Environmental Indicators in the Meat Chain

Ilija Djekic and Igor Tomasevic

Abstract This chapter gives an overview of the main environmental indicators in the meat chain. The meat sector is considered as one of the leading polluters in the food industry where its impact affects the entire meat chain. Regardless of the research methodology, environmental impacts of the meat chain occurs in three dimensions—climate change, revealing the necessity of analyzing greenhouse gas emissions in perspectives of global warming potential, consumption of natural resources mainly water and energy, and polluting the environment with waste (both organic and inorganic) and polluted wastewater. Bottom-up approach in analyzing environmental indicators provides new evidence relating to the meat sector. It can help environmental specialists and managers in the meat sector, directing them as to how to improve environmental practices on-site. Finally, this chapter gives an overview of improvement perspectives and future research dimensions.

Keywords Meat chain · Environmental indicators · Life cycle Environmental impact · Environmental footprints

1 Introduction

Human beings have a long history of consuming meat, and meat products are considered as omnivores. The first human beings were scavengers and/or hunters (Speth 1989). Depending on the type of animal, carnivores (meat eaters) have digestive systems equipped to fully consume and use animal foods whether through predation or scavenging. On the other side, herbivores (plant eaters) have

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specialized organs to digest cellulose such as bovines (sheep, deer, goats, etc.), equines (horses), and lagomorpha (rabbits and hares). Consequently, eating meat from herbivores is an efficient way for humans to indirectly make the most of plants, grass, and any type of natural pasture. It has been recorded that human ancestors were eating meat as early as 1.5 million years ago (Domínguez-Rodrigo et al. 2012). Since then, humanity is consuming meat from different types of animals and meat consumption became part of our culture.

As a result of world's population growth and overall consumption of meat per capita, it is obvious that meat production is increasing every year (Henchion et al. 2014). One of the reasons for expanding meat production is trade liberalization and globalization of food systems (Delgado 2003). The second reason may be found within the nutritional needs and accepted dietary patterns by consuming foods with higher content in animal protein (Hawkesworth et al. 2010; Mathijs 2015). Finally, consumers worldwide are fond of meat products mainly because of their sensory attributes and cultural habits (Font-i-Furnols and Guerrero 2014).

On the other side, meat is considered as a type of food product holding the greatest environmental impact throughout the food chain (Röös et al. 2013). Regardless of the perspective, environmental impacts of this chain influences three dimensions: (i) climate change in respect to the global warming potential, acidification potential and eutrophication potential; (ii) consumption of natural resources mainly water and energy; and (iii) polluting the environment with discharge of wastewater and various types of waste (Djekic 2015). In order to compare the environmental performances over time and against other companies in the meat chain, it is necessary to develop and make available environmental indicators (Đekić and Tomašević 2017b; Jasch 2000). Due to the economic, environmental, and social implications of the meat chain, meat production, and meat consumption are linked to the three sustainability pillars—economy, society, and environment (Allievi et al. 2015).

Mapping the process(es) and setting the scope and boundaries are important in order to clarify environmental impacts of the food chain analyzed from a "farm to fork" perspective (Djekic et al. 2018). Wider perspective of the meat chain identifies five main stakeholders: (i) farm(er)s, (ii) slaughterhouses, (iii) meat processors, (iv) customers (HoReCa, supermarkets, butcheries, retailers), and (v) consumers (Borrisser-Pairó et al. 2016; Djekic and Tomasevic 2016).

"Farming" is the first stage in the meat chain and it covers all livestock activates where the two major environmental contributors are feed production and waste/manure management (McAuliffe et al. 2016). "Slaughterhouse" covers reception of live animals, livestock handling, animal welfare, slaughtering, and chilling while "meat processing plant" start at the incoming control of carcasses and ends up with the storage of (processed) meat products, including but not limited to thermal meat processing and waste handling (Djekic et al. 2015). Under certain occasions, these two stages can take place at the same premises. Main environmental impacts in slaughterhouses and meat processing plants are usage of energy, usage of water, waste handling, and wastewater discharge (Djekic et al. 2016). "Customers" are recognized as points of sale of meat and meat products such as supermarkets,

grocery shops, or butcher's shops (Djekic and Tomasevic 2016). Finally, "consumers" are considered as the final link the meat chain and household use covers all activates after purchasing of meat and meat products such as refrigeration of meat (Coulomb 2008), meat preparation, and cooking (Xu et al. 2015), as well as discharge of packaging waste and bio-waste (Skunca et al. 2018).

The objective of this chapter is to give an overview of the main environmental indicators in the meat chain. Section 2 gives an overview of the meat production in the world. Section 3 analyses environmental indicators that exist in the meat chain, deployed in three levels of indicators. Section 4 shows generic meat chain indicators and further deploys them from a case study perspective for pork meat, beef meat, and poultry meat. Section 5 analyses environmental impacts of the meat chain highlighting routes to improvements. Concluding remarks are given in Sect. 6.

2 Meat Production

Overall world meat production is estimated at around 320 million tons in 2016, with a growth in the Americas and Europe and a slight downturn in China and Australia (OECD/FAO 2017b). Among various meat sectors, poultry, and bovine meat production expanded, while pig meat and sheep meat production have expressed a slight decline. The poultry sector expanded, coming in at more than 117 million tons in 2016 with a forecast of nearly 118 million tons in 2017 (Table 1).

Excluding China, aggregate meat production of the rest of the world is expected to rise by almost 2.0% year on year. Deployed by category, bovine meat is expected to show the largest growth in production, with marginal increases for poultry and ovine meat, and a slight fall for pork meat. The global meat trade has recovered during the year 2016, rising by 5% to 30 million tonnes.

Table 1 World balance for meats by type (OECD/FAO 2017b)

	2015	2016 (estimate)	2017 (forecast)	Change: 2017 over 2016
	Million tonnes			%
Production	**320.5**	**321.0**	**322.0**	**0.3**
Bovine meat	67.6	68.3	69.6	1.6
Poultry meat	116.9	117.2	117.7	0.4
Pig meat	116.1	115.6	114.7	−0.8
Ovine meat	14.4	14.4	14.5	0.6
Trade	**29.9**	**31.2**	**32.0**	**2.5**
Bovine meat	9.2	8.9	9.0	0.8
Poultry meat	12.2	12.8	13.2	2.9
Pig meat	7.2	8.3	8.6	4.1
Ovine meat	1.0	0.9	0.9	−2.0

Numbers in bold present overall share of production and trade of meat

Global meat production is projected to be 13% higher in 2026 compared to the base period (2014–2016). Developing countries will mainly influence the total increase and consequently will have a more intensive use of feed in the production process. Poultry meat is recognized as the primary driver of the growth in total meat production, in response to expanding global demand for this more affordable animal protein compared to red meats. Low production costs and lower product prices are the main triggers to making poultry becoming the most favorable meat for both producers and consumers in developing countries (OECD/FAO 2017a).

Over the last 50 years, global meat consumption rose from 23.1 kg per person per year in 1961 to 42.2 kg per person per year in 2011 (Sans and Combris 2015). Meat consumption worldwide per capita is expected to stagnate at 34.6 kg retail weight equivalent by 2026. In relation to the population growth rates in the developing world, total consumption is expected to increase by nearly 1.5% per annum (OECD/FAO 2017a).

Driven by economic development and urbanization over the last 50 years, animal-based protein consumption has increased worldwide, rising from 61 g per person per day in 1961 to 80 g per person per day in 2011 (Sans and Combris 2015). It is estimated that 1–9% of human beings are vegetarians in developed countries and 40% in India (Ruby 2012). Flexitarians (person who eats mostly as a vegetarian but sometimes includes meat, fish, or poultry) are more and more numerous. They have different moral drivers than vegetarians raising concerns about animal welfare more than full-time meat eaters but less than vegetarians (De Backer and Hudders 2015). Taking into account the vegetarians and other voluntary dietary habits such as veganism (exclusion from animal products), raw foodism (dietary practice of eating only uncooked, unprocessed foods), fruitarianism (diet that consists entirely or primarily of fruits and possibly nuts and seeds, without any animal products), and various religious restrictions, we can say that a large majority of the human population eat meat regularly or occasionally. In summary, humanity used to and still relies on meat and meat products.

3   Environmental Indicators in the Meat Chain

Evaluation of environmental impacts depends on the approach and methods used (Carvalho et al. 2014). The very common approach is by introducing and calculating environmental performance indicators (EPIs). EPI is "a measurable representation of the status of operations, management or conditions related to environmental aspects" (ISO 2015). Henri and Journeault (2008) highlight two main reasons for calculating reliable numeric indicators: organization's legal responsibility on environmental issues and achievement of certain environmental objectives. They also conclude that financial indicators are understood as backward-looking, with limited ability to explain environmental performance.

Fig. 1 Levels of EPIs
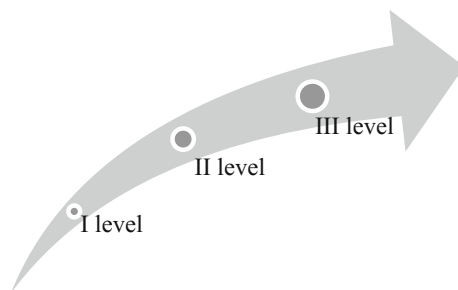
Rule of the thumb for all EPIs are that they should be (i) measurable; (ii) objective; (iii) verifiable; (iv) repeatable; and (v) technically feasible (Đekić 2009). In general, there are three levels of EPIs that are related to the maturity of implemented environmental practice (Đekić and Tomašević 2017a) Fig. 1.

3.1 First-Level Indicators

The first level of EPIs is basic indicators with numerical values (Đekić and Tomašević 2017a). They can be divided into two categories with no connection between the indicators. The first category consists of generic environmental indicators such as energy and water consumption, wastewater discharge. The second category comprises of indicators related to meat production. Some first-level EPIs related to meat production are presented in Table 2.

3.2 Second-Level Indicators

The second-level EPIs are calculated from at least two first-level EPIs. In order to evaluate food production, it is necessary to define a unit in which the impacts are

Table 2 First-level EPIs

Generic environmental EPIs		Meat production EPIs	
Indicator	Unit	Indicator	Unit
Consumption of electric energy	MJ/kWh	Livestock production	t/kg
Consumption of thermal energy	MJ/kWh	Carcass production	t/kg
Consumption of fossil fuels	t/m^3	Fresh meat production	t/kg
Consumption of water	m^3/L	Production of meat products	t/kg
Consumption of chemicals	L/kg	Consumption of additives	t/kg
Wastewater discharge	m^3/L	Consumption of spices	t/kg
Waste discharge	t/kg	Consumption of packaging	units/kg

presented such as 1 kg of food, and to define a formula for calculation of this type of EPIs. The functional unit (FU) is the unit to which the results are expressed and a basis for comparisons (Djekic et al. 2018). This approach to environmental performance shows the relationship between production performance and the environment, depicting environmental impacts of the processes within a meat company (Dubey et al. 2015).

Proper choice of the FU is of utmost importance since different functional units can lead to different results for the same (meat) production systems (Djekic and Tomasevic 2016). In the meat chain, the most common FUs are 1 kg of livestock (Basset-Mens and van der Werf 2005; Dalgaard et al. 2007); 1 kg of carcass (Nguyen et al. 2011; Williams et al. 2006); and 1 kg of meat/meat products (Cederberg and Flysjö 2004).

Most common second level of EPIs in the meat production are meat yield (share of lean meat in live animals and/or in carcass), solid output per FU (in farming mostly manure, in slaughtering/deboning percentage of by-product such as offal, bones, fat, and skin), and resource consumption per FU (energy/water) (Đekić and Tomašević 2017a). Focus in the meat chain is calculation of consumptions and discharges per meat FUs such as energy-to-meat ratio, water consumption per meat product, wastewater discharge per meat product, and chemical usage per FU (Djekic et al. 2015; IPPC 2006; UNEP 2000). Table 3 gives an overview of the most common second-level EPIs in the meat chain.

Further deployment of this indicator can help in specifying environmental impacts within the meat chain. Energy is used in all parts of the meat chain basically for machines and equipment, for controlling temperature regimes (heating/ refrigerating), and for transportation purposes (Djekic 2015; IPPC 2006). Energy deployment should go towards clarifying consumption of electric energy, thermal energy, and other sources of energy such as types and quantities of fossil fuels. Water is very important throughout the meat chain. It is necessary for live animals at farms and when entering the slaughterhouse and plays a significant role in hygiene and sanitation of slaughterhouses, meat processing plants, and retail. Finally, it is used at households for meat preparation (Djekic and Tomasevic 2016; IPPC 2006).

Waste discharge can determine types and quantities of waste (organic vs. inorganic waste, hazardous vs. nonhazardous waste, etc.). Types of waste can further be separated depending on the waste material (plastic, metal, wooden, paper, food waste, and cardboard). Within the meat chain, there are two main types of wastes—inedible products (bones, fat, heads, legs, skins, hair, and offal) and various packaging materials (Djekic et al. 2016; Kupusovic et al. 2007). Some quantities of organic waste are a result of consumer demands. They prefer lean meat, which causes the production of (organic) waste in both slaughterhouses and meat processing plants (Rahman et al. 2014). Handling this type of animal by-products is regulated by the law in developed markets, like in the EU (EC 2009).

Wastewater is a result of cleaning and sanitation and covers washing of livestock, carcasses, and offal, cleaning and sanitation of equipment and work environment and workers' personal hygiene (Kupusovic et al. 2007). At slaughterhouses, when

Table 3 Overview of the most common second-level EPIs

Meat chain	Indicator	Formula (unit)
Farm	Consumption of water per FU	$\dfrac{\text{Consumption of water (L)}}{\text{FU (kg of livestock)}}$
	Consumption of energy per FU	$\dfrac{\text{Consumption of energy (MJ)}}{\text{FU (kg of livestock)}}$
	Consumption of fossil fuels per FU	$\dfrac{\text{Consumption of fuels (L)}}{\text{FU (kg of livestock)}}$
	Discharge of wastewater per FU	$\dfrac{\text{Discharge of wastewater (L)}}{\text{FU (kg of livestock)}}$
	Discharge of waste per FU	$\dfrac{\text{Discharge of waste (kg)}}{\text{FU (kg of livestock)}}$
Slaughter house	Consumption of water per FU	$\dfrac{\text{Consumption of water (L)}}{\text{FU (kg of carcass)}}$
	Consumption of energy per FU	$\dfrac{\text{Consumption of energy (MJ)}}{\text{FU (kg of carcass)}}$
	Consumption of fossil fuels per FU	$\dfrac{\text{Consumption of fuels (L)}}{\text{FU (kg of carcass)}}$
	Discharge of wastewater per FU	$\dfrac{\text{Discharge of wastewater (L)}}{\text{FU (kg of carcass)}}$
	Discharge of waste per FU	$\dfrac{\text{Discharge of waste (kg)}}{\text{FU (kg of carcass)}}$
Meat processing	Consumption of water per FU	$\dfrac{\text{Consumption of water (L)}}{\text{FU (kg of meat product)}}$
	Consumption of energy per FU	$\dfrac{\text{Consumption of energy (MJ)}}{\text{FU (kg of meat product)}}$
	Consumption of fossil fuels per FU	$\dfrac{\text{Consumption of fuels (L)}}{\text{FU (kg of meat product)}}$
	Discharge of wastewater per FU	$\dfrac{\text{Discharge of wastewater (L)}}{\text{FU (kg of meat product)}}$
	Discharge of waste per FU	$\dfrac{\text{Discharge of waste (kg)}}{\text{FU (kg of meat product)}}$
Retail	Consumption of water per FU	$\dfrac{\text{Consumption of water (L)}}{\text{FU (kg of meat product)}}$
	Consumption of energy per FU	$\dfrac{\text{Consumption of energy (MJ)}}{\text{FU (kg of meat product)}}$
	Discharge of waste per FU	$\dfrac{\text{Discharge of waste (kg)}}{\text{FU (kg of meat product)}}$
Household	Consumption of water per FU	$\dfrac{\text{Consumption of water (L)}}{\text{FU (kg of meat product)}}$
	Consumption of energy per FU	$\dfrac{\text{Consumption of energy (MJ)}}{\text{FU (kg of meat product)}}$
	Discharge of waste per FU	$\dfrac{\text{Discharge of waste (kg)}}{\text{FU (kg of meat product)}}$

FU functional unit. In meat industry it is 1 kg of livestock or 1 kg of carcass or 1 kg of meat product (depending on the role in the meat chain)

discharged, water is an effluent with high organic loads coming from manure, blood, and fat and undigested stomach contents (UNEP 2000). Beyond quantity of wastewater, this indicator can analyze wastewater load and quality of wastewater such as values for biological oxygen demand and/or chemical oxygen demand in terms of FU.

3.3 Third-Level Indicators

The third level of EPIs provides information on different environmental footprints (Đekić and Tomašević 2017a). Environmental footprint is a quantitative measurement that calculates or describes the misuses of natural resources by humans (Hoekstra 2008). Footprint tools are tools for footprint calculations and suggested reduction in terms of prevention of pollution or environmental improvement (Čuček et al. 2015).

Three most recognized members of the footprint family are ecological, water, and carbon footprints (Herva et al. 2011). The ecological footprint is related to the natural, social, cultural, and economic environment and is not commonly calculated in the meat chain (Đekić and Tomašević 2017a). It refers to the number of individuals who can be supported in a given area within natural resource limits, without degrading the environment for present and future generations (Kratena 2008). The water footprint is built on the concept of virtual water related to all links in the meat chain and refers to total water used during the production of all goods and services in the entire meat chain (Herva et al. 2011). It consists of blue (consumption of surface and groundwater), green (consumption of rainwater stored within the soil as soil moisture), and gray (volume of freshwater required for assimilating the load of pollutants based on existing ambient water quality standards) water footprints (Čuček et al. 2015; Mekonnen and Hoekstra 2010). As presented before, meat companies calculate various second-level EPIs related to water consumption so further calculations of this footprint are possible.

Carbon footprint measures all greenhouse gas emissions caused directly and indirectly and is expressed in CO_2 equivalent since the largest single contributor to climate change is CO_2 (Herva et al. 2011). The predominant greenhouse gases (GHG) emitted from agriculture are methane (CH_4) and nitrous oxide (N_2O). They possess 21 and 310 times of the global warming potential (GWP) of carbon dioxide, respectively (IPPC 2006; MacLeod et al. 2013). The main GHGs are CO_2, CH_4, N_2O, hydrochlorofluorocarbons (HCFCs), hydrofluorocarbons (HFCs), and ozone in the lower atmosphere (WMO 2017). It is considered that emission of GHG leads to increased droughts, floods, losses of polar ice caps, sea-level rising, soil moisture losses, forest losses, changes in wind and ocean patterns, and changes in agricultural production (Čuček et al. 2015).

Influence of climatic conditions on food safety, incidence, and prevalence of food-borne diseases becomes an important connection between climate change and the food chain (Bezirtzoglou et al. 2011; Holvoet et al. 2014; Lal et al. 2012;

Miraglia et al. 2009). Temperature and precipitation changes and patterns, both locally and globally, are related with the transport, growth, and survival of enteric bacteria (Liu et al. 2015). Most of the published publications related to climatic condition and food safety, are from the farms (Holvoet et al. 2014; Kirezieva et al. 2015; Liu et al. 2013; Uyttendaele et al. 2015). Also, intensive precipitations are linked with contamination pathway of pathogens in the meat chain such as from manure at livestock farms and from grazing pastures (Parker et al. 2010) as well as the microbial contamination of vegetables coming from fecal waste into the soil or contaminated water (Holvoet et al. 2014).

It is important to note that the majority of environmental footprints and models used to evaluate environmental impacts were developed by environmental scientists. They all are generic regardless of the type of companies or products with limited environmental models/footprints for the food industry and with no specific model/footprint tailored for the meat chain (Djekic et al. 2018).

Latest researches confirm that carbon footprint is used in presenting environmental impact of the meat chain (Đekić and Tomašević 2017a). Livestock and activities at the farms contribute to global warming potential directly coming from enteric fermentation and manure management and indirectly as a result of feed production (Gerber et al. 2015; Röös et al. 2013). The global warming potential within the meat chain can be calculated as follows:

$$GWP = \sum_{i}^{n} GWP_i x m_i \left[kgCO_{2eq} \right]$$

where m_i—mass of emitted gas (kg) and GWP_i—global warming potential of the emitted gas. The GWP is usually calculated for every part of the meat chain.

Acidification potential is an indicator that calculates the potential of acidifying pollutants (SO_2, NO_x, HCl, NH_3, and HF) to form H^+ ions and damage plants, animals, and the ecosystem (Čuček et al. 2015). Ammonia is the main source of acidifying emissions during animal production released from manure in farms and during manure handling (Djekic et al. 2015). Liquid manure handling systems emit less ammonia than solid manure but liquid/slurry storage stimulates CH_4 production, due to anaerobe conditions (IPCC 2006). This potential is usually expressed in SO_2 equivalents. The acidification potential within the meat chain can be calculated as follows:

$$AP = \sum_{i}^{n} AP_i x m_i [kg\, SO_{2e}]$$

where m_i—mass of emitted substance (kg) and AP_i—acidification potential of the emitted substance. The AP is usually calculated for every part of the meat chain.

Eutrophication potential increases the aquatic plant growth attributable of nutrients left by overfertilization of water and soil such as nitrogen and phosphorus (Čuček et al. 2015). At the farm level, nitrates are accumulated during feed

production and ammonia release from manure handling and as such dominate the emissions of eutrophying substances. It is considered as the main contributors to eutrophication within the meat chain (Röös et al. 2013). This potential is expressed in PO_3^{4-} equivalents. The eutrophication potential within the meat chain can be calculated as follows:

$$EP = \sum_{i}^{n} EP_i x m_i [\text{kg PO}_{4e}]$$

where m_i—mass of emitted substance (kg) and EP_i—eutrophication potential of the emitted substance. The EP is usually calculated for every part of the meat chain.

Ozone depletion potential is expressed as CFC-11 or R11 equivalents and is calculated as the potential for reducing the protective stratospheric ozone layer where ozone-depleting substances are freons, chlorofluorocarbons, carbon tetrachloride, and methyl chloroform (Čuček et al. 2015). It is known that keeping products at low temperatures inhibits the growth of potentially harmful microorganisms (Sofos 2014) and that the cold chain plays a significant role in keeping meat safe. The effectiveness of the cold chain depends on the time/temperature ratio, the kind of refrigerators, and the position of meat/meat products within it (Baldera Zubeldia et al. 2016). However, the cold chain requirements have an impact on ozone layer depletion due to the use of refrigerants for chilling/freezing and affect the entire meat chain (Djekic et al. 2015). The ozone depletion potential within the meat chain can be calculated as follows:

$$ODP = \sum_{i}^{n} ODP_i x m_i [\text{kg R11}]$$

where m_i—mass of emitted gas (kg) and ODP_i—ozone depletion potential of the emitted gas. The ODP is usually calculated for every part of the meat chain.

4 Meat Chain Indicators—Case Study

Life-cycle assessment (LCA) is considered as the best method in calculating environmental impact from all stages of agricultural and food production (Djekic 2015). The methodology is outlined in an international standard (ISO 14040:2006) and comprises of the following steps: (i) mapping the process, (ii) setting scope and boundaries, (iii) collecting inventory data, and (iv) interpreting the results (ISO 2006). Mapping the process joint with setting the scope and boundaries is to clarify which part of the meat chain is analyzed from the "farm to the fork" perspective (Djekic 2015). Collecting inventory data is the most important but the most challenging part, since uncertainty may occur due to imprecise data. Analysis of inventory requires calculation of environmental impacts defined in the goal of the
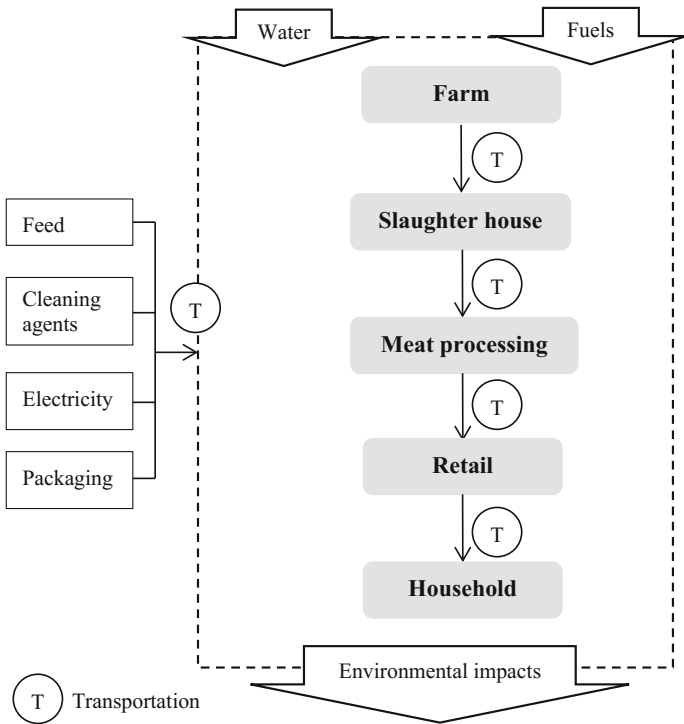
Fig. 2 Generic system boundaries of the meat chain. Gray boxes are premises where the environmental impacts occur

LCA in order to determine potential environmental impacts (McAuliffe et al. 2016). Interpretation of the results is the final stage that enables mitigation strategies in relation to environmental improvements. Generic system boundaries of the meat chain are presented in Fig. 2.

In order to convert data from the "whole of subsystem basis" to a "functional unit basis", it is necessary to allocate inputs and outputs. For this purpose, it is common to use one of the three main allocation methods economic allocation, physical allocation, and system expansions (de Vries and de Boer 2010). Still, there are differences in LCA model assumptions, system boundaries taken into account, functional units defined within the meat chain, data collection methods and data processing, environmental impact categories and emission factors, normalization methods, and weighting factors which make comparisons difficult (Carvalho et al. 2014; Djekic and Tomasevic 2016; Pennington et al. 2004).

Table 4 gives a generic overview of inventory data needed to perform a LCA of the entire meat chain.

Due to the fact that the highest level of environmental impacts occurs at the farms, some other important issues that should be considered, and wherever possible included in the LCA, are:

Table 4 Global inventory for the production of meat (entire meat chain)

	Unit	Subsystem				
		1	2	3	4	5
Input — materials						
Water	L/kg FU	●	●	●	●	●
Cleaning agents (alkaline)	L or g/kg FU		●	●	○	
Cleaning agents (acid)	L or g/kg FU		●	●	○	
Feed	kg/kg FU	●				
Input — energy						
Electric energy	kWh or MJ/kg FU	●	●	●	●	●
Thermal energy	MJ/kg FU		○	○	○	
Fossil fuels						
LPG	kg/FU	●	●	●	●	○
Natural gas	m^3/FU	●	●	●	●	○
Petrol	L/FU	●	●	●	●	○
Diesel	L/FU	●	●	●	●	○
Packaging materials						
HDPE	g/kg FU			●	●	○
PVC	g/kg FU			●	●	○
PET	g/kg FU			●	●	○
PP	g/kg FU			●	●	○
PE	g/kg FU			●	●	○
Cardboard/paper	g/kg FU			●	●	○
Aluminium foil	g/kg FU			●	●	○
Shrink foil	g/kg FU			●	●	○
Styrofoam	g/kg FU			●	●	○
Refrigerants	g/kg FU		●	●	●	○
Cooking oil	mL/kg FU					●
Output						
Production						
Annual production of meat	kg or tonnes	●	●	●		
Annual sale of meat	kg or tonnes				●	
Annual consumption of meat	kg					●

	Unit	Subsystem				
		1	2	3	4	5
Waste						
Waste — confiscate (food waste)	kg/kg FU	●	●	●	●	●
Waste — manure / slurry	m³/kg FU	●	●			
Other types of waste						
HDPE	g/kg FU			●	●	●
PVC	g/kg FU			●	●	●
PET	g/kg FU			●	●	●
PP	g/kg FU			●	●	●
PE	g/kg FU			●	●	●
Cardboard / paper	g/kg FU			●	●	●
Aluminium foil	g/kg FU			●	●	●
Shrink foil	g/kg FU			●	●	●
Wood	g/kg FU		●	●	●	
Waste water	L/kg FU	●	●	●	○	○

Subsystem 1 farm; *subsystem 2* slaughterhouse; *subsystem 3* meat processing plant; *subsystem 4* retail; *subsystem 5* household

FU functional unit: 1 kg of livestock or 1 kg of carcass or 1 kg of meat product (depending on the role in the meat chain)

HDPE high density polyethylene; *PVC* polyvinyl chloride; *PET* polyethylene terephthalate; *PP* polypropylene; *PE* Polyethylene

Signs: ● mandatory data; ○ data "nice to have"

– Type of breed.
– Type of production system.
– Pre-fattening period.
– Slaughtering age and weight.
– Male–female ratio.
– Mortality rate.
– Replacement rate.
– Feed production.
– Feed formulation.
– Direct on-farm emissions (N_2O, CH_4, NH_3, NO_3, PO_4, etc.).
– Good agricultural/veterinary practice in place.

At slaughterhouses, some of the issues that should also be considered are:

– Wastewater treatment system in place.
– Quality of wastewater (biochemical oxygen demand, chemical oxygen demand, total organic carbon, total suspended solids, total nitrogen, and phosphorus, etc.).
– Waste management in place.
– Maintenance of equipment and infrastructure.
– Good manufacturing/hygiene practice.

Meat processing plants should take into account:

– Maintenance of equipment and infrastructure.
– Meat product portfolio.
– Allocation factors of inventory to each type of meat product.
– Good manufacturing/hygiene practice.

At retail, issues to be considered are:

– Size of retail.
– Type of products sold at retail.
– Allocation factors of inventory to each type of meat product.
– Good retail/hygiene practice.

At households, the following should be investigated:

– Purchasing habits.
– Consumption patterns at home.
– Food preparation habits.
– Dietary issues.
– Allocation factors of meal preparation related to meat/meat product.

Overall, the good environmental practice should be evaluated at each stage of the meat chain. This is important since the level of environmental practices in respect to the size of meat companies shows that smaller companies have a lower level of environmental practice in place. They usually take environmental actions only as a reaction to threats and sanctions from legal authorities (Djekic et al. 2016). The absence of any environmental practice is due to the lack of knowledge and experience and limited resources (Santos et al. 2011). Other criteria that affect environmental practices are the parts of the meat chain in which they operate and whether they have a certified environmental management system (Djekic et al. 2016).

Finally, in order to fully understand LCA as a methodology, Table 5 gives advantages and disadvantages of using LCA in meat the meat chain, modified from (Čuček et al. 2015; Djekic et al. 2018; Djekic and Tomasevic 2016).

Main advantages are that this methodology is accepted worldwide and many scientific papers justify this methodology where the number of papers in the food

Table 5 Advantages and disadvantages of using LCA in the meat chain

Advantages	Disadvantages
Accepted in science	Difficulty in collecting data
Standardized method (ISO 14040)	Uncertainty of collected data
Useful for the whole meat chain	Inventory influences results
Identifies "critical" spots	Allocation method influences results
Potential for eco-labelling	Limitation of study influences results
Optimization within a life cycle	System boundaries influence results
Technology comparison	Functional units influence results
	May be subjective
	Different software solutions

industry is increasing (Djekic et al. 2018). Standard ISO 14040 explains the methodology for performing an LCA study (ISO 2006). Due to the "cradle to grave" methodology outlined in LCA, it is very useful for analyzing food/meat chains. Good LCA can identify critical environmental spots that seek for optimization and environmental improvements. Calculations and results can be used in eco-labeling and marketing of meat product. Also, it can be used for technology comparisons.

On the other side, disadvantages are mainly related to the possibility to influence final results depending on the quality of data, allocation methods used, depth of inventory analysis, system boundaries used and functional units in which the results are presented. Since there is a large number of different software used, this may influence results and benchmarking of results. Finally, the focus of LCA is more on environmental impacts than on sustainability.

4.1 Pork Meat

The pig sector is considered as being one of the biggest contributors to global meat production, with over 37% and it is expected that global demand for pork meat will grow by over 35% until 2030 (MacLeod et al. 2013). Besides the economic part, the pork industry demands consumption of natural resources (water and energy) and generates remarkable waste flows (Noya et al. 2017). The evaluation of the contribution of pig production to environmental impacts is an ongoing story (Reckmann et al. 2012). Table 6 present a short summary of manuscripts covering LCA of least one part of the pork meat chain.

From the Table 6, it can be concluded that the majority of research was focused on farms, with a limited number of studies covering retail and households. The common potentials were global warming potential (GWP), acidification potential (AP), and eutrophication potential (EP) as well as energy consumption, mainly in retail.

Table 6 Summary of studies linking environmental impacts to pork meat chain

Authors	Research focus	System boundaries					Environmental impact
		1	2	3	4	5	
McAuliffe et al. (2016)	LCA of pig production	✓					GWP, AP, EP
de Vries and de Boer (2010)	LCA of livestock products	✓					GWP, AP, EP, LC, EC
Basset-Mens and van der Werf (2005)	LCA pig production	✓					EP, GWP, AP, EC, LC
Nguyen et al. (2012a)	LCA of pork production	✓					GWP, AP EP, HT, FEP, WC
Reckmann et al. (2012)	LCA of pork production	✓	✓				GWP, AP, EP, OLD, EC, LC
Djekic et al. (2015)	LCA of pork production	✓	✓	✓			GWP, EP, AP, OLD, HT
Roy et al. (2012)	LCA of meats (pork, beef, chicken)	✓	✓	✓	✓		GWP
Carlsson-Kanyama (1998)	LCA of food consumption	✓	✓	✓	✓	✓	GWP, EC

Subsystem 1 farm; *subsystem 2* slaughterhouse; *subsystem 3* meat processing plant; *subsystem 4* retail; *subsystem 5* household use

GWP global warming potential; *AP* acidification potential; *EP* eutrophication potential, *OLD* ozone layer depletion; *HT* human toxicity; *LC* land competition/use; *EC* energy consumption; *WC* water consumption; *FEP* fresh water aquatic ecotoxicity

FU: 1 kg of pork; 1 kg of bone and fat free meat; 1 kg of carcass; 1 kg of pork meat product

Results from review papers covering 20 pork meat-related LCA studies show the range of GWP per kg of bone-free meat (farms and slaughterhouses) from 3.6 to 8.9 kg CO_{2eq} (Cherubini et al. 2014; Röös et al. 2013). These papers emphasize differences in respect to countries (developed vs. developing), production systems (organic, conventional) as well as economic perspective (high and low profit). In Serbia, overall GWP throughout the life cycle (from farms to retails) is over 9 kg CO_{2eq} per kg of FU (Djekic et al. 2015) while European LCA studies show an average GWP of pork production of 3.6 kg CO_{2eq} per kg pork, ranging from 2.3 to 6.4 kg CO_{2eq} for different FU (1 kg of pork, 1 kg of bone, fat-free meat, and 1 kg of carcass) (Reckmann et al. 2012). Results from Japan show GHG emission of pork (farm gate, including manure) to be 5.57 CO_{2eq}/kg-meat while in slaughterhouses the GWP is estimated to be 0.12 kg CO_{2eq}/kg-meat (Roy et al. 2012).

Work from Röös et al. (2013) show that AP results are in the range from 0.026 to 0.156 (kg SO_{2eq}) covering farms and slaughterhouses with the FU being 1 kg of bone-free meat. On the other side, the analysis of nine pork production LCA studies performed by de Vries and de Boer (2010) show the range from 0.043 to 0.741 kg SO_2/kg.

EP results show a range from 0.015 to 0.102 kg PO_{4eq} (Röös et al. 2013). Similar to AP, de Vries and de Boer (2010) point that EP of the same product shows large variations.

As pointed above, the highest environmental impacts arise at the farm stage and latest research show segmentation of the pig production into piglet production and weaning to slaughtering (Basset-Mens and van der Werf 2005). The weaning to slaughtering stage contributes more since this stage lasts longer compared to piglet production and due to the weight of the pigs—the higher the weight, the more feed they eat and thus excrete more manure (Reckmann et al. 2012).

4.2 Beef Meat

Livestock production, particularly beef supply chain is considered as another major contributor to GHG emission of the meat chain (Bragaglio et al. 2018). In analyzing LCA of beef meat, many different circumstances have to be considered. The first issue is the production system. Some LCA cover analysis and/or comparison of intensively reared dairy calves and suckler herds (Nguyen et al. 2010). Other studies compare extensive cow-calf production, fattening system, cow-calf intensive, or traditional beef production system (Bragaglio et al. 2018). Finally, the introduction of "organic" production brings a new dimension (Buratti et al. 2017). Within the production systems, differences occur due to the origin of calves, duration of fattening period, diet formulation, etc. (Bragaglio et al. 2018). Other issues are related to the scope and system boundaries in terms of production of only beef meat, or production of beef meat and dairy products.

As Table 7 presents, the majority of studies are only focused on farms, specifically the production systems that are in place and comparison of the systems. Within the beef chain, common potentials were global warming and eutrophication as well as resource use (energy and water).

Due to the great variety in production systems, environmental impact of beef production showed the highest level of differences in results, when compared between each other. GHG emissions vary from 8.6 up to 35.2 kg CO_{2eq} per kg of edible beef while another interesting indicator, land use also varies from 12.1 to 47.2 m^2 (De Vries et al. 2015).

The belief that organic is always more environmental friendly was confirmed in works of Tsutsumi et al. (2018). GWP of organic production was 29.3 kg CO_{2eq}/kg of cold carcass steer weighs compared to 35.1 kg CO_{2eq}/kg of cold carcass steer weighs for conventional production. However, this was opposed by the research of Buratti et al. (2017). The organic system produces 24.6 kg CO_{2eq}/kg of live weight compared to the conventional that produces 18.2 kg CO_{2eq}/kg of live weight. The same study confirmed that enteric fermentation contributes with 50% of the total GHG emissions.

Table 7 Summary of studies linking environmental impacts to beef meat chain

Authors	Research focus	System boundaries					Environmental impact
		1	2	3	4	5	
Nguyen et al. (2010)	LCA beef production systems	✓					GWP, AP, EP, LC, EC
Bragaglio et al. (2018)	LCA beef production systems	✓					GWP, AP, EP, WC, LC
Buratti et al. (2017)	LCA beef production systems	✓					GWP
Tsutsumi et al. (2018)	LCA beef production systems	✓					GWP, AP, EP, EC
Ogino et al. (2016)	LCA beef production systems	✓					GWP, AP, EP, EC
Huerta et al. (2016)	LCA beef production	✓	✓		✓		GWP, AP, EP, LC, WC, RD, HT
Nguyen et al. (2012b)	LCA beef production systems	✓					GWP, AP, EP, EC
Dick et al. (2015)	LCA beef production systems	✓					GWP, LC, WC, RD

Subsystem 1 farm; *subsystem 2* slaughterhouse; *subsystem 3* meat processing plant; *subsystem 4* retail; *subsystem 5* household use

FU: 1 kg of beef meat; 1 kg of bone and fat free meat; 1 kg of beef meat (slaughter weight); 1 kg of beef meat product

GWP Global warming potential; *AP* acidification potential; *EP* eutrophication potential; *OLD* ozone layer depletion; *HT* human toxicity; *LC* land competition/use; EC energy consumption; WC water consumption; FEP fresh water aquatic ecotoxicity; RD resource depletion

4.3 Poultry Meat

It is considered that the poultry sector is the fastest-growing livestock sector as a result of the global dietary demand for healthy high-protein and low-fat type of meat (FAO 2013; OECD-FAO 2016). Globally, poultry is the most consumed meat after pork (13.8 compared to 15.3 kg/capita/year, respectively) (FAO 2015). Similar to other types of meat, EPIs in the poultry sector are water and energy consumption, feed production, wastewater discharge, and waste treatment (Bengtsson and Seddon 2013; González-García et al. 2014). The predominant environmental footprints related to the chicken meat chain are global warming potential, acidification potential, eutrophication potential, and cumulative energy demand, as well as ozone layer depletion (Skunca et al. 2018). Deeper analysis of the papers shows that Pardo's study is concentrated on potential improvements and not on in-depth LCA analysis of all five subsystems (Pardo et al. 2012) while others focus their research on farms and slaughterhouses. There is also a big diversity in functional units presented in these papers (live weight chicken, carcass weight, packaged broiler chicken, and broiler chicken products). Finally, different inventory was used in all studies raising concern on the comparability of the data.

Table 8 Summary of studies linking environmental impacts to poultry meat chain

Authors	Research focus	System boundaries					Environmental impact
		1	2	3	4	5	
Cesari et al. (2017)	LCA of broiler farm and slaughterhouse	✓	✓				GWP, AP, EP, CED
Pishgar-Komleh et al. (2017)	LCA of broiler chicken farms	✓					GWP, CED
Wiedemann et al. (2017)	LCA of chicken production	✓	✓	✓			GWP, CED
Kalhor et al. (2016)	LCA of broiler farm and slaughterhouse	✓	✓				GWP, AP, EP, OLD
González-García et al. (2014)	LCA of broiler chicken production	✓	✓				GWP, AP, EP, CED
Da Silva et al. (2014)	LCA of broiler chicken production system	✓	✓				GWP, AP, EP, CED
Thévenot et al. (2013)	LCA of poultry production	✓	✓				GWP, AP, EP, CED
Leinonen et al. (2012)	LCA of broiler production systems			✓			GWP, AP, EP, CED
Grandl et al. (2012)	Environment impacts and selected import sources	✓			✓		CED
Pardo et al. (2012)	Environmental improvement through LCA methodology	✓	✓	✓	✓	✓	GWP, AP, EP, CED

System boundaries: 1 chicken farm; 2 slaughterhouse; 3 meat processing plant; 4 retail; 5 household use

FU: 1 kg live weight chicken; 1 kg carcass weight; 1 kg packaged broiler chicken; 1 kg tray of sliced chicken breast packaged in modified atmosphere; 1 kg broiler chicken product

GWP global warming potential; AP acidification potential; EP eutrophication potential; CED cumulative energy demand; OLD ozone layer depletion

Table 8 present a short summary of manuscripts covering at LCA of least one part of the poultry meat chain.

Overall results show a large range of results for all environmental potentials. GWP ranges from below 0.25 kg CO_{2eq}/FU up to over 6.5 kg CO_{2eq}/FU depending on the subsystems observed, inventory and FU. AP reaches values up to 0.25 kg SO_{2eq} per kg of FU while EP goes from 0.002 to 0.085 kg PO_{4e}^{3-}.

The most examined subsystems are farms in line with the opinion that the highest impacts are on farms. However, Skunca et al. (2018) in their research covering more than 100 farms, slaughterhouses, meat processors, and retailers, as well as 500 households confirm that the average score of 1.81 kg CO_{2eq} was obtained at farms as in all other four subsystems together. This brings to attention the need to analyze all subsystems, namely retail and households since dietary and

household habits influence environmental impacts among consumers. The differences are observed in terms of energy efficiency of refrigerators and freezers, different storage time of chicken meat, and chicken meat products in refrigerator and/or freezer and different cooking time of chicken meat and chicken meat products. GWP results were between 0.12 and 1.19 kg CO_{2eq}, CED results ranged between 1.77 and 23.2 MJ, while OLD results were between 0.32 and 318 µg CFC-11$_{eq}$ (Skunca et al. 2018).

Farm activities have the highest environmental impacts in all footprints—GWP, AP, EP, and CED and crucial environmental hotspot for environmental impact categories is production of feed (Skunca et al. 2018).

5 Environmental Impact of the Meat Chain

Considering the environmental impact throughout the meat chain, Fig. 3 depicts the severity and timescale of environmental impacts on the five links in the meat chain from a functional unit point of view. The most severe and long-lasting environmental impact is at the farm stage. Slaughtering is an activity that lasts short (related to one animal) but the overall impact of slaughtering is high. Within retails, meat can be stored for a long period of time, but the environmental impact is not so high. Finally, the lowest impact is within meat processing where the meat processing activity (per FU) is short and at households where meat is often consumed within 7 days from purchasing. At both premises, environmental impact is not considered as high.

Sensitivity analysis is usually performed to distinguish between the influence and the importance of certain input parameters on the change of results. This type of analysis classifies parameters that identify potential mitigation strategies (Groen et al. 2016; Tassielli et al. 2018).

Figure 4 shows the influence and importance of parameters related to sensitivity analysis within the meat chain with four quadrants. The horizontal axis ranks the most influential parameters (ranked from low to high), and the vertical axis ranks the most important parameters (ranked from low to high). Reduction of influential

Fig. 3 Severity and timescale of environmental impacts on the five links in the meat chain

Influence

		Low	High
Importance	High	**Important parameters**: energy; purchasing habits and dietary patterns; cleaning agents	**Essential parameters**: feed, production system, type of breed, on-farm emissions; waste / waste water treatment
	Low	**Minor parameters**: water consumption; meat portfolio	**Influential parameters**: good agricultural/veterinary/hygiene practice; transportation;

Fig. 4 Influence and importance of parameters related to sensitivity analysis in the meat chain

parameters may cause reduction of environmental impacts while important parameters reflect output uncertainty. Essential parameters are both influential and important, while minor parameters have low influence and importance (Skunca et al. 2018).

5.1 Environmental Management Systems in Meat Production

An environmental management system (EMS) is part of the management system used to manage environmental aspects, fulfill compliance and address risks and opportunities (ISO 2015). Most of implemented EMS worldwide are based on ISO 14001 (latest version from 2015) and an EMS is a part of an integrated management system (Labodová 2004). In the food industry (including the meat chain), EMS is usually integrated with quality management and/or food safety systems (Djekic et al. 2014). Besides food safety/quality dimensions, other standards/requirements often seen in meat production are standards covering animal welfare that measure conditions resulting from bad management practices, neglect, abuse of animals, or inadequately designed equipment (Grandin 2010) or requirements related to the religious component of slaughtering. Two global commercially accepted religious slaughtering methods are the "Halal" and "Kosher" methods of slaughtering practiced by Muslims and Jews respectively (Farouk 2013). Religious slaughtering in the EU is carried out in licensed slaughterhouses by authorized slaughter-men of the Jewish and Islamic faiths (Velarde et al. 2014).

As of the end of 2016, more than 340,000 EMS certificates were issued in over 200 countries, where the food chain participates with less than 3% (ISO 2017). A growing number of EMS certificates worldwide recognizes EMS as one of companies' priorities (Kimitaka 2010). However, there is no data regarding for the number of certificates in the meat chain worldwide (Djekic and Tomasevic 2016).

Companies interested in implementing an EMS expect to improve their environmental performance and enhance better company image (Massoud et al. 2010)

or to enter international markets (Zeng et al. 2005). In order to develop an EMS and improve its environmental performance, a food organization has to assess its impacts and set environmental targets to reduce them (Djekic et al. 2014). Standard ISO 14001 promotes deployment of environmental impacts towards sustainable resource management and climate change mitigation including life cycle approach and effective communication with stakeholders (ISO 2015). Djekic et al. (2016) indicated significant differences in the levels of implementation of environmental practice with respect to the size of the meat companies, certification status, and meat sector—slaughterhouse or meat processing plant.

5.2   Route to Environmental Improvements

Environmental improvements in meat production have two opposed strategies, from changing dietary habits to specific improvement scenarios. Avoiding meat due to its environmental impact and/or animal welfare misses the goal due to the complexity of meat chain compared to other food chains (Röös et al. 2014). Swedish research on dietary changes in line with prevailing guidelines for a healthy meat intake confirmed that reduction of meat intake reduces GWP change, but variations in production systems and uncertainties in the calculation methodologies affect the results and conclusions much more (Hallström et al. 2014). Sustainable food industry should focus on pollution prevention, environmental, and technological improvements rather than discussing nutritional needs (Djekic and Tomasevic 2016).

In order to decrease the GWP and AP in meat production, focus should be on (1) manure management and (2) improving feeding strategy (Djekic et al. 2015). Gerber et al. (2015) suggest balancing feed ration and feed supplementation as well as animal health improvements at the farm stage. McAuliffe et al. (2016) believe that environmental impact of this developing technology in pig production will utilize manure as a source of biogas through anaerobic digestion. Also, manure management should be focused on improving on-site practices and/or manure quality (Djekic et al. 2015). Besides manure management, improvement of environmental management throughout the meat chain by fostering best environmental practices should be implemented (Djekic et al. 2016; Gerber et al. 2015). Also in line with (environmental) practices on-site, focus should be on the cold chain by decreasing the use of refrigerants with high GWP and developing new environmental and ozone-friendly refrigerants throughout the cold chain (Xu et al. 2015).

Finally, consumers in the meat chain are becoming more demanding in terms of diet requirements, food preservation technologies, and promotion of novel non-thermal technologies and food packaging, and these issues should also be considered in future analysis of environmental impact of the meat chain (Djekic et al. 2018).

6 Concluding Remarks

Analysis of the environmental impact of the meat chain is very complex and this food chain is considered as one of the food chains with global environmental impacts. Main challenges are due to different model assumptions and system boundaries when setting the LCA as well as various functional units in which environmental impacts are calculated making benchmarking throughout the meat chain difficult.

Regardless of the type of meat produced and technology applied, eating habits and cultural diversity, this type of production influences climate change in respect to global warming, acidification and eutrophication potentials and ozone depletion substances and has a high ratio of consumption of water and energy resulting in waste and wastewater discharge.

Three edges of the "environmental meat chain triangle" are the consumer, the environment, and the meat producers. The area within the triangle represents the improvement opportunity and potentials for future development in terms of consumers' dietary habits and sustainable meat production.

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