Austrian Journal of Agricultural Economics and Rural Studies, Vol. 32.4
https://oega.boku.ac.at/de/journal/journal-informationen.html
DOI 10.15203/OEGA_32.4, ISSN 1815-8129 I E-ISSN 1815-1027

Carbon footprint of Austrian beef in an international context

Carbon Footprint von österreichischem Rindfleisch im internationalen Kontex

Mathias Kirchner[1,*], Werner Pölz[2], Hans Mayrhofer[3], Michaela Hickersberger[3] und Franz Sinabell[4]

[1]Centre for Global Change and Sustainability, University of Natural Resources and Life Sciences Vienna, AT
[2]Environment Agency Austria, Vienna, AT
[3]Ecosocial Forum Austria & Europe, Vienna, AT
[4]Austrian Institute of Economic Research, Vienna, AT

[*]*Correspondence to:* mathias.kirchner@boku.ac.at

Received: 23 Januar 2023 – Revised: 3 Juli 2023 – Accepted: 17 Juli 2023 – Published: 15 Dezember 2023

Corrected: 6 February 2024

Summary

We calculate carbon footprints (CFP) for selected beef production systems and provide a comparative analysis with other findings in the literature. Our results indicate that Austrian beef has one of the lowest CFP globally, despite high ranges of different production systems. It would thus have a competitive advantage, if GHG emissions from cattle production were priced. Since Austria is a net exporter of beef, this export surplus likely has a small negative impact on global GHG emissions from beef. Further mitigation measures should be applied, but total potential emission reductions are assumed to be only between 5% and 19%. Current climate mitigation goals will thus require a further reduction of global beef production and consumption.

Keywords: carbon footprint, beef, Austria, global, climate mitigation, life cycle analysis

Zusammenfassung

Wir berechnen den Carbon Footprint (CFP) für ausgewählte Rindfleischproduktionssysteme und bieten eine vergleichende Analyse mit anderen Ergebnissen in der Literatur. Unsere Analyse zeigt, dass österreichisches Rindfleisch, trotz hoher Bandbreiten unterschiedlicher Produktionssysteme, einen der niedrigsten CFP weltweit aufweist. Würden die THG-Emissionen der Rinderproduktion bepreist, hätte Rindfleisch aus Österreich Wettbewerbsvorteile. Da Österreich ein Nettoexporteur von Rindfleisch ist, hat dieser Exportüberschuss wahrscheinlich einen geringen negativen Einfluss auf die globalen THG-Emissionen von Rindfleisch verglichen mit einer Situation, in der das Rindfleisch woanders erzeugt wird. Es sollten weitere Minderungsmaßnahmen ergriffen werden, aber es wird davon ausgegangen, dass die potenziellen Emissionsminderungen insgesamt nur zwischen 5% und 19% liegen. Die derzeitigen Klimaschutzziele erfordern daher eine weitere Reduzierung der weltweiten Rindfleischproduktion und des Rindfleischverbrauchs.

Schlagworte: CO_2-Fußabdruck, Rindfleisch, Österreich, global, Klimaschutz, Ökobilanzierung

1 Introduction

Austria's commitment to contribute its fair share to the Paris Climate Accords will lead to increasing pressure to reduce greenhouse gas (GHG) emissions in all sectors. Although agriculture's share of total Austrian GHG emissions is currently rather low with about 10 % in the year 2020 (Umweltbundesamt, 2022), it nonetheless will need to contribute to mitigation efforts as the current policy goal of the Austrian government is to reach net-zero GHG emission in 2040. Additionally, agriculture's GHG emissions are higher if one looks at consumption-based emission instead of production-based emissions with widely varying figures due to uncertainties regarding data and system boundaries. In both accounting approaches enteric fermentation is the major contributor to agricultural GHG emissions, i.e. the methane produced and emitted during the digestion process of ruminants. From a production-based perspective cattle is currently responsible for 87% of agricultural and 64% of total methane emissions (Umweltbundesamt, 2022). From a consumption-based perspective beef remains the food with the highest carbon footprint (CFP) (Pieper et al., 2020). Beef production systems in Austria are heterogeneous and it is not possible to select one system that represents all of them. In addition, systems prevailing in Austria differ from production systems in other countries from which beef may be imported, for example South America. Therefore, we want to investigate:

1. What is the CFP of selected beef productions system in Austria and in South America?
2. What measures can contribute to reduce GHG emissions of beef production?

To answer these two research questions, we apply a life cycle analysis (LCA) for four different beef production systems (two for Austria and two for South America) to estimate their CFP. Based on an expert workshop (twelve people from breeding and husbandry, processing, marketing, trade, advocacy and science), we decided to investigate the following four production:

1. AT-int: Austria - intensive fattening
2. AT-ext: Austria - pasture / grass silage fattening
3. SA-int: South America - grassland based with intensive finishing,
4. SA-ext: South America - grassland based, suckler cow, extensive, separated from the mother herd after 9 months.

Furthermore, we conduct a selected literature review on CFPs for beef production systems globally as well as on potential mitigation measures. In addition, stakeholder workshops were held to (a) solicit expertise on beef production systems and (b) validate and evaluate our findings. Our study can thus provide a rather novel comparison of national CFP efficiency ranges considering different production systems, studies, and regional characteristics.

2 CFP method and data

LCAs enable the multi-criteria analysis of the life cycles of products regarding their environmental impact. Here we focus only on one environmental indicator, the carbon footprint (CFP). CFP "is a measure of the exclusive total amount of carbon dioxide emissions that is directly and indirectly caused by an activity or is accumulated over the life stages of a product." (Wiedmann and Minx, 2008, p. 5). The unit of measurement for this is CO_2-equivalent (CO_2eq) emissions. For our analysis, the GEMIS model (Global Emission Model of Integrated Systems) is applied. GEMIS is a computer-based tool that allows the environmental impacts of different systems and processes to be calculated and compared comprehensively.

The results of CFPs depend heavily on what is considered in the calculations and methodology. For this analysis, an extended cradle-to-gate approach is taken according to ISO 14067, namely cradle-to-slaughterhouse. This means that in addition to the emissions up to the point where the product leaves the (farm) gate, we also consider the emissions from the gate to the point where the product is processed, i.e. a slaughterhouse. As we are interested in whether South American beef or Austrian beef has a lower CFP for Austrian consumers, we include transport emissions from South America to Europe.

The specific parameters considered to calculate the CFP for beef include:

- cattle rearing (feeding days, carcass weight, CH_4 and N_2O emissions from animal husbandry, manure management, suckler cow management);
- feed production (energy use, material use, cultivation, management, harvest);
- cooling (energy use, slaughterhouse, processing site);
- transport of animals and feed (means of transport, transport distance, utilization per means of transport).

Our calculations do not include emissions from land use and land use change (LULUC) resulting from the provision of feed or cattle management (see section 4 for more information). Furthermore, the production of stables and related infrastructure and its energy use (e.g. lighting, ventilation, etc.) are not taken into account. No effects of fertilization were taken into account, neither nitrous oxide emissions through nitrogen application, nor the production of fertilizer nor any substitution effects.

Our chosen production systems and their underlying data assumptions (see also Table 1) are of a generic type and do not represent a specific production system per se. Our aim is to compare intensive and extensive production systems in both regions. Hence, an expert workshop was used to obtain data (ranges) regarding feed types and feed quantities, feeding days and carcass weights, especially regarding the consideration of suckler cow husbandry for these production

Table 1: Input parameters for the CFP calculations for different beef production systems in two different regions

Category	Parameter	Unit	AT-int	AT-ext	SA-int	SA-ext
Feeding	feeding days	Days	550	700	500	600
	carcass weight	kg	400	360	400	400
	pasture grazing	kg DM total feeding time	no	yes	no	yes
	pasture fodder			4,900		
	grass silage		6,000	4,900		2,050
	Hay		150	1,000	150	
	Grains		1,500	100		1,500
	crushed corn		250	25	1,500	250
	soy meal, extracted				600	
Transport	transport distance of purchased feed	km	300	50	700	700
	shipping distance from SA to European port	km			9,000	9,000
	truck transport to slaughterhouse	km	50	50	700	700
Manure management & enteric fermentation	manure CH_4 emissions – 1st year	kg CO_2eq / animal	47	42	47	47
	manure CH_4 emissions – 2nd year		101	92	101	101
	manure N_2O emissions– 1st year		114	114	114	114
	manure N_2O emissions– 2nd year		179	179	179	179
	enteric fermentation – 1st year		697	596	697	697
	enteric fermentation – 2nd year		1,379	1,249	1,379	1,379
(Suckler) Cow	attribution of GHG emissions from (suckler) cow to calf	kg CO_2eq / animal	518	518	518	518

Note: DM … dry matter
Sources: GEMIS, Umweltbundesamt (2021), expert inputs

system types. In our calculations, both the feed quantities and the GHG emissions from animal husbandry for cattle and the milk quantity for the calf are considered.

In addition to values from GEMIS and Umweltbundesamt (2021), experts were consulted to indicate ranges of parameters of typical production systems and the final choice (see Table 1) was discussed in one of the workshops with stakeholders. Feeding days are necessary for the scaling of the emissions from digestion and manure management. Different emission behavior is assumed for the first or second year of life. Carcass weight in kg is an input for the calculation of CFP per kg beef. Feed quantities are needed for the calculation of the production emissions of the respective feed. No emissions are included in the calculation for pasture grazing. Feed quantities and carcass weight are also included in the calculation of emissions from transport operations. Feed transport was considered for grain and concentrated feed, and transport was always assumed by truck. Transport of cattle to the slaughterhouse was also assumed by truck. For South American cattle we assumed that it will be shipped to a European port and then be transported to Austria by truck. The transport of residual feed for South American cattle is carried out over long distances by truck. Specific GHG emissions from manure management and enteric fermentation are used which are updated and revised yearly (Umweltbundesamt, 2021). The GHG quantities of CH_4 and N_2O are multiplied by their respective global warming potential over 100 years, i.e. 25 for CH_4 and 298 for N_2O.

We differentiate between solid bedding (straw) for pasture-based fattening and slatted floors for intensive fattening. Emissions from (suckler) cows (i.e. milk consumed by the calf before weaning it off) are attributed to calves with the same amount in all production systems.

We apply the same feed transport GHG emission factors for all production systems (in kgCO_2eq / tkm): truck transport (0.218), truck transport refrigerated (0.251), ship transport (0.009), hay (0.055), grass silage (0.060), barley (0.317), soybean (0.390), corn (0.446). Cooling in the slaughterhouse is assumed to account for 250 kWh per animal.

3 CFP results

The CFP results for our selected beef production systems are presented in Table 2 and are differentiated according to main categories: cattle rearing (enteric fermentation and manure management), animal feed, transport, cooling and the attribution of suckler cow. We provide both, total CFP results per carcass weight (CW) and per animal.

Intensive beef production in South America has the highest CFP both per CW (9.6 kg CO_2) and per animal (3.8 t CO_2). The lowest CFP per CW is found for intensive beef production in Austria (8.4 kg CO_2) and the lowest CFP per animal is found for extensive beef production in Austria (3.3 t CO_2). The results highlight that enteric fermentation and manure management dominate the results and contribute 39% (SA-int) to 68% (AT-ext) to total CFP. Animal feed and transport are the second most important category (except for AT-ext), contributing 12% (AT-ext) to 35% (SA-int) to total CFP. CFP results for South American (SA) production systems indicate that longer transport distances for feedstuff can lead to significant increases in CFP.

Results also show that more intensive production systems have lower cattle rearing emissions (due to faster fattening) but this can be offset due to higher GHG in animal feed and feed transport – as is the case for SA-int beef but not for AT-int beef.

and system boundaries, these ranges are also due to high regional differences and the variety of production systems that exist for beef production. Figure 1 summarizes all CFP results identified for this study. The reference value for Austria is based on Leip et al. (2010), as our study is not representative enough of Austrian production systems. The reference value for Brazil is based on a weighted mean value of the production systems in Cardoso et al. (2016).

Comparing the mean CFP value of Leip et al. (2010) for Austria (16.7 without LULUC) to all other values indicates that Austria has one of the lowest average CFPs for beef. Combing production data from Statistik Austria and the production systems by Hörtenhuber and Zollitsch (2020), which is the most comprehensive study on Austrian beef production systems so far, would indicate an even lower mean value (ca. 11.5 without LULUC). However, this value comes with a lot of uncertainty as Statistik Austria and Hörtenhuber and Zollitsch (2020) use quite different cattle categories. Looking at the uncertainty ranges in Figure 1 allows to make a robust conclusion: namely, that the beef CFP in Austria is very likely to be at the lower end compared to other average country values. Taking LULUC into account would strengthen this finding even further. A main reason for Austria's low CFP is the, on average, relatively high extensive use of grassland in combination with highly productive cattle management (Leip et al., 2010).

Table 2: CFP results for the four selected beef production systems; Note: CW = Carcass Weight

GHG source	Unit	AT-int	AT-ext	SA-int	SA-ext
Cattle rearing	kg CO_2eq / CW	4.25	5.96	3.68	4.82
Animal feed	kg CO_2eq / CW	2.39	1.09	3.33	1.78
Transport (animal & feed)	kg CO_2eq / CW	0.36	0.08	1.12	0.99
Cooling (slaughter house)	kg CO_2eq / CW	0.12	0.14	0.12	0.12
Attribution suckler cow (milk)	kg CO_2eq / CW	1.29	1.44	1.29	1.29
Total per carcass weight	kg CO_2eq / CW	8.41	8.71	9.55	9.00
Total per animal	kg CO_2eq / animal	3 364	3 135	3 820	3 598

Source: Own calculations, 2023.

4 CFP comparisons

This section provides an overview and comparison of CFP calculations for beef in the recent literature. To make the results comparable, the results have been standardized as much as possible, regarding:

- Functional unit: kg CO_2eq per kg carcass weight (kg CO_2eq / kg CW)
- 100-year global warming potential (GWP): 25 for CH_4 and 298 for N_2O
- System boundary: cradle-to-farm gate (thus not considering downstream transport emissions).

For this purpose, we only use results that were published detailed enough to allow such a standardization and deducted all emissions attributed from farm gate to retailer from our own estimations (i.e. transport after farm gate and slaughterhouse cooling). We also provide information on LULUC emission where available: Land use (LU) emissions occur when feed is produced on land that is already available (e.g., soil carbon content on pasture); Land use change (LUC) emissions occur either directly, e.g. when rainforest is converted to grassland for beef production, or indirectly, e.g. when rainforest deforestation occurs due to market impacts.

The identified CFPs in Table 3[1] indicate a wide range between and within countries. Apart from different data bases

1 Due to space constraints not all data is shown, but can be requested from the corresponding author.

5 Climate mitigation measures

5.1 GHG impacts due to trade

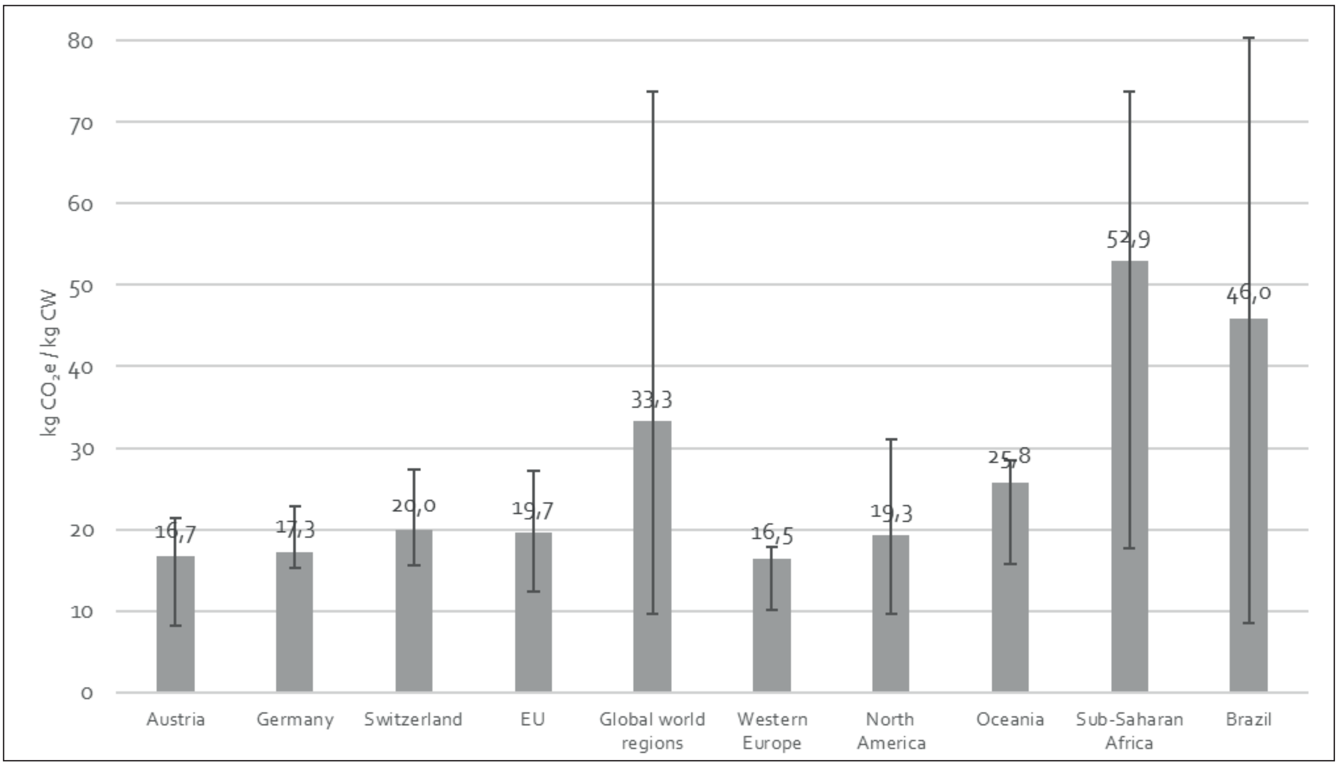
Based on the findings in section 4, one may assume that higher exports of Austrian beef could contribute to mitigating global GHG if they substitute beef with higher CFP. At the same time, the substitution of Austrian beef by imports with higher CFP would increase global GHG emissions. Using trade data from EUROSTAT (2021) and the CFPs presented in section 4, we calculate the effects of such hypothetical scenarios (see Table 4). To cover the range of CFP values we apply five different CFP value scenarios: (1) Worst case (maximum CFP

Table 3: Selected CFP for different beef production systems in different regions from the literature (in kg CO2eq / kg CW). Note: CW = Carcass Weight

Source	**Region**	**Production system** (if applicable)	**CFP** *without LULUC*	**CFP** *with LULUC*	**LULUC** *LU*	*LUC*
Own	Austria	AT-int	8.2			
		AT-ext	8.5			
Kral (2011)		Conventional	11.5	15.1		3.6
		Organic	12.6	12.6		0.0
Leip et al. (2010)		Ø	16.7	15.5	-1.6	0.3
Hörtenhuber and Zollitsch (2020)		Bull fattening (grass) - dairy	9.7	9.7		0.0
		Bull fattening (corn) – dairy	9.7	10.6		0.9
		Slaughter dairy cow	10.4	10.4		0.0
		Ox - dairy cow	13.3	13.5		0.1
		Bull from suckler cow	18.5	18.9		0.4
		Heifer from suckler cow	21.4	21.4		0.0
Own	South America	SA-ext	8.6			
		SA-int	9.1			
Cederberg et al. (2011)	Brazil	Ø	28.0	44.0		16.0
		Legal Amazon	28.0	180.0		152.0
Leip et al. (2010)		Legal Amazon	48.5	80.0		31.5
Alig et al. (2012)		Mato Grosso	32.5	39.1		6.6
Cerri et al. (2016)		Mato Grosso – Farm 7	9.0			
Cardoso et al. (2016)		Cerrado – degraded	58.3			
		Cerrado - fertilized	29.5			
Ruviaro et al. (2015)		Rio Grande de Sul – natural	80.4			
		Rio Grande de Sul – cultivated	37.7			
Leip et al. (2010)	Netherlands		12.3	18.2	2.0	4.0
	Germany		17.3	20.3	1.5	1.5
	Cyprus		21.6	45.1	12.8	10.7
	Latvia		27.3	43.5	0.0	16.2
	EU27		19.7	23.6	1.4	2.6
Nguyen et al. (2010)	EU27	Suckler cow-calf	26.8	27.3	0.5	0.0
		Bull calves – concentrates	12.6	27.3	3.4	11.3
		Steers – extensive	22.3	19.9	-2.4	0.0
Alig et al. (2012)	Switzerland	Dairy cow - eco-standard	15.5	15.7		0.2
		Dairy cow – organic	17.5	17.5		0.0
		Suckler cow - eco-standard	27.3	27.3		0.0
		Suckler cow – organic	26.4	26.4		0.0
	Germany		15.2	15.7		0.5
FAO (2017)	Global		33.3	39.8		6.5
	East Asia and Southeast Asia		43.7	43.8		0.2
	Eastern Europe		12.9	14.2		1.2
	Latin America & the Caribbean		37.5	57.0		19.6
	Near East and North Africa		38.1	38.1		0.0
	North America		19.3	19.3		0.0
	Oceania		25.8	26.3		0.5
	Russian Federation		12.6	13.1		0.5
	South Asia		68.9	68.9		0.1
	Sub-Saharan Africa		52.9	53.1		0.2
	Western Europe		16.5	17.4		0.9

Sources: See column "Source".

Figure 1: Country comparison of beef CFP (excluding LULUC) with uncertainty range.



Note: The uncertainty range refers to minimum and maximum values from (1) production systems (Austria, Switzerland, EU, Global World Regions, Western Europe, North America, Oceania, Sub-Saharan Africa, Brazil), and/or (2) studies (Austria, Germany, Brazil, EU), and/or (3) regional characteristics (Germany, EU, Global World Regions, Brazil).
Source: See column “Source” in Table 3.

for Austria, minimum CFP for all others), (2) Minimum (minimum CFP for all), (3) Average (average values for all), (4) Maximum (maximum CFP for all), (5) Best case (minimum CFP for Austria, maximum CFP for all others).

Our scenario calculations show that exports of Austrian beef potentially could save 93 to 873 kt CO_2eq without LULUC and 642 to 1.160 kt CO_2eq with LULUC (excluding extreme scenarios). In the alternative scenario, the substitution of Austrian beef by imports results mostly in higher GHG emissions ranging from -20 kt CO_2eq to +425 t CO_2eq without LULUC and from +215 to +592 kt CO_2eq with LULUC (excluding extreme scenarios). Since exports outweigh imports, we find a positive net trade effect: Without Austrian beef exports, global GHG could potentially increase by 127 to 448 kt CO_2eq (without LULUC) and 360 to 568 kt CO_2eq (with LULUC), excluding extreme scenarios. In this static comparative analysis, an underlying assumption is that other trade flows and prices would not change.

Table 4: Substitution scenarios - GHG effect through trading in kt CO2eq

	Export substitution		**Import substitution**		**Net Effect**	
CFP value scenarios	*Without LULUC*	*With LULUC*	*Without LULUC*	*With LULUC*	*Without LULUC*	*With LULUC*
Worst case (AT max - Other min)	800	513	-337	-171	462	342
Minimum	-873	-1 160	425	592	-448	-568
Average	-93	-710	25	350	-69	-360
Maximum	-107	-642	-20	215	-127	-426
Best case (AT min - Other max)	-1 779	-2 314	742	978	-1 037	-1 336

Source: Own calculations, data based on sources presented in Table 2 and Table 3.

5.2 Technical mitigation measures

Leip et al. (2010) argue that technical measures could lead to reductions in beef CFP by 15 to 19%, but uncertainty remains high due to regional heterogeneity and lack of data for some measures. Experts at our second stakeholder workshop only saw a total savings potential of 5 to 10%. The issue is complicated by the need to account for interactions between measures. For example, if one decreases CH_4 emission from enteric fermentation by increasing the share of concentrated feed, this increases CO_2 emission from feeding at the same time, especially if LULUC emission come into play.

On the basis of our literature review and the second stakeholder workshop, the following mitigations measures seem particularly suitable to experts: (1) vertical cooperation, i.e. short distances and replacement of concentrated feed imports (especially soybean meal from Brazil) by regional protein supply; (2) improvement of farm manure management (e.g. near-ground manure application, covering of manure pits, admixture of straw, increase of pasture share), (3) breeding programs and (4) biogas production (anaerobic fermentation of farm manure). Some experts were skeptical about the following climate protection measures: (a) improvement of feed quality and (b) feed additives. Feed quality is said to be already very high in Austria and emission reductions are hardly achievable without trade-offs to other sustainability aspects (e.g. biodiversity). Feed additives are mostly experimental[2] and only have a substantial long-term effect on a synthetic, but not plant-based, basis.

6 Conclusions and Limitations

Our analysis comes with several caveats:

- Our own results are within the uncertainty range of comparable results but at the lower end. They therefore are not likely to represent average values for Austria and should only be used as a lower bound.
- The inclusion of even more literature would provide more robust figures regarding Austrian beef CFP in an international context.
- Our trade effects analysis rests on very simply assumptions. A detailed modelling of changes in trade flows and productions systems would provide more robust figures.
- The potential savings range from trade effects is very low compared to current total Austrian GHG emissions and it is likely that there are limits to the expansion of Austrian beef production systems with low CFP.

Despite these caveats we think that our analysis can show that Austrian beef is very likely to have an advantage when global GHGs are considered, especially if the social costs of GHGs were factored into the price of beef.

This rather optimistic conclusion is met by two pessimistic findings: Total further saving potentials are low (ca. 5% to 19%) and even the low CFP values for Austrian beef are higher by many factors compared to other non-ruminant meat products and especially vegetarian or vegan products (Gerber et al., 2013; Pieper et al., 2020).

All of this strengthens the argument that climate protection measures must continue and accelerate. How much global beef consumption can be reconciled overall with the Paris Climate Accord and to what extent Austria could expand its beef production to substitute beef from other countries that is less climate efficient, cannot be elicited in this study. There remain good arguments for not reducing cattle production to zero, inter alia, because of its contribution to (1) regional development, (2) global food security and (3) biodiversity. Austria-specific studies indicate that cattle farming contributes to regional development (Sinabell et al., 2019), largely utilizes biomass that is not digestible by humans (Ertl et al., 2016), and contributes to the preservation of biodiversity-rich cultural landscapes with extensive pasture management (Umweltbundesamt, 2019).

Achieving the Paris Climate Accord will require a substantial reduction in global beef consumption. This study suggests that, while demand and thus production will need to be reduced, Austrian agriculture could make an important contribution to the remaining demand based on its current climate efficiency. For climate protection, and in order not to lose this pioneering role, efforts should also be made to further reduce GHG emissions in Austrian beef production.

A final decision regarding climate protection measures for beef production (including its cessation or a significant reduction in consumption/production) should be made considering other sustainability aspects such as biodiversity, food security, animal welfare and regional economic development.

Acknowledgements

This research work is part of the project “Resilience: Corona Crisis and Agricultural and Forestry Value Chains - Lessons Learnt” funded by the Austrian Federal Ministry of Agriculture, Regions and Tourism (project number 101598). The author team would like to thank Stefan Hörtenhuber and Werner Zollitsch and other participants in the workshops for their technical support and expertise.

Literatur

Alig, M., Grandl, F., Mieleitner, J., Nemecek, T. and Gaillard, G. (2012) Ökobilanz von Rind-, Schweine- und Geflügelfleisch. Executive Summary. Agroscope Reckenholz-Tänikon ART. Zürich.

Cardoso, A. S., Berndt, A., Leytem, A., Alves, B. J. R., de Carvalho, I. das N. O., de Barros Soares, L. H., Urquiaga,

2 Recently, the European Food Safety Authority approved the feed additive 3-NOP (https://www.efsa.europa.eu/en/efsajournal/pub/6905)

S. and Boddey, R. M. (2016) Impact of the intensification of beef production in Brazil on greenhouse gas emissions and land use. Agricultural Systems 143, 86–96. https://doi.org/10.1016/j.agsy.2015.12.007.

Cederberg, C., Persson, U. M., Neovius, K., Molander, S., Clift, R. (2011) Including Carbon Emissions from Deforestation in the Carbon Footprint of Brazilian Beef. Environmental Science & Technology. 45, 5, 1773–1779. https://doi.org/10.1021/es103240z.

Cerri, C. C., Moreira, C. S., Alves, P. A., Raucci, G. S., de Almeida Castigioni, B., Mello, F. F. C., Cerri, D. G. P. and Cerri, C. E. P (2016) Assessing the carbon footprint of beef cattle in Brazil: a case study with 22 farms in the State of Mato Grosso. Journal of Cleaner Production 112, 2593–2600. https://doi.org/10.1016/j.jclepro.2015.10.072.

Ertl, P., Knaus, W. and Zollitsch, W. (2016) An approach to including protein quality when assessing the net contribution of livestock to human food supply. Animal 10, 11, 1883–1889. https://doi.org/10.1017/S1751731116000902

EUROSTAT (2021) EU Handel nach HS6 seit 1988. EUROSTAT.

FAO (2017) Global database of GHG emissions related to feed crops: A life cycle inventory. Version 1. Livestock Environmental Assessment and Performance Partnership. Rome: FAO.

GEMIS and Umweltbundesamt (2021) xy

Gerber, P. J., Steinfeld, H., Henderson, B., Mottet, A., Opio, C., Dijkman, J., Falcucci, A. and Tempio, G. (2013) Tackling climate change through livestock: a global assessment of emissions and mitigation opportunities. Rome: FAO.

Hörtenhuber, S. and Zollitsch, W., 2020. Klimawirkungen unterschiedlicher österreichischer Rindfleischproduktionssysteme. Endbericht. ARGE Rind. Wien.

Kral, I. (2011) Treibhausgasemissionen von Rind- und Schweinefleisch entlang der Produktionskette Landwirtschaft bis Großküche unter besonderer Berücksichtigung der landwirtschaftlichen Produktionsform. Master's Thesis. Universität für Bodenkultur Wien. Wien.

Leip, A., Weiss, F., Wassenaar, T., Perez, I., Fellmann, T., Loudjani, P., Tubiello, F., Grandgirard, D., Monni, S. und Biala, K. (2010) Evaluation of the livestock sector's contribution to the EU greenhouse gas emissions (GGELS). Final Report (No. AGRO-). European Commission, Joint Research Centre (JRC).

Nguyen, T. L. T., Hermansen, J. E. and Mogensen, L. (2010) Environmental consequences of different beef production systems in the EU. Journal of Cleaner Production 18, 756–766. https://doi.org/10.1016/j.jclepro.2009.12.023

Pieper, M., Michalke, A. and Gaugler, T. (2020) Calculation of external climate costs for food highlights inadequate pricing of animal products. Nature Communication 11, 6116, 1–13. https://doi.org/10.1038/s41467-020-19474-6

Ruviaro, C. F., de Léis, C. M., Lampert, V. do N., Barcellos, J. O. J. and Dewes, H. (2015. Carbon footprint in different beef production systems on a southern Brazilian farm: a case study. Journal of Cleaner Production, 96, 435–443. https://doi.org/10.1016/j.jclepro.2014.01.037

Sinabell, F., Bock-Schappelwein, J., Firgo, M., Friesenbichler, K.S., Piribauer, P., Streicher, G., Gerner, L., Kirchner, M., Kantelhardt, J., Niedermayr, A., Schmid, E., Schönhart, M. and Mayer, C. (2019) Eine Zwischenbilanz zu den Wirkungen des Programms der Ländlichen Entwicklung 2014-2020 (No. 2019/143/A/WIFO-Projektnummer: 1618). Wien: Österreichisches Institut für Wirtschaftsforschung, Universität für Bodenkultur Wien, Statistik Austria.

Umweltbundesamt (2022) Austria's National Inventory Report 2022 (No. REP-0811). Submission under the United Nations Framework Convention on Climate Change and under the Kyoto Protocol. Vienna: Environment Agency Austria.

Umweltbundesamt (2021) Austria's National Inventory Report 2021 (No. REP-0761). Submission under the United Nations Framework Convention on Climate Change and under the Kyoto Protocol. Vienna: Environment Agency Austria.

Umweltbundesamt (2019) Zwölfter Umweltkontrollbericht - Umweltsituation in Österreich (Report No. REP-0684). Wien: Umweltbundesamt GmbH.

Umweltbundesamt (2012). Österreichische Luftschadstoffinventur - Austria´s Annual Greenhouse Gas Inventory 1990-2010. Submissions under Decision 280/2004/EC. Wien.

Wiedmann, T. and Minx, J. (2008) A definition of 'carbon footprint.' Ecological economics research trends 1, 1–11.