, we separated the available ha for direct human consumption and the available ha for animal feeding, firstly, considering the ha necessary for a plant-based self-sufficiency degree of 100% based on the PHD and, secondly, subtracting remaining shares from processing oil and flour. The remaining shares were considered for animal consumption (cf., Table SI12). We then decreased the output (milk, eggs and animal growth rate, cf., Table A4), as within this utopia, mainly grass land and lucernes remain for animal feed. Also the "output" of dual-use animals was included.

As mentioned above, the necessary m²/capita for the plant-based consumption share based on the PHD and 2,150 kcal adds up to 358 m²/capita. The available crop land per capita based on a seven-year crop rotation system varies between 206 m² (region 2) and 955 m² (region 4). Looking at the overall region of Hesse (region 1), each person would have 420 m² (instead of 521 m² potentially available for direct human consumption without a crop rotation system) for a plant-based diet as well as 318 m² for animal feeding (cf., Table S13). To feed the amount of livestock necessary based on the PHD, 305 m²/capita crop land would be necessary and 393 m²/capita grass land (available: 467 m²/capita) in region 1. In per cent, the land consumption for the plant-based share would be 85% of the available crop land and 96% for the consumption of animal products (total 81%). Regions 3, 4 and 6 also could satisfy local demand, the population intensive areas 2 and 5 could not cover local demand and would have to be supplied by other Hessian regions. Figure 7 illustrates the available grass land in comparison to the necessary grass land (*extensive*) as well as the available crop land in comparison to the necessary crop land including its division between human consumption and animal feed.

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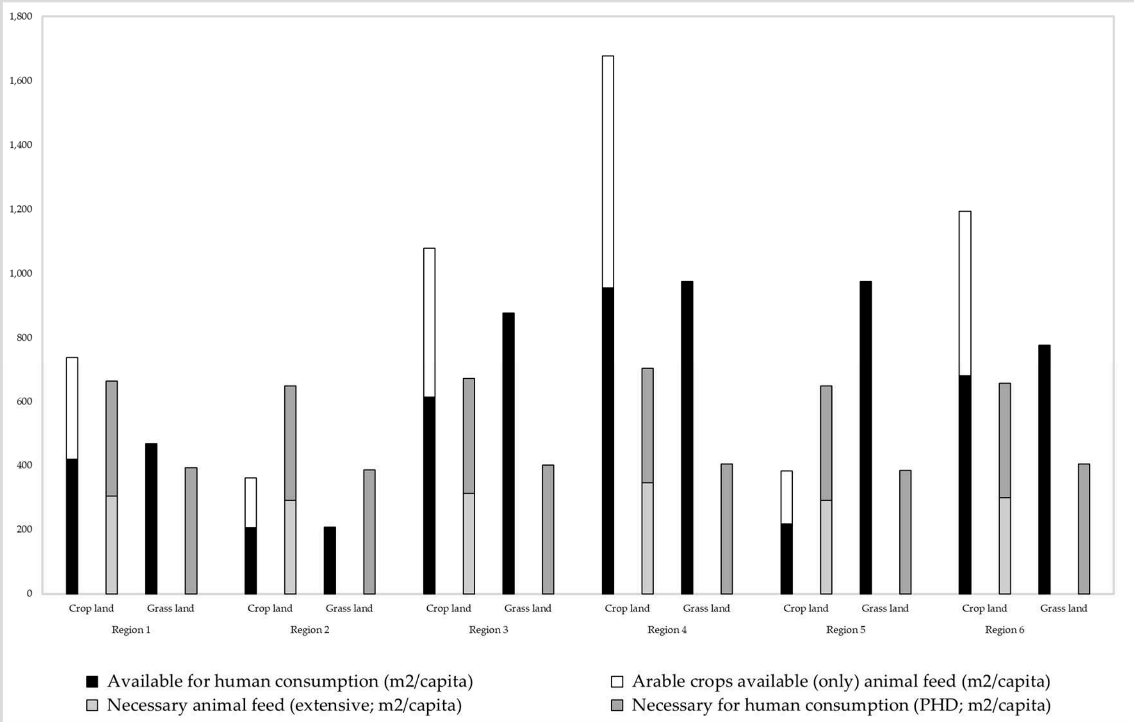

Figure 7. Shares of Available Crop Land in Comparison to Necessary Crop Land for Direct Human Consumption (PHD) and for Animal Feed (Extensive Husbandry), Regions 1 to 6. The shares were calculated based on a seven-year crop rotation system and extensive husbandry (feed only lucerne/glover grass, remaining crops not perfectly suitable for human consumption).

Looking at each crop in particular, the main challenge would be to cover the demand of local oil from oil seeds, which could not be satisfied on base of our calculations (cf., Table S13). The proportion of fatty acids in rapeseed is 45%, so only this proportion can be assumed for the supply of oilseed crops. Based on the crop rotation assumed here, the supply of vegetable oils from the region cannot be ensured. However, as crop land in reality is not shared in 49 shares as done mathematically in our scenario, but by farm and their smaller crop rotation systems, the possibility to feed ourselves is given, even so much that arable land is left over to grow other interesting arable crops to meet the need for seeds (as replacement of the PHD-proposed need for nuts, cf., Table S13: total land consumption, region 1: 81%).

We conclude that a local, diverse and sustainable diet within planetary boundaries and based on peasantry and agroecological farming is possible if the population drastically reduces its consumption of animal products, farmers cultivate on the basis of crop rotation systems, animals are kept extensively again and dual-purpose animals find their way back into our consumption behaviour. Such a diet (low rate of sugar and animal products) and farming practices would not only be good for the environment, biodiversity and soils, but also lead to healthier lifestyles and less obesity among the population. According to experts, the use of crop rotation systems drastically reduces the need for pesticides and fertilisers.

4. We must Change our Consumption Level

Short food supply chains have a positive impact on health, climate and the local economy, as stated above, but only if local supply and demand match. Our results of the calculated self-sufficiency levels based on current consumption patterns show that regions 1 to 6 are not able to feed the local population and are thus far from food sovereignty or independence of global supply chains. The current prevailing consumption does not allow these regions to turn away from industrialised agriculture nor a transformation towards peasant farming on a broader scale. Ergo, if the status quo prevails, short food supply chains can only be built successfully for a small consumers group, but not for the masses.

However, we were also able to indicate how land consumption could decrease if all people consumed as the Planetary Health Diet recommends, at least for a certain range of food groups. We are aware that we excluded a wide range of foodstuff, such as fruits, nuts and fish, but also beverages, like coffee, tea, juice, wine, beer etc., processed food, sweets like ice-cream, chocolate, cookies, and snack food like crisps etc., but also tobacco and other luxury foods. This exclusion indicates two things: firstly, the resource consumption alone for our entire diet is much bigger than shown in this study, secondly, if it is that much bigger, should not each of us try to keep the footprint of staple food as small as possible, so that occasionally, we can enjoy other foodstuff without constantly stretching planetary boundaries? The diet proposed by the Planetary Health Diet can give us a good orientation as it indicates a healthy diet and one within our planetary boundaries. Nonetheless, it seems important that we adjust it to our local cuisine, culture as well as cooking time and capabilities.

In the case of the state of Hesse, or rather central Europe as such, the medium potato consumption indicated by the PHD is too low. Instead, we propose to leave current consumption levels, as in this region, potatoes are usually eaten whole and only to a lesser extent in the form of starch (the reason, why the PHD does not recommend it more). To maintain the recommended calorie intake, the consumption of cereals, for example, could be reduced accordingly. The recommended consumption of poultry at 3.6 animals per capita per year is quite high. This number of poultry can only be produced with factory farming, a form of husbandry that, as critics say (and we could not agree more), cannot do justice to animal welfare. It might therefore make more sense to use this land to grow special crops such as hemp, flax, buckwheat, quinoa, chickpeas etc. instead of feeding them to poultry, to provide a more varied plant-based diet at the local level. The same accounts for fish, although it is not part of this study due to the insignificant amount of locally produced fish: is an annual intake of almost 9 kg of fish per capita necessary or could we not rather consume similar healthy food, such as local plants, but also algae and equivalents? Examples of balanced, varied vegan diets show that a sufficient consumption of proteins deriving from plants is possible [59].

In most parts of the state of Hesse, the current production of fruits and especially nuts is irrelevant, besides perhaps cherries, strawberries and apples, latter to produce beverages. By looking into local gardens, however, tons of fruits are produced, often rotting on trees and bushes. Rethinking could be initiated here by making the advantages of local fruit varieties in season or preserved fruit socially attractive again. The PHD also recommends a high intake of nuts (15.7 kg per capita and year). Most nuts such as almonds, cashews, Brazil nuts and peanuts are not native here and its cultivation requires a large amount of water. Instead of campaigning to eat more nuts, the focus could be on local nuts, such as hazelnuts and walnuts, but especially on the consumption of local seeds, such as hemp seeds, linseed, pumpkin and sunflower seeds.

Vegetables can grow on fields, research from the UK indicate that gardening lots and small market gardening farms can produce a multiple of yield per m^2, using ecologically sound cultivation methods and aids, such as own compost or sheep wool pellets etc. [60]. More research should go into compost and biochar as an alternative to animal manure, as the calculated amount of nearly 215,000 grazing animals (region 1) plus pigs is not enough to fertilise 464,000 ha crop land and nearly 300,000 ha pasture land (according to experts from organic farming, one livestock unit is needed per hectare for fertilising [42]).

We calculated with conventional yields taken from statistical reports. If we had calculated with the current organic yields, we could not mathematically achieve 100% self-sufficiency on the basis of the Planetary Health Diet, as these are, as of today, about 60% of the conventional yields in the regions analysed here[42]. Cultivating on base of conventional agricultural methods, however, neither is sustainable nor does it help getting independent from big corporates or countries producing fertilizer and pesticides. Research on agroecology already indicates that sustainable farming practices can feed the world, especially when using leguminous cover crops as fertilizer [61], and combat climate change [12,62,63]. Still, more research is needed on sustainable farming, also to increase yields/m^2, including traditional practices, such as mixed cropping and intercropping systems, non-tillage, the

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impact of different soil microbiomes on plants, but also innovations, such as precision farming, artificial intelligence and plant breeding (such as Riceberry Rice) [64,65].

Not neglected should be the impact of pets (cats and dogs) on the environment. In Germany, there live 16.7 million cats and 10.3 million dogs, the share for the population of Hesse would be about 770,000 dogs and 1.25 million cats. For cats (mean value of 3-5 kg), this roughly adds up to about 55,000 tons of meat per year and for dogs, based on the weight of the ten most popular dog breeds and the mean value of different feeding practices (besides so-called raw feeding), about 13,000 tons of meat, 3,100 tons of vegetables and 3,100 tons of cereals of feeding are demanded. Converted into land used to feed the animals being fed to pets, and considering cattle, poultry and sheep (incl. the herd/stable place factors of Table A4), one average dog needs nearly 2,000 m² of crop land and 2,000 m² of pasture land per year. Cats need more meat and use about 6,000 m² of crop land and about 7,000 m² of pasture land and as such a multiple of the land consumption of human beings (especially when living on base of the PHD). To date, these numbers can be relativised, because most of the meat consumed by pets is slaughter waste (including bones) or animals, not eaten by humans, such as brother cocks or retired dairy cows. Thus, the amount of additionally raised livestock for pets is currently much smaller. What if, though, all humans ate as the PHD recommends? Then far fewer animals would have to be slaughtered and, consequently, less slaughter waste would be produced. How could the number of pets than be fed? Provocatively spoken, should not we, as a society, overthink keeping animals for our pleasure, when millions of people go hungry and we currently need three worlds to cover our consumption patterns?

Back to our findings, which show the urgency of decreasing our consumption of animal products, being in line with other scholars [22,23]. To quickly reduce greenhouse gas emissions and at the same time get humanity healthier on the one hand and well-nourished on the other side, we urgently need to transform our food systems. One important step could be the reversal of the Green Revolution towards peasantry and agroecology farming, prioritizing food for the people and not neo-liberal policies and international trade. That this could be a potentially viable path also indicate our results on the scenario *extensive husbandry*. We propose to get farmers back into thinking in terms of circular economy and cultivating food for people and not food for livestock. As farmers practices adapt their farming methods to the political will and are demand-driven, demand must change. Nothing will change if consumers are not willing to consume less animal products throughout the Global North as well as to pay fair prices for regional goods. To redress imbalances, cheap food and mass-production of animal products need to be priced based on true cost accounting [66], at the same time, food waste must be decreased, while farmers growing climate-friendly and healthy food must be remunerated. A side effect of this transition might be to get young people excited again about (good) food production, bringing back local processing businesses such as mills, oil presses, slaughter houses and butchers, and to make regional logistics efficient. Until then, scenario *extensive husbandry* will remain a utopia.

Without political pressure, nothing will change regarding food production and agriculture, with 66% of 4,778 farmers surveyed believing that climate change is happening and only 8% attributing it to human activity [67]. If public school and day-care providers are not even prepared to buy regionally and sustainably as discussions on the ground repeatedly show, how is the shift towards more sustainability supposed to work? The German government has published a nutrition strategy focusing on a climate friendly and healthy diet for all. This is to be achieved through a "systemic approach of behavioural and prevention, which takes into account the effects on the environment and climate as well as the different lifestyles […]" [11]. The EU commission has published its common agricultural policy (CAP) 2023-27 seeking to ensure a sustainable future for European farmers, providing more targeted support to smaller farms, focussing on climate change action, environmental care, preserving landscapes and biodiversity etc. [68].

Although, these approaches are laudable, simultaneously, the European Union works on free trade agreements, such as Mercosur, ensuring that more and not less agricultural products, including cattle and resources for feeding livestock are transported from long distances and at small prices [69]. If the prices of products from small regional farmers remain many times more expensive than

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industrial, tax-privileged products from third countries, how is a change in mindset of price-sensitive consumers supposed to take place? What is the answer of politicians to their own counter-running policies to such urgent questions as revolutionising our global food system?

Supplementary Materials: The following supporting information can be downloaded at the website of this paper posted on Preprints.org, Figure S1: title; Table S1: title; Video S1: title.

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Appendix A

Table A1. Available Crop Land per Regions 1 to 6 in ha and Yields per Region and Crop in decitonnes per hectare. 1 decitonne (dt) is equivalent to 100 kg, or 1 quintal. Each region (1-6) is divided into the complete quantity of hectares of the respective arable crop as well as the respective share of organic and the share of organic in percent.

Available Crop Land in Hectare, Regions 1 to 6 (I)

Region		Operating farms	Crop land total	Cereals total	thereof						
					Wheat, spelt, Einkorn	Rye	Triticale	Barley	Oat	Corn maize / Corn-Cob-Mix	Other cereals
1 Hesse	in total	15,128	464,437	289,347	143,606	15,059	19,342	87,266	9,277	13,470	1,327
	thereof organic	2,108		22,296	9,318	2,383	3,101	3,655	2,496	787	556
	in %	14%		8%	6%	16%	16%	4%	27%	6%	42%
2 GD Da	in total	4,935	145,714	88,511	48,442	4,670	2,440	23,057	2,458	6,963	481
	thereof organic	486		4,506	1,925	467	372	712	534	389	108
	in %	10%		5%	4%	10%	15%	3%	22%	6%	22%
3 GD Gi	in total	3,832	113,216	72,640	33,400	3,658	5,657	23,318	3,039	3,198	370
	thereof organic	743		8,677	3,523	962	1,292	1,402	1,060	235	202
	in %	19%		12%	11%	26%	23%	6%	35%	7%	55%
4 GD Ka	in total	6,361	204,239	128,197	61,764	6,731	11,244	40,892	3,780	3,310	476
	thereof organic	879		9,113	3,870	954	1,437	1,541	902	163	247
	in %	14%		7%	6%	14%	13%	4%	24%	5%	52%
5 F MPA	in total	3,207	112,825	69,097	38,528	3,991	1,825	16,787	1,614	5,967	385
	thereof organic	323		3,691	1,578	392	282	480	378	330	65
	in %	10%		5%	4%	10%	15%	3%	23%	6%	17%
6 M-B	in total	1,106	29,664	19,765	8,189	1,417	1,791	5,777	889	1,619	83
	thereof organic	197		2,625	918	370	449	471	277	103	35
	in %	18%		13%	11%	26%	25%	8%	31%	6%	42%

Available Crop Land in Hectare, Regions 1 to 6 (II)

Region		Silage maize	Sugar beets	Potatoes	Winter oilseed rape	Pulses	Vegetables	Grassland	Permanent Crops	Clover grass/lucerne
1 Hesse	in total	43,897	16,504	4,421	43,204	13,410	7,494	294,288	5,855	501
	thereof organic	1,425	318	495	179	4,666				
	in %	3%	2%	11%	0%	35%				
2 GD Da	in total	11,689	8,845	3,192	11,406	3,303	6,582	83,574	4,888	133
	thereof organic	188	157	187	52	881				
	in %	2%	2%	6%	0%	27%				
3 GD Gi	in total	10,198	1,486	487	11,465	3,737	150	92,089	202	116
	thereof organic	550	52	103	71	1,595				
	in %	5%	3%	21%	1%	43%				
4 GD Ka	in total	22,010	6,173	742	20,333	6,371	763	118,627	726	251
	thereof organic	688	109	205	57	2,190				
	in %	3%	2%	28%	0%	34%				
5 F MPA	in total	9,155	7,361	1,014	7,773	2,463	4,569	54,763	1,400	104
	thereof organic	115	69	127	0	762				
	in %	1%	1%	13%	0%	31%				
6 M-B	in total	2,490	313	77	2,200	941	35	19,311	21	339
	thereof organic	152		22		538				
	in %	6%	0%	29%	0%	57%				

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Table A2. Yields per Crop in dt/ha (a); Yields dt per Region and Crop (b) based on [37].

a)	Field Crop	Yield dt/ha Hesse (Year: 2021)
	Cereals total incl. Corn maize and corn-cob-mix	67.9
	Cereals total excluding corn maize and corn-cob-mix	66.7
	Wheat (mean value winter and summer wheat)	65.95
	Rye	56.3
	Barley (mean value winter and summer barley)	64.5
	Oilseed rape (winter)	35.5
	Potatoes	420.6
	Sugar beets	847.3
	Corn maize	93.3
	Silage maize	547.9
	Forage (permanent grassland)	60
	Forage (cultivation on arable land)	61.8
	Clover grass/alfalfa (dry mass)	60.3
	Field beans	37.9
	Field peas	35.4
	Sweet lupines	33.5
	Soybeans	34
	Sunflower seeds	26.1

b)	Yields per Region and Crop in dt per Hectare (I)							
		there of						
Region	Cereals total	Wheat, spelt, Einkorn	Rye	Triticale	Barley	Oat	Corn maize / Corn-Cob-Mix	Other cereals
1 Hesse	19,100,767	9,274,372	847,822	1,275,605	5,628,657	447,267	1,256,751	33,175
2 GD Da	5,836,665	3,128,484	262,921	160,918	1,487,177	118,506	649,648	12,025
3 GD Gi	4,798,879	2,157,041	205,945	373,079	1,504,011	146,518	298,373	9,250
4 GD Ka	8,465,290	3,988,847	378,955	741,542	2,637,534	182,243	308,823	11,900
5 F MPA	4,555,467	2,488,218	224,693	120,359	1,082,762	77,815	556,721	9,625
6 M-B	1,306,996	528,863	79,777	118,116	372,617	42,861	151,053	2,075

Yields per Region and Crop in dt per Hectare (II)						
Region	Silage maize	Sugar beets	Potatoes	Winter oilseed rape	Pulses	Vegetables
1 Hesse	21,884,168	13,726,924	1,852,673	1,422,695	350,516	2,148,383
2 GD Da	5,827,370	7,356,680	1,337,646	375,596	86,335	1,886,931
3 GD Gi	5,084,055	1,235,955	204,083	377,539	97,679	43,002
4 GD Ka	10,972,744	5,134,289	310,944	669,560	166,528	218,737
5 F MPA	4,564,083	6,122,388	424,929	255,963	64,379	1,309,843
6 M-B	1,241,351	260,332	32,268	72,445	24,596	10,034

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Table A3. Extrapolated Consumption per Regions 1 to 6 in kg (a) and hectares (b) for Current Diet and Planetary Health Diet.

Current Consumption and Recommended Consumption per Region in kg

Food group (in kg)	Current consumption region 1	Consumption recommended by PHD region 1	Current consumption region 2	Consumption recommended by PHD region 2	Current consumption region 3	Consumption recommended by PHD region 3	Current consumption region 4	Consumption recommended by PHD region 4	Current consumption region 5	Consumption recommended by PHD region 5	Current consumption region 6	Consumption recommended by PHD region 6
Cereals	523,745,414	458,433,354	335,010,125	293,233,718	87,423,648	76,521,751	101,311,642	88,677,885	245,660,896	215,026,510	20,681,606	18,102,570
Pulses	15,737,543	148,200,438	10,066,410	94,795,383	2,626,913	24,737,635	3,044,220	28,667,420	7,381,638	69,512,880	621,443	5,852,124
Potatoes	375,183,013	98,800,292	239,983,214	63,196,922	62,625,594	16,491,757	72,574,205	19,111,613	175,978,238	46,341,920	14,815,189	3,901,416
Vegetables	688,674,860	592,801,751	440,506,102	379,181,532	114,953,691	98,950,540	133,215,067	114,669,679	323,020,457	278,051,521	27,194,324	23,408,496
Fruits	453,870,726	395,201,167	290,315,264	252,787,688	75,760,157	65,967,027	87,795,305	76,446,453	212,886,426	185,367,681	17,922,402	15,605,664
Plant-Oil	148,562,401	102,357,102	95,026,910	65,472,011	24,798,054	17,085,460	28,737,437	19,799,631	69,682,658	48,010,229	5,866,417	4,041,867
Nuts	31,475,085	98,800,292	20,132,820	63,196,922	5,253,825	16,491,757	6,088,440	19,111,613	14,763,275	46,341,920	1,242,885	3,901,416
Sugar	204,588,053	61,256,181	130,863,330	39,182,092	34,149,863	10,224,889	39,574,860	11,849,200	95,961,288	28,731,991	8,078,753	2,418,878
Milk, equiv. diary	2,553,258,895	494,001,459	1,633,174,358	315,984,610	426,190,284	82,458,783	493,894,253	95,558,066	1,197,596,868	231,709,601	100,822,831	19,507,080
Eggs (pcs.)	1,498,214,046	407,747,236	958,322,232	260,812,694	250,082,070	68,061,218	289,809,744	78,873,324	702,731,890	191,252,369	59,161,326	16,101,082
Red meat total	264,390,714	27,664,082	169,115,688	17,695,138	44,132,130	4,617,692	51,142,896	5,351,252	124,011,510	12,975,738	10,440,234	1,092,396
White meat	82,464,723	57,304,169	52,747,988	36,654,215	13,765,022	9,565,219	15,951,713	11,084,736	38,679,781	26,878,314	3,256,359	2,262,821
Fish	79,946,716	55,219,889	51,137,363	35,321,019	13,344,716	9,217,311	15,464,638	10,681,559	37,498,719	25,900,690	3,156,928	2,180,517
Beef	514,302,889		328,970,279		85,847,501		99,485,110		241,231,914		20,308,741	
Sheep and goat	59,173,160		37,849,702		9,877,191		11,446,267		27,754,957		2,336,624	
Pig	3,777,010		2,415,938		630,459		730,613		1,771,593		149,146	
Other meat	195,145,527		124,823,484		32,573,715		37,748,328		91,532,305		7,705,887	
Meat total (red and white + industry)	6,295,017		4,026,564		1,050,765		1,217,688		2,952,655		248,577	

b)

Necessary ha of Crops for Direct Human Consumption for Self-Sufficiency Degree of 100% (baseline: current consumption)

Region	Cereals total (wheat, spelt, Einkorn, Rye, Barley, Oat, Other Cereals)	Sugar from sugar beets 20% sugar per beet	Potatoes	Oil from oilseed rape 2.3 kg per 1 l oil	Legumes (95% in Hesse for livestock)	Vegetables	Sum
1-Hesse	78,523	12,073	8,920	96,252	6,733	24,022	226,522
2-GD Da	50,226	7,722	5,706	61,567	4,306	15,366	144,893
3-GD Gi	13,107	2,015	1,489	16,066	1,124	4,010	37,811
4-GD Ka	15,189	2,335	1,725	18,619	1,302	4,647	43,818
5-F MPA	36,831	5,663	4,184	45,147	3,158	11,268	106,250
6-M-B	3,101	477	352	3,801	266	949	8,945
Necessary ha of Crops for Direct Human Consumption for Self-Sufficiency Degree of 100% (baseline: Planetary Health Diet)							
1-Hesse	68,731	3,615	2,349	66,316	63,401	20,678	225,090
2-GD Da	43,963	2,312	1,503	42,418	40,554	13,227	143,977
3-GD Gi	11,473	603	392	11,069	10,583	3,452	37,572
4-GD Ka	13,295	699	454	12,828	12,264	4,000	43,541
5-F MPA	32,238	1,696	1,102	31,105	29,738	9,699	105,578
6-M-B	2,714	143	93	2,619	2,504	817	8,888

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Table A4. Herd Factor/Stable Place Factor, Slaughter Weight and Output Conventional and Extensive Husbandry.

Livestock	Herd factor	Herd factor (extensive husbandry)	Herd share producing "output"/ stable place (slaughter quota)	Output kg milk/animal; eggs/animal	Output slaughter weight/animal in kg [1)]	Output (extensive husbandry)
Dairy cow	1.33		0.67	9,358.4		5,150 kg/milk p.a.
Cattle	2.7	3	0.37		230	
Sheep			0.5		21.4	
Goats			0.5		10.8	
Fattening pigs			2		98	1.5
Laying hen				288		180 eggs/hen p.a.
Broiler chicken			10		2	
Geese			4.1		5.2	
Turkeys			2.9		10	
Ducks			4.3		2.2	

[1)] Adapted from [70,71].

Additional Information on A4: Herd Factor/Stable Place Factor

Dairy cows

The herd factor of dairy cows is 1.33 (dairy cow herd plus 33% offspring), since the offspring give birth to their first calf at about 2-2.5 years of age and thus give milk and a dairy cow is slaughtered after approx. 6 years. Before that, the cow has to live in the herd without giving milk. Thus, the herd share producing milk is 67%.

We considered the current dairy cows, added 1/3 of offspring and calculated that 67% of this herd produces x kg of milk (9358.4 kg currently or 5.150 kg milk/cow p.a. for extensive husbandry) [72].

Cattle

Taking into account the Hessian statistics *Agricultural holdings with cattle husbandry and cattle population on 1 March 2020 by regional unit, Statistics Hesse* [73], calculating the decrease of animals in age groups, we calculated a slaughter quota of 0.37. The average slaughter weight of calves, young cattle and cattle is 230 kg/animal. To slaughter 37% of a herd, each slaughtered animal has to be multiplied with 2.7 (1/0.37) to keep the herd size stable. If cattle is kept extensively, the multiplying factor has to be 3 (1 animal lives for three years to get an adequate slaughter quote). To calculate the produced cattle meat in kg based on current livestock plus retired dairy cows, we took the current livestock minus dairy cows, multiplied them with the slaughter quote (0.37) and slaughter weight (230kg) and 17% of the dairy cows and a slaughter weight of 250 kg.

Sheep and goats:

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These differences are less significant for sheep and goats as most farms in the state of Hesse keep sheep on pasture and grass silage and for meat production. The number of goats is included, and a few dairy goat farms exist, but the number is rather insignificant accounting for only 2% of the available grazing animals.

Calculating the number of goats, sheep and the other animals is easier than for cattle as they are slaughtered a few weeks/months after being born. We did not calculate a different livestock for extensive husbandry as most goats and sheep are held extensively anyway. Also, the amount of animals necessary to satisfy the need is not high and as a much lower number of cattle is necessary, grazing land would be available. There would no broiler chickens be necessary as the demand could be covered by dual-purpose hens and their brothers. We included a slaughter quote of 0.5 for sheep and goats and a slaughter weight of 21.4 kg for sheep and 10.8 kg for goats.

<u>Fattening pigs:</u>

The included slaughter weight of fattening pigs is 98 kg. The slaughter quota is 2, as each pig lives max. 6 months, and thus per stable place, 2 pigs can be fattened per year. In case of extensive husbandry, we assumed pigs being slaughtered after 8 months, thus the slaughter quota changes to 1.5.

<u>Breeding sows and equine:</u>

The current number of breeding sows per region are included, but are not changed for the other scenarios b)-d)

<u>Laying hens and pullets:</u>

The current laying performance is on average 288 eggs/hen p.a. and for dual-use chickens 180 eggs/hen p.a. [74] The pullets are included in the current livestock.

<u>Broiler chicken:</u>

To calculate the currently produced chicken meat in kg, we used the current livestock multiplied by 2 kg slaughter weight (average of light, medium, heavy fattening according to [71]) and 10 (as on average broiler chicken are replaced after 37 days). For extensive husbandry, chicken are slaughtered after 81 year (slaughter quota: 4.5).

<u>Other poultry:</u>

Geese, turkeys and ducks accounts for 12% consumption share in the region. The slaughter quota of geese is estimated to be 6.1 (slaughtered after 90 days) weighing 5.2 kg, turkeys: 3.3 (slaughtered after 126 days), slaughter weight: 10 kg and ducks: 2.6 after 84 days, weighing 2.2 kg.

<u>Regarding all livestock:</u>

All calculations of necessary livestock (*SSD 100%, PHD, extensive*) were calculated by dividing the necessary production for SSD 100% in kg by the output, multiplied by the herd factor (Table A4).

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Table A5. Calculated Shares of Plants Used for Energy Production. Because this share of arable land is not used to produce food or fodder, it is excluded from further calculations from the outset.

Percentages of Crops for Energy Purposes and Industry (excl. Starch Production)							
	Cereals total	**Wheat, spelt, Einkorn**	**Silage maize**	**Sugar beets**	**Potatoes**	**Winter oilseed rape**	**pulses**
		2.10%	9.00%	1.84%	0.40%	7.20%	1.00%

Hectares Used per Region (1 to 6) for Crops for Energy Purposes and Industry (excl. Starch Production)							
Region	**Cereals total**	**Wheat, spelt, Einkorn**	**Silage maize**	**Sugar beets**	**Potatoes**	**Winter oilseed rape**	**pulses**
1 Hesse	6 002	2 979	3 955	303	16	3 128	133
2 GD Da	1 836	1 005	1 053	163	12	826	33
3 GD Gi	1 507	693	919	27	2	830	37
4 GD Ka	2 659	1 281	1 983	113	3	1 472	63
5 F MPA	1 433	799	825	135	4	563	24
6 M-B	410	170	224	6	0	159	9

Additional information on Table A5 and S4: German-wide, about 20% of the total crop land is used for energy sourcing or industrial purposes, mainly biogas (53%, thereof two thirds maize), followed by fuel (36%, thereof 74% rape seed) and ethanol (26%, mainly wheat, rye, sugar beet and corn maize). About 11% of these 20% are used for technical purposes (46%) or for starch (45%), for industrial sugar (5%) or colouring plants (4%). About 60% of the total ha crop land are used for livestock fodder. Only about 20-22% of the crops produced are for human consumption. Specific data for Hesse was not available, thus, we assumed the same shares. For further calculations, these shares were deducted

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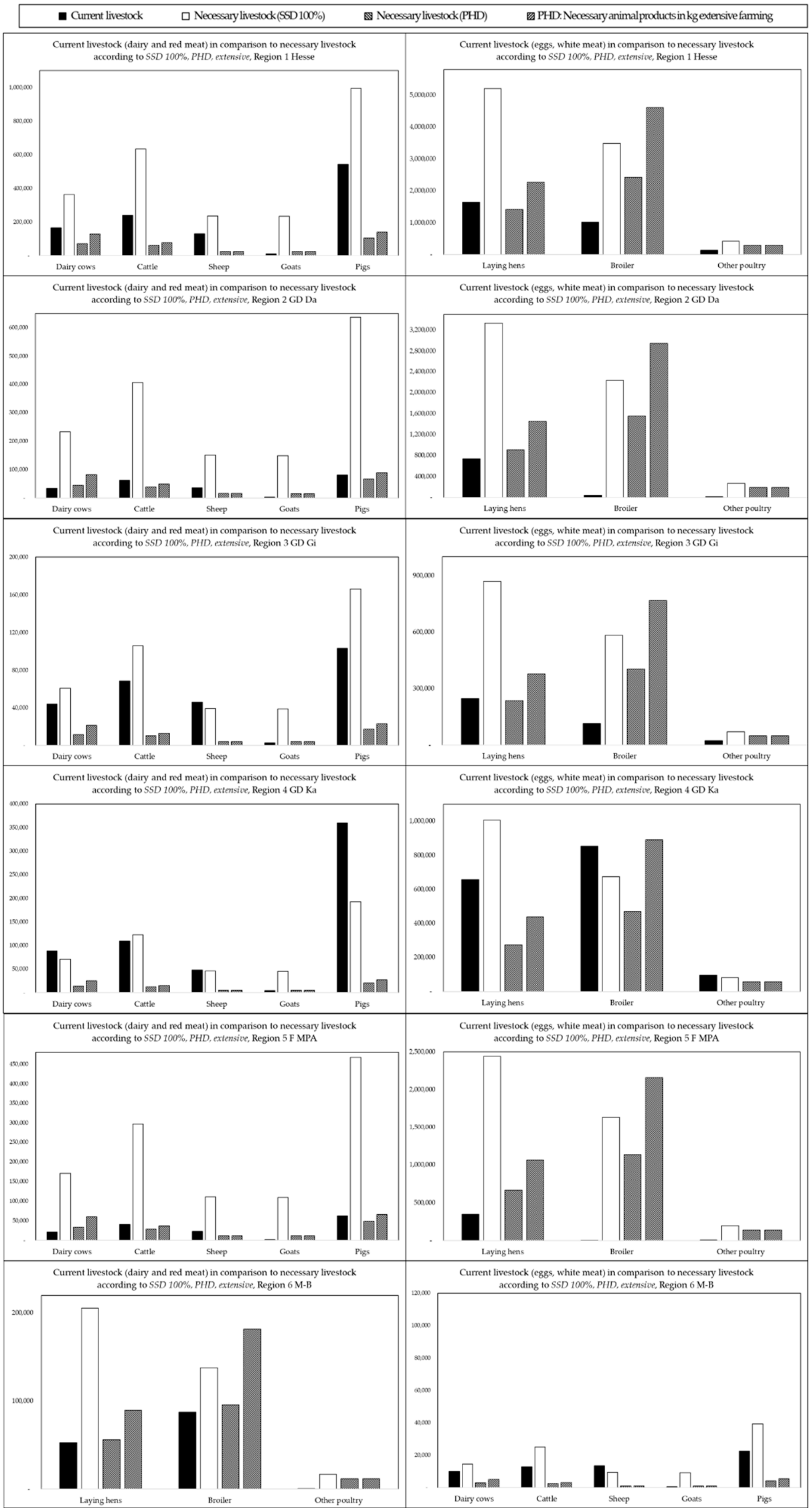

Figure A1. Current Livestock for Meat, Dairy and Eggs in Comparison to Necessary Livestock According to SSD 100%, PHD, extensive, Regions 1 to 6.

Table A6. Available ha for Direct Human Consumption (a) and Self-Sufficiency Degree for Current Consumption (b) and Consumption Recommended by Planetary Health Diet) (c).

a)	Available ha for Direct Human Consumption, Regions 1 to 6						
Region	**Cereals total**	**Sugar beets**	**Potatoes**	**Rape seeds**	**Legumes (5%)**	**Vegetables**	**Sum**
1-Hesse	256,535	16,504	4,421	43,204	671	7,494	328,829
2-GD Da	79,108	8,845	3,192	11,406	165	6,582	109,298
3-GD Gi	63,785	1,486	487	11,465	187	150	77,560
4-GD Ka	113,643	6,173	742	20,333	319	763	141,973
5-F MPA	61,305	7,361	1,014	7,773	123	4,569	82,145
6-M-B	16,355	313	77	2,200	47	35	19,027
b)	Self-Sufficiency Degree of Direct Human Consumption per Crop, Regions 1 to 6 (Current Consumption)						
Region	**Cereals total**	**Sugar beets**	**Potatoes**	**Rape seeds**	**Legumes (5%)**	**Vegetables**	**Sum**
1-Hesse	327%	137%	50%	45%	10%	31%	145%
2-GD Da	158%	115%	56%	19%	4%	43%	75%
3-GD Gi	487%	74%	33%	71%	17%	3.7%	205%
4-GD Ka	748%	264%	43%	109%	24%	16%	324%
5-F MPA	166%	130%	24%	17%	4%	41%	77%
6-M-B	527%	66%	22%	58%	18%	3.7%	213%
c)	Self-Sufficiency Degree of Direct Human Consumption per Crop, Regions 1 to 6 (PHD)						
Region	**Cereals total**	**Sugar beets**	**Potatoes**	**Rape seeds**	**Legumes (5%)**	**Vegetables**	**Sum**
1-Hesse	373%	457%	188%	65%	1.1%	36%	146%
2-GD Da	180%	383%	212%	27%	0.4%	50%	76%
3-GD Gi	556%	246%	124%	104%	1.8%	4.3%	206%
4-GD Ka	855%	883%	163%	159%	2.6%	19%	326%
5-F MPA	190%	434%	92%	25%	0.4%	47%	78%
6-M-B	603%	219%	83%	84%	1.9%	4.3%	214%

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