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Research Article

Net food production of different livestock: A national analysis for Austria including relative occupation of different land categories

Netto-Lebensmittelproduktion der Nutztierhaltung: Eine nationale Analyse für Österreich inklusive relativer Flächenbeanspruchung

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Summary

The discussion on the role of livestock in human food security is often controversial. Therefore, the aim of the present study was to assess the net contribution of different livestock to human food protein and energy supply. Furthermore, the proportions of feed protein and feed energy derived from different land categories were estimated. National data from 2011–2013 for the main Austrian livestock categories (cattle, dairy cows, growing-fattening bulls, swine, broiler chickens, laying hens, turkeys, sheep, and goats) were used in this case study. Cattle were the only species that were net contributors to both the human protein and energy supply. When accounting for the differences in protein quality between human-edible plant inputs and animal products, not only cattle, but also laying hens, sheep, and goats increased the value of protein available for human consumption. Except for growing-fattening bulls, about 50% of the feed protein and energy for ruminants was derived from permanent grassland, which could otherwise not be used for human food production. The results of this study showed that depending on the production system, the transformation process of feed into food of animal origin results in either an increase or decrease of the available food for human consumption, but it always increases protein quality.

Keywords: Food security, animal production, efficiency, feed versus food, land use

Zusammenfassung

Der Beitrag der Tierhaltung zur menschlichen Ernährungssicherung wird aufgrund der ineffizienten Umwandlung von pflanzlichen Futtermitteln in tierische Produkte sehr kontrovers diskutiert. Das Ziel der vorliegenden Arbeit war es daher, anhand von nationalen Daten für die Jahre 2011–2013 den Beitrag von verschiedenen Tierkategorien (Rinder, Milchkühe, Maststiere, Schweine, Masthühner, Legehennen, Puten, Schafe und Ziegen) zur Netto-Lebensmittelproduktion in Österreich zu ermitteln. Zusätzlich wurde die relative Beanspruchung von unterschiedlichen Flächenkategorien geschätzt. Rinder erzielten als einzige Nutztierart sowohl für Energie als auch für Protein eine positive Netto-Lebensmittelproduktion. Werden allerdings auch die Unterschiede in der Proteinqualität zwischen pflanzlichen und tierischen Proteinen berücksichtigt, so lieferten zusätzlich auch Legehennen, Schafe und Ziegen einen positiven Beitrag zur Bereitstellung von Protein für die menschliche Ernährung. Abgesehen vom Futter für das intensive Stiermastsystem kamen rund 50 % des Futterproteins und der Futterenergie für Wiederkäuer vom Grünland, welches ansonsten nicht für die Lebensmittelproduktion zur Verfügung stehen würde. Die Ergebnisse dieser Untersuchung zeigten, dass eine generelle Kritik an der schlechten Effizienz von Nutztieren bezüglich der Netto-Lebensmittelproduktion nicht zulässig ist und dass die Rolle der Tierhaltung hinsichtlich der Verfügbarkeit von Nahrungsmitteln sehr diversifiziert betrachtet werden muss.

Schlagworte: Ernährungssicherung, Effizienz, tierische Produktion, Nahrungsmittelkonkurrenz, Flächennutzung

1. Introduction

The discussion on the role of livestock with regard to human food production is often controversial. On the one hand, the low efficiency of animals in converting plant nutrients into animal products is often criticized, and livestock production is associated with a loss of available food for humans because a high amount of animal feeds is potentially suitable for direct (and hence, more efficient) human consumption. Thus, from this perspective, shifting consumption patterns away from animal products could increase the overall food availability (Goodland, 1997; Aiking, 2011; Sabate and Soret, 2014). On the other hand, however, livestock can convert human-inedible plant biomass (such as grasses or by-products from the food industry) into high-quality animal products, and hence increase global food availability, as this biomass would otherwise not be accessible by humans as a food source (Smith et al., 2013; Schader et al., 2015; Van Kernebeek et al., 2016). Whether livestock increases or reduces the amount of food available to humans mainly depends on the potential suitability of feedstuffs for direct human consumption. Therefore, reducing the amount of human-edible feed in livestock diets is a key factor toward more sustainable livestock systems (Eisler et al., 2014; Schader et al., 2015)

Although various studies have investigated the role of different livestock systems in the human food supply (Council for Agricultural Science and Technology, 1999; Wilkinson, 2011; van Zanten et al., 2016), data is still limited on the actual amount of potentially edible feeds for different livestock categories and the resulting net food production based on national data and practical feeding conditions. However, in order to develop future strategies for reducing human-edible inputs into livestock diets and increasing the net food production of livestock systems, systematic investigations of the status quo are needed. Therefore, the aim of the present study was to investigate the amount of potentially human-edible feeds in the diets of different livestock categories and to assess the net contribution of these animals to the human food supply. National data for the main Austrian livestock species (cattle, swine, chickens, turkeys, sheep, and goats) were used for a case study. Due to the fact that animals are not only competing directly with humans for food, but also indirectly via the occupation of arable land for feed production (van Zanten et al., 2016), a further aim of this study was to estimate the proportion of dietary protein and energy derived from different land categories for different livestock.

2. Materials and Methods

2.1 Study design

The contribution of different livestock categories to human food supply in Austria was estimated by contrasting the animal products produced with the feedstuffs fed to the respective livestock category on a national basis. The human-edible feed conversion efficiency (heFCE) was taken as an indicator of the net food production. The heFCE was defined as human-edible output via the animal products divided by potentially human-edible input via feedstuffs (Wilkinson, 2011; Ertl et al., 2015), and calculated on a gross energy and a crude protein basis for the years 2011, 2012, and 2013 for the following livestock categories: cattle, dairy cows, growing-fattening bulls, swine, laying hens, broiler chickens, turkeys, sheep, and goats. The heFCEs were calculated for two different scenarios: For the "CURR" scenario, the current food consumption habits were presumed when calculating human-edible outputs and inputs (i.e., the human-edible fractions of feedstuffs were estimated based on the common achievable extraction rates for human-edible nutrients from feeds), whereas for the "MAX" scenario, the potential maximum extraction rates of human-edible protein and energy based on today's technology were presumed for both sides.

2.2 Data sources

Production data for cattle, swine, poultry, sheep, and goats were obtained from Statistics Austria for the years 2011, 2012, and 2013 (Bundesanstalt für Agrarwirtschaft, 2016; Statistics Austria, 2016). The units given were: gross domestic production in metric tons of carcass per year for meat products, production in metric tons per year for eggs, and the sum of milk sold and used on farm in metric tons per year for cow, sheep, and goat milk.

The total feed inputs (including both nationally grown and imported feeds) for each livestock category were taken from the national annual feed balance in metric tons of dry matter per year for the years 2011, 2012, and 2013 (Statistics Austria, 2015). The values in the national feed balance are estimates, derived with a software that calculates the feed demand and distribution of feeds over different livestock categories, as explained in more detail in Eurostat (2002), Steinwidder and Krimberger (2003), and Klapp and Theuvsen (2013).

2.3 Calculation of human-edible outputs

The human-edible outputs were calculated as the amount of energy and protein in the human-edible portions of the livestock products. For the CURR scenario, the amount of bones, as well as losses between slaughter and consumption and the amount used as pet food were subtracted to calculate the amount of edible meat from the total bone-in carcass weight. The respective factors (% of carcass weight) are given in Table 1. For the MAX scenario, only the amount of bones was subtracted from the carcass. The compositions of animal carcasses and eggs were obtained from the USDA Nutrient Database (USDA, 2016), whereas for the composition of cow, sheep, and goat milk, national data were used (Mayer and Fiechter, 2012; ZuchtData, 2014). For goat carcass composition, the protein content of sheep carcasses was taken from USDA (2016), and the fat content was calculated as an average from the results reported by Ringdorfer et al. (2006) for Austrian conditions. The gross energy content of animal products was calculated from the respective nutrient contents, using the caloric factors 23 kJ/g (protein), 38.9 kJ/g (fat), and 17.2 kJ/g (carbohydrates) (Persson, 2011). The presumed composition of animal products and the respective references are summarized in Table 2.

Besides edible meat, the following animal by-products were considered as human-edible output: For the CURR scenario, the "fancy meats" heart, liver, kidney, and tongue, which are usually considered marketable (Ockerman and Hansen, 2000) plus 25% of the blood of cattle and swine (which is approximately the percentage of blood that is used as human food in Austria (Walter et al., 2008)). For the MAX scenario, all potential human-edible animal by-products, as well as 100% of the blood of cattle and swine, and the edible kill fat were considered as human-edible outputs. According to Venegas Fornias (1996), the amount of human-edible animal by-products, including blood, accounts for 12, 14, and 14% of the live weight of cattle, swine, and sheep (also taken for goats). The chemical composition of animal by-products was calculated from the weighted averages using animal by-product yields given in Ockerman and Hansen (2000), and the chemical composition of each by-product given in Venegas Fornias (1996) and USDA (2016). The amounts of by-products considered in the calculations, as well as their nutrient composition, are summarized in Table 3.

2.4 Calculation of human-edible inputs

The human-edible inputs comprised the potentially human-edible amount of protein and energy in the feedstuffs, as well as in the bought-in young stock (calves as input into the growing-fattening bull system). Seventy-nine feedstuffs out of the 176 listed in the national feed balance were actually present in the years 2011–2013 (Statistics Austria, 2015). The potentially human-edible amounts of protein and energy from feedstuffs were calculated by estimating the potentially edible fractions of feedstuffs based on the available literature. Where available, potentially human-edible fractions from the low and high scenarios given by Ertl et al. (2015) were taken for the CURR and MAX scenario in the present study, respectively. For all other feedstuffs, the potentially human-edible

Table 1. Amounts (% of carcass) subtracted from the total carcass weight to calculate the amount of edible meat for different animals (based on Wildling (2016), personal communication)
Tabelle 1. Berücksichtigte Faktoren (% vom Schlachtkörper) zur Berechnung des essbaren Fleischanteils von unterschiedlichen Nutztieren ausgehend vom Schlachtkörper (basierend auf Wildling (2016), mündliche Mitteilung)

Carcass category	Bones	Losses from slaughter to consumption	Pet food
Beef	15.5	9.0	8.5
Veal	18.0	9.0	8.5
Swine	12.0	9.0	8.5
Chicken	28.0	4.0	8.5
Turkey	17.0[1)]	4.0	8.5
Sheep	16.0	9.0	8.5
Goat	16.0	9.0	8.5

[1)] From Kauffman (2001)

Table 2. Presumed protein and energy contents of animal products and respective references
Tabelle 2. Angenommene Protein- und Energiegehalte von tierischen Produkten, sowie zugehörige Quellenangaben

Animal product	Protein content (g/kg)	Energy content (kJ/g)[1)]	USDA nutrient database number (USDA, 2016) or other reference
Beef whole carcass	173	13.34	13001
Veal carcass	194	7.08	17088
Swine carcass	139	16.84	10001
Chicken meat and skin	186	10.14	05006
Turkey meat and skin	216	7.17	05165
Sheep carcass	167	12.70	17062
Goat carcass	167	10.89	17062 and Ringdorfer et al. (2006)
Cow milk	34.0	3.22	ZuchtData (2014)
Sheep milk	52.1	4.23	Mayer and Fiechter (2012)
Goat milk	31.5	2.92	Mayer and Fiechter (2012)
Whole chicken egg	126	6.71	01123

[1)] Calculated from the nutrient composition using the caloric factors 23 kJ/g protein, 38.9 kJ/g fat, and 17.2 kJ/g carbohydrates (Persson, 2011).

fractions were estimated based on the methods described in detail in Ertl et al. (2015). In total, 35 feedstuffs were found to have the potential to be at least partly edible for humans. Of these feedstuffs, the presumed potentially human-edible fractions of protein and energy are summarized in Table 4. These fractions were estimated based on current processing methods and do not consider that the proportion of what is considered as human-edible might be changed via bio-refining in the future. The potentially human-edible fractions of protein and energy were then multiplied for each feedstuff with the respective protein and gross energy content. The energy and protein contents for most concentrate feeds and industrial by-products were taken from INRA et al. (2015). For concentrate feeds not listed in INRA et al. (2015) and for forages, the nutrient composition was taken from the German Society of Agriculture (Universität Hohenheim-Dokumentationsstelle, 1997), and the gross energy content was calculated using the equation provided by GfE (2001) (gross energy = 0.0239 × crude protein (g/kg DM) + 0.0398 × crude fat (g/kg DM) + 0.0201 × crude fiber (g/kg DM) + 0.0175 × nitrogen-free extracts (g/kg DM)).

2.5 Allocation to livestock categories

Cattle, swine, laying hens, broiler chickens, turkeys, sheep, and goats were considered as being raised in closed systems; thus, all inputs and outputs were assigned to the respective livestock category, and no allocation of inputs and outputs to different categories within species was necessary. For dairy cows and growing-fattening bulls, the following allocations were considered: Besides cow milk, culled cows and calves from dairy cows not needed for replacement (with a presumed average live weight of 45 kg) were considered as outputs of the dairy system. The number of culled cows was calculated as the total number of dairy cows divided by the average productive live span for the respective year. The number of calves from dairy cows was calculated as the total number of dairy cows × 365 / average calving interval × 0.96 (considering a stillbirth rate of 4% (ZuchtData, 2014)). The number of replacement calves for the dairy systems was calculated as the number of culled cows × 1.05 (considering 5% rearing losses (Fürst-Waltl and Fürst, 2012). Accordingly, the feed required for replacement calves was also considered as an input for the dairy system. The output of the growing-fattening bull system was defined as the net weight gain between the start of the growing-fattening period and slaughter. The live weight at the beginning of the growing period was either 150 kg (about 60% of the animals) or 280 kg, depending on the system from which the bulls came (conventional calf rearing or suckler calves) (Statistics Austria, 2015). The numbers of animals entering the systems at the two live weights were taken from the national feed balance (Statistics Austria, 2015). The gross output of the growing-fattening bull system was the number of animals entering the system minus 1% (estimated losses) times the average slaughter weight for bulls derived from Statistics Austria (2016).

Table 3. Presumed yields (% of live weight) and protein and energy contents of animal by-products for different animal species (calculated with data from Venegas Fornias (1996), Ockerman and Hansen (2000) and USDA (2016))
Tabelle 3. Angenommene Erträge (% vom Lebendgewicht) und Protein- und Energiegehalte von tierischen Nebenprodukten unterschiedlicher Nutztierarten

		Species				
		Cattle	Swine	Sheep/Goats	Chicken	Turkey
Blood						
	Yield	2.4	2.0	0.0	0.0	0.0
	Protein (g/kg)	178	185	-	-	-
	Energy (MJ/kg)	4.13	4.29	-	-	-
Fancy meats[1)]						
	Yield	3.68	2.65	2.7	0.0	0.0
	Protein (g/kg)	184	181	193	-	-
	Energy (MJ/kg)	6.23	5.94	6.14	-	-
Total by-products (without blood and edible kill fat)						
	Yield	9.6	12.0	14.0	3.6	3.6
	Protein (g/kg)	202	148	167	166	179
	Energy (MJ/kg)	6.80	13.99	5.59	6.09	6.43
Edible kill fat						
	Yield	4.0	2.4	12.0	0.0	0.0
	Protein (g/kg)	0.0	0.0	0.0	-	-
	Energy (MJ/kg)	32.09	32.09	32.84	-	-

[1)] heart, liver, kidney, and tongue.

2.6 Assessment of protein quality

The protein quality of different human-edible inputs and outputs was assessed using the protein digestible indispensable amino acid score (DIAAS), which has been proposed recently as the preferred method for determining protein quality (FAO 2013). When available, the DIAAS for feedstuffs and cow milk were taken from Ertl et al. (2016). Additionally, DIAAS were calculated for oats and field beans, according to the methods described in Ertl et al. (2016), resulting in protein quality scores for the feedstuffs, which accounted together for about 95% of the total human-edible protein input (scores shown in Table 4). For all animal products except cow milk, the amino acid composition was taken from USDA (2016). Due to the lack of values on the ileal amino acid digestibility of these animal products, the protein digestibility (meat: 94%, milk: 95%, and eggs: 97% (FAO/WHO, 1991)) was taken instead for the calculation of the DIAAS, as proposed in FAO (2013). The resulting DIAAS of the animal products are shown in Table 5. To compare the differences between the protein quality of human-edible inputs and outputs, the protein quality ratios (PQR = protein score for the protein in the animal product / protein score for the protein in the human-edible feeds fed to the respective livestock category) were calculated from the weighted average amino acid scores of inputs and outputs, respectively (Ertl et al., 2016).

2.7 Estimation of occupation of different land categories

To compare different livestock categories with regard to their use of arable land, feedstuffs were grouped in the following four categories: 1) feedstuffs being the main crop from arable land (A-MAIN) (e.g., feed grains, alfalfa, annual forages), 2) feedstuffs being a co-product from arable land (A-Co) (e.g., oilseed cakes, feed straw), 3) feedstuffs from permanent grassland (according to its current use) (GRASS), and 4) other feedstuffs (e.g., fish meal, feed yeast) (OTHERS). In the next step, the amount of feed

Table 4. Presumed human-edible fractions (% of protein and energy) of feedstuffs for a current (CURR) and a maximum (MAX) scenario (based on Ertl et al., 2015 and own calculations according to the same methods) and the calculated digestible indispensable amino acid score (DIAAS) of the main human-edible feed protein sources (Ertl et al., 2016)
Tabelle 4. Angenommene humanernährungstaugliche Anteile von Futtermitteln unter einem derzeitigen (CURR) und einem Szenario mit maximalen Ausbeuten (MAX) (basierend auf Ertl et al., 2015 und eigenen Berechnungen nach denselben Methoden), sowie Score für Proteinqualität (DIAAS) (Ertl et al., 2016)

	Protein (%)		Energy (%)		DIAAS (%)
Feedstuff[1)]	CURR	MAX	CURR	MAX	
Barley	40	80	40	80	47.2
Cottonseed cake	63	80	42	50	n.d.[2)]
Field beans	70	90	37	90	57.0
Fish meal	0	80	0	80	n.d.
Flax seed cake	5	19	10	15	n.d.
Gluten (from starch production)	0	80	0	80	n.d.
Maize, grain	70	90	70	90	42.4
Maize, silage	19	45	19	45	42.4
Maize, whole plant	19	45	19	45	42.4
Molasses (from sugar beets)	0	80	0	80	n.d.
Oats	50	75	50	75	56.7
Other grains	51	82	51	82	n.d.
Other oilseed cakes	27	52	22	31	n.d.
Other oilseeds	28	68	53	62	n.d.
Other pulses	63	81	33	81	n.d.
Palm-kernel cake	50	80	21	27	n.d.
Peas	70	90	37	90	64.7
Plant fats and oils	-	-	0	80	n.d.
Potato-protein feed	0	80	0	80	n.d.
Potatoes	0	80	0	80	n.d.
Rapeseed	30	87	64	74	70.2
Rapeseed cake	30	87	26	47	70.2
Rye	60	100	60	100	47.6
Rye, bran and middlings	0	20	0	20	n.d.
Skimmed milk, fluid	0	80	0	80	115.9
Soybean cake	50	92	42	65	97.0
Soybeans	50	93	51	93	99.6
Sugar	-	-	0	80	n.d.
Sunflower	14	46	64	68	47.8
Sunflower cake	14	46	20	30	46.4
Triticale	60	100	60	100	49.8
Wheat	60	100	60	100	40.2
Wheat, bran and middlings	0	20	0	20	48.8
Whey, fluid	0	80	0	80	115.9
Whole cow milk for feeding, fluid	30	50	30	50	115.9

[1)] Feedstuffs not included in this table (n = 44) were considered as human-inedible.
[2)] n.d. = not determined.

protein and energy derived from feedstuffs from each category was calculated as percentage of the total dietary protein and energy for each livestock category.

3. Results and Discussion

3.1 Human-edible content of livestock diets

The percentage of human-edible protein and energy in diets of different livestock categories is shown in Table 6. Irrespective of the animal species, the amount of potentially human-edible feeds in livestock diets is a key factor when assessing the net contribution of livestock to the human food supply. Feeding less human food to livestock not only increases the total amount of food available, but it also reduces the environmental impacts of food production (Eisler et al., 2014; Schader et al., 2015). Due to their forestomach system, ruminants can digest fibrous human-inedible plant materials well, meaning that, from a nutrition ecology perspective, ruminants do not compete with humans for food (Hofmann, 1989). The digestive systems of pigs and poultry, however, are similar to that of humans, resulting in similar demands with regard to the nutrient composition of their diets. Although the composition of diets for our farm animals has been optimized over time to maximize productivity, these evolutionary differences still result in profound differences in the amount of potentially human-edible feed in the diets of different livestock categories (Table 6). With potentially human-edible energy and protein contents generally ranging from 9% for the CURR scenario to slightly under 20% for the MAX scenario, the diets of ruminants (except the growing-fattening bull system) comprise substantially less potentially human-edible food than the diets of monogastric animals, in which around 50% (CURR scenario) to about 80% (MAX scenario) of the dietary protein and energy can be considered to be human-edible. For swine and poultry, these values are similar to the proportions reported for diets in other countries. The Council for Agricultural Science and Technology (1999) reported fractions for human-edible energy of 0.73 (USA) and 0.58 (South Korea) for swine; 0.62 (California) and 0.65 (South Korea) for broilers; and 0.62 (USA) for laying hens. For typical rations in the UK, Wilkinson (2011) estimated the human-edible proportions of the diets' dry matter at 0.64 (swine), 0.75 (broilers), and 0.65 (laying hens). While there seems to be a certain agreement on the proportion of potentially human-edible food in diets for monogastric animals, the values reported for ruminants vary strongly between different countries. For instance, Wilkinson (2011) reported human-edible proportions of 0.36 for dairy cow diets and 0.47 for beef cattle and sheep diets in the UK, whereas the Council for Agricultural Science and Technology (1999) found proportions of the human-edible energy ranging from 0.09 (South Korea) to 0.30 (USA) for dairy cow diets and 0.12 (South Korea) to 0.69 (Nebraska) for beef cattle diets. This suggests that, for ruminant systems, the proportion of potentially human-edible feed depends strongly on the (regional) preconditions (availability and price of concentrate feeds versus quality, availability, and price of forage feeds), whereas for monogastric animals, the composition of diets seems to be quite similar across countries with regard to their proportion of potentially human-edible food. This is most likely due to the limited capability of monogastric animals to digest fibrous (human-inedible) feeds and to the similar production environments for intensive pig and poultry production systems across different countries.

Table 5. Calculated digestible indispensable amino acid scores (DIAAS) for animal products using amino acid composition from USDA (2016)
Tabelle 5. Berechnete Scores für Proteinqualität (DIAAS) für tierische Produkte (Aminosäuren-Zusammensetzung von USDA (2016))

Animal Product	DIAAS (%)
Beef	109.3
Pork	113.9
Chicken meat and skin	108.2
Turkey meat and skin	83.1[1)]
Sheep / Goat meat	116.8
Cow milk	115.9[2)]
Sheep milk	109.1
Goat milk	123.5
Whole chicken egg	116.4

[1)] Low score due to a low valine content given in USDA (2016).
[2)] Score from Ertl et al. (2016).

3.2 Net food production and feed conversion ratios of different livestock categories

The heFCEs of different livestock categories under the current feeding conditions are shown in Table 7. Dairy cows had the highest heFCE both for energy and protein. Except for dairy cows and cattle in total, all livestock categories had heFCE < 1 for both the CURR and MAX scenarios. Livestock systems with heFCE > 1 are net contributors to the human food supply, whereas at heFCE < 1, livestock consume more human-edible food through their feeds than they produce. The finding that dairy cows have the highest net food production among all analyzed livestock categories is in agreement with Wilkinson (2011), and can be explained by two facts: dairy cows' rations include only small potentially human-edible fractions (Table 6) and dairy cows are relatively efficient in converting feed dry matter and feed nutrients into milk (Cassidy et al., 2013; Peters et al., 2014). By contrast, swine and turkeys have the lowest heFCE for protein and energy, respectively. The substantial difference between the heFCE for protein and energy in turkeys is due to the relatively higher protein content as compared to the low energy (low-fat) content of turkey meat, whereas the relatively higher heFCE for energy compared to heFCE for protein in swine can be explained by the low protein content of pig meat in contrast to its high energy content (Table 2). Except for swine, under the MAX scenario, the heFCE was always higher for protein than for energy (Table 7). This is in agreement with results from Wilkinson (2011), where – except for dairy cows – the heFCE was always higher for protein than for energy.

Besides the quantitative changes, the transformation of plant protein into animal protein through livestock systems also affects the protein quality of the human-edible protein. The high values for PQR found for different livestock categories in this study (ranging from 1.11 for turkeys to 1.94 for sheep (Table 7)) clearly support the idea that these differences in the protein quality need to be included in the debate about the net food production of livestock (Ertl et al., 2016). The variations in PQR are the result of differences in the protein quality of the animal products (Table 5), as well as differences in the protein quality of the human-edible protein inputs (Table 4). However, it is questionable whether the distinctly lower (i.e., as compared with other animal products) DIAAS calculated for turkeys in this study (Table 5) truly reflects the reality. According to the procedure described in FAO (2013), the DIAAS only considers the first limiting ileal digestible indispensable amino acid. Thus, if the content of one single indispensable amino acid given in the official database is an outlier (i.e., extraordinarily low, as for example, valine in the case of turkey meat), the quality of this protein might be under- or over-estimated. Therefore, PQR for turkeys should be interpreted with care.

As a result of combining PQR with heFCE for protein (PQR × heFCE), not only cattle in total and dairy cows, but also laying hens, sheep, and goats achieved values > 1 for the CURR scenario, meaning that, these systems can be considered to be net contributors to the human protein supply (Table 7). From the perspective of the net food production, the critique on the low efficiency of livestock systems should, therefore, not be generalized. Although it is true that animals require about 6 kg of plant protein to produce 1 kg of animal protein (Pimentel and Pimentel, 2003), the conclusion that about 85% of the protein is,

Table 6. Calculated percentages of potentially human-edible protein and energy in the total dietary protein and energy[1)], respectively, of different Austrian livestock categories for a current scenario (CURR) and a scenario with maximum human-edible fractions (MAX) (average over the years 2011–2013)

Tabelle 6. Berechneter Anteil an potenziell humanernährungstauglichem Protein sowie humanernährungstauglicher Energie in den Rationen von österreichischen Nutztierkategorien in % von Gesamtprotein und -Energie in der Ration[1)] für ein derzeitiges (CURR) und ein Szenario mit maximalen angenommene Extraktionsraten (MAX) (Durchschnitt für die Jahre 2011–2013)

Livestock category	$Protein_{CURR}$	$Protein_{MAX}$	$Energy_{CURR}$	$Energy_{MAX}$
Cattle	9.0	17.3	9.1	17.2
Dairy cows	10.0	18.6	10.3	18.6
Growing-fattening bulls	19.8	41.2	17.4	36.7
Swine	47.3	82.3	51.3	78.2
Laying hens	46.9	82.7	51.0	77.2
Broiler chickens	45.6	84.3	48.5	76.2
Turkeys	45.7	83.6	48.9	76.2
Sheep	10.0	18.8	10.3	19.1
Goats	10.2	19.6	9.4	17.3

[1)] The total amounts of dietary protein and energy for each livestock category were calculated based on the quantities fed of each feedstuff (Statistics Austria, 2015) multiplied with their respective crude protein and gross energy contents. For calculation of the human-edible protein and energy, the gross energy and crude protein contents of feeds were multiplied with their respective human-edible fraction prior to multiplication with their respective amounts.

thus, wasted in the food chain (Aiking, 2011) is misleading, because it considers neither the human-inedible plant protein inputs, nor the differences in the protein quality between the plant and animal proteins.

3.3 Scales of feed conversion ratios and factors affecting the net food production

The feed conversion ratios (FCR = kg feed dry matter per kg bone-in carcass weight) for pork, broiler chicken, and turkey found in this study (Table 8) are in overall agreement with the results from other countries. Peters et al. (2014) found a FCR of 3.6 (pork), 2.6 (broiler chicken meat), and 3.4 (turkey) for the US production system, whereas Wilkinson reported a FCR of 3.6 for pork and 2.0 for poultry for typical production systems in the UK. These results indicate that these systems are very similar over different countries (genetic potential of animals, feeding intensity, type of diet, and so on). The FCR for the growing-fattening bull system is not directly comparable with the results from other studies, because in this study, we only considered the last phase of the growing-fattening period, and not the whole life of the bulls. However, the broad range found for the FCR for different beef production systems in the UK (7.8–27.5 kg (Wilkinson, 2011)) indicates that the beef production systems are less uniform than the meat production systems involving monogastric animals, which could already be seen when comparing the potential human-edible content of livestock diets over different countries.

The comparison of the different meat production systems shows that the net food production of a livestock system is mainly influenced by three parameters: 1) the potentially human-edible fraction of the animals' diet; 2) the FCR; and 3) the nutrient composition of the animal product. For protein, the PQR can be seen as a fourth influencing factor. Unfavorable results in one of these parameters can be compensated with favorable results in one or several of the others when assessing the net food production of a production system. Table 8, for example, shows that the growing-fattening bull system requires about two to four times more feed protein and feed energy to produce the human-edible protein or energy in the animal product as compared with other meat production systems, whereas the net food production of the different meat production systems is similar. The low efficiency of converting feed nutrients into animal products in beef production systems compared with other meat production systems (higher FCR) can, thus, be compensated by the lower proportion of human-edible nutrients in the ration (Table 6).

3.4 Occupation of different land categories

The concept of heFCE allows a quantitative comparison of the human-edible inputs and outputs of livestock systems under the current feeding conditions. However,

Table 7. Human-edible feed conversion efficiencies (heFCE = human-edible output / human-edible input) for protein and energy for a current scenario (CURR) and a scenario with maximum potentially human-edible fractions (MAX) for different Austrian livestock categories (average over the years 2011–2013)

Tabelle 7. Lebensmittelkonversionseffizienzen (heFCE = humanernährungstauglicher Output / humanernährungstauglicher Input) für Protein und Energie für die wichtigsten österreichischen Nutztierkategorien (Durchschnitt für die Jahre 2011–2013)

	heFCE protein		heFCE energy		PQR[1]	PQR × heFCE protein	
Livestock category	CURR	MAX	CURR	MAX		CURR	MAX
Cattle	1.52	0.87	1.06	0.62	1.84	2.81	1.60
Dairy cows	1.98	1.11	1.44	0.83	1.90	3.78	2.10
Growing-fattening bulls	0.45	0.31	0.26	0.19	1.66	0.73	0.53
Swine	0.36	0.29	0.35	0.34	1.74	0.64	0.50
Laying hens	0.63	0.36	0.31	0.21	1.63	1.04	0.58
Broiler chickens	0.52	0.36	0.30	0.24	1.43	0.76	0.51
Turkeys	0.50	0.33	0.17	0.13	1.11	0.56	0.36
Sheep	0.54	0.39	0.31	0.31	1.94	1.04	0.75
Goats	0.82	0.46	0.64	0.40	1.86	1.53	0.86

[1] PQR = protein quality ratio (Ertl et al., 2016, weighted average protein score of human-edible output / weighted average protein score of human-edible input); average for both scenarios.

this concept does not consider the fact that the human-inedible feeds could be grown on land suitable for the cultivation of crops for direct human consumption (van Zanten et al., 2016). In order to include the potential suitability of land currently used to grow feeds to cultivate food crops, we classified all feedstuffs based on the land category from which they were derived. The percentages of the total feed protein and energy derived from different land categories are shown in Table 9. Except for the growing-fattening bull system, about 50% of the feed protein and energy for ruminant systems was derived from permanent grassland, whereas the feed protein and energy for monogastric animals was nearly exclusively derived from arable land; either as a main crop (41–51% of the feed protein and 67–76% of the feed energy) or as a co-product. This clearly explains why reducing the amount of food-competing feeds would result in a drastic decline in the numbers of pigs and poultry (Schader et al., 2015). The fact that only about 10% of the feed protein and energy for growing-fattening bull systems is derived from permanent grasslands suggests that, in this respect, highly intensive ruminant feeding systems are relatively similar to the feeding systems for monogastric animals. The role of co-products was more important for the provision of feed protein than for feed energy over all livestock categories. This indicates that in systems where animals are mainly fed co-products from crop production to increase sustainability and land use efficiency (as proposed by Schader et al. (2015) or Van Kernebeek et al. (2016)), the energy supply, especially for monogastric animals, might be more challenging than the provision of protein.

The fact that about 50% of the feed energy and protein for cattle, sheep, and goats is derived from permanent grassland emphasizes the important role that ruminants play from a food security perspective, because this land category would otherwise be virtually unsuitable for human food production (Schader et al., 2015). The argument that the current permanent grassland might partly be suitable for growing food crops is true, but with regard to the negative effects on soil erosion and soil carbon emissions, the conversion of grassland to arable land should be avoided (Janzen, 2011; Soussana et al., 2010). In addition to permanent grasslands, growing perennial forage crops on arable land as feed for ruminants (e.g., alfalfa or clover) contributes to maintaining or improving soil fertility by replenishing soil organic matter, preventing erosion, or fixing nitrogen (Janzen, 2011).

3.5 Methodological considerations

Many different methods are available to assess and compare the specific elements of sustainability of different livestock systems (e.g., life cycle assessments (de Vries and de Boer, 2010), land use efficiency (van Zanten et al., 2016), fossil energy requirements (Pimentel and Pimentel, 2003), or the efficiency of livestock in producing food for humans (Wilkinson, 2011)). However, the results from these different methods are often contradictory, making it nearly impossible to rank different livestock systems in terms of their sustainability. Pork, chicken meat, eggs, and milk, for example, require similar areas of land to produce one kg of protein (de Vries and de Boer, 2010; Nijdam et al., 2012), but regarding the net protein production for hu-

Table 8. Comparison of different feed conversion parameters for major Austrian meat production systems (current scenario, average over the years 2011–2013)
Tabelle 8. Vergleich von unterschiedlichen Futtereffizienz-Parametern der wichtigsten österreichischen Fleischproduktionssysteme (derzeitiges Szenario, Durchschnitt für die Jahre 2011–2013)

Meat production system	Feed conversion parameter[1]				
	FCR	$FCR_{protein}$	FCR_{energy}	$FCR_{he\text{-}protein}$	$FCR_{he\text{-}energy}$
Growing-fattening bull	11.54	11.35	22.56	2.24	3.91
Pork production	3.68	5.89	5.63	2.79	2.89
Broiler chicken	2.18	4.23	6.88	1.92	3.34
Turkey meat	3.25	4.41	12.11	2.01	5.92

[1] FCR = kg feed dry matter / kg bone-in carcass; $FCR_{protein}$ = kg feed protein / kg human-edible protein in the animal product; FCR_{energy} = kJ feed energy / kJ human-edible energy in the animal product; $FCR_{he\text{-}protein}$ = kg human-edible feed protein / kg human-edible protein in the animal product; $FCR_{he\text{-}energy}$ = kJ human-edible feed energy / kJ human-edible energy in the animal product.

man consumption and the use of non-arable grassland, milk is superior to meat products (Wilkinson, 2011; Table 7 and Table 9). However, irrespective of the method used to assess the sustainability of different livestock categories, reducing the amount of potentially human-edible feeds is a key factor to more sustainable livestock systems (Eisler et al., 2014; Schader et al., 2015). Estimating the potentially human-edible fractions of livestock diets and calculating the heFCE based on actual national data allows livestock categories to be rated with regard to their current contribution to the net food production, and it also allows conclusions to be drawn on the changes in the livestock numbers or livestock diets that might be needed in the future in order to improve the net food production of livestock in general.

4. Conclusions

The results of this study clearly show that due to their different digestive systems, ruminants (except in intensive growing-fattening bull systems) consume only small proportions of feedstuffs that are in direct competition with human foods as compared with monogastric animals. More than 50% of their required feed energy and protein is derived from permanent grasslands, which is not utilizable for human food production without the transformation by ruminants. Under the current feeding conditions in Austria, cattle are the only species that are the net contributors to both the human protein and energy supplies. However, when differences in the protein quality between the human-edible plant inputs and animal products are considered, not only cattle, but also laying hens, sheep, and goats increase the value of protein available for human consumption under the current conditions. Although monogastric animals consume large amounts of feeds that originate from land where feedstuffs are only a co-product, they do not only directly compete with humans for food, but they do also compete for arable land that would be suitable for the cultivation of crops for direct human consumption. Therefore, the suggestions issued by various groups to replace red meat with white meat because of the better feed to food conversion efficiencies of monogastric animals may be counterproductive from a net food production perspective.

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Table 9. Relative occupation of different land categories for the production of feed protein and energy for main livestock categories in Austria (% of the total feed protein and energy derived from respective land category, average for the years 2011–2013)
Tabelle 9. Relative Flächenbeanspruchung für die Produktion von Futterprotein und –Energie (% gesamt) für die wichtigsten österreichischen Nutztierkategorien (Durchschnitt für die Jahre 2011–2013)

	Protein				Energy			
Livestock category	A-MAIN[1)]	A-Co	GRASS	OTHER	A-MAIN	A-Co	GRASS	OTHER
Cattle	32.3	15.3	52.3	0.0	39.4	8.8	51.8	0.0
Dairy cows	34.8	17.0	47.8	0.4	41.2	10.2	48.3	0.3
Growing-fattening bulls	58.3	31.0	10.7	0.0	77.4	13.1	9.5	0.0
Swine	50.7	48.3	0.1	0.9	75.5	24.0	0.1	0.4
Laying hens	48.8	50.7	0.0	0.5	73.7	26.1	0.0	0.3
Broiler chickens	39.1	58.6	0.0	2.3	67.1	32.0	0.0	0.9
Turkeys	40.7	56.9	0.0	2.4	68.9	30.2	0.0	0.9
Sheep	34.8	10.4	54.2	0.6	41.6	6.1	51.9	0.4
Goats	34.3	13.9	51.6	0.2	40.7	7.6	51.6	0.2

[1)] A-MAIN: feed protein and energy from arable land where the feedstuff is the main crop; A-Co: feed protein and energy from arable land where the feedstuff is a co-product; GRASS: feed energy and protein from grassland; OTHER: other origin (e.g., fish-meal, feed yeast).

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