A transferable strategy to reduce competition for food and feed production in the establishment of agroforestry systems for energy production

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Abstract: *Based on the revealed preference for agricultural products in Germany (shopping basked), a so-called bottom-up-calculation approach was developed to calculate the area needed for food/feed and non-food production. This is applied in order to determine the potential area for the establishment of agroforestry systems (AFS) – the production of food, feed and non-food products on the same plot. The system is based on the cereal unit (CU) as common denominator and by considering crop yields.*

Within the research area in Brandenburg, area-weighted supply responsibilities for other regions (Capital Berlin, State of Brandenburg), has been considered. As a baseline, the current self-sufficiency rate with food and feed is maintained. A further scenario includes 100% self-sufficiency within the model region. The calculations result in a current potential for the non-food and non-feed production of 8,500 ha in the model region (60% of the UAA). Since a maximum of 2,800 ha is needed for ideal establishment of AFS, about 5,700 ha remain available for further utilization, e.g. for the fulfilment of the food supply for urban regions. When looking at Berlin/State of Brandenburg as well as Germany, the fulfilment of the food supply is currently only partially achievable – due to the comparably low agricultural production potential of the area. A deficit of around 1,400 ha (10%) and 1,700 ha (12%) turns out, that no area is available for AFS when aiming at a supply mission for Brandenburg/Berlin or Germany.

Keywords: *agroforestry; food vs. fuel; IACS data; land-use efficiency; agricultural statistics; common agricultural policy*

Introduction

Background and problem definition

Competition for land is on the rise, in particular between food and feed on one side and bioenergy production on the other. Environmental beneficiary extensification of land use can put additional pressure on this trend. The consequences are increasing prices for food and feed and rising land rents. One way to defuse this tension is to reduce the non-agricultural use due to development and transport. Other ways are sustainable intensification, to increase the area productivity, for example, by optimizing the use of scarce acreage or a sustainable improvement of cultivation methods.

Agroforestry systems (AFS) are also claimed to offer a contribution to reduce conflict for land, since different products are produced in one plot compared to their individual production. However, this is no simple solution since it depends largely on the average yields. Meanwhile politicians in Europe are very cautions when the idea of attributing additional land resources to the production of non-food agricultural products. Three main concerns are frequently raised: 1) The public is concerned that their landscape quality is altered, as experienced by increased maize cultivation for biogas in Germany, 2) Moral concerns are raised that food production should be priority, and 3) claimed environmental and climatic benefits lag behind the expectations and in some instances cause detrimental effects on site or elsewhere in the World.

Currently, about 2,200 m² of the total utilized agricultural area (UAA) are available per inhabitant of Germany (Statistisches Bundesamt 2016a, 2016b) to meet different demands, like food, bioenergy and fodder. However, the UAA is decreasing for years, mainly due to the conversion into transport, settlement and industrial areas as well as environmental compensation areas (Statistisches Bundesamt, 2016). Due to the vast expansion of biomass production for renewable energy and materials starting 2003, additional pressure has been created on the remaining area. In addition, the food and animal feed supply situation is increasingly attracting attention due to the globally rising demand for animal products and the consequences of climate change (Klapp, 2011).

Ensuring the supply of food is a major component of sustainable agriculture and has priority in Germany (BmELV, 2012). This has to be considered in a large-scale implementation of agroforestry systems, especially for wood-based energy production. The cultivation of trees requires land and is thus, especially in high productive areas, in direct competition with food and feed.

In order to develop integrated solutions for complex problems the advancement of agroforestry systems (AFS) and its implementation into agricultural practice could be a suitable approach. This needs clearly communicated advice based on facts from a trusted source, that politics and administrations can rely on. The question arises as to how a purposeful use of agricultural land can mitigate competition with regard to the production of food and feed during the establishment of AFS. Central condition for this is that only such area is used for trees, which is not needed for the production of food and feed.

Classification of AFS in terms of competition with food and feed production

Besides being a promising approach to mitigate the competition for land, planting AFS with their versatile abiotic environmental services as well as high energy and climate protection potential, agricultural production can be made more sustainable. Recent studies have shown that AFS – under the regional conditions of the study area – even contribute to securing food and nutrition by increasing agricultural crop yields (Mirck et al., 2016) and stabilizing yield variations. In many nutrient-poor locations in Brandenburg, fast-growing wood can be superior to annual agricultural crops and economically feasible. An additional positive effect results from income diversification for farmers as well as regional value-added.

Which agricultural areas are particularly suitable for AFS in order to minimize competition for use?

Lovett et al. (2009) recommend avoiding potential land-use conflicts by growing primarily on marginal sites. Murach et al. (2008) show that fast-growing tree species in Brandenburg can be more productive than annual agricultural crops, especially on low-yielding, nutrient-poor sites (sandy soils) with groundwater levels that can only be tapped by deeper-rooted trees, but not for agricultural crops. Additionally, AFS are able to enhance the soil quality of marginal sites and post-mining areas. These areas are relevant for the study region and with less competition for food production. In locations with limited agricultural productivity, for example due to a poor supply of water and nutrients, AFS can lead to an increase in area productivity due to a positive impact of the energy wood strips on the crop due to microclimatic effects (especially reduction of wind speed).

Which areas should be avoided?

Agricultural efficiency is assessed by means of "arable field number" and "grassland value". According to Piorr et al. (2010), a higher number of arable crops is associated with an increase in earning capacity. Areas that, due to their high yielding capacity, are better suited for the production of feed and food are priority areas for food production. On these productive sites, the establishment of AFS should be viewed more cautious. However, high-productivity areas should not be excluded generally for agroforestry use. At sites with a high susceptibility to wind erosion, AFS save soil fertility through wind protection and humus structure (Wiesmeier et al., 2018). In addition to possible positive yield effects due to the protective effect of the trees and the associated improvement of the microclimate, a higher yield stability of the arable crops can also be achieved.

Land potentials for biomass in the literature – testing of the approaches

Available land for non-food biomass has already been estimated in numerous national and international studies (Simon, 2007; Schönleber, 2009; Zeddies et al., 2012). Depending on the level of focus, very different methods are used. The potential studies range from simple static estimates of current potentials to complex models with dynamics and consideration of the future.

In static considerations, the scope of the potential areas available at a given time is calculated – without considering future developments. Piorr et al. (2010) calculated that nearly 30% of the arable land in the state of Brandenburg, a total of around 300,000 ha, is theoretically available for the production of renewable raw materials with an own supply of the population of Brandenburg and Berlin. Graf et al. (2010), in their study for the Free State of Thuringia, also derive the land potential for energy crop cultivation from the deduction of the acreage required for food production from the total UAA. The calculation results in a potential area of approx. 20% of the arable land for biomass cultivation in Thuringia.

In contrast to the static consideration, a dynamic potential estimation also considers future developments such as a change in eating habits, population numbers or political conditions. By the Öko-Institut e. V. (2004), the tool HEKTOR was developed and revised by Simon (2007). Schultze et al. (2008) adapted HEKTOR to the district level, taking into account the co-provision for urban regions. Majer (2013) takes into account the effect of changing yields, population, nature reserves and livestock on the land area required for food and feed production for the years 2010 to 2030.

A comprehensive study on sustainable biomass utilization strategies in the European context (EU-27 + Turkey) was carried out by Thrän (2005). Henze and Zeddies (2007) also follow the approach by Thrän (2005), but do not distinguish between grassland and farmland. Schönleber (2009) considered in particular a reduction of the competition between food production and bioenergy production for the years 2000, 2010 and 2020. A global analysis and estimation of the biomass land use potential was carried out by Zeddies et al. (2012).

The studies on bioenergy potential published in recent years show some major differences (Table 1). For Germany, the calculated land potentials for biomass vary within a range of 9%

(Simon, 2007) to 15% of the UAA (Thrän, 2005; Henze and Zeddies, 2007). In all studies with dynamic potential estimation, an increase in the possible acreage for renewable resources is forecast. However, also here the results of the various studies vary greatly, as shown for Germany. Simon (2007) estimates that biomass will account for 17% of Germany's UAA in 2020, while Henze and Zeddies (2007) as well as Thrän (2005) estimate the share of area to be 42.5% and 42.9%, respectively. The significant differences are mainly due to the parameters considered, different methodological approaches, data sources and assumptions taken. This applies in particular to the definition of available surplus areas such as fallow land and set-aside areas, assumptions on nature and environmental protection goals as well as future yield expectations and production conditions (e.g. expansion of organic farming, expansion of domestic protein supply). The parameters are varied differently by scenarios, which can lead to high maximum values. In addition, some of the studies only refer to arable land, while other studies consider the potential for the entire UAA.

Table 1. Overview on the different approaches of potential area estimates.

Source	model	data base	time period	reference area	resolution	potential land
Piorr et al. (2010)	–	unknown	2007	BB	Federal state	30% (BB)
Graf et al. (2010)	–	BMELV, FAO, TLL	2010	TH	Federal state	20% (TH)
Öko-Institut e. V. (2004); Simon (2007)	HEKTOR	Eurostat, BMVEL, FAOSTAT, ZMP, BA Ministry of Agriculture	2000-2030	GER, BA, PL, CZ, HU	Federal state	9,1% (BA) 11,8-8,8% (GER)
Schultze et al. (2008)	HEKTOR	unknown	2010, 2020	Chiemgau	District	14,5%
Majer (2013)	–	Federal Statistics Office, KTBL	2010, 2015, 2020, 2025, 2030	GER, Federal states	Federal state	17% (BB)
Thrän (2005); Henze and Zeddies (2007)	–	FAOSTAT, Eurostat, Federal Statistics Office	2000-2003 2010, 2020	EU	Country, (GER)	14,2%
Zeddies et al. (2012)	GAPP	FAOSTAT, UN	2007, 2015, 2020, 2030, 2040, 2050,	global	Countries, (GER)	13,3% (GER)
Schönleber (2009)	–	OECD, FAOSTAT, Eurostat, BMELV, Federal Statistics Office	2000, 2010, 2020	EU	Countries, (GER)	18% (GER)

Country codes: BB – Brandenburg; TH – Thuringia; BA – Bavaria; GER – Germany; PL – Poland; CZ – Czech Republic; HU – Hungary

The methodology of demand-based top-down analysis used in all approaches presented is well suited at the national or federal state level. In this case, the assumption is true that this is a supply unit and that production is based on demand. It can be used on the official statistics as a data source, a spatial differentiation by location reference is not necessary. However, the presented methods are not suitable for determining a regional land potential, e.g. at municipal level, because the assumptions are too unspecific and the cultivation conditions of agricultural crops in Germany vary greatly according to region (Wulf, 2008). Although partly local production conditions such as cultivation priorities and regional average yields are considered (see Schultze et al., 2008), this does not mean the actual farming structures are reflected (e.g. cultivated areas of crops, animal numbers). However, according to Wulf (2008), a differentiated analysis of the structures, both on the supply and the demand side, is necessary for an area-based potential assessment on a regional or municipal scale.

Therefore, a so-called bottom-up calculation, which is a comparison of the existing agricultural food and feed production with the required one, is suitable for determining a potential at the community level. From a potential overproduction freely available areas are obtained, which could be used for non-food production. A major challenge remains; data collection is a particular difficulty at the municipal level. Official statistics on land use and agricultural cultivation or animal numbers are available only at national level or for individual federal states or districts in general. Secondly, since the so-called food vs. fuel debate has become more differentiated nowadays and the competition between different energy plants has its own debate, the competition within the potential area for AFS should not be ignored.

Material and methods

Quantification of consumption and production of food and feed

Identifying the requirements and real production of food and feed within a defined area requires a differentiated approach. A sole quantitative summation is not possible. Agricultural products are very heterogeneous, due in part to the diverse production structures. On the basis of aggregation, the inhomogeneous individual quantities are harmonized using a common denominator in such a way that an addition is possible and combined into a superordinate complex, the aggregate (Besch and Wöhlken, 1973; Becker, 1988).

Internationally, both monetary and physical aggregation scales are used. Self-sufficiency based on monetary aggregation is more a measure of the competitiveness of agriculture than of security of supply. At FAO, the key nutrients of agricultural products serve as a physical aggregation measure.

Which method is suitable for the accounting of agricultural products for Germany?

Klapp (2011) identifies various methods and concludes that the cereal unit (CU) designed specifically for nutritional issues, which assesses agricultural products based on their energy feed value, is the most appropriate system. An aggregation over calories is suitable for the representation of the human consumption. However, since most agricultural products in Germany are not directly used for human consumption but flow into the feed industry, this approach is used to aggregate production against the background of a satisfactory supply of the main nutrients (Klapp, 2011).

In contrast to the exclusive consideration of the main nutrients for human consumption, the CU can be used to model the flow of material between crop production and animal production (Klapp and Theuvsen, 2011) and the nutritional capacity of a given area (Besch and Wöhlken, 1973). Also according to Besch and Wöhlken (1973) and Thiede (1980), the CU is well suited as a reference unit for the quantification of agricultural production and demands since it is very close to the natural production conditions.

In Germany, the CU already serves as a physical aggregation method for the documentation of agricultural production output (gross soil production, food production), for the assessment of the supply situation in the context of supply balances and self-sufficiency, or for the collection and presentation of material flows in agriculture by the Federal Ministry of Food and Agriculture (BMEL, 2015). The physical aggregation of agricultural production using CU is also used by EUROSTAT (Klapp and Theuvsen, 2011). In addition to administrative use, the CU is used in scientific studies to estimate area capacities for renewable energy sources (Henze and Zeddies, 2007), as a harmonizing comparative measure, e.g. to compare yields of different crops or crop rotations (Schneider et al., 2012) or for life cycle assessments (LCA) (Brankatschk and Finkbeiner, 2014).

The cereal unit (CU) as the aggregation basis of agricultural production

CU is a measure reflecting the energy yield of a product in relation to the calculated energy yield of feed barley, depending on the usage mode of the agricultural product in feeding. The animal products are not valued according to their own net energy content, but according to the content of metabolisable energy of the feed, which is necessary on average for their production (Schulze Mönking, 2013).

CU was developed during the World War II due to food shortage and associated food rationing. Woermann (1944) paralleled the CU with the average nutritional value of one kg of the most common cereals for ruminants and assessed all crops as feed by means of recovery. He judged crops not suitable for feeding after a comparison crop. The animal power corresponded to the required feed consumption. The principle of converting animal production into unit quantities of the crop area, i.e. the feed basis, has the advantage that a direct comparison of the two production branches in natural units is made possible. Non-marketable feed can also be included (Thiede, 1980).

Padberg (1970) updated the CU catalogue developed by Woermann (1944), adapted it to technological progress and included further agricultural products. Products for which the net energy value for animal nutrition cannot give a benchmark (e.g. wine, fruit, vegetables) are assessed by reference to comparative plant and economic values derived from yield, soil and work demand (Thiede, 1980). In 1988, a further revision of the CU by Becker (1988) took place on the base of an advanced level of knowledge in animal nutrition and progress in agricultural production. He introduced as a reference one quintal (q) feed barley (~100 kg) and calculated the CU for the first time based on the convertible energy (i.e. the metabolic energy, abbreviated to ME).

The weighted energy content of one quintal of feed barley is calculated from the animal-specific energy values and the proportions of animal species in feed consumption (Klapp, 2011). In this way the energy losses from the gross energy up to the level of the convertible energy were taken into account, which depend on the type of animal under consideration due to the different nature of the digestive systems and specific feed (Becker, 1988).

The metabolisable energy (ME), that is, the energy that can be used by the animals, is available for the preservation of vital functions and for synthesis such as milk or egg production and represents the appropriate stage for the comparison of all agricultural products. In addition, Becker (1988) assessed herbal production no longer solely after their use by ruminants, but after their utilization by all farm animals, according to their respective shares of total consumption. An update and supplement of the methodological foundations was done by Schulze Mönking (2013). He adapted the conversion factors to the current level of technological progress of agricultural practice. Currently, the weighted energy content of one quintal feed barley is 12.56 MJ ME. Calculation of CU according to Becker (1988), Klapp (2011) and Schulze Mönking (2013) according to:

$$CU_{animalproduction} = \frac{energy\_demand\_per\_kg\_product[MJ_{ME}]}{animal\_specific\_energy\_content\_of\_barley[MJ_{ME}]}$$

$$CU_{forage} = \frac{\sum(a_{forage} * x_{forage})}{\sum(a_{barley} * x_{barley})}$$

a = animal species specific energy content

x = share of animal species in forage

$$CU_{otherplanproducts} = \frac{reference\_yield[CU]}{yield}$$

Characterization of the study region

The study area is located in the eastern part of the Brandenburg district of Elbe-Elster , Germany and includes six municipalities. The region is characterized by a low population density combined with a decline in population numbers and weak economic growth. Large-scale field structures with comparatively low-yielding soils dominate and marginal land on post-mining landscapes is frequently found (Fig. 1). Due to the annual precipitation of

560 mm, which is far below the national average, and the predominantly sandy soils, which can only store a small amount of water, southern Brandenburg will be particularly affected by the effects of climate change (Meiser and Toussaint, 2017).

The GIS evaluation of the agricultural land use turns out a total UAA of 14,912 ha, of which 10,308 ha (69%) is arable land and 3,840 ha (26%) is grassland. In addition, there are 242 ha (2%) for the cultivation of permanent crops (mainly fruit trees, strawberries, asparagus, energy crops) and 522 ha garden land (3%), see Fig. 1.

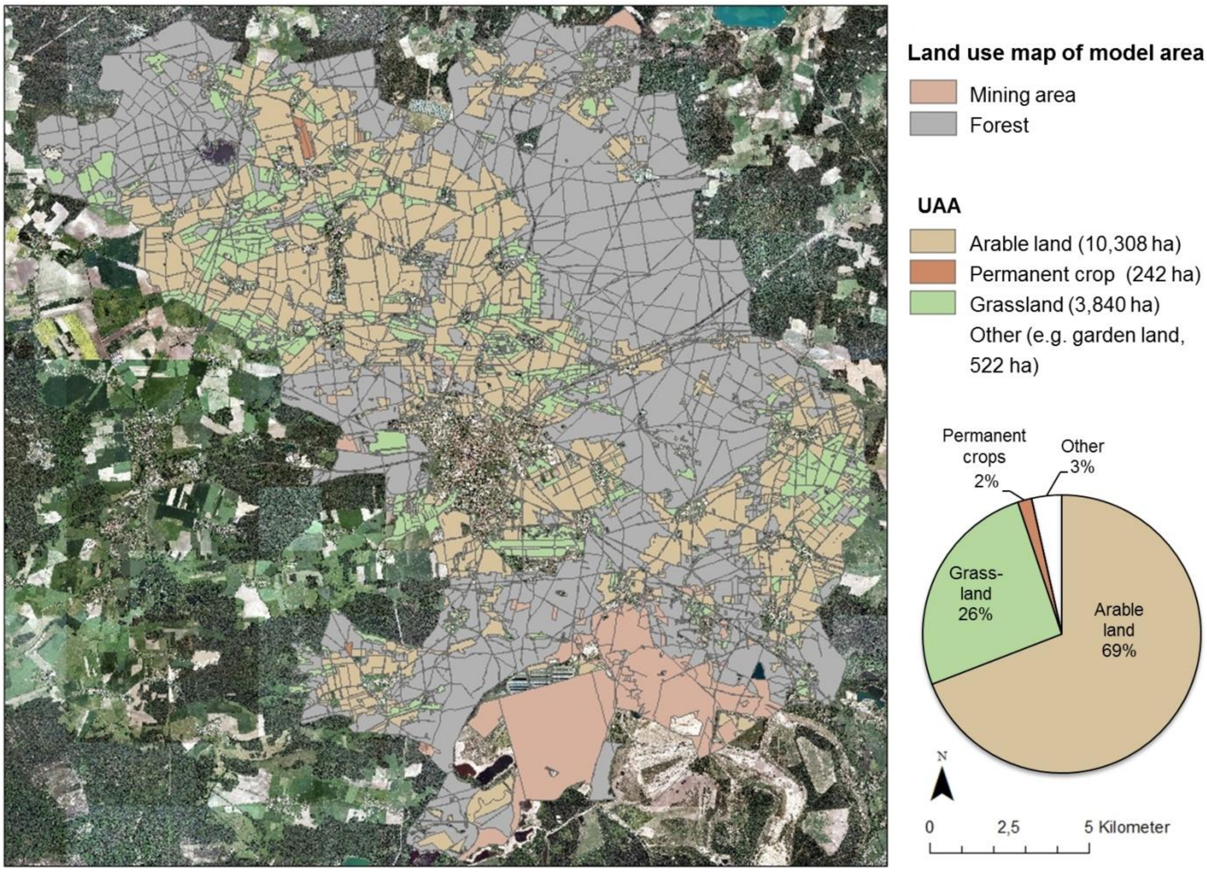

Figure 1. Study area and land use categories.

Sources: Digital data from Landesamt für Bergbau, Geologie und Rohstoffe Brandenburg (© GeoBasis-DE/LGB 2015), IACS data from LKEE (2016)

The farmland is used for cash crops and fodder production (Fig. 2). Concerning cereals, the main crops are winter rye (2,500 ha) due to good site adaptation and winter wheat (1,300 ha). Winter rape has the largest share of oilseed crops (1,300 ha) and silage maize (1,560 ha) for green crops. The grassland is mainly used as meadow for mowing or meadow for pasture.

Land use is dominated by few large farms with large operating area (average farm size ~216 ha). Only five hectares are managed organically, less than 1%, whereas the average of the state of Brandenburg is 10.3% (BMEL, 2018). Around 75% of the agricultural land is leased land. The average stocking rate is 1.44 $LU*ha^{-1}$ (calculation from data by LKEE (2016)). Poultry (in particular poultry for fattening) has the highest proportion of the farm animals. Hog and cattle farming is also important (LKEE, 2016) and looking on livestock units, cattle and hogs account for more than 90% of LUs. The lower agricultural production potential is offset by an above-average milk yield per cow.

Two large biogas plants with a total electrical capacity of 1,437 kW are operated in the model region. For the necessary biomass production about 700 ha of agricultural land is needed. This corresponds to around 5% of the UAA. Furthermore, around 11 ha of short-rotation coppice and 10 ha of switchgrass are cultivated in the model region.

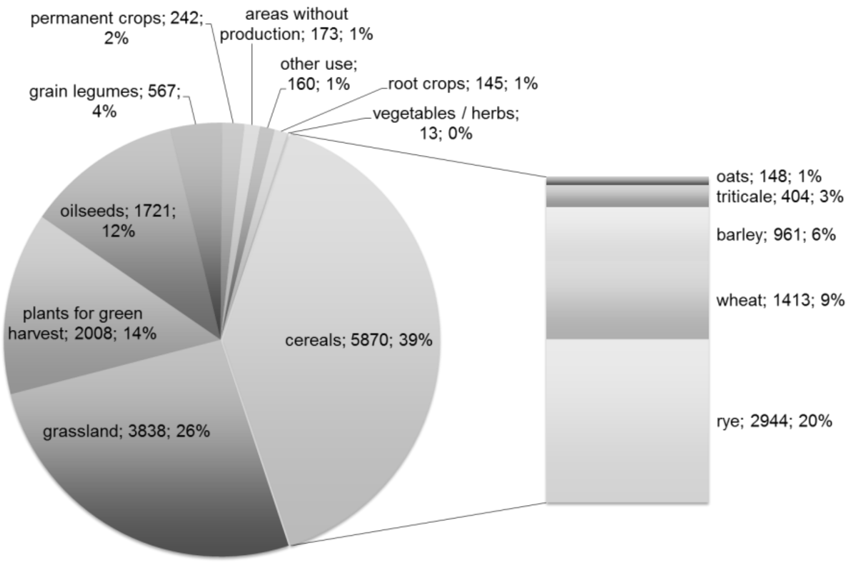

Figure 2. Area of the different product groups on the agricultural area of the model region.

Source: data form LKEE (2016)

Potential area for AFS – developed methodology and calculation

In principle, every agricultural area, i.e. arable land and grassland that is not essentially needed for the production of food and fodder under the present level of self-sufficiency is regarded as a potential area, taking into account import and export. Claims due to construction and traffic as well as the interests of nature conservation etc. are treated as a constant. To ensure sustainability in land use, ecologically high value areas such as fallow land, set-aside and ecological priority areas (HNV-areas) are also not considered available as potential areas and are kept constant.

In a first step, the demands of the population for agricultural products and the feed requirements of the livestock in the model region are determined. In a second step, agricultural food and feed production in the model region is quantified. From a comparison of demand and supply, unused area potentials can be derived. The reference unit for aggregation is the cereal unit (CU) and accounting for consumption and production is based on Kreitmair (1989).

Results

Demand side

Per capita demand for food

Continuing on the current level of self-sufficiency, food requirements in the region amount to 11.04 CU per capita and year. Figure 3 shows the annual per capita consumption according to all product groups. Dairy products such as yoghurt cream, buttermilk and cheese, for example, make up the milk product group and different cereals such as wheat, rye and other cereals represent the product group cereals. Meat consumption (especially pork and beef) accounts for the largest share of food consumption measured in cereal units. With approximately 44% (4.86 $CU*cap*a^{-1}$) it significantly influences the total consumption. In total, 8.46 CU (76.6%) of animal production and 2.58 CU (23.4%) of crop production (mainly grain) per capita and year are consumed.

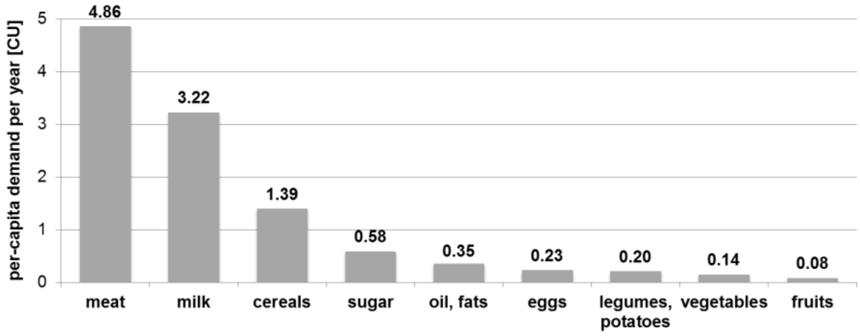

Figure 3. Annual per capita consumption in CU considering the current self-sufficiency level.

An extrapolation of the per capita consumption to the population size of the model region results in 291,412 CU, which should be produced annually within the model region. If Berlin and Brandenburg are considered as the supply area, the demand is 675,223 CU, compared to 734,142 CU countrywide (Table 2).

Table 2. Overview according to population numbers per supply area.

Supply area	Modell region	Brandenburg	Berlin/BB	Germany
Population to be supplied	26,388	25,327	61,143	66,478
Cereal units (CU)	291,412	280,142	675,223	734,142

Demand for animal feed

A total of 457.106 CU of feed from local production and import was consumed in 2015 in the model region. As shown in Fig. 4, the feeding of the approximately 12,000 heads of cattle with approximately 350,000 CU (75%) accounts for the largest share. For the approximately 64,000 hogs, the feed requirement is about 95,924 CU (20%), for poultry with about 238,300 animals at 16,568 CU (3.4%). The remaining feed amounting to 7,444 CU (1.6%) is for feeding sheep, alpacas, fallow deer and rabbits.

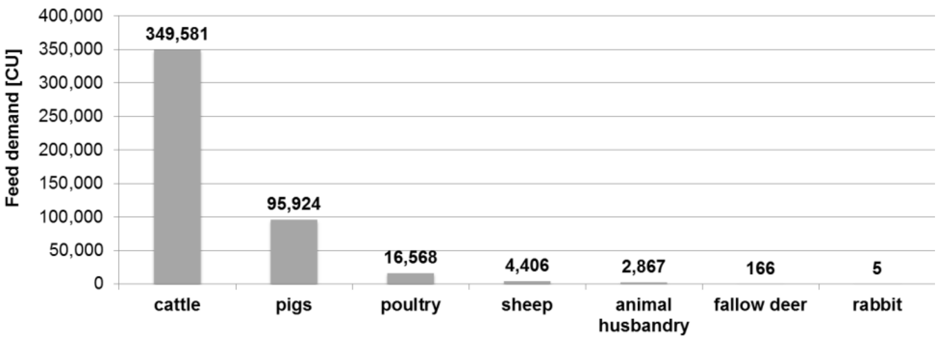

Figure 4. Feed requirement in cereal units by animal species.

After deducting the proportion of feed recycled from the food industry and non-food processing (domestic production 8%), animal feed (0.7%) and imported feed (11%), the model region has a total requirement for feed crops of 379,370 CU (Table 3).

Table 3. Calculation procedure for feed requirement in cereal units.

Total demand for feed	469,518
- recycle from the food industry, non-food processing (domestic production)	35,683
- animal feed	3,287
- imported feed content	49,769
= feed requirement from domestic crop production	*379,370*

Overall, the model region would need to provide 694,243 CU to feed the local population and livestock. If Berlin and Brandenburg are considered as one supply unit, it amounts to 1,083,686 CU; assuming a German-wide view, the supply mandate increases to 1,201,828 CU.

Production side

Plant production

Aggregate production (gross production) on areas with food production is 630,413 CU in the reference year 2015 in the model region. After deduction of 9,308 CU for seeds (1.5%), 14,327 CU for losses (2%), 17,027 CU (3%) for industrial use, 48,849 CU for energy (8%) and 379,370 CU for feed (66%), the net plant food production is 161,531 CU (Table 4). The two biogas plants in the model region have a substrate requirement of 6,600 CU rye whole plant silage, 1,096 CU grass and 36,312 CU maize silage. In addition, 300 CU switchgrass or sugar millet with a cultivation area of 15 ha, are occupied by biogas production. Due to the pure energetic utilization of the inputs, however, this does not go into the calculation of food production.

Table 4. Calculation procedure for crop production and resulting cereal units.

Total vegetable production of food and feed (gross production)	630,413
- seeds	9,308
- losses	14,327
- industrial use for non-food / non-feed purposes	17,027
- energy usage	48,849
- plant feed requirement from domestic production	379,370
= vegetative food and feed production (net production)	*161,531*

A detailed view shows, after deduction of 34.165 CU for internal use, cereal production accounts for 283.141 CU, thus has the largest share of net production. Crops for green harvest have the second highest share with 160,787 CU net production, mainly in the form of silage maize as fodder. Grassland contributes 80,430 CU to feed production. For oilseeds, production amounts to 58,267 CU. About 48,000 CU are produced by permanent crops, root crops, grain legumes, vegetables and culinary herbs (Fig. 5).

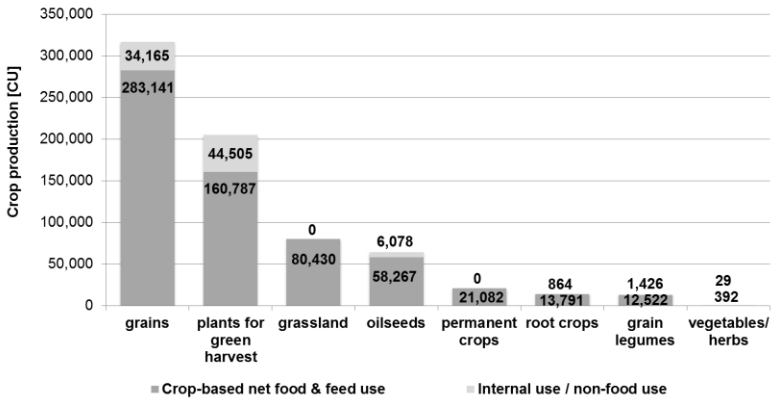

Figure 5. Crop production in cereal units on areas with food production.

Figure 6 shows the average CU yield per hectare valid for the model region aggregated for food-production groups. Root crops and permanent crops (89 and 80 CU*ha^{-1}, resp.) have the highest output of cereal units per unit area, with grain legumes accounting for the least with 20 CU*ha^{-1}. According to this, 2,936 m^2 UAA are needed for human consumption per capita, taking current self-sufficiency rate into consideration.

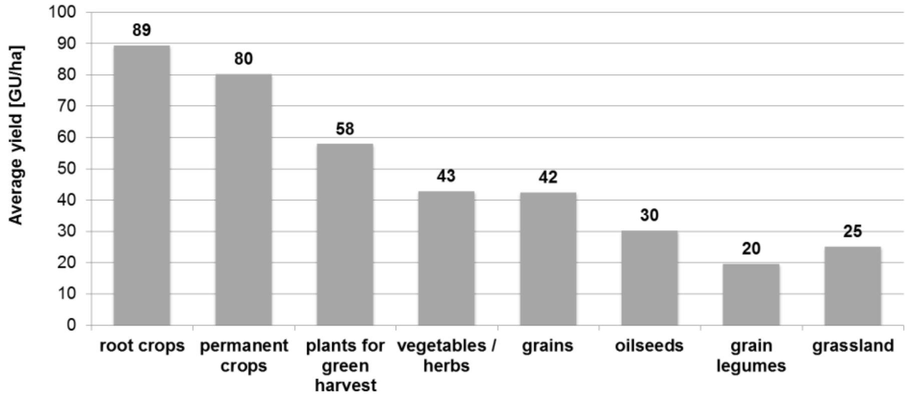

Figure 6. Average yield per hectare for the model region by product group.

Animal production

Animal production is 466.434 CU from which cattle production accounts for 349,581 CU (75%) including milk production. 95,924 CU (21%) is in hog production and 16,568 CU (3.5%) in poultry and egg production. Other animal production (sheep, fallow deer, rabbits) account for less than 1% (4,361 CU) (Fig. 7).

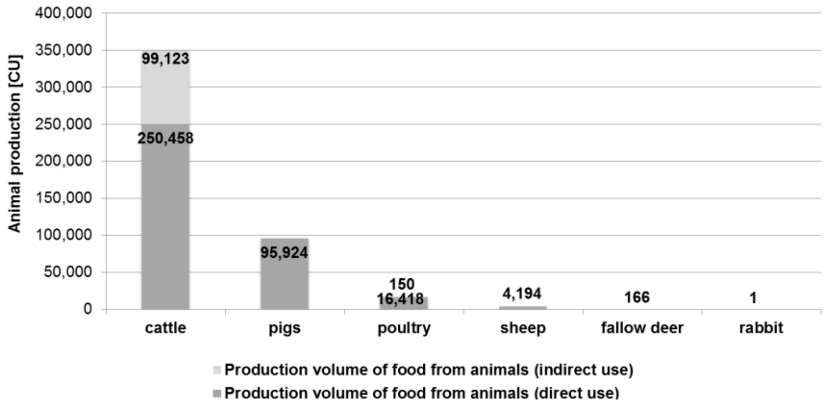

Figure 7. Result for animal production by product groups in cereal units.

Net food production from animals, after deduction of internal use of 4,664 CU (1%), amounts to 461,770 CU (Table 5).

Table 5. Calculation procedure for animal production and resulting cereal units.

Total animal production of food and feed (gross production)	466,434
- internal use	4,664
= animal food production (net production)	*461,770*

Summarizing the animal production expressed in cereal units in relation to the demand for animal food or food of animal origin, it becomes clear which supply surpluses or deficits exist in the model region. For beef, overproduction is around 210,000 CU (85%), for pork 40,000 CU (43%) and for mutton about 1,000 CU (30%). For poultry meat, production and demand are close to (-0.7%). In game there is a shortage of about 3,000 CU (-170%). In total, 248,867 CU (68%) of meat are produced more than the demand in the model region. In the case of foodstuffs of animal origin, about 13,000 CU (13%) of milk are produced more than needed and 5,000 CU are missing for eggs consumed. Here, the production would have to be increased by factor 40 to meet the demand.

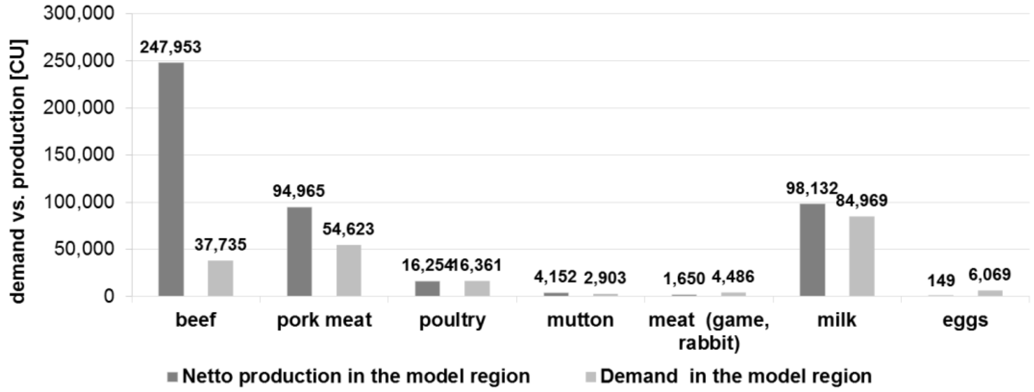

Figure 8. Comparison of animal based net production and demand within the study region.

Total agricultural production of food

Gross agricultural production amounts to 1,096,847 CU in total. After deduction of internal use, losses, feed and other uses, 608.168 CU stay available for human consumption (Fig. 9).

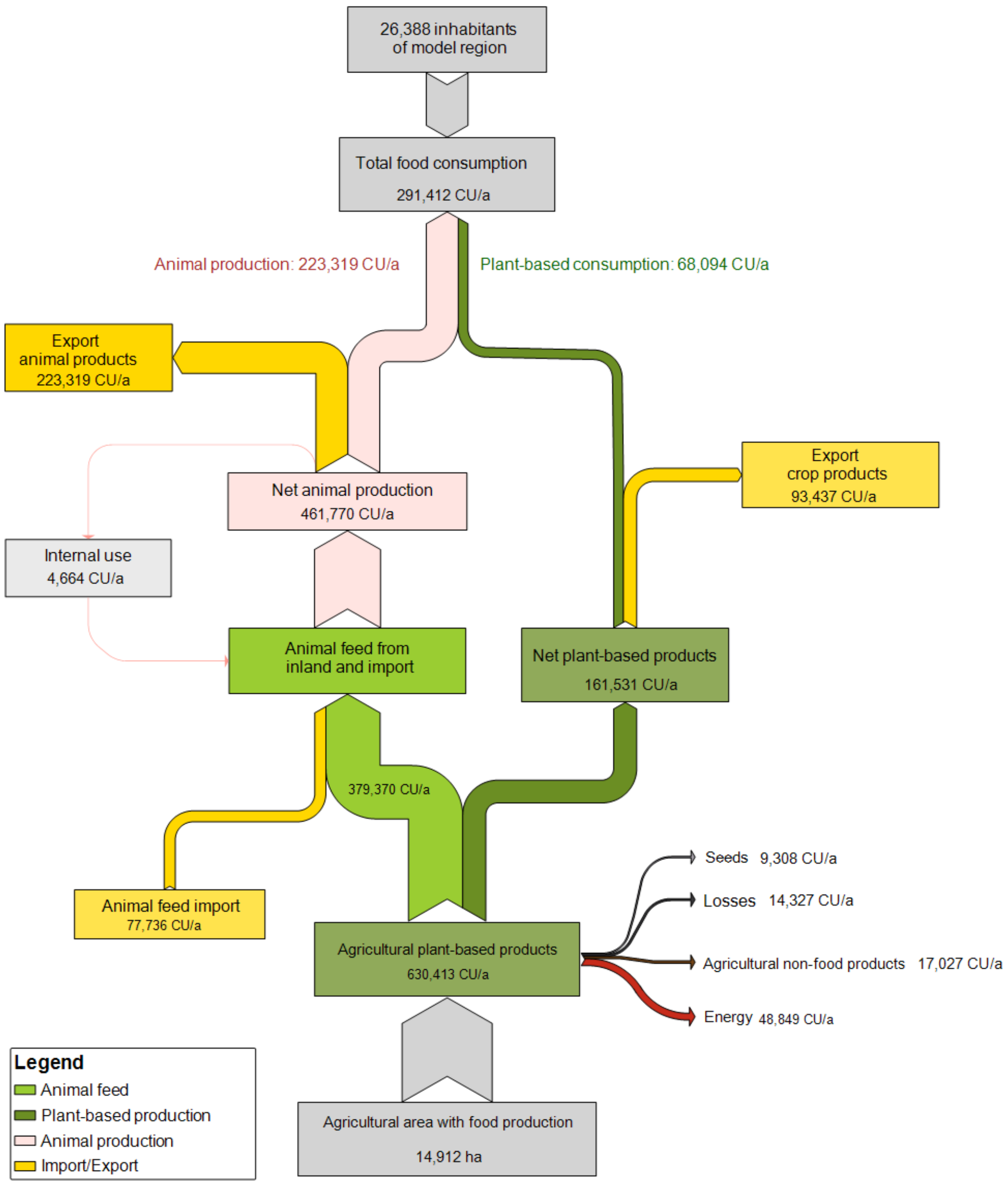

Figure 9. Overview on flows of CU assuming current self-sufficiency rates for the study region (baseline szenario).

Land potential for non-food and non-feed production and agroforestry systems

Steady level of self-sufficiency, no export

Under the assumptions made and taking into account the demand of the inhabitants of the model region, a comparison of supply and demand results in an overproduction of 331.889 CU. Based on the weighted average output of 37.6 CU per hectare, this can be converted into a very large free area potential of 8,827 ha (59% of the present UAA).

This is available for uses other than food and feed production if no exports would take place. Of this, 160 hectares are currently occupied by the cultivation of Christmas trees, switchgrass, short rotation coppice, green manure and grass seed propagation and another 173 ha for land use without production (e.g. fallow land, set aside, storage areas). Subtracting this land used for non-food production (total 333 ha or 2% UAA) gives a free area potential of 8,504 ha (representing 57% of the UAA).

Steady level of self-sufficiency, responsible for Berlin & Brandenburg and nationwide

Considering Berlin and Brandenburg in a supply mandate, this results in a missing production of 51,921 CU, which corresponds to a deficit of 1,381 ha (9% UAA). Further deduction of the already occupied non-food area and non-production area, the deficit is increasing to 1,714 ha (11.5%).

On a national perspective, 110,841 CU or 2,948 ha (20% UAA) are missing for food production and 3,281 ha (22% UAA) less than the land requirement for non-food production.

Comparison of area potential and area requirements for agroforestry systems

When converting all arable land (10,308 ha) into AFS, the area required for the tree strips at the recommended woody cultivar proportions of 5%, 10% and 20% (Fig. 10) according to Hübner et al. (2017), the area will be between 515 ha and 2,062 ha.

Figure 10. Visualization of an AFS for the comparison of the actual state a) compared to AFS from a type of a single wood species (poplar) with variable woody areas on the plot staggered by b) 5%, c) 10% and d) 20% share.

If grassland (3,840 ha) is taken into consideration for agroforestry, there is an additional posibility for woodland between from 192 ha to 768 ha (Table 6).

Table 6. Areas required for AFS for different areas of woodland.

share of wooded land	required wooded land on arable land	required wooded land on grassland	required wooded land in total
5%	515 ha	192 ha	707 ha
10%	1,031 ha	384 ha	1,415 ha
20%	2,062 ha	768 ha	2,830 ha

When continuing with current levels of self-sufficieny in the model region and fully cut exports, there are 8,504 ha available for non-food production. Of these, a total of 2,830 ha for woody crops will be claimed for complete conversion of arable land and grassland into AFS with a land share of 20%. For other uses or export, at least 5,700 ha remain available. When considering Berlin/Brandenburg or Germany as a supply unit, there is currently no potential for AFS due to the area deficit for food and feed production.

Discussion

Critical consideration of the procedure for the estimation of the area potential

The aim was to develop a transferable methodology for calculating area potential for AFS on a municipal scale, taking into account competition with food and feed production. The chosen bottom-up-calculation approach, despite its high effort needed in obtaining the data base, is in the eyes of the authors well suited for the calculation of land potential at the community level. Since it takes into account the actual growing conditions, it is more meaningful than the demand-oriented approach pursued in previous studies on land potential in Germany (Simon, 2007; Schultze et al., 2008). In addition, interesting results can be derived from the results on the production conditions and the agricultural structures in the model region.

The chosen method of accounting for agricultural production using cereal units (CU) is also appropriate for the presentation of consumption and agricultural production. The accounting method of Kreitmair (1989) was successfully transferred to the municipal level. However, the quantitative calculation of CU also has their limits. For example, the nutritional value of the products is not taken into account when aggregating over CU (Besch and Wöhlken, 1973). In addition, economic aspects of production are also ignored.

The methodology was designed so that it could be transferred to other study regions and different spatial scales. The use of data from the Integrated Administration and Control System (IACS data) in this work can be criticized in this context. However, it can be assumed that these data will increasingly find application in agricultural research in the future. At the national level or at the level of a federal state, for example, the required data could also be obtained from the land use survey. At the district level, numbers of animals and land are often published by the agricultural administrations.

Only about 90% of agricultural land within the model region had IACS data. For example, there is a lack of data from farms that have not submitted a multiple application due to a farm size too small. In addition, those holdings with their data also fall out, although they manage areas within the model region, but their company headquarters lies beyond the boundaries of the involved municipalities. The extrapolation of the areas applied for as part of the application for agricultural subsidies to the entire UAA of the model region within the framework of this thesis represents an uncertainty in the calculation of the area potential.

Overall, the quality and timeliness of the data is crucial to the validity of the calculation. Here are suggestions for improvement of the model:

- Data on internal use in animal production and on foreign feed were used for reasons of simplification from the literature and federal statistics and transferred to the model region on a flat-rate basis. Regionalization and adaptation to local livestock and farming practices could significantly improve the accuracy of land-use averaging at the community level.
- IACS data is missing a differentiation of the acreage by the use as feed, food or material or energetic use which leads to inaccuracies in the calculation. A regional adjustment could also refine the result here.
- A differentiation of the land potentials according to grassland and arable land would also make sense. In the context of this work, however, this was dispensed with due to the complexity of the calculations and the lack of data base for animal feeding in the model region. For the individual animal production directions, an exact breakdown of the feed use of the different arable crops would have to be available.
- Ultimately, the result could also by differentiated by considering other use claims such as e.g. nature conservation or non-agricultural land use (Simon, 2007). For the purposes of this work, other uses than those for food and feed production were only taken into account by not including land uses such as fallow land, decommissioning areas and ecological focus areas (EFA) in the calculation of the land potential.

Results of the potential estimation and comparison with other studies

The results show that the potential for non-food /non-feed production in the model region currently stands at around 8,504 ha, around 60% of the UAA, continuing the current level of self-sufficiency. The woodland area scenario in AFS is a maximum of 2,830 ha (20% of the total UAA).

From this result it can be deduced that the land-use conflicts in relation to the agricultural area with only supply of the population of the model region or with consideration of a supply mandate for the federal state Brandenburg are small. A supply of the population of the model region and a fulfillment of the supply contract for Brandenburg can be ensured even with a large-scale implementation of AFS.

When considering complete supply responsibilities for the urban area of Berlin & Brandenburg or the whole of Germany, there are currently no areas for the establishment of energy wood in AFS or other uses in the area of non-food and non-feed production due to the low profitability of the regional soils. The low production potential of the study region is reflected in the agricultural yields of the model region. For example, yields of winter rye and wheat are 20% and 25%, respectively, well below the national average (BMEL, 2015). According to Zeddies et al. (2012), with an area yield of 6.7 tons of grain in Germany and a requirement of 11.78 CU*cap*a^{-1}, approx. 5.7 people per hectare could be supplied with food, compared to only 3.3 in the model region. To feed one person 2,936 m^2 of UAA are required under the production conditions of the model region. This value is well above the result of other studies in regions with higher agricultural productivity. Graf et al. (2010), for example, calculated that Thuringia's nutritional requirements were only 1,370 m^2 UAA per inhabitant.

All these are arguments against fulfillment of a complete supply mandate for urban regions or against a calculation of the population to be served solely by way of a proportion of the agricultural area per inhabitant. Lower yielding regions would be severely disadvantaged compared to high potential regions.

In the case of a national supply mandate or a consideration at the level of the federal states Berlin/Brandenburg, therefore, as with Schulze Mönking (2013) considers the yield potential of the agricultural land in such calculations and compensates for this by the average regional soil number and the ratio of the average national soil number.

The calculated potential area refers to the current crop rotation in the model region. Further potential could be created if agricultural land was expanded in favor of high yielding crops with respect to CU per hectare, such as root crops and green harvest crops. Competitions on food and feed production could be further mitigated by the consideration of land use productivity in the establishment of AFS. On grassland, which has a CU output of around 21 CU*ha^{-1} and about 50% less than farmland, land use conflicts on the food vs. fuel debate may be less severe than on arable land.

Also by an increase in performance in animal production through breeding and technical progress, for example, by improving feed intake and utilization as well as increasing milk yield, additional areas could be released in the future. Calculations for area release with respect to performance increases are, however, difficult to carry out due to the lack of data and the complexity of the calculations (Schönleber, 2009) and are not considered in the majority of studies for the estimation of land potentials for biomass in Germany. Moreover, the potential in this sector is considered rather low. According to Thrän (2005), feed conversion in Germany has improved relatively consistently in the last few decades, but only by about 0.5% per year.

Animal production claims a comparatively large area due to the poor efficiency of feed conversion by the animals. Here, the production of beef, which shows significant overproduction in the model region, has the largest land requirements. The degree of self-sufficiency in Germany is well over 100%. Reducing overproduction could also result in additional land available. The fall in prices following the expiry of the quota system for milk in

2015 lead to some market consolidation in milk production, and may have an effect on the potentials for grassland (Schönleber, 2009).

Finally, a change in eating habits would have a major impact on the potential area. Supplying the population with meat-based food is above the scientifically recommended level. According to Woitowitz (2007), a reduction of the consumption of animal food in Germany, according to the recommendation of the German Nutrition Society, would lead to a cut by half of the present livestock in LU thus would result in an enormous release of land. Further scenarios include population trends, change in dietary habits, and a possible change in yields, in order to take into account the expected future development for the years 2020 and 2030.

All mentioned factors can influence the potential area. Ultimately, in addition to the needs of the farm (feed requirement, need for biogas plant) but above all, the proceeds of crops on the use of agricultural land decides.

Outlook

The calculation of a potential for AFS provides a theoretical clue about the level of land-use conflicts in the focus of the AUFWERTEN project region and can thus contribute to the mitigation of competition for food and feed production. The model can foster the dialogue between scientists and decision/policy makers in order to provide arguments, whether the proposed AFS is a suitable contribution to attenuate today's problems in agricultural production. The calculation of this land potential could be improved by regional adaptation of the data base, for example by conducting expert workshops on nutrition trends, the impact of climate change on agricultural yields, animal husbandry and feeding, self-sufficiency, etc.

It would also be interesting to consider the conflict at the level of a land-based unit area using a GIS. Through a dedicated site assessment with regard to conflict-relevant criteria such as high productivity and synergy effects, for example at risk of erosion, etc., suitable areas for the establishment of agroforestry could be designated and inappropriate areas in the recommendation for the establishment of agroforestry systems for energy wood production can be excluded. On the basis of the development of different systems and the coordination of these systems with the suitability for the area, the area requirement for AFS could be quantified even more precisely and the area competition for food and feed production, irrespective of administrative boundaries, could be further mitigated.

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