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New Technology Tools and Life Cycle Analysis (LCA) Applied to a Sustainable Livestock Production

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Abstract

Agriculture 4.0, a combination of mechanical innovation and information and communication technologies (ICT) using precision farming, omics technologies and advanced waste treatment techniques, can be used to enhance the biological potential of animal and crop productions and reduce livestock gaseous emissions. In addition to animal proteins being excellent nutritional ingredients for the human diet, there is a growing concern regarding the amount of energy spent converting vegetable crops into animal protein and the relevant environmental impacts. Using the value chain analysis derived from the neoclassic production theory extended to industrial processing and the market, the hypothesis to be tested concerns the sustainability and convenience of different protein sources. The methodology implies the use of life cycle analysis (LCA) to evaluate the efficiency of different livestock diet ingredients. The use of feeding products depend upon various factors, including cost reduction, consumer acceptance, incumbent industry response, civil society support, policy consensus, lower depletion of natural resources, improved sustainable agri-food supply chain and LCA. EU policy makers should be aware of these changes in livestock and market chains and act proactively to encourage the use of alternative animal proteins.

Keywords: livestock, smart farming, genomics, LCA

Introduction

Despite the progress achieved in recent years, hunger and malnutrition still represent one of the main problems in various regions of the planet. According to a FAO report (1), 11% of the world's population still suffers from poverty and does not have access to a sufficient level of nutrition. At the beginning of the 1990s, 17% of the world population chronically suffered from hunger. Although this percentage gradually decreased until 2015, it subsequently started to rise again. Over the last decade, we have witnessed a significant increase in food production. However, one billion people still do not have access to a sufficient level of nutrition. The main projects of international organizations (e.g., World Bank and the European Union) to reduce hunger and malnutrition by 2030 are mainly based on sustainable agriculture and stable systems for the production and distribution of food (2). Although population growth seems to be decreasing in Western countries and in some Asian countries, population growth seems to be decreasing, whereas in other regions, exponential growth is observed. The forecasts of at least 9.5 billion inhabitants of the planet for 2050 are considered realistic.

Several studies have shown that climate change has the potential to adversely affect animal health, with consequences for animal welfare, greenhouse gas emissions, productivity and human health (3). In almost all regions of the world, climate change could lead to an increase in temperature, an altered photoperiod and a decrease in rainfall, which may cause a reduction in the quality and quantity of food, less water availability and a high susceptibility to diseases (4). According to a report prepared in 2018, the increase in temperature observed since the mid-20th century is probably due to an increase in man-

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made greenhouse gas (GHG) emissions, while it is very unlikely that climate change is due only to natural causes (5). The sustainability of food production is a topic of growing public concern, and different conflicting demands are expressed by a large number of stakeholders: private citizens, industries, consumers, communities, environmentalists and policy makers. Furthermore, future food production must satisfy four goals of a composite scenario: i) growing population with changing consumers' habits and diet preferences due to higher income; ii) foreseeable impact on climate change iii) reduction of per capita natural resources and arable land, decline in soil productivity, water shortage and pollution; iv) scientific and technological progress that creates expectations and possible concern among the world population (6).

1. Scenarios

Numerous factors, such as the rising population, urbanization and incomes, have contributed to the global increase in meat consumption in 2018 by 59% (43 kg per capita) compared to the 1990s values (1). In the same period, global fish consumption per capita increased from 13.5 kg per person/year to more than 20 kg. In 2018, meat production accounted for 330 million tons (MT) worldwide, of which 120.5 MT of poultry, 118.7 MT of pork, 70.8 MT of beef and other bovine species and 14.8 MT of sheep (1). According to the indications of the World Health Organization, FAO and the United Nations Organization, the amount of animal products in human diets should be equal to one-third of the daily protein requirement (7). The suggested daily human consumption of protein per capita is 0.66–1 g/kg body weight. Data published by the FAO (2) on global animal protein production indicate a current availability of 24 g/day per capita. The FAO (8) predicts an increase in animal production products of 1–3% per year for the next 30 years. Parallel to the demographic increase, the demand for food is growing, and FAO's future projections outline a scenario by 2050, in which more than 500 MT of meat per year will be needed for human consumption. Approximately 800 billion t of cereals are currently used to produce animal feed; they will exceed 1.1 billion t by 2050. Most of this product will compete with human food, and the proportion of arable land used to produce new feeds will further increase (8). The possible conflict in the use of agricultural products, in particular cereals, for human or animal diets is one of the various challenges in the realization of sustainable production. Cattle use 60% of the total vegetal biomass that is produced, converting grass, pasture fodder and other inedible products for humans to edible human protein and improving the overall efficiency of the system. On the other hand, the limitation of arable lands due to urbanization, salinization and desertification requires great attention to the sustainability of production systems. Furthermore, the excessive exploitation of natural resources and global warming, with uncontrollable meteorological phenomena and drought, could negatively impact agricultural and aquatic production systems. Approximately 8% of the total water consumption is used to irrigate crops for animal feed (9, 10). Future sustainability of production systems will depend on the ability to create and introduce new production methods characterized by reduced energy demand and limited stress on terrestrial and aquatic ecosystems. Changes in eating habits and diet will also be indispensable. In the future, livestock production methods will probably change and show substantial differences between developed countries and developing countries, and consequently, between high-intensity production and small-scale agro-pastoral systems. The future demand for products of animal origin can only be met through a sustainable intensification of a low-carbon economy. On the other hand, the need to adapt to climate change and reduce GHG emissions will undoubtedly increase the costs of production and processing of raw materials, and therefore, of the finished product to the final consumer.

Different international institutions of the agricultural and food sector have estimated (for the short term, the year 2030 and for the long term, 2050) the ability of natural resource systems to absorb external climate shocks (6). Crop production will increase by 80% compared to current levels due to the adoption of different innovative cultivation techniques. Unfortunately, the growth rate of non-GM cereal cultivation has declined from 3.2% per year in the 1960s to 1% in recent years (7). Meat production will continue to expand globally. The livestock feed alternatives, which are discussed in depth in this document, must be evaluated in relation to their social acceptance (consumer approval), environmental sustainability, economic viability (costs and benefits) and technological feasibility (11).

1.1 Population and consumer trends

Population dynamics are one of the most crucial drivers of future scenarios. According to the FAO outlook, the human population will increase globally from the present seven billion people to approximately 9–10 billion people in 2050, despite a decline in the birth rate (6). Three changes are expected in the future: the first change is the concentration of population growth, mainly in Asia and Africa. The second change is the advance in urbanization that will continue at an accelerated rate: approximately 70% of the world's population will be urbanized in 2050 compared to the actual 49%. The third change is the change in the consumption patterns due to the income growth of the middle class in the least developed countries (LDCs). Globally, the average world citizen income is currently approximately $11,000 US/year, which is twice the income level in 1970. Per capita food consumption is expected to rise from 2,860 kcal in 2015 to 3,070 kcal in 2050 (4). Most developed countries have substantially completed the transition to livestock-based diets, while not all developing countries will likely shift, in the foreseeable future, to meat consumption levels, which are typical of Western diets (4). This shift requires a 70% increase in food production with a growing demand for red meat and dairy products to 80% (12). The expected global population and meat consumption increase are reported in Table 1.

The major meat increase is expected for poultry: a higher conversion rate will maintain a convenient price and will par-

Table 1. Expected population (billion) and meat consumption increase (MT) in the world during the period: 2010-50

	Year								
Item	2010		2020		2030		2050		CAGR[1]
		%		%		%		%	
Human population	6.90		7.67		8.31		9.15	0.71	0.71
Meat consumption:									
Pig	102.30	38.07	115.30	36.11	129.90	34.11	140.70	30.34	0.80
Poultry	85.90	31.97	111.00	34.76	143.50	37.68	193.30	41.68	2.05
Bovine	67.30	25.05	77.30	24.21	88.90	23.35	106.30	22.92	1.15
Sheep/Goat	13.20	4.91	15.70	4.92	18.50	4.86	23.50	5.07	1.45
Total meat	268.70	100	319.30	100	380.80	100	473.80	100	1.37

[1] CAGR: consumer annual growth rate
Source: (6)

tially replace beef and pork meat. In the US, pork consumption has maintained a range between 20 kg/person and 25 kg/person per year; beef consumption has fallen from 43 kg per year in 1975 to 24 kg per year in 2015; poultry meat has displayed a mirror-image response over the same time period, soaring from 21 kg/year to 48 kg/year, an increase of nearly 130% (13). The livestock production system in the European Union represents 40% of the total agricultural activities, with the employment of approximately four million people. Animal proteins comprise 50% of the total proteins of milk-based diets. Per capita consumption in the context of the European Union is 65.5 kg of meat and 236 litres of water per person/year. Over 40% of British people are reducing their meat intake, and 35% of Americans obtain most of their protein from plant sources. These changes are driven by consumer economics; for example, the relative cost of poultry meat during the last 6 months of 2020 was 4.2 US $/kg, whereas the relative cost of beef averaged 12.5 USD/kg. The increase in the world population and requirements of dietary changes for healthier nutrition are placing increasing pressure on changing the agricultural production system by adopting lower impact technologies.

1.2 Foreseeable impacts

A modern sustainable animal production farm should fulfil the following economic, environmental and social requirements: i) economic sustainability, i1) continuous process control in real time (improves efficiency of the use of production factors), i2 continuous real-time connection to external data sources (more convenient decisions based on market information), ii) environmental sustainability, ii1) better management of crops and harvest times (improves the use of nutrients in the field and quality of food for livestock, ii2) better coverage of the needs of animals (improvement in the production performance of animals with a lower impact per unit of product, ii3) better management of manure with reduced emissions, and iii) social sustainability (ethics and animal welfare), improved real-time monitoring of animals. The directions towards new sustainable strategies of carbon reduction are based on three actions: 1) Tebe, technology innovation and business models. Most existing technology innovation will take a long time to become economically feasible and will require substantial investments. Another problem is the threshold for GHGs, such as ammonia: 10,000 kg of ammonia per year (the amount that would be generated by 40,000 chickens, 2,000 pigs or 750 piglet-bearing sows). This high limit has allowed large factories, collecting common agricultural policy (CAP) subsidies, to simply game the system by legally dividing their operations up to the maximum allowed by the regulations before requiring authorizations. 2) Sece, socio-economic and consumer changes towards new food habits. Assess the relative resource intensity of different diets and food groups, and obtain a common definition of a ‘sustainable diet’, both across different cultures and in view of future resource constraints and the growing global demand for calorie- and protein-rich foods; 3) Ecsa, external change and socioeconomic adaptation. The primary drivers of consumer food choice are price, taste, and convenience production method. Several studies concluded that a 50% reduction in the current consumption of livestock products in the EU would make a significant contribution to climate change mitigation and align the current intake of animal protein and fats with WHO recommended dietary guidelines (12). This contribution could lead to 40% less reactive nitrogen emissions from agriculture and a 23% reduction in cropland area.

Agricultural activities use 80–90% of freshwater and cause 24% of global GHG emissions (8). A quarter of all food, measured by MJ content, is wasted from “farm to fork”, and 8% of the losses occur upstream of the value chain. Intensive agri-food chains are responsible for soil erosion and pollution due to fertilizers, pesticides, deforestation and irrigation. However, to meet the Sustainable Development Goals (SDGs) targets envisaged by the 2030 Agenda for Sustainable Development, additional efforts should be made to reduce GHG emissions, compel the demand for resource-intensive animal food crops and reduce food loss and waste along the food supply chain. Another target for 2030 is to reduce the "triple burden" of malnutrition: undernourishment, micronutrient deficiencies, and obesity.

2. Technology advance

2.1 Precision livestock farming (PLF)

Novel tech–biotech techniques pursue three goals: intelligent growth of agri-food production, inclusive growth of agri-food production, and sustainable growth of agri-food production (15, 16). Agriculture 4.0 is a combination of mechanical innovations and information and communication technologies (ICTs) for automatic machinery devices, robots, AI, 3D vision, irrigation, fertilization, precision farming, waste treatment, and advanced biopharming methods (17-25). All these technologies are targeted to improve farmers' decision performance. The labour utilized in routine operations could be substituted with intelligent labour techniques. Precision animal husbandry represents a new opportunity for the animal production sector, improving the efficiency of the overall systems and enhancing both animal welfare (due to the possibility of monitoring and managing individual animals and not only the group) and production sustainability. The agricultural sector is considering with growing interest the adoption of ICT methods to improve the management process (with reduction of costs) and reduction of the environmental impact (mitigation of emissions). Digital and technical information is produced by sensors or other devices capable of measuring variables of interest. PLF techniques, as outlined in Table 2, are based on the integrated use of all the information available on the farm.

The most common PLF technologies are milking technologies: automated milking (robot); localization and attack of milking systems; colour sensors; electrical conductivity sensors; flow metres; near infrared reflectance (NIR) analyser; flow analysers (urea and beta-hydroxybutyrate (BHB), L-lactate dehydrogenase (LDH), progesterone); Body Condition Score (BCS) automated assessment systems; housing environment: microclimate (temperature and relative humidity); lighting (time and lux intensity); gas (N_2O, CH_4, CO_2, and NH_3; powders ($PM_{2.5}$ and PM_{10}); animal feeding: field sensors (satellite) for harvesting and conservation (ensiling and hay making) decisions; conservation sensors (thermography); in line sensors (NIR); and animal welfare and health: location, movement, breathing, body temperature, ingestion and rumination (26-34). The application of sensors (Fig. 1) in the animal production sector is still in its infancy and has yet to be developed in the future.

An improvement in economic farm efficiency is the improved use of production resources. In the livestock sector, feed represents more than 30% of the production costs (35). Today, methods for a rapid near infrared reflectance (NIR) spectroscopy analysis of feeds are available. These methods can be used to quickly analyse the mixed feeds that are loaded into the mixer wagon for the preparation of cattle diets. These systems are very important, especially in agricultural areas where large quantities of wet silage, maize and grass silage are employed. These feeds are characterized by high and variable humidity. The importance of this method relies on the

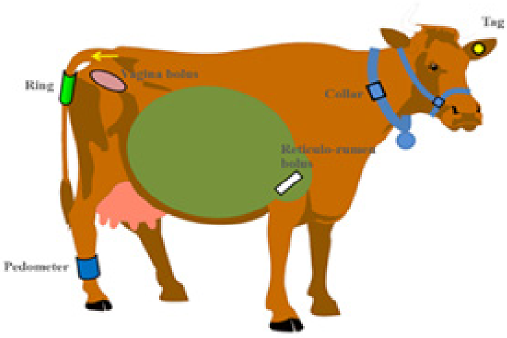

Figure 1. Example of cow sensors: behaviour activity (oestrus, activity and health) measured on ears, legs and neck; calving alert using the vaginal temperature; rumen functions (temperature, pH and drinking) using a rumen bolus.

Table 2. List of precision livestock farming applications in the animal production sector

Environmental control
- weather information systems
- recording systems and microclimate control, animal housing, air quality, water quality
- lighting and photoperiod control systems
- bioacoustics
Animal nutrition
- automatic forage analysis systems: in the field, at harvesting or during the storage (including biomass temperature detection systems, e.g. *Near Infrared* Reflectance spectroscopy (NIR) with thermography)
- integrated systems for intelligent feed preparation and distribution (e.g. corrections based on NIR analysis)
- automated forage transfer systems
- feeding / nursing robots
- physical-chemical quality control systems for distributed feeds
- control systems / estimation of food intake
- food digestibility estimation systems
- control of emissions
Animal behavior and welfare
- activity detection meters (pedometers, activometers, collars, earphones)
- biomarkers in milk (somatic cell count, conductivity, lactate dehydrogenase)
- calving alert detectors (vaginal temperature)
- rumen function (rumen bolus (temperature, pH, drinking)
- position location (GPS)
-Boby condition score (BCS) (using 3D imaging)
Automatic Milking systems (AMS) (individual)
- individual/quarter production detection (including milk flow registration)
- diagnostic breast detection (color, conductivity, enzymes, California Mastitis Test (CMT), somatic cells (UV fluorescence), thermography)
- macro-component detection (fat, protein, lactose) (Near Infrared, NIR)
- nutritional diagnostic detection (urea, ketone bodies)
- reproductive diagnostics (progesterone)
- milking robot
Animal manure
- manure cleaning robot
- manure analysis systems
- emission recordings
Management control
- energy consumption control systems
- work organization and company operational time recording
- integrated warehouse management systems
Product quality control
-integration with transformation phases
- integration of company information with other operators in the supply chain
Data
- big data management, statistical processing and analysis, information generation within decision support systems (DSS)
Phenomics
- use of information for monitoring, management or genetic improvement of production animals

advantage of determining, in real time, the actual amount of dry matter and the risk of potential quality deterioration. Currently, the method for the detection of oestrus is widely utilized at the market level via algorithms that interpret variations in animal activity (36). Individual milk production (milking robot) allows correct dietary animal management (e.g., placing a cow in the most suitable production group or providing a food supplement using individualized automatic systems) (35). Less common are the macro-components of milk analysis (e.g., urea and beta-hydroxy-butyrate), which can provide additional information about the nutritional status of an animal, allowing us to correct the composition of the diet. PLF may allow high and efficient livestock production. The possibility of automatically recording and managing a large amount of data is related not only to milk production (even of each quarter of the animal udder) but also to analysing the flow (peak and average), total milking time and other variables (37). On the other hand, the correct and updated knowledge, day by day, of the individual production level allows an easier and faster adjustment of the diet to support the best production performance. For ruminates, the main objective is to optimize the protein synthesis of rumen microorganisms. This result is obtained by feeding animals the required amount of amino acids and fats, and by this way, reducing the polluting emissions (N and methane) (39). The improvement of livestock feed efficiency can also cause additional positive economic and social effects (40). Managing and analysing "big data" obtained on farms involves several activities. First, it is necessary to standardize the data obtained from multiple sources (internal and external to the farm) in real time, which can provide better opportunities for diagnosing risks and identifying alternatives (39). Large amounts of data (often from heterogeneous sources) require 1) large-scale collections, 2) storage, 3) pre-treatment, 4) modelling, and 5) analysis. Recently, artificial intelligence methods have been proposed for PLF data analysis. Several approaches are available, such as supervised learning (with data labelling and training datasets) and unsupervised learning methods that independently utilize data (41).

2.2 New genomic tools

With the advent of omics technologies, it is possible to identify genetic variants (polymorphisms) at the DNA level and single genes (single nucleotide polymorphisms and SNPs) with significant effects on quantitative traits (QTLs). The identification of these polymorphisms in domestic species has enabled the genotype of a large number of animals and the use of several thousands of molecular markers via the use of SNP chip arrays (42). By means of these latest generation genomic tools, we are therefore able to identify new associations between the genetic variants (SNPs) and traits of interest. In particular, we can select animals with a "lower environmental impact" in terms of reduced feed consumption and methane emissions and increased metabolic efficiency (43). Among the various climatic variables, thermal stress has been reported as the most damaging factor for the economy of the livestock sector. There are numerous candidate genes associated with the adaptation of ruminants, monogastrics and poultry to heat stress. For example, genes that encode leptin (LEP), thyroid hormone receptor (THR), insulin growth factor-1 (IGF-1) and growth hormone receptors (EGF family) are associated with the effects of heat stress on several physiological animal processes (milk, meat and egg production; thermoregulation; and oestrus cycles) (44). Genetic selection is an important method for improving the feeding efficiency of beef and dairy cattle. Food efficiency is traditionally measured as the ratio between distributed food and weight gain. Genetic analysis of traits such as the food conversion ratio (FCR) or g CO_2/dry matter intake is difficult to measure, as more emphasis is placed on the trait with greater genetic variability (45). For this reason, the residual feed intake (RFI) trait is preferred to select animals with lower methane emissions (46). This trait is moderately heritable (0.26–0.43) and is obtained by a precise individual measure of food intake. The value of RFI can also be corrected for the back fat value (RFIfat). Animals selected for a low RFI value will show a better conversion rate and lower dry matter ingestion. The selection of these animals will allow the reduction of enteric CH_4 emissions (15–25%). de Haas et al. (47) predicted the RFI and CH_4 emissions (based on DMI and diet composition) and suggested that 10 years of selection for the nutrition efficiency trait could reduce the CH_4 emissions by 11–26%. Yan et al. (48) analysed the data of experiments using a calorimetric chamber and suggested the selection of cows with greater energy efficiency. In 2018, the Holstein Friesian Genetic Center (Cremona, Italy) started a new project, named "Latteco", with the aim of measuring two traits for each individual bull: dry matter ingestion and greenhouse gas emissions (enteric methane and carbon dioxide). The experimental test starts after the quarantine period, and the bulls are divided into homogeneous groups according to age and weight. The young bulls were fed ad libitum during the whole test. The individual ingestion of dry matter (kg/d) and eating behaviours were evaluated using the Roughage Intake Control system (RIC, Hokofarm Group). A manager allows the calculation and monitoring of daily ingestions. Emissions of CO_2 and CH_4 (g/d) were measured using the "GreenFeed" system (C - Lock Inc., Rapid City, SD, USA). The emissions are recorded through a feeder at each individual access of the animal to the feeding box. The initial results showed that more efficient animals emit less GHG. In addition, as the weight, chest circumference, height at the withers and ingestion capacity of individual bulls increase, methane and carbon dioxide emissions increase. One of the first objectives proposed is therefore to select more efficient animals to reduce emissions.

New biotechnology technologies and genome editing, such as the CRISPR/Cas9-12 method, can be employed to improve the productivity of animal and vegetable crops. Institutions and policy makers should promote regulatory environmental legislation to encourage the diffusion of these new technologies and investment through the entire livestock production chain.

3. Edible protein content in animal species

The role of most diffused domestic animal species, ruminants and monogastrics is to convert rough feedstuffs of minimal or no biological value for humans into higher-quality proteins with balanced essential amino acid composition and higher nutritional value. The need to increase the efficiency in the meat and milk production chain by reducing the time from cradle to farm, input costs and impact has induced farmers to adopt intensive breeding techniques based on crops responsible for rapid growth: corn grain, corn silage and soybean meal. The United Soybean Board has estimated that 46% of the soybean meal produced in the United States is used for feeding broilers, layers and turkeys; pigs use another 25% and ruminants account for approximately 21%. The high quantity of digested protein and amino acids in soybean meal provides the best combination with cereals for producing the least-cost rations for swine, poultry and beef. It has also been stated that the composition of essential amino acids is pertinent to human consumption; hence, soy could be applied almost indifferently to feed animals for meat production or for human nutrition.

The most important issue today is to examine the convenience of producing alternative protein sources by evaluating the livestock enterprise in a broader contest, including costs, species, nutritional value, consumer preferences, environmental impact, energy consumption, and land/water resource constraints. One important observation is the selection of species: ruminants can convert edible protein of high biological value (milk and meat) into a large number of vegetable crops, permanent meadows and pastures, fodder and roughage rich in fibre, cellulose and lignin. The analysis proceeded in three steps: the first step was to evaluate the quantity of vegetable proteins digested by animals; the second step was to evaluate the animal protein content for the most diffuse animal species; and the third step was to globally balance vegetable and animal proteins, impact and costs.

The first step starts with examining the quantity of crude vegetable proteins (CP) produced by one ha of land converted to the human edible fraction of protein using the human edible feed conversion efficiency index (heFCE) (49). A list of the most diffused crops currently used for feeding animals is examined. Table 3 reports the crude protein yield production per ha and heFCE for some vegetable crops.

The results suggest that soybean, soymeal and sunflower have the best heFCE indexes, followed by cereals and rapeseed. The second step of this analysis is to evaluate the protein content of the most common animal species employed in the livestock sector (Table 4).

The results concerning the protein contents in animal-based

Table 3. Crude protein production per ha and the human edible feed conversion efficiency index (heFCE) for some vegetable crops used for animal and human consumption

Feedstuff	Production	Dry Matter	Crude Protein		heFCE[1]		Index
	t/ha	%	g/kg DM	Kg/ha	CP %	Kg/ha	heFCE/ production
Barley	6	88	125	750	80	600	0.10
Maize	12	88	106	1272	80	1017.6	0.08
Wheat	6	88	138	828	80	662.4	0.11
Soybeans	4.5	90	404	1818	80	1454.4	0.32
Rapeseed meal	2.8	88	406	1136.8	20	227.36	0.08
Soybeans meal	1.8	90	513	923.4	80	738.72	0.41
Maize silage	60	35	86	5160	0	0	0.00
Sunflower meal	2.5	88	410	1025	80	820	033

[1] heFCE - human edible feed conversion efficiency index

Source: (52)

Table 4. Average values of human edible fraction of protein content in some animal species

	Average (g/Kg edible product)	Range (g/Kg edible product)
Milk (cows)	34	33.3 -34
Beef	200	185-209
Pigs	182	150-220
Poultry	201	190-212
Eggs	125	120-130

Source: (52)

food are presented as follows: milk (between 30.8 and 37.0 g/kg), beef (170–250 g/kg equivalent to 17–25%), pork (129–240 g/kg, or 12.9–24%), poultry meat (182–300 g/kg or 18–30%), and eggs (110–130 g/kg or 11–13%). While it is quite easy to compute the protein content in some animal products, such as milk, whey or eggs, it is more difficult to quantify the protein content obtained using different evaluation methods. Two conversion indexes are utilized for this evaluation: i) index to convert live weight (LW) to carcass weight (CW) (HSCW – hot standard carcass weight). Current values of this index are beef: 53%; pork: 75%; and poultry: 70% (51); ii) index to convert CW into edible protein, that is, the edible fraction of the CW. Additionally, in this case there are different evaluations. Some common values are reported: milk protein: 30.8–37 g/1 kg milk; beef meat: 170–227 g/kg. The quantity of protein produced by LW is reported in the table 5.

To evaluate the efficiency of animal protein production, the feed quantity converted to 1 kg of live weight (LV) was employed. To produce 1 kg of animal protein, in general, from 3 to 16 kg of vegetable protein depending on the animal breed, feedstock, breeding method, environmental conditions and other factors are required.

We present a synoptic view of the protein efficiency conversion following the approach suggested by Flachowsky et al. (52) for the conversion of vegetables to animal proteins for most common breed species. The computation of human edible protein yield (HEPY) is defined as the protein output contained in the edible animal crop divided by the edible protein intake. A value >1 suggests a net yield of protein, whereas if the value is less than 1, there is protein loss. In our case, only milk and broiler have a value >. 1 They are good converters of vegetables into animal proteins, while pig and veal have a score < 1.

Finally, an overview (Table 6) of the protein efficiency conversions for different species is presented.

Table 5. Conversion of body mass into protein for some species

	Body mass	Conversion (%)	Conversion (%)	Protein
Product	LW^{1}	LW-CW (HSCW)^{2}	CW-heCW^{3}	Kg/LW
Beef	600	55	20	66
Pigs	120	75	25	22.5
Poultry	3	70	25	0.525

^{1} LW= live weight; ^{2} LW-CW(HSCW) (CW – carcass weight) (HSCW – hot standard carcass weight); ^{3} CW-heCW ((CW – carcass weight) (heCW – edible protein of carcass weight)

Source: (52)

Table 6. Overview of the protein efficiency conversion for some species

Species	Body Weight	Performance	Dry Matter intake	Forage/ concentrate	Edible fraction	Edible Protein (EP)	Edible Protein Yield (EPY)	HEPY
	kg	Kg/d	Kg/d	%DM	%BW	g/kg	g/d	g/kg BW/d
		1	2	3	4	5=4*CP%	6=1*5*+95	7=6/1
Dairy cow	600	30	29	22/7	95	34	969	1.615
Fattening veal	250	1.2	7.4	4.65/2.76	50	328	196.8	0.7872
Pig	120	0.6	0.37		65	120	36	0.3
Broiler	3	0.067	0.096		60	150	5.025	1.675

Source: (52)

4. Livestock environmental impact

The livestock sector is one of the main users of natural resources. According to Sere and Steinfeld (49), livestock animals use 3.4 billion hectares of grazing land and production from approximately one-quarter of the world's crop lands. In total, livestock comprise more than two-thirds of the agricultural world's surface and one-third of the total global land area (49).

Two different types of accounting systems are used to calculate the total emissions for the global livestock sector: 1) inventory of emission sources and 2) LCA. The first method describes the direct emission sources (e.g., enteric fermentation) that are aggregated into sectors (i.e., farming) with geographic units (e.g., nations). This form of accounting is employed by countries according to the United Nations Framework Convention on Climate Change (UNFCCC) via the International Panel for

Climate Change (IPCC) guidelines. According to a study of OECD/FAO (50), the sum of livestock emissions from enteric fermentation, manure and cropland related to feed is approximately 4–5 Gt CO_2 eq or 8.8% of the total. The second method is based on accounting for the direct and indirect emissions produced along the entire production chain for a particular product or service. This method is often applied when the goal is to understand where in a value chain, resource use and environmental impacts occur. According to a revised FAO study, livestock-related emissions along the whole value chain, including direct and indirect emissions, amount to 8.1 Gt CO_2 eq or 16.5% of the total in 2010. LCA is an important tool for supporting political and economic decisions about the diffusion of activities having consequences for the agri-food chain and community. Methods used to make an LCA are indicated in the ISO standards (ISO 14040 (53); ISO 14044 (54)). The LCA method involves four phases: (1) objective definition, (2) inventory and data collection, (3) calculation of the environmental impact, and (4) discussion of the results. The LCA describes the product, process or activity requirements for energy and material during its entire life cycle and the emissions and waste released to the environment. The results of LCA studies have comparative significance rather than providing absolute values to evaluate the environmental impacts (40). Sustainability and LCA literature supports the idea that a plant-based diet is better for the environment (55). A variety of impacts are considered in the agricultural LCA: GHG emissions, global warming potential (GWP), acidification, biodiversity, release of nitrogen in various forms (eutrophication), etc. The most commonly employed LCA indicators are land use, m^2; fossil energy use, MJ; global warming, kg CO_2 eq.; acidification, kg SO_2 eq.; and eutrophication, kg PO_4 eq. The greenhouse effects are different for the different gases involved and are equalized using the "CO_2 equivalent" (56): carbon dioxide, 1 kg of CO_2 = 1 kg of CO_2 equivalent; methane 1 kg of CH_4 = 28 kg of CO_2 equivalent; and nitrous oxide, 1 kg of N_2O = 298 kg of CO_2 equivalent. The units of measurement in animal husbandry are kg of CO_2 eq. per animal per day or year; kg of CO_2 eq./kg of milk or meat; and kg of CO_2 eq./kg of dry matter ingested. A list of impact categories and environmental indicators used in environmental studies are reported in Table 7.

Table 7. List of impact categories and environmental indicators used in environmental studies

Impact categories	Environmental indicators
Consumption of non-renewable resources	Fossil fuels
	Fertilizers-NPK
Greenhouse effect	CO_2, CH_4, N_2O
Fertility and soil function	Accumulation of heavy metals
	NH_3, NOx, SO_2
Water quality (ground and surface water)	N-fertilizers, nutrient balance, nitrate leaching
	Fertilizer, P budget, P drainage
Human and environmental toxicity	Herbicides and antibiotics, nitrates
	NH_3, PM_{10}, $PM_{2.5}$
Biodiversity	Number of species, breeds and varieties
Landscape	Pastoral activities, variety of environments
Animal welfare	Structures, reproduction, health care
Others	Smells, noises, ozone layer, etc.

The stages of production, processing and transport of feed used in the livestock sector constitute approximately 45% of total GHG emissions (57). The fodder is grown in 33% of the cultivated land, while grazing constitutes 30%. The water footprint (WFP) of livestock animals is larger, in some cases 20 times, than that of crops with the same nutritional value. The consumption of Kcal fossil energy per kg of production and LCA data of several products are reported in Table 8.

As the price elasticity of livestock meat consumption is estimated to be 0.75, future consumption is expected to grow quite steadily with the decline in prices. The World Wide Fund for Nature (WWF) estimates that 280 million hectares will be needed in 2030 to produce the soy and corn needed to feed all livestock. In the EU, pasture and cultivated land is 173 million hectares, or 39% of the total (7). The production of animal proteins is an intensive water consumption activity. In several countries, this resource could limit animal production even more than land use (58). It takes 2364 litres of water to produce 1 kg of soybean protein (10638 m^3/ha), and 4525 litres is needed to produce 1 kg of chicken (59).

Conclusion

This paper started with FAO scenarios based on the search for a sustainable approach to produce convenient protein foods to feed a growing population (10 billion to 2050), changing consumers' habits, scarcity of land and water resources and reducing livestock GHG emissions. The goal is to increase global an-

Table 8. Consumption of Kcal fossil energy to produce 1 kg of different foods and LCA

Food	Conversion Ratio[1]	Grain[2]	Forage[2]	Emission Kg CO_2	Energy Kcal	Water use m^3	Land use m^2
1 liter or Kg of milk	14	3	0.83	2.4	420	1.02	40
1 kg of poultry meat	4	2.3	-	3-5	2390	4.525	70
1 kg of pig meat	14	5.9	-	5-8	2690	5.99	110
1 kg of beef meat	40	13	30	28-32	2500	17	1640
1 kg of maize					3500	1.22	

[1] Kcal fossil energy required to produce 1 kcal of product

[2] Grain, forage and concentrate (kg) requested to produce 1 Kg of product.

Source: (57)

imal protein production to satisfy the future food demand. In the future, increased meat production will help to achieve some of the goals of the FAO. However, there are some concerns about land depletion, the maintenance of soil fertility, climate change, the scarcity of water in some areas and the conservation of natural resources. It is evident that, the driving forces for a transition to a low-emissions food system must be derived from a robust policy framework. Several studies conclude that a reduction in the current GHG livestock emissions in the EU would contribute to a climate change mitigation. The most important issue today is to examine the convenience of producing alternative protein sources by evaluating the livestock enterprise in a broader contest, including costs, species, nutritional value, consumer preferences, environmental impact, energy consumption, and land/water resource constraints. One important observation is the selection of species: ruminants can convert edible protein of high biological value (milk and meat) into a large number of vegetable crops, permanent meadows and pastures, fodder and roughage rich in fibre, cellulose and lignin. According to FAO, livestock-related emissions along the whole value chain, including direct and indirect emissions, amount to 8.1 Gt CO_2 eq or 16.5% of the total. LCA is an important tool for supporting political and economic decisions about the diffusion of activities having consequences for the agri-food chain. The results of LCA studies have comparative significance rather than providing absolute values to evaluate the environmental impacts. Sustainability and LCA literature supports the idea that a plant-based diet is better for the environment.

References

1. FAO report 2018.OECD & Food and Agriculture Organization of the United Nations (2019), OECD-FAO Agricultural Outlook 2019–2028. (Rome: FAO: 2018).
2. FAO report 2017.The future of food and agriculture– Trends and challenges. (Rome: FAO: 2017).
3. Gaber PJ, Steinfeld H, Henderson B, Mottet A, Opio C, Dijkman J, Falcucci A, Tempio G. Tackling climate change through livestock: a global assessment of emissions and mitigation opportunities. (Rome: FAO: 2013).
4. Angel SP, Amitha JP, Rashamol VP, Vandana GD. Climate change and cattle production – impact and adaptation. J Vet Med Res 2018; 5: 1134.
5. Grossi G, Goglio P, Vitali A, Williams AG. Livestock and climate change: impact of livestock on climate and mitigation strategies. Anim Front 2019; 9: 69–76.
6. FAO 2012. World agriculture towards 2030/2050, the 2012 revision. (Rome: FAO: 2012).
7. FAO 2013. Sustainable Food Consumption and Production. (Rome: FAO: 2013).
8. Alexandratos N and Bruinsma J. World agriculture towards 2030/2050.The 2012 revision. ESA Working Paper No. 12–03. (Rome: FAO: 2012).
9. FAO 2009. Global agriculture towards 2050. In How to Feed the World 2050 1–10. (Rome: FAO: 2009).
10. Foley JA, Ramankutty N, BraumanKA, Cassidy ES, Gerber JS, Johnston M, Mueller ND, O'Connell C, Ray DK, West PC, Balzer C (2011) Solutions for a cultivated planet. Nat 2011 478: 337.
11. Delgado C, Rosegrant M, Steinfeld H, Ehui, S, Courbois C. Livestock to 2020: the next food revolution. IFPRI Food, Agriculture, and the Environment Discussion Paper 28. (Washington: IFPRI: 1999).
12. Wilkinson JM, Lee MRF. Review: Use of human-edible animal feeds by ruminant livestock. Animal 2018; 12(8): 1735–1743.
13. de Vries M, de Boer JM. Comparing environmental impacts for livestock products: a review of life cycle assessments. Livest Sci 2010 128: 1–11.
14. ILCD. International reference life cycle data system

(ILCD) handbook—general guide for life cycle assessment - detailed guidance. (Luxembourg: UE: 2010).

15. Borchers MR, Bewley JM. An assessment of producer precision dairy farming technology use, pre-purchase considerations, and usefulness. J Dairy Sci 2015; 98: 4198–4205.
16. Caja G, Castro-Costa A, Knight CH. Engineering to support wellbeing of dairy animals. J Dairy Res 2016; 83: 136–147.
17. De Marchi M, Toffanin V, Cassandro M, Penasa M. Invited review: mid-infrared spectroscopy as phenotyping tool for milk traits. J Dairy Sci 2014; 97: 1171–1186.
18. Egger-Danner C, Cole JB, Pryce JE, Gengler N, Heringstad B, Bradley A, Stock KF. Invited review: overview of new traits and phenotyping strategies in dairy cattle with a focus on functional traits. Animals 2015; 9: 191–207.
19. Gargiulo JI, Eastwood CR, Garcia SC, Lyons NA. Dairy farmers with larger herd sizes adopt moreprecision dairy technologies. J Dairy Sci 2018; 101: 5466–5473.
20. Halachmi I, Guarino M, Bewley J, Pastell M. Smart animal agriculture: application of real-time sensors to improve animal wellbeing and production. Annu Rev Anim Biosci 2019; 7: 403–425.
21. Hartung J, Banhazi T, Vranken, E, Guarino M. European farmers' experiences with precision livestockfarming systems. Anim Front 2017; 7: 38–44.
22. Kaniyamattam K, De Vries A. Agreement between milk fat, protein, and lactose observations collected from the Dairy Herd Improvement Association (DHIA) and a real-time milk analyzer. J Dairy Sci 2014; 97: 2896– 2908.
23. Koltes JE, Cole JB, Clemmens R, Dilger RN, Kramer LM, Lunney JK, McCue ME, McKay SD, Mateescu RG, Murdoch BM. A vision for development and utilization of high-throughput phenotyping and big data analytics in livestock. Front Genet 2019; 10: 1197.
24. Lokhorst C, de Mol RM, Kamphuis C. Invited review: big data in precision dairy farming. Animals 2019; 13: 1519–1528.
25. Neves RC, LeBlanc SJ. Reproductive management practices and performance of Canadian dairy herdsusing automated activity-monitoring systems. J Dairy Sci 2015; 98: 2801–2811.
26. Rutten CJ, Velthuis AGJ, Steeneveld W, Hogeveen H. Invited review: Sensors to support healthmanagement on dairy farm. J Dairy Sci 2013; 98: 1928–1952.
27. Sauls JA, Voelz BE, Hill SL, Mendonça LGD, Stevenson JS. Increasing estrus expression in the lactating dairy cow. J Dairy Sci 2017; 100: 807–820.
28. Song X, Bokkers EAM, van Mourik S, Groot Koerkamp PWG, van der Tol PPJ. Automated body condition scoring of dairy cows using 3-dimensional feature extraction from multiple body regions. J Dairy Sci 2019; 102: 4294–4308.
29. Steeneveld W, Hogeveen H, Lansink AGJMO. Economic consequences of investing in sensor systems on dairy farms, Comput. Electron Agric 2015; 119: 33-39.
30. Steeneveld W, Hogeveen H. Characterization of Dutch dairy farms using sensor systems for cow management. J Dairy Sci 2015; 98: 709-717.
31. Tse C, Barkema HW, DeVries TJ, Rushen J, Pajor EA. Effect of transitioning to automatic milking systems on producers' perceptions of farm management and cow health in the Canadian dairy industry. J Dairy Sci 2017; 100: 2404–2414.
32. Van De Gucht T, Saeys W, Van Nu el A, Pluym L, Piccart K, Lauwers L, Vangeyte J, Van Weyenberg S. Farmers' preferences for automatic lameness-detection systems in dairy cattle. J Dairy Sci 2017; 100: 5746–5757.
33. Van Hertem T, Maltz E, Antler A, Romanini CEB, Viazzi S, Bahr C, Schlageter-Tello A, Lokhorst C, Berckmans D, Halachmi I. Lameness detection based on multivariate continuous sensing of milk yield, rumination, and neck activity. J Dairy Sci 2013; 96: 4286–4298.
34. Van Hertem T, Rooijakkers L, Berckmans D, Peña Fernández A, Norton T, Berckmans D, Vranken E. Appropriate data visualisation is key to Precision Livestock Farming acceptance. Comput Electron Agric 2017; 138: 1–10.
35. Abeni F, Galli A. Monitoring cow activity and rumination time for an early detection of heat stress in dairy cow. Int J Biometeorol 2017; 61 (3): 417-425.
36. Cabrera VE, Kalantari AS. Economics of production efficiency: Nutritional grouping of the lactating cow. J Dairy Sci 2016; 99: 825-841.
37. Carlström C, Pettersson G, Johansson K, Strandberg E, Stålhammar H, Philipsson J. Feasibility of using automatic milking system data from commercial herds for genetic analysis of milkability. J Dairy Sci 2013; 96: 5.
38. Lawson LG, Pedersen SM, Sørensen CG, Pesonen L, Fountas S, Werner A, Oudshoorn FW, Herold L, Chatzinikos T, Kirketerp IM. A four nation survey of farm information management and advanced farming systems: A descriptive analysis of survey responses. Comput Electron Agric 2011; 77: 7–20.
39. Pimentel D. Livestock production: energy inputs and the environment. Can Soc Anim Sci 1997; 47: 17–26.
40. Aiking H. Future protein supply. Trends Food Sci Technol. 2011; 22 (2–3): 112-120.
41. D'Agaro E. New Advances in NGS Technologies. In: New Trends In Veterinary Genetics. (London: Intech Editions: 2017).
42. D'Agaro E. Artificial intelligence used in genome analysis studies. Eurobiotech J 2018; 2(2): 78-88.
43. Berckmans D. General introduction to precision livestock farming. Anim Front 2017; 7: 6–11.
44. Rexroad C, Vallet J, Matukumalli LK, Reecy J, Bickhart D, Blackburn H, Boggess M, Cheng H, Clutter A, Cockett N. Genome to phenome: improving animal health, production, and well-being—a new USDA blueprint for animal genome research 2018-2027. Front Genet 2019; 10: 327.
45. van der Werf HMG, Garnett T, Corson MS, Hayashi K, Huisingh D, Cederberg C. Towards eco-efficient agriculture and food systems: theory, praxis and future challeng-

es. J. Clean. Prod. 2014; 73: 1–9.

46. Connor EE, Hutchison JL, Norman HD, Olson KM, Van Tassell CP, Leith JM, Baldwin RLV. Use of residual feed intake in Holsteins during early lactation shows potential to improve feed efficiency through genetic selection. J Anim Sci 2013; 91: 3978–3988.
47. de Haas Y, Windig JJ, Calus M, Dijkstra J, de Haan M, Bannink A, Veerkamp RF. Genetic parameters for predicted methane production and potential for reducing enteric emissions through genomic selection. J Dairy Sci 2011 94: 6122–6134.
48. Yan T, Mayne CS, Gordon FG, Porter MG, Agnew RE, Patterson DC, Ferris CP, Kilpatrick DJ. Mitigation of enteric methane emissions through improving efficiency of energy utilization and productivity in lactating dairy cows. J Dairy Sci 2010; 93: 2630–2638.
49. Sere, C.; Steinfeld, H. World livestock production systems: current status, issues and trends. Animal Production and Health Paper No 127. (Rome: FAO: 1996).
50. OECD/FAO 2016. OECD-FAO Agricultural Outlook. OECD Publishing: Paris, France, 2016.
51. USDA. USDA Nutritional Database for Standard Reference Release 27. USDA Agricultural Research Service. (Washington: USDA: 2014).
52. Flachowsky G, Meyer U, Südekum KH. Land Use for Edible Protein of Animal Origin—A Review. Animals 2017; 7(3): 25.
53. ISO 2006a. Environmental Management - Life Cycle Assessment-Principles and Framework. EN ISO 14040:2006. EN ISO 14040. (Geneva: ISO: 2006).
54. ISO 2006b. Environmental Management - Life Cycle Assessment-Requirements and Guidelines. EN ISO 14044:2006. EN ISO 14044:2006. (Geneva: ISO: 2006).
55. Pimentel D, Pimentel M. Sustainability of meat-based and plant-based diets and the environment. Am J Clin Nutr 2003; 78: 660-663.
56. IPCC 2014. Climate change 2014: Impacts, adaptation, and vulnerability. Part A: Global and sectoral aspects. Contribution of Working Group II to the Fifth Assessment Report of the Inter-governmental Panel on Climate Change. (Cambridge (UK): Cambridge University Press: 2014).
57. Sonesoon U, Davis J, Ziegler F. Green-House Gases from livestock production EU27. (Göteborg: Swedish Institute for Food and Biotechnology: 2011).