Research Article

Received: 3 February 2020 Revised: 19 June 2020 Accepted article published: 4 August 2020 Published online in Wiley Online Library: 17 September 2020

(wileyonlinelibrary.com) DOI 10.1002/jsfa.10704

Can we associate environmental footprints with production and consumption using Monte Carlo simulation? Case study with pork meat

Ilija Djekic,[a*] Ivana Bozickovic,[b] Vesna Djordjevic,[c] Sergiy Smetana,[d] Nino Terjung,[d] Jovan Ilic,[a] Ana Doroski[a] and Igor Tomasevic[e]

Abstract

BACKGROUND: Growing population demands more animal protein products. Pork remains one of the traditional and relatively sustainable types of meats for human consumption. In this paper, life-cycle assessment was performed using data from 12 pig farms. In parallel, a survey on the consumption of pork meat products was conducted analyzing responses from 806 pork meat consumers. The study aims to provide a quantitative calculation of six environmental footprints associated with the consumption of pork meat products in Serbia by analyzing data from pig farms and a pork meat consumption survey.

RESULTS: Results revealed that pork meat production is responsible for the emission of 3.50 kg $CO2_e$ kg^{-1} live weight, 16.1 MJ_e kg^{-1}, 0.151 mg $R11_e$ kg^{-1}, 31.257 g SO_{2e} kg^{-1}, 55.030 g PO_{4e} kg^{-1} and 3.641 kg 1.4 dB_e kg^{-1}. Further calculations reveal that weekly emissions of various environmental potentials associated with an average consumer of pork meat products in Serbia are estimated at values of 4.032 kg CO_{2e} $week^{-1}$, 18.504 MJ_e $week^{-1}$, 0.17435 mg $R11_e$ $week^{-1}$, 35.972 g SO_{2e} $week^{-1}$ and 63.466 g PO_{4e} $week^{-1}$.

CONCLUSIONS: Results show that, on the one hand, pork products are responsible for environmental production impacts that mainly occur on farms while, on the other hand, consumption is characterized with high meat inclusion rates. As a leverage strategy it is recommended for producers to concentrate on lowering the production impacts rather than trying to reach consumers for sustainability conciseness.

Keywords: pig farms; pork meat consumption; environmental potentials; life-cycle assessment; meat sustainability

INTRODUCTION

There has been a significant increase in global pork consumption over time, driven by a growing world population and declining prices,[1] as outlined by the Food and Agriculture Organization (FAO). The average prices for pork in 2018 were 2.2% lower than in 2017, reflecting the annual average declining of meat values. Trade liberation, globalization and urbanization highly influence overall pork consumption.[2, 3] The global pork consumption on a *per capita* basis is expected to decline slightly over the years 2019–2028, with consumption reaching saturation levels in most developed countries.[4] Still world pork production is expected to increase up to 131 million tons in 2028 from 121 million tons in 2018. The temporal trend in pork production is given in Fig. 1.[5]

Overall, the increase in global pork production will decelerate over the next decade because pork is not an important element of national diets in many developing regions. At the global level, growth in demand for animal protein in the next decade is projected to slow down as well. The trend of pork protein supply over the years is depicted in Fig. 1.[4, 5] Despite the fact that pork meat has nutritional value, its consumption is associated with several adverse health issues such as cancer and diabetes.[6] The debate on pros and cons has expanded lately by introducing the environmental dimension and criticizing pork meat production and consumption.

* Correspondence to: I Djekic, Faculty of Agriculture, University of Belgrade, Nemanjina 6, Belgrade – Zemun 11080, Republic of Serbia. E-mail: idjekic@agrif.bg.ac.rs; idjekic@mts.rs

a Institute of Food Technology and Biochemistry, Faculty of Agriculture, University of Belgrade, Belgrade, Republic of Serbia

b Institute of Animal Science, Faculty of Agriculture, University of Belgrade, Belgrade, Republic of Serbia

c Institute of Meat Hygiene and Technology, Belgrade, Republic of Serbia

d German Institute of Food Technologies, Quakenbrück, Germany

e Department of Animal Origin Products Technology, Faculty of Agriculture, University of Belgrade, Belgrade, Republic of Serbia

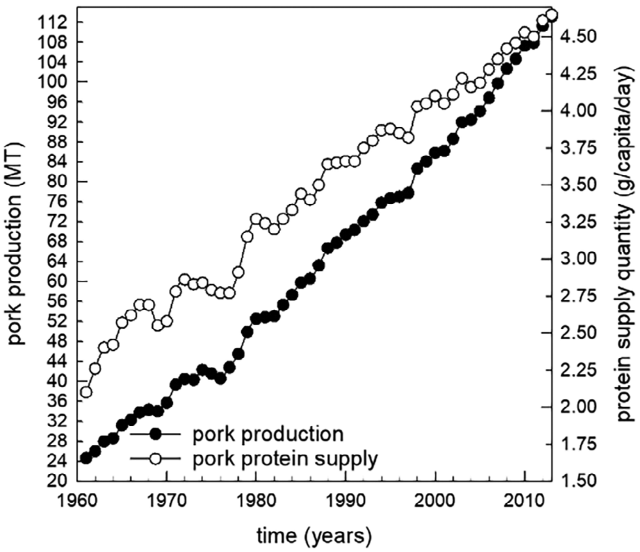

Figure 1. Temporal trends in pork production and pork protein supply over the years (MT, million tons).

Regarding pig farms, large pig production systems worldwide have a defined level of uniformity related to animal genetics, feed and housing systems, while in developing countries, large portions of the pig population are small in scale where pigs are sources of nutrition and income and play a role in cultural traditions.[7] In general, there are three main types of pig farming systems – indoor, outdoor and free range. In Serbia, over 75% of pig producers are backyard farms, around 20% are family farm producers with below 100 pigs and there are only a limited number of large commercial farms.[8] When it comes to feed, Serbian pig producers either produce their own compound feed or complement feed with purchased premixes where larger pig producers work closely with feed companies.

The environmental impact of production–consumption chains is accounted for through a life-cycle approach, when the impacts on the environment are calculated for a unit of production or service (functional unit) with allocation from all the stages of production.[9] In the food chain, typical stages cover agriculture, processing, transportation, storing, cooking and waste treatment.[10] The impacts are associated with the environments of release (air, water, soil) and weighted according to the representative selected impact units. Global warming potential (GWP) accounts for emissions into air and represents the damage level in kg CO_2 equivalent (CO_{2e}) comprising weighted impacts of greenhouse gases for the timeframe of 100 years.[11] Cumulative energy demand (CED) is a parameter accounting for the use of energy sources, expressed in MJ, for production/consumption, consisting of non-renewable and renewable sources.[12] Acidification potential (AP) for emissions to air calculates the impact of acidifying substances on soil, groundwater, surface water, organisms and ecosystems. It involves calculating the potentials of all acidifying pollutants relative to the acidifying effect of SO_2 and is expressed as kg SO_2 equivalents per kg emission.[13] In pig farms, ammonia is identified as the main AP source released from manure and during manure management.[14] Eutrophication includes all impacts due to excessive levels of macronutrients in the environment caused by emissions of nutrients to air, water and soil. Eutrophication potential (EP) is based on the stoichiometric procedure of Heijungs,[15] and expressed as kg PO_4 equivalents per kg emission. At farms, EP mainly comes from nitrates associated with feed production and ammonia from manure.[14]

Ozone depletion potential (ODP) calculates the destructive effects of halogenated hydrocarbons on the stratospheric ozone layer over a time horizon of 100 years. The impacts of chemical compounds are weighted in relation to the impact of trichlorofluoromethane (R-11 or CFC-11).[12] Human toxicity potential (HTP) refers to fate, exposure and effects of toxic substances on human health, usually for an infinite time horizon.[16] For each toxic substance, HTP is expressed as 1,4-dichlorobenzene equivalents (kg 1.4 DB eq) per unit of production.

Several life-cycle assessment (LCA) studies have highlighted that pork production contributes to the deterioration of aquatic systems through excretion of nitrogen and phosphorus. The main focus is directed to climate change effects from greenhouse gas emissions associated with manure storage and its application to fields, as well as to AP and EP mainly occurring at farm levels.[17] There are large differences in environmental impacts of pork production reported in the literature, which are connected with variations in feed conversion rates,[18] system boundaries and functional units,[19] geographical boundaries and associated established production systems.[17] Focusing only on pig farms, besides feed production and formulation, variations in environmental footprints occur depending on types of breed and production systems, slaughtering age/weight/male–female ratio and good veterinary practice in place.[14] Röös *et al.*[20] reported that the majority of all environmental impacts in the meat supply chain originate at farms with only 12% derived from post-farm activities, such as meat processing, transportation and retail. At the end of the pipeline, consumer/household levels comprise purchasing habits, kitchen practices and dietary habits affecting ODP associated with maintaining the cold chain[21] and GWP linked with energy consumption in kitchens and food waste.[22]

Therefore, the aim of the study reported here was to provide a quantitative calculation of six selected environmental footprints associated with the consumption of pork meat products in Serbia by combining data from pig farms and values from a pork meat consumption survey.

MATERIALS AND METHODS

Pork meat consumption

In order to collect data on pork meat consumption in Serbia, a field survey was conducted during the second half of 2018 using a questionnaire designed according to European Food Safety Authority (EFSA) guidelines.[23] The tested population sample was older than 20 years and living in large cities. Data collection was obtained through personal interviews. Brief explanations about the objectives of this research were given to the respondents. Although demographic characteristics were not stratified, this method represents a 'convenience sample' and evaluates the dietary habits relating to meat products of urban populations.[24] The rationale for choosing to perform this field survey was that data on consumption of pork meat in Serbia are mainly published in statistical yearbooks,[25] with no national studies of the consumption per pork meat products.

Sample size was determined in line with published dietary surveys covering different types of assessments in Europe where the sample size ranged from 303 in Cyprus to more than 10 000 in Germany.[26] Out of 900 interviewees, 94 of them did not

Table 1. Demographic profile of the sample (N = 806)[a]

	Total	Average intake of pork meat (kg)[b]
Gender		
Male	399 (49.5%)	0.78 ± 0.74
Female	407 (50.5%)	1.51 ± 1.21
Total		1.15 ± 1.07
Age		
Less than 24 years	329 (40.8%)	1.01 ± 0.98
25–34 years	195 (24.2%)	1.29 ± 1.13
35–49 years	142 (17.6%)	1.39 ± 1.20
50–64 years	89 (11.0%)	1.12 ± 1.01
Over 65 years	51 (6.4%)	0.97 ± 0.79
Average body weight (kg)	73.96 ± 15.98	1.15 ± 1.07

[a] *N* represents the number of respondents; (%) represents their share in the sample.
[b] Based on a 7-day recall.

consume any type of pork meat product in the last 7 days so further calculations were based on responses from 806 respondents.

The questionnaire consisted of two sections. The first section included general demographic information about the respondents, i.e. gender, age and weight (Table 1). The second section examined consumption patterns of selected pork meat products sold and consumed in Serbia. The respondents had an opportunity to recall types and quantities (in grams) of meat products consumed in the last 7 days. A recall period of 7 days was chosen as a more efficient way to estimate personal diets since the EFSA suggests more recording/recall days per person to estimate habitual patterns, as opposed to one-day recall surveys.[23]

Before the field research, the authors placed all investigated pork meat products on plates/dishes as usually served, determined values of product portions (in grams) and made photographs of the products. In terms of visual aid, the interviewees were provided with photographs of meat products and provided weights of portions. Pork meat content in the analyzed products is presented in Table 2. The values were captured from the literature covering meat technology practices in Serbia.[27–30]

Pig production

During the first half of 2019, the authors visited 12 pig farms and collected inventory data corresponding to the main environmental impacts that occur on site. Criteria for choosing pig farms were that they represent two typical types of pig production in Serbia – family pig farm producers and commercial pig farms. Prior to visiting the farms, a LCA-based questionnaire was designed[14] and sent in advance to aid farm managers in providing data on a '1 year basis' with information gathered for 2018 corresponding to the year of the consumption survey. Inventory data covered feed, resources (energy, water), cleaning agents and outputs, mainly waste (organic/inorganic/manure) and wastewater (Table 3).

All farms included in this study used standard feed mixtures for different classes of pigs. All mixtures contained maize predominantly (58–65%, depending on type of mixture), mostly as ground corn grain, and far less as corn distillers' grain with solubles. Besides maize, wheat flour byproducts (5–17%) were used as a carbohydrate feed. In Serbia, it is usual practice to use wheat flour byproducts as a replacement for maize in nutrition of older classes of pigs. As a source of protein, soybean-based feeds are used: soybean meal, soybean hulls and commercial soybean protein products. These feeds represent about 29% of mixture for the youngest class of animals decreasing to 3% of mixture in the diet

Table 2. Content of meat in pork meat products included in this study and average weekly intakes

Meat product group	Type of meat product	Portion (g)	Content of meat in final product (%)
Fresh processed meat products	Minced pork meat	200	100
	'Ćevapčići' – grilled uncased pork sausages	150	97
	Pork hamburger	200	97
	Raw sausage	160	97
Average intake of this group of products – 7-day recall (kg)			0.54 ± 0.49
Raw (dry) fermented sausages	Fermented sausage type 'čajna'	15	97
	Fermented sausage type 'sremska'	25	97
	Fermented sausage type 'kulen'	20	97
	Frankfurter	105	40
	Sausage Parisien	50	75
Average intake of this group of products – 7-day recall (kg)			0.41 ± 0.39
Cooked cured meat products	Cooked ham	20	85
Average intake of this group of products – 7-day recall (kg)			0.16 ± 0.11
Raw cured meat products	Pork prosciutto	80	97
	Bacon	70	97
	Dry pork neck	80	97
	Pancetta	60	97
Average intake of this group of products – 7-day recall (kg)			0.52 ± 0.49
Other pork meat product	Pork hock	100	97
	Pork ribs	440	97
	Pork ham	85	97
Average intake of this group of products – 7-day recall (kg)			0.33 ± 0.28

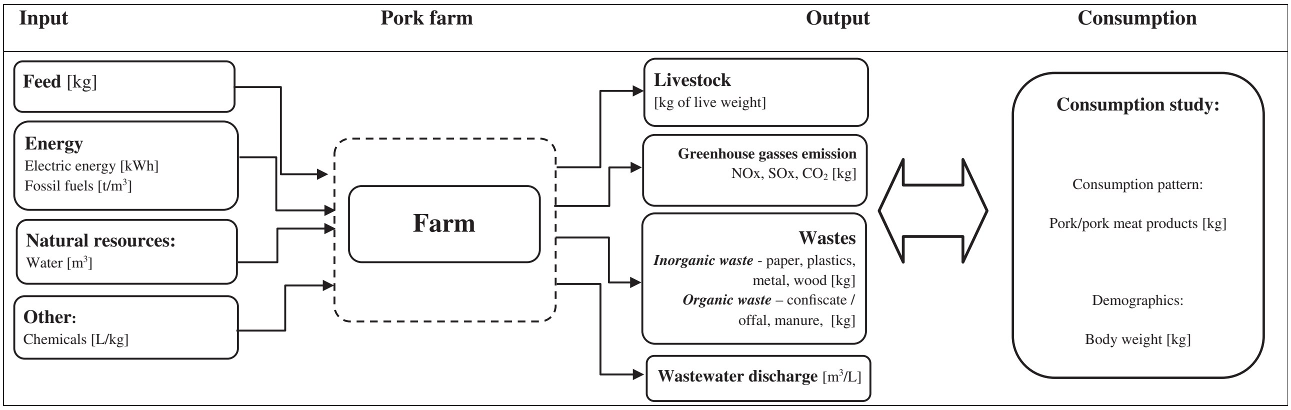

Figure 2. System boundaries of the life-cycle study.

of pigs at the end of fattening. In older classes of animals, the percentage of soybean feeds decreases, and they are replaced with sunflower meal and yeast in amounts up to 12% and 5%, respectively. Based on total quantity of different mixtures used, the amount of specific feeds was obtained and used for further calculations. Farm animals were either of domestic population of Landrace breed, or combination of Landrace boars and Yorkshire sows, which also fully corresponds to the general situation in pig production in Serbia.

Environmental potentials

In order to evaluate the selected environmental potentials of pork meat production, a LCA at pig farms was performed through four phases: (i) mapping the process of pig production at farms, (ii) setting scope and boundaries at the farm gate, (iii) collecting data from farms and (iv) calculating environmental potentials.[9] The selected functional unit (FU), which confers a reference for inputs and outputs, was set as 1 kg of live weight at the farm gate.

The 'pork farm' stage covered all livestock activities including the contribution of feed production and waste/manure management.[21] The 'consumption' stage covered quantities of consumed pork meat products. Figure 2 depicts the system boundaries of this life-cycle study. Activities that occur from 'pork farm' to 'consumption' were not included in this assessment. Inventory calculation (Table 3) of environmental impacts was performed using data from CCaLC and ecoinvent databases.[31] Environmental footprints calculated in this study covered GWP, AP, EP, CED, ODP and HTP.

Estimated weekly environmental potentials

All environmental potentials associated with pork meat consumption were calculated as estimated weekly potential (EWP) using consumption data based on the 'seven-day recall', combining data from the field survey and content of meat in pork meat products defined in Table 2 and impacts coming from pork farms expressed in defined FU:[32]

$$\mathrm{EWP}_7 = \sum_{i=1}^{n} Q_i \times E_\mathrm{e} \qquad (1)$$

where Q_i is the reported amount of each pork-meat product consumed on a weekly basis (kg) and E_e is the emission per kg of FU. Depending on the type of environmental impact calculated, the following applies: GWP (kg CO_{2e} kg^{-1}); AP (g SO_{2e} kg^{-1}); EP (g PO_{4e} kg^{-1}); CED (MJ_e kg^{-1}); ODP (mg R_{11e} kg^{-1}); HTP (kg 1.4 DB_e kg^{-1}). Estimated weekly environmental emission per body weight (EWE_{bw}) was calculated by dividing the values from Eqn (1) with reported body weight of the interviewees expressed in kg. Methodology for combing production and consumption data and calculating environmental potentials on a weekly basis are explained in the work of Djekic *et al.*[32]

Statistical analysis

Collected and calculated data related to environmental impacts at farm level were further processed with 10 000 iterations using Monte Carlo simulation. Since no publications have reported characterization of data distributions of these impacts at farms, and having a low number (12 pig farms), a triangular distribution was assumed.[33] Minimum and maximum were defined as lowest and highest values of the range collected during the field survey while mean values were considered as modes.[32]

Monte Carlo analysis of 100 000 simulations was employed to estimate six environmental footprints associated with the consumption of pork-meat products. Probability distribution fittings for body weight and intake of pork-meat products (Table 1) were performed.

Monte Carlo as a probabilistic simulation tool was employed to estimate the environmental impacts combining data from production and consumption of pork meat products in line with guiding principles developed by the Environmental Protection Agency, FAO and World Health Organization.[34, 35] The uncertainty of Monte Carlo variation was calculated as confidence intervals (95%) of the mean values.

RESULTS AND DISCUSSION

Consumption of pork meat products in Serbia

Table 1 indicates an equal distribution of both genders during the survey. As for age of respondents, the majority of them were young (below age of 24, comprising 40.8%), followed by mid-range age of between 25 and 49 years of age comprising 41.8% of the sample. Average body weight of the sample was around 74 kg, which is slightly above EFSA assumptions stating that body weight of 70 kg is an average for an adult population in Europe.[36] Survey shows that Serbian consumers eat around 1.15 kg of pork meat and meat products per week or around 0.165 kg a day. Results are slightly above average pork consumption in Europe that is estimated at 35.5 kg *per capita* in 2018.[37]

Table 3. Summary of data sources considered in this study

Input/output	Source
Energy	
Electricity (Serbian profile)	International Energy Agency (IEA, 2013)
Liquefied petroleum gas (LPG)	CCaLC database[31]
Diesel fuel	CCaLC database[31]
Feed	
Maize for feed	CCaLC database[31]
Wheat for feed	CCaLC database[31]
Soybean for feed	CCaLC database[31]
Barley for feed	CCaLC database[31]
Sunflower for feed	Ecoinvest database from CCaLC database[31]
Feed for pigs	CCaLC database[31]
Cleaning agents	
Acid chemicals	CCaLC database[31]
Alkaline chemicals	CCaLC database[31]
Water	
Tap water at user (Europe)	Ecoinvest database from CCaLC database[31]
Waste	
Biodegradable waste (confiscate/offal)	CCaLC database[31]
Manure	Reserve Livestock Calculation Tool (RLCT, 2012)
Solid manure	Ecoinvest database from CCaLC database[31]
Waste water – industrial treatment	CCaLC database[31]
Landfill – wood/wood products	CCaLC database[31]
Landfill – plastics	CCaLC database[31]
Landfill – paper/carton pack	CCaLC database[31]
Landfill – municipal waste	CCaLC database[31]

Consumption of meat and meat products corresponds with the nutritional needs for higher content in animal protein.[38, 39] Today meat continues to supply nutrients and plays a vital role in human life as meat is an energy- and nutrient-dense food.[40] Finally, these products are consumed all over the world due to their sensory characteristics and to cultural habits.[41] Additionally, for evaluating protein quality in human foods, the digestible indispensable amino acid score (DIAAS) is recommended by the FAO. Bailey *et al.*[42] determined the values for pork products stating that they have values greater than 100 whilst curing and cooking may increase DIAAS. In comparison, DIAAS values for whey protein isolate, soy protein concentrate and pea protein concentrate are 100, 84 and 62, respectively.[43] Therefore, if one considers changing a diet to a more plant protein-based one with the idea of replacing meat proteins by plant proteins in sausages, and reducing meat consumption or associated CO_2 emission, the changing DIAAS values also need to be considered.

Environmental impact of pork meat production in Serbia

Derived from the on-site survey, six environmental potentials associated with production of 1 kg of live weight were calculated (Fig. 3; Table 4). The range of CO_2 emissions from pig farms was between 1.99 and 5.50 kg CO_{2e}, mainly due to different distributions of various classes of pigs and feed conversion. On average, 3.50 kg CO_{2e} corresponds to production of 1 kg of live weight. These results correlate well with the results for European pork production where 1 kg of live weight resulted in 2.4–6.2 kg CO_{2e}.[17] Alig *et al.*[44] calculated GWP for Switzerland, Germany and Denmark, and identified impacts of 1 kg live weight in the range 3.3–3.9 kg CO_{2e}. Results slightly differ when they are expressed as slaughterhouse weight with 3.22 kg CO_{2e} in German slaughterhouses [45] and 3.5 kg CO_{2e} in Brazilian slaughterhouses.[46] Typical Austrian pork in slaughterhouses impacts the environment at a rate of 4.75 kg CO_{2e}.[47] Danish pork production and frozen distribution is mentioned as one of the most efficient when impacts of byproducts are allocated and substituted. The production of pork products resulted in 3.4 kg CO_2 eq. per kg of product and with distribution to China or Australia it increased to 3.7 kg CO_2 eq. per kg.[18]

AP and EP values were in the range from 12.63 to 55.05 g SO_{2e} kg^{-1} of live weight and between 23.49 and 95.06 g PO_{4e} kg^{-1} of live weight, respectively. The average values of these two potentials were 31.26 g SO_{2e} kg^{-1} (AP) and 55.03 g PO_{4e} kg^{-1} (EP). AP values are in line with results of the study of Kebreab *et al.*[17] for European pork production with values between 33.3 and 50.0 kg SO_{2e} (AP) associated with 1 kg of live weight. As for EP, our results were higher than average values for Europe estimated between 11.5 and 16.0 g PO_{4e}. In Australia and Brazil, pork in slaughterhouse impacts AP at rates of 61.5 and 76.13 g SO_{2e}, respectively.[46, 47] German pork production is similarly environmentally efficient: 57.1 g SO_{2e} (AP) and 23.3 g PO_{4e} (EP) per kg pork as slaughter weight.[45] LCA of nine pork productions estimate AP from 43 to 741 g SO_{2e} kg^{-1} and EP from 15 to 102 g PO_{4e} kg^{-1}.[48]

Average value of CED in Serbian pig farms corresponds to 16.1 MJ_e kg^{-1} of live weight with the values falling between 7.12 and 23.84 MJ_e kg^{-1}. Study from Switzerland, Germany and Denmark show slightly higher values of 23.5–31.8 MJ_e kg^{-1}.[44] In Brazil, Cherubini *et al.*[46] estimate that Brazilian pork at slaughterhouse is responsible for consumption of 21.5 MJ_e kg^{-1}. The average value of HTP was 3.64 kg 1.4 DB_e kg^{-1} of live weight, with the values falling in the range between 0.77 and 7.09 kg 1.4 DB_e kg^{-1}.

The uncertainty of this LCA study is of moderate level, considering sample size (12 farms), quality of data collected from farms and calculated values for the six environmental potentials. Results of uncertainty analysis of Monte Carlo variation are provided in Table 4. Slight differences in results originate in respect to countries at macro level (developed *versus* developing), economic perspectives of pig farms at micro level (high and low profit) and production systems employed.[14] Main mitigation strategies aimed at decreasing environmental impacts at farms should focus on feed, animal husbandry and nutrient, manure and resource management.[49]

Environmental impacts associated with consumption of pork meat products

Consumption of meat is nowadays investigated not only from a nutritional point of view, but also in terms of its environmental impact.[50] The FAO recently introduced a new term coined 'sustainable diet' focused on diets optimally healthy and with low environmental impacts.[51] Although authors associate climatic impact of food with both production and consumption,[50] typical GWP data in the literature are only linked to production.

Based on the Monte Carlo simulation we have employed, the average Serbian pork meat consumer is responsible for emitting around 4 kg CO_{2e} $week^{-1}$ and affecting AP and EP with almost

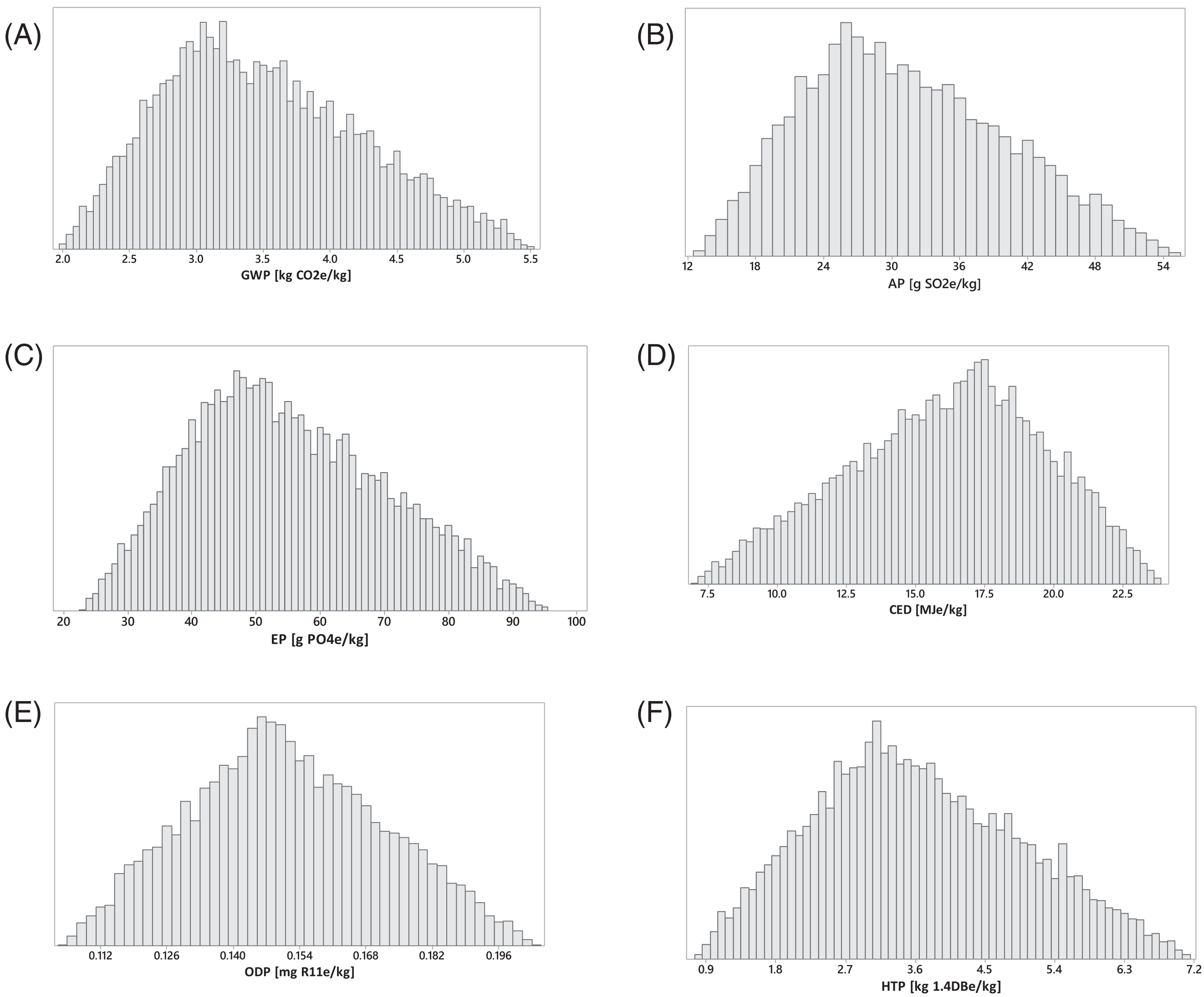

Figure 3. Estimated environmental impacts of pork meat production at farm gate after a Monte Carlo analysis of 10 000 simulations. Functional unit: 1 kg of live weight. (a) GWP (kg CO_{2e} kg^{-1}); (b) AP (g SO_{2e} kg^{-1}); (c) EP (g PO_{4e} kg^{-1}); (d) CED (MJ_e kg^{-1}); (e) ODP (mg $R11_e$ kg^{-1}); (f) HTP (kg 1.4DB_e kg^{-1}).

36 g SO_{2e} week^{-1} and 63 g PO_{4e} week^{-1}, respectively (Fig. 4). Each week, energy consumption associated with eating pork meat products is estimated at 18.5 MJ_e per consumer. Just for comparison, a quick look at LCA databases used for our inventory analysis shows the following estimation for CO_2 emissions of food often consumed during lunch: home-made portion of lamb curry and rice (*ca* 0.55 kg), 4.66 kg CO_2; home-made portion of chicken curry and rice (*ca* 0.55 kg), 1.80 kg CO_2; 0.5 L of water in

Table 4. Estimated environmental impacts of pork meat production at farm gate (functional unit: 1 kg of live weight)

	GWP (kg CO_{2e} kg^{-1})	AP (g SO_{2e} kg^{-1})	EP (g PO_{4e} kg^{-1})	CED (MJ_e kg^{-1})	ODP (mg $R11_e$ kg^{-1})	HTP (kg 1.4 DB_e kg^{-1})
Mean	3.5009	31.257	55.030	16.100	0.15135	3.6409
Minimum	1.9967	12.632	23.486	7.122	0.10453	0.7741
1st quartile	2.9401	24.614	43.645	13.620	0.13671	2.6555
3rd quartile	4.0138	37.514	65.566	18.673	0.16572	4.5890
Maximum	5.5018	55.052	95.056	23.836	0.20328	7.0957
95% confidence interval of mean	3.4864–3.5153	31.085–31.430	54.736–55.324	16.031–16.169	0.15095–0.15174	3.6149–3.6670

All values are derived from 10 000 runs of Monte Carlo simulation.

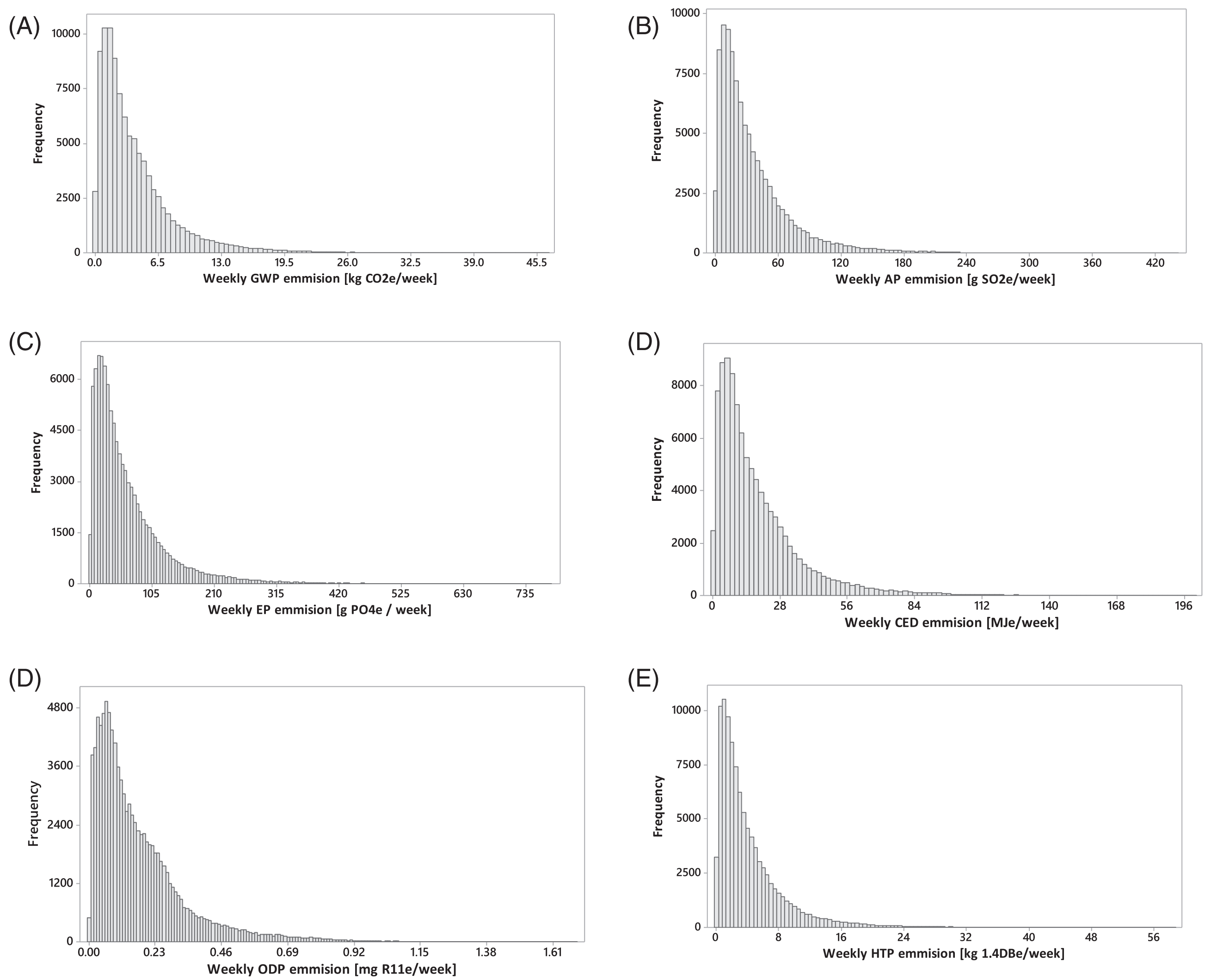

Figure 4. Estimated weekly emissions of environmental impacts associated with the consumption of pork meat products after a Monte Carlo analysis of 100 000 simulations. (a) GWP (kg CO_{2e} week^{-1}); (b) AP (g SO_{2e} week^{-1}); (c) EP (g PO_{4e} week^{-1}); (d) CED (MJ_e week^{-1}); (e) ODP (mg $R11_e$ week^{-1}); (f) HTP (kg $1.4DB_e$ week^{-1}).

poly(ethylene terephthalate) packaging, 0.950 kg CO_2; 1 L of beer in glass bottle, 0.878 kg CO_2; and 1 L of red wine in glass bottle, 1.06 kg CO_2.[31] This means that depending on the type of food consumed during lunch, one can be responsible for emitting over 5 kg of CO_2 every day, or over 35 kg of CO_2 a week.

Deployment of data with respect to body weight (bw) of consumers gives the following data: GWP, 55.828 g CO_{2e} bw^{-1} week^{-1}; AP, 0.4982 g SO_{2e} bw^{-1} week^{-1}; EP, 0.8790 g PO_{4e} bw^{-1} week^{-1}; CED, 0.25619 MJ_e bw^{-1} week^{-1}; ODP, 0.002414 mg $R11_e$ bw^{-1} week^{-1}; HTP, 0.05794 kg 1.4 DB_e bw^{-1} week^{-1} (Table 5). These results contribute to the overall discussion on the environmental impact of pork meat consumption. Even at first glance, it is obvious that values are affected by two main factors – impacts from pig farms and dietary patterns. In order to decrease the overall environmental impacts, the main question that arises is whether it is reasonable to shift the (environmental) focus from farms to consumers.

Although we are experiencing various climate change debates with certain environmental pressures focused on changing dietary habits, scientific models are still prevailing compared to observed changes in everyday food consumption. One of a few studies that connected dietary habits and environmental impacts was conducted by Westhoek *et al.*,[52] where replacement of animal-origin food with plant-based substitutes revealed a potential for decreasing environmental impacts by changing eating patterns. Debate on means for changing diet behavior is another obstacle in creating a food sustainable environment focused on plant-based food. Rijsberman[53] emphasizes that switching to vegan/vegetarian cuisine is a major change, and all 'major changes' are very challenging. One should bear in mind that reduction in meat consumption does not imply lower environmental impact depending on replacing a type of food.[50] Finally, environmentally friendly diets may also lead to nutrient deficits.[54]

An additional question is: how does 'global environmental concern' affect consumption of meat? A recent study performed in Germany and Poland uncovered that pig production with limited (zero) carbon footprint was considered as least important to consumers[55] compared to animal welfare issues, the health and safety of pigs. Although GWP is associated with climate change as a global concern compared to other impacts such as AP and EP that are observed as local problems,[56] no other environmental information has been identified as interesting for any food

Table 5. Estimated environmental weekly impacts of consumption of pork meat and pork meat products per average consumer

	GWP		AP		EP	
	(kg CO_{2e} week^{-1})	(g CO_{2e} bw^{-1} week^{-1})	(g SO_{2e} week^{-1})	(g SO_{2e} bw^{-1} week^{-1})	(g PO_{4e} week^{-1})	(g PO_{4e} bw^{-1} week^{-1})
Mean	4.0318	55.828	35.972	0.4982	63.466	0.8790
Minimum	0.0346	0.381	0.235	0.00264	0.371	0.0047
1st quartile	1.3790	18.690	11.881	0.16118	21.064	0.2854
3rd quartile	5.3438	73.791	47.682	0.65644	83.660	1.1547
Maximum	46.3595	917.014	420.700	7.25547	777.235	12.643
95% confidence interval of mean	4.0075–4.0562	55.482–56.174	35.748–36.197	0.49501–0.50139	63.070–63.862	0.8733–0.8846
	CED		ODP		HTP	
	(MJ_e week^{-1})	(MJ_e bw^{-1} week^{-1})	(mg $R11_e$ week^{-1})	(mg $R11_e$ bw^{-1} week^{-1})	(kg 1.4 DB_e week^{-1})	(kg 1.4 DB_e bw^{-1} week^{-1})
Mean	18.504	0.25619	0.17435	0.002414	4.1831	0.05794
Minimum	0.117	0.00151	0.00163	0.000019	0.0162	0.00022
1st quartile	6.299	0.08251	0.06094	0.000823	1.3012	0.01762
3rd quartile	24.797	0.34049	0.23406	0.003212	5.4833	0.07536
Maximum	199.332	3.64051	1.68582	0.030970	58.4002	1.07361
95% confidence interval of mean	18.392–18.616	0.25460–0.25777	0.17332–0.17537	0.002399–0.002429	4.1557–4.2105	0.05755–0.05833

bw, body weight. All values are derived from a 100 000 runs of Monte Carlo simulation.

consumer. Carbon footprint labels associated with animal production, if introduced, will have limited to no effect on consumers of these products.[57] Therefore, targeting consumers for environmental impact reduction might be not as efficient as developing climate-resilient sustainable meat production which can efficiently focus on pollution prevention and environmental and technological improvements rather than discussion of nutritional needs.[21, 53] Macdiarmid *et al.*[58] in their study emphasize that a sustainable diet meeting all nutritional needs with low impacts can also be obtained with meat and/or dairy products on the table. This implies a necessity for a more holistic approach in combating dietary emissions rather than blaming livestock production and consequently only meat consumption.[50]

CONCLUSIONS

This study is one of the first of its kind connecting pig farms and consumption of pork meat and meat products as two sides of the pipeline. As such, it gives an additional dimension towards evaluating environmental footprints associated with consumers and their consumption habits, indicating rather high meat consumption rates, and associated environmental impacts. Under certain cautions, these results may be considered in a broader sense as generic, emphasizing that consumer-based data (consumed quantities and body weight) as well as calculated environmental potentials are in line with other published pork meat-related consumption/LCA studies in Europe.

Considering pork meat consumers, pig producers and the environment as cornerstones of an interactive triangle, the area within gives a perspective for improvement opportunities in terms of consumers' dietary habits and sustainable pork meat production at farms. The authors believe that the pathway in promoting sustainable diets should be towards providing consumers with both nutritional and environmental values associated with all types of food and leaving the consumers with a free choice as opposed to aggressive campaigns against meat consumption.

This study has several limitations. The estimation of the consumed quantities of pork meat and pork meat products was based on the '7-day' recall study and consumption of imported pork meat/pork meat products was not taken into account. A second limitation is associated with environmental data extracted from various LCA databases. Finally, since this study explored two ends of the meat supply chain continuum (pork farms and pork meat consumers), not all activities that occur from 'pork farm' to 'consumers' were analyzed, and this also may be considered as a limitation of the study.

Future studies should explore this scenario for other types of meat, challenging environmental and nutritional theories. Consideration of additional environmental footprints could be a benefit in further research.

REFERENCES

1 Palmer C, The demand for meat and patterns of consumption: an introductory guide, in *Nutrition and Climate Change: Major Issues Confronting the Meat Industry. Proceedings of the Langford Food Industry Conference*, Bristol, UK, 30 June–1 July 2010. Nottingham University Press, pp. 139–157 (2011).
2 Delgado CL, Rising consumption of meat and milk in developing countries has created a new food revolution. *J Nutr* **133**:3907S–3910S (2003).
3 Henchion M, McCarthy M, Resconi VC and Troy D, Meat consumption: trends and quality matters. *Meat Sci* **98**:561–568 (2014).
4 OECD, OECD-FAO Agricultural Outlook in OECD Agriculture Statistics: Ed. Organisation for Economic Co-operation and Development, OECD Headquarters, Paris, France (2019).
5 FAOSTAT. 2019. Food and agriculture data [Online]. Food and Agriculture Organization of the United Nations. Available: http://www.fao.org/faostat/en/#home [27 January 2020].

6 Verbeke W, Pérez-Cueto FJA, Barcellos MD, Krystallis A and Grunert KG, European citizen and consumer attitudes and preferences regarding beef and pork. *Meat Sci* **84**:284–292 (2010).
7 MacLeod M, Gerber P, Mottet A, Tempio G, Falcucci A, Opio C *et al*., *Greenhouse Gas Emissions from Pig and Chicken Supply Chains: A Global Life Cycle Assessment*. Food and Agriculture Organization of the United Nations, Rome (2013).
8 van Bussel-van Lierop A, van Wagenberg C and Somers D, Serbian Pig Sector: An Overview: Fact Finding Mission: Opportunities for Collaboration between Serbia and The Netherlands. Wageningen UR Livestock Research, Wageningen, NL (2015).
9 ISO, ISO 14040:2006. Environmental management – Life cycle assessment – Principles and framework. International Organization for Standardization, Geneva, Switzerland (2006).
10 Djekic I, Sanjuán N, Clemente G, Jambrak AR, Djukić-Vuković A, Brodnjak UV *et al*., Review on environmental models in the food chain: current status and future perspectives. *J Clean Prod* **176**: 1012–1025 (2018).
11 IPCC, Climate change 2013: the physical science basis, in *Report of the Intergovernmental Panel on Climate Change*, ed. by Stocker TF, Qin D, Plattner G-K, Tignor M, Allen SK, Boschung J *et al*. Cambridge University Press, Cambridge, MA (2013).
12 Hischier R, Weidema B, Althaus H-J, Bauer C, Doka G, Dones R *et al*., Implementation of life cycle impact assessment methods. Final report ecoinvent v2.2 (2010).
13 Čuček L, Klemeš JJ and Kravanja Z, Overview of environmental footprints, in *Assessing and Measuring Environmental Impact and Sustainability*. Elsevier, Oxford, UK, pp. 131–193 (2015).
14 Djekic I and Tomasevic I, Environmental indicators in the meat chain, in *Quantification of Sustainability Indicators in the Food Sector*, ed. by Muthu SS. Springer, Singapore, pp. 55–82 (2018).
15 Heijungs W, Environmental life cycle assessment of products: guide. Technical report of Centre of Environmental Science, NOH Report 9266, Leiden, The Netherlands (1992).
16 Hertwich EG, Mateles SF, Pease WS and McKone TE, Human toxicity potentials for life-cycle assessment and toxics release inventory risk screening. *Environ Toxicol Chem* **20**:928–939 (2001).
17 Kebreab E, Liedke A, Caro D, Deimling S, Binder M and Finkbeiner M, Environmental impact of using specialty feed ingredients in swine and poultry production: a life cycle assessment. *J Anim Sci* **94**: 2664–2681 (2016).
18 Bonou A, Colley TA, Hauschild MZ, Olsen SI and Birkved M, Life cycle assessment of Danish pork exports using different cooling technologies and comparison of upstream supply chain efficiencies between Denmark, China and Australia. *J Clean Prod* **244**:118816 (2019).
19 McAuliffe GA, Chapman DV and Sage CL, A thematic review of life cycle assessment (LCA) applied to pig production. *Environ Impact Assess Rev* **56**:12–22 (2016).
20 Röös E, Ekelund L and Tjärnemo H, Communicating the environmental impact of meat production: challenges in the development of a Swedish meat guide. *J Clean Prod* **73**:154–164 (2014).
21 Djekic I and Tomasevic I, Environmental impacts of the meat chain: current status and future perspectives. *Trends Food Sci Technol* **54**: 94–102 (2016).
22 Djekic I, Miloradovic Z, Djekic S and Tomasevic I, Household food waste in Serbia: attitudes, quantities and global warming potential. *J Clean Prod* **229**:44–52 (2019).
23 EFSA, General principles for the collection of national food consumption data in the view of a pan-European dietary survey. *EFSA J* **7**: 1–51 (2009).
24 Djekic I, Udovicki B, Kljusurić JG, Papageorgiou M, Jovanovic J, Giotsas C *et al*., Exposure assessment of adult consumers in Serbia, Greece and Croatia to deoxynivalenol and zearalenone through consumption of major wheat-based products. *World Mycotoxin J* **12**:431–442 (2019).
25 Yearbook, *Statistical Yearbook of the Republic of Serbia for 2018*. Statistical Office of the Republic of Serbia, Belgrade, Serbia (2019).
26 EFSA, Evaluation of the increase of risk for public health related to a possible temporary derogation from the maximum level of deoxynivalenol, zearalenone and fumonisins for maize and maize products. *EFSA J* **12**:3699 (2014).
27 Tomic N, Tomasevic I, Radovanovic R and Rajkovic A, "Uzice beef prshuta": influence of different salting processes on sensory properties. *J Muscle Foods* **19**:237–246 (2008).
28 Tomasevic I, Stanisic N, Novakovic S, Milovanovic B, Kljajevic N and Milojevic L, Effect of pork to beef meat ratio on the physicochemical properties of frankfurters. *Sci J Meat Technol* **58**:26–31 (2017).
29 Tomasevic I and Djekic I, HACCP in fermented meat production, in Fermented Meat Products, ed. by Nevijo Z. CRC Press, Boca Raton, FL, pp. 512–534 (2016).
30 Tomašević I, Nedeljkovic A, Stanišic N and Pu P, Authenticity assessment of cooked emulsified sausages using Raman spectroscopy and chemometrics. *Fleischwirtschaft* **96**:103–107 (2016).
31 CCaLC, Carbon Calculations over the Life Cycle of Industrial Activities, University of Manchester, Manchester, UK (2018).
32 Djekic I, Petrovic J, Božičković A, Djordjevic V and Tomasevic I, Main environmental impacts associated with production and consumption of milk and yogurt in Serbia: Monte Carlo approach. *Sci Total Environ* **695**:133917 (2019).
33 Zhao X, Schaffner DW and Yue T, Quantification of aflatoxin risk associated with Chinese spices: point and probability risk assessments for aflatoxin B1. *Food Control* **33**:366–377 (2013).
34 Firestone M, Fenner-Crisp P, Barry T, Bennett D, Chang S, Callahan M *et al*., *Guiding Principles for Monte Carlo Analysis*. US Environmental Protection Agency, Washington, DC (1997).
35 FAO/WHO, Principles and methods for the risk assessment of chemicals in food, in *Environmental Health Criteria*. Food and Agriculture Organization of the United Nations/World Health Organization, Geneva, p. 240 (2009).
36 EFSA, Guidance on selected default values to be used by the EFSA scientific committee, scientific panels and units in the absence of actual measured data. *EFSA J* **10**:2579 (2012).
37 OECD, OECD-FAO agricultural outlook, in *OECD Agriculture Statistics*. OECD, Paris, France (2019).
38 Hawkesworth S, Dangour AD, Johnston D, Lock K, Poole N, Rushton J *et al*., Feeding the world healthily: the challenge of measuring the effects of agriculture on health. *Philos Trans R Soc Lond B* **365**: 3083–3097 (2010).
39 Mathijs E, Exploring future patterns of meat consumption. *Meat Sci* **109**:112–116 (2015).
40 Pereira PMCC and Vicente AFRB, Meat nutritional composition and nutritive role in the human diet. *Meat Sci* **93**:586–592 (2013).
41 Font-i-Furnols M and Guerrero L, Consumer preference, behavior and perception about meat and meat products: an overview. *Meat Sci* **98**:361–371 (2014).
42 Bailey H, Berg E and Stein H, Protein quality evaluation in processed human foods by the digestible indispensable amino acid score methodology, in *EAAP Scientific Serie*. Wageningen Academic Publishers, pp. 423–424 (2019). https://doi.org/10.3920/978-90-8686-891-9_130
43 Mathai JK, Liu Y and Stein HH, Values for digestible indispensable amino acid scores (DIAAS) for some dairy and plant proteins may better describe protein quality than values calculated using the concept for protein digestibility-corrected amino acid scores (PDCAAS). *Br J Nutr* **117**:490–499 (2017).
44 Alig M, Grandl F, Mieleitner J, Nemecek T and Gaillard G, *Ökobilanz von Rind-, Schweine-und Geflügelfleisch*. Forschungsanstalt Agroscope Reckenholz-Tänikon ART, Zürich, p. 151 (2012).
45 Reckmann K, Traulsen I and Krieter J, Life cycle assessment of pork production: a data inventory for the case of Germany. *Livest Sci* **157**: 586–596 (2013).
46 Cherubini E, Zanghelini GM, Alvarenga RAF, Franco D and Soares SR, Life cycle assessment of swine production in Brazil: a comparison of four manure management systems. *J Clean Prod* **87**:68–77 (2015).
47 Winkler T, Schopf K, Aschemann R and Winiwarter W, From farm to fork: a life cycle assessment of fresh Austrian pork. *J Clean Prod* **116**:80–89 (2016).
48 de Vries M and de Boer IJM, Comparing environmental impacts for livestock products: a review of life cycle assessments. *Livest Sci* **128**:1–11 (2010).
49 Kipling RP, Taft HE, Chadwick DR, Styles D and Moorby J, Challenges to implementing greenhouse gas mitigation measures in livestock agriculture: a conceptual framework for policymakers. *Environ Sci Policy* **92**:107–115 (2019).
50 Hyland JJ, Henchion M, McCarthy M and McCarthy SN, The role of meat in strategies to achieve a sustainable diet lower in greenhouse gas emissions: a review. *Meat Sci* **132**:189–195 (2017).
51 Burlingame B and Dernini S, Sustainable diets and biodiversity: directions and solutions for policy, research and action, in *International*

Scientific Symposium, Biodiversity and Sustainable Diets United Against Hunger, Rome, Italy, 3–5 November 2010. Food and Agriculture Organization of the United Nations (FAO) (2012).

52 Westhoek H, Lesschen JP, Rood T, Wagner S, De Marco A, Murphy-Bokern D *et al*., Food choices, health and environment: effects of cutting Europe's meat and dairy intake. *Glob Environ Chang* **26**:196–205 (2014).

53 Rijsberman F, The key role of the meat industry in transformation to a low-carbon, climate resilient, sustainable economy. *Meat Sci* **132**: 2–5 (2017).

54 Meier T and Christen O, Environmental impacts of dietary recommendations and dietary styles: Germany as an example. *Environ Sci Technol* **47**:877–888 (2012).

55 Grunert KG, Hieke S and Wills J, Sustainability labels on food products: consumer motivation, understanding and use. *Food Policy* **44**: 177–189 (2014).

56 Picasso VD, Modernel PD, Becoña G, Salvo L, Gutiérrez L and Astigarraga L, Sustainability of meat production beyond carbon footprint: a synthesis of case studies from grazing systems in Uruguay. *Meat Sci* **98**:346–354 (2014).

57 Van Loo EJ, Caputo V, Nayga RM Jr and Verbeke W, Consumers' valuation of sustainability labels on meat. *Food Policy* **49**:137–150 (2014).

58 Macdiarmid JI, Kyle J, Horgan GW, Loe J, Fyfe C, Johnstone A *et al*., Sustainable diets for the future: can we contribute to reducing greenhouse gas emissions by eating a healthy diet? *Am J Clin Nutr* **96**: 632–639 (2012).

