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LIVESTOCK PRODUCTION FOR A SUSTAINABLE DEVELOPMENT

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ABSTRACT

The development of society is based on the existence of food resources. The past half-century has seen marked growth in food production, allowing for a dramatic decrease in the proportion of the world's people that are hungry, despite a doubling of the total population. Recently, the FAO predicted a higher increase of the consumption of foods of animal origin by 2050. So far, the increased demand for food has been supplied by agriculture due to an improvement of techniques, an increase of cultivated land areas and an increase of water and energy consumption. The environmental assessment of human activities is presently a hot topic. It is not only important from an ecological perspective, but also from the view of efficient utilization of limited natural resources. The livestock sector that increasingly competes for scarce resources (land, water, and energy) has a severe impact on air, water and soil quality because of its emissions. The environmental impact of food of animal origin is currently quantified by so-called CO_2eq-footprints. Therefore, in the future, it will be necessary to achieve a sustainable supply of food, especially of animal origin, because land and other production factors are not unlimited resources. This lecture deals with related problems linked to the production of foods of animal origin and some possible sustainable solutions for the increasing demand of these products, by means of a detailed analysis of the carbon footprint by the livestock, as well as the land requirement, biodiversity, energy and water footprint in livestock production.

Keywords: Food, livestock production, sustainability

INTRODUCTION

"Sustainable development of food supply chains" or "diet eco-friendly" are increasingly the attention not only of experts, but also of the media, to draw consumers' attention to the quality of products. The production of quality food, made with sustainable production systems, is increasingly felt by most consumers, as well as also by the producers, now aware that a careful production environment can lead to savings of energy, resources and materials that also translate into economic benefits.
What, then, do we now understand by agricultural "Sustainable Development"? The concept of Sustainable Development is multidimensional, and sustainability can be measured on various levels, in time and space. This provides a wide field for the search of methods of measuring "sustainability", which are addressed to different sustainability aspects. These indications were a product of the Conference in Rio de Janeiro (1992), and therefore the need to establish a set of sustainability measures and indicators to monitor the progress of the implementation of this concept on the global and individual country level. The indicators of sustainability were established in Agenda 21 **(reviewed in Majewski, 2013).**
It is common assumption that agricultural sustainability implies a net reduction in input use (e.g. best genotypes and best ecological management), thus making such systems essentially extensive. This could be erroneous because this type of agriculture requires more land to produce the same amount of food (e.g. vegetable, fruits, meat, milk, eggs). However, many different expressions have come to be used to imply greater sustainability in some agriculture systems over prevailing ones (both preindustrial and industrialized). These include biodynamic, community based, ecoagriculture, ecological, environmentally sensitive, extensive, farm fresh, free range, low input, organic, permaculture, sustainable and wise use. There is continuing and intense debate about whether agricultural systems using some of these terms can qualify as sustainable **(Pretty, 2008)**. The idea of agricultural sustainability can be compared to agricultural systems that tend to be multifunctional within landscapes and economies **(Dobbs and Pretty, 2004)**.An agriculture that jointly produces food and other goods for farmers and markets, but also contributes to preserve clean water, wildlife and habitats, as well as carbon sequestration. In other words, a sustainable agriculture seeks to make the best use of nature's goods and services. Technologies and practices must be locally adapted and fitted to place **(Pretty, 2008)**; for **Runowski (2007)** the ethical aspects of farming in line with the sustainability paradigm and a need of balancing environmental, economic and ethical objectives play an important role.
The development of society is based on the existence of food resources. The past half-century has seen marked growth in food production, allowing for a dramatic decrease in the proportion of the world's people that are hungry, despite a doubling of the total population **(Godfray *et al.*, 2010)**. However, a total of 842 million people in 2011–13, or approximately one in eight people in the world, were estimated to be suffering from chronic hunger, regularly not getting enough food to conduct an active life **(FAO, 2013)**. In this contest, the mission of the researchers involved in the human food chain is to contribute through research to produce sufficient quantities of food of appropriate quality nutritional and healthcare in order to meet the world's population, also according to sustainable agricultural systems. The International Food Policy Research Institute has developed a 2020 Vision of a world where every person has economic and physical access to sufficient food to sustain a healthy and productive life, where malnutrition is absent, and where food originates from efficient, effective, and low-cost food and agricultural systems that are compatible with sustainable use and management of natural resources. The world's natural resources are capable of supporting the 2020 Vision, if current rates of degradation are reduced and replaced by appropriate technological change and sustainable use of natural resources **(Pinstrup-Andersen and Pandya-Lorch, 1998)**. The right to food is satisfied if the permanent access and unlimited access to food (food security) and the availability of food of adequate quality (food safety) are guaranteed.
Recently, the **FAO (2009)** predicted a higher increase of the consumption of foods of animal origin by 2050 (+73% meat and meat products, +58% milk and milk products), while individual daily consumption of foods of plant origin (cereals, fruits and vegetables) should remain fairly stable. This dramatic increase of the demand for products of animal origin is expected to occur due to: i) the exponential growth of the world's population (China, India, Africa) which should reach 9 billion people in 2050 **(Lutz, 2011; PRB, 2008)**, ii) the process of urbanization which will likely lead in 2030 to a concentration of 60% of the population in urban areas (Figure 1; **Pretty, 2008**), and iii) the increase in income of a large part of the population in emergent countries, such as China and India, which will result in a sharp increase in individual demand for animal products **(Fogel, 2006; Godfray *et al.*, 2010)**. Over the next 20 years in emerging countries, China and India in particular, there is expected an increase in the

annual consumption per person of meat and dairy products which will rise to 37 kg and 66 kg, respectively, contrary to what will happen in the developed countries where individual consumption of these products will remain substantially constant **(FAO, 2003)**. So far, the increased demand for food has been supplied by agriculture due to the improvement of techniques, an increase of cultivated land areas and an increase in water and energy consumption. In other words, the agricultural productivity growth makes food more sustainable by reducing the resources required for production, in particular land and water that are not unlimited **(Reilly and Willenbockel, 2010)**.

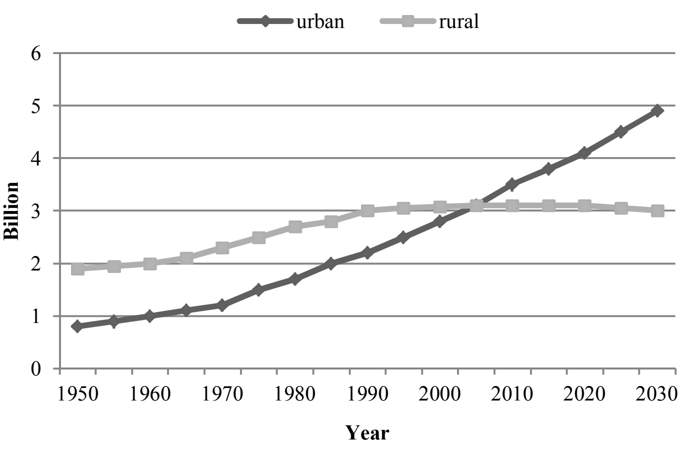

Figure 1 Rural and urban world population (1950-2030; from UN (2005)). (Source: **Pretty, 2008**).

Only 40% of the earth's entire surface (13 billion of hectares) is used for agriculture: 11.5% is arable, while 26% is grassland (Avery, 2001), spanning a range of climate conditions from arid to humid. This latter percentage is used for the zoo-technical activities and there are no interferences with the vegetable productions. A recent study reported by **Bauman and Capper (2011)** compared the global population with available land per person from 1960 to 2050 (Figure 2).

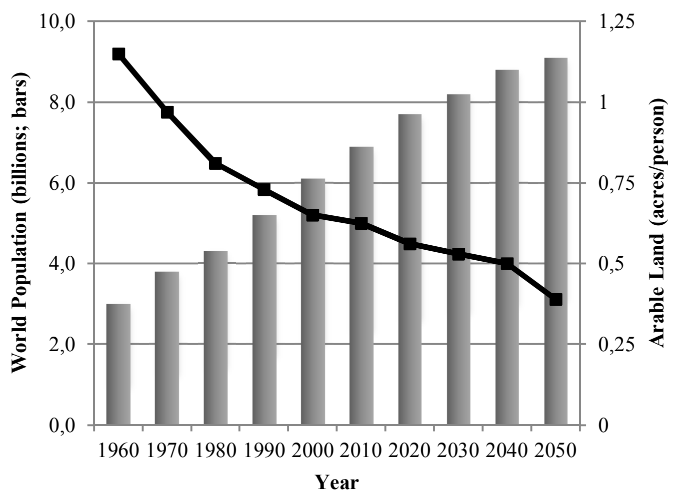

Figure 2 Comparison of the global population with available arable land per person from 1960 to 2050. Figure constructed by authors using World population estimates from the U.S. Census Bureau (2008) and arable land/person estimates from Bruinsma (2009). (Source: **Bauman and Capper, 2011**).

According to the FAO (2005), the worldwide livestock production significantly has increased: fourfold increase in numbers of chickens, twofold increase in pigs and 40–50% increase in numbers of cattle and small ruminants (Figure 3). However, animals are increasingly raised intensively and fed with cheap cereals. About one-third of global cereal production is fed to animals **(FAO, 2006)**. The conversion efficiency of plant into animal matter is ~10%; thus, there is a prima facie case that more people could be supported from the same amount of land if they were vegetarians. Nowadays, in industrialized countries, 73% of cereals are fed to animals and per capita annual demand is 550 kg of cereal and 78 kg of meat; while in developing countries, some 37% of cereals are fed to animals and per capita annual demand is 260 kg of cereal and 30 kg of meat **(Pretty, 2008)**. However, the argument that all meat consumption is bad is overly simplistic. First, there is substantial variation in the production efficiency and environmental impact (cereals and water use, methane emissions) of the major classes of meat consumed by people. Second, although a substantial fraction of livestock is fed on grain and other plant protein that could feed humans, there remains a very substantial proportion that is grass-fed **(Godfray *et al.*, 2010)**. Livestock production is also a major source of methane, a very powerful greenhouse gas, though this can be partially offset by the use of animal manure to replace synthetic nitrogen fertilizer.

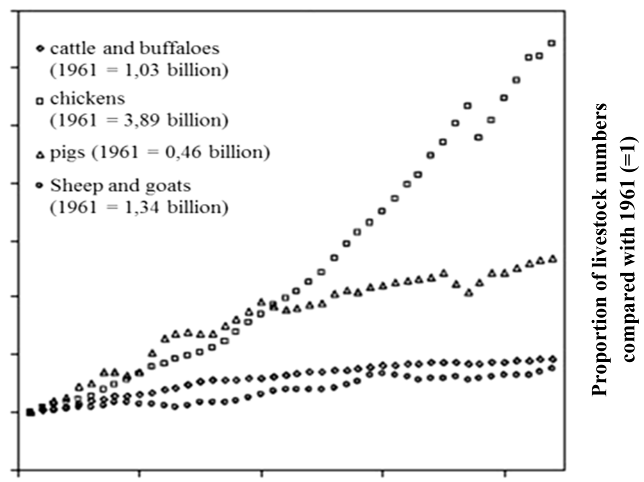

Figure 3 Head of livestock, world (1961-2004; from FAO (2005)), (Source: **Pretty, 2008**).

Agricultural systems, including livestock, are among the few who can help improve the global balance of carbon and water, not only in terms of reducing emissions and consumption, but as well as an increase in carbon sequestration and water saving. In addition, livestock systems can help to reduce the cereals consumed by animals. A method could consist to feed the animals with industrial wastes and food not in competition with the humans.

Recently, **Kitzes *et al.* (2008)** have defined the concept of Ecological footprint, in terms of the amount of total resources which humans use for their own lives. Originally, the global ecological footprint defined the maximum population sustainable planet. Practically, Kitzes and coworkers suggested that the Ecological Footprint estimates the contribution that the unit of product or service brings to the consumption of resources and environmental pollution. In other words and in particular: i) the measure of the total amount of emissions of greenhouse gases (GHG) emissions derived from the entire production cycle, sometimes also including the final destination (**Joint Research Centre - JRC, European Commission, 2007**), defined as carbon footprint. Its measure is expressed as GWP (Global Warming Potential), translating the effect of greenhouse gases other than carbon dioxide (methane, nitrous oxide, sulfur hexafluoride, etc.) in units of CO_2 equivalent; ii) the amount of virtual water incorporated or consumed, water footprint; iii) the amount of energy consumed, energy footprint; iv) the amount of eroded soil, soil footprint; v) the reduction of biodiversity, biodiversity footprint.

Among the many methods that have the goal of an overall assessment of the impact of individual products or entire production processes and their environmental sustainability, which are most widely used, are the so-called carbon footprint and the "life cycle assessment" (LCA). The LCA, a technique recognized internationally (ISO 14040-14044), is a holistic method to evaluate the environmental impact during the entire life cycle of a product. Two types of environmental impact are considered during the life cycle of a product: use of resources such as land or fossil fuels, and emission of pollutants such as ammonia or methane **(Guinée *et al.*, 2002)**. Many studies have used LCA to assess the environmental impact of livestock products, such as pork, chicken, beef, milk, or eggs **(de Vries and de Boer, 2010)**.

Agriculture can definitely help to improve the balance of the global carbon and water, not only in terms of reducing emissions and fuel consumption, but also as an increase in carbon sequestration (the capture and secure storage of carbon that would otherwise be emitted to or remain in the atmosphere) and water saving.

In the context of agriculture, livestock comes under particular scrutiny because it is more emissions intensive than many other forms of food production. Impacts on land use are of particular concern. Demand for land to grow feed crops or for pasture has been a major driver of land use change a deforestation, especially in developing countries **(Stephenson, 2010)**. But, at the same time, in developing countries, and in particular for many poorer communities, the livestock is indispensable for millions of people. It represents: milk and meat (the most concentrated source of some vitamins and minerals), which are important for individuals such as young children; manure to provide a local supply, and can be a vital source of income; animals are also used for ploughing and transport. In this context, grassland-or rangeland-based livestock production is often one of

the few available agriculture options. In fact, the carbon sequestration potential of grasslands and rangelands could be used to partly mitigate the GHG emissions of the livestock sector **(Soussana *et al.*, 2010)**.
Considering the higher increase in the consumption of foods of animal origin, an increasing part of the ecological footprint of agriculture depends on herds of livestock. In this regard, **Pulina *et al.* (2011)** suggested the animal footprint as the ecological impact of livestock production measured in terms of GHG emitted, water consumption, land eroded and damaged biodiversity per unit (usually per kg) of product of animal origin.

CARBON FOOTPRINT BY THE LIVESTOCK

Greenhouse gas emissions from animal production are substantial contributors to global emissions. Animals contribute with CO_2 emissions of breathing, with the rumen fermentation and enteric CH_4, and CO_2, CH_4 and N_2O produced by chemical reactions and biological processes that occur in the waste. Estimates suggest (Livestock's long shadow, LLS) that livestock agriculture contributes between 8 and 18% of global GHG emissions **(FAO, 2006; de Vries and de Boer, 2010)**. Whereas other recent studies have demonstrated that the GHG emissions from livestock production, especially in countries with a technologically developed animal husbandry, the contribution of livestock is much less, with values from 2-4% to 3-8% of the total emissions in Western countries **(Capper *et al.*, 2009a; Gill *et al.*, 2010)**. Milk and egg yields are more clearly defined animal outputs of production than food from slaughtered animals **(Flachowsky and Kamphues, 2012)**. In 2009, in Europe (EU-27) the GHG emission in the sector agriculture amounted to 10% of global emissions and decreased 21% compared to the emission of the period 1990-2009. This reduction contributed greatly to the economic crisis of 2009, when one considers that the reduction 2000-2008 was only 6% **(Valli, 2012)**.
In 2009, for example, in Italy the contribution of agriculture to GHG emissions (expressed as CO_2 equivalents) was 7% (also in Italy has been detected a significant reduction) and the GHG amount from the livestock has accounted approximately the half (3%) **(Pulina *et al.*, 2011; Valli, 2012)**. In addition, a recent study conducted in Italy showed that the "Animal Carbon Footprint" is due to 56% from cattle for milk production, to 18% from beef production, to 12% from swine production and to 14% from others species reared. The result of this study agrees with the suggestion of **Flachowsky and Hachenberg (2012)**. These authors reported that there is also no difference in GHG produced between the conventional and organic production system. Numerous studies have shown that the most efficient way to cut GHG is the intensification of animal husbandry and accuracy. In fact, CO_2 equivalent emitted from dairy herds in the United States from 1944 to 2007 increased from 13.5 to 27.8 kg d^{-1} $bovine^{-1}$, due to the increased ingestion of food, but the production of CO_2 equivalents per kg of milk has been severely reduced from 3.65 to 1.35 kg of GHG. On the other hand, waste outputs were similarly reduced with modern dairy systems (24% of the manure, 43% of CH_4, and 56% of N_2O per billion kg of milk) compared with equivalent milk from historical dairying. The carbon footprint per billion kilograms of milk produced in 2007 was 37% of equivalent milk production in 1944 **(**Figure 4; **Capper *et al.*, 2009b)**. This has been possible thanks to the decrease in the number of animals and the increase of the milk production per unit of cow, both number of animals and the production changed linearly during the period observed. The increase in production has also led to an increase in the amount of feed administered to animals, and consequently an increase in the area for crops and a reduction of the pasture, with a consequent reduction in the capacity of carbon sequestration by grasslands. Several studies have shown that the mitigation of GHG emissions from ruminants can be achieved improving feed conversion efficiency and the reproduction efficiency. Inter alia, the decreases in CH_4 production have been obtained using different approaches that induce changes in metabolic pathways, that alter the rumen microbial consortium and/or that influence the animal digestive physiology. Grazing management and genetic selection also hold promise. In addition, the use of livestock manure to produce energy **(**e.g. biogas; **Kebreab *et al.*, 2006)** can help to reduce the production of GHG. In fact, the manure used as field application do not seem able to provide an effective long-term carbon sink by soil **(Baker *et al.*, 2007)**.

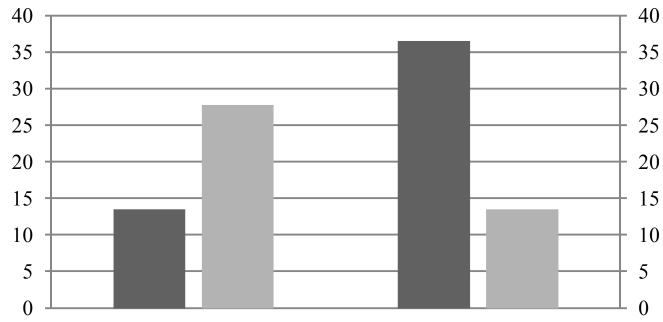

Figure 4 Carbon footprint per cow and per kilogram of milk for 1944 and 2007 US dairy production systems. The carbon footprint per kilogram of milk includes all sources of greenhouse gas emissions from milk production including animals, cropping, fertilizer, and manure. (Source: **Capper et al., 2009b**).

USE OF LAND, BIODIVERSITY AND FOSSIL ENERGY

In recent decades, the livestock activity in all of Europe has highlighted some changes, such as the reduction in the number of farms and the concentration of production in a few specialized units, with the abandonment of traditional practices in favor of intensive systems rather than extensive ones. Intensive rearing systems have also allowed to produce food (e.g. concentrate) for animals in different areas from breeding. Therefore, this has led to a surplus of nutrients in the area surrounding the farm (availability of pasture) and a depletion of organic matter and nutrients in the production area of the concentrate **(Pulina *et al.*, 2011)**. Animal farming, including the cultivation of feed, uses 70% of agricultural land and one third of the land surface of the planet. Broadening the horizon, recent estimates quantify that 33% (470 million of ha) of the total arable land in the world is utilized to produce food for animals, while the area available for grazing in the world is estimated in 3.4 billion ha. However, we must consider that 20% of the grazing in the world is degraded due to overexploitation and scarcity of rain **(FAOSTAT, 2006)**. Land use varied among livestock products (Figure 5). With regard to meat products (pork, chicken and beef), production of 1 kg of pork required 8.9-12.1 m^2 and 1 kg of chicken 8.1-9.9 m^2 of land, whereas production of 1 kg of beef required 27-49 m^2 of land. The large amount of land needed for beef production is due to differences in feed efficiency and reproduction rates, which is more favorable for pig and chickens. Production of 1 kg of beef protein also had the highest impact (144-258 m^2), followed by pork protein (47-64 m^2), whereas chicken protein (42-52 m^2) and eggs protein (35-48 m^2) had the lowest impact. Whereas, production of 1 kg of milk required only 1.1-2.0 m^2,and 1 kg of protein of milk production required 33-59 m^2 **(de Vries and de Boer, 2010)**. Expressing the land use per amount of average daily intake of each product daily, **De Vries and de Boer (2010)** have observed that the consumption of beef had the highest land use (1.65-2.96 m^2), followed by consumption of milk (0.62-1.1 m^2), chicken (0.60-0.73 m^2) and pork (0.73-0.99 m^2), and the consumption of eggs (0.16-0.22 m^2) resulted in the lowest land use. These findings explained why consumption of beef was responsible for the largest part of the land use and GWP **(de Vries and de Boer, 2010)**. It would be interesting to compare the data obtained from cattle reared in the pastures of North Europe with animals reared in intensive systems (mainly in Italy). However, if on the one hand, the intensive farming reduces the use of resources per unit of output and its impacts, the extensive livestock system contributes to the creation of ecosystems characterized by high plant and animal biodiversity and play a vital role in the maintenance of protected areas; all this is in line with the guidelines of the new EU agricultural policy (CAP). The abandonment of these practices would result in a degradation of meadows and pastures that gradually would leave the place to the woods, with a consequent loss of biodiversity **(reviewed in Pulina *et al.*, 2011)**.

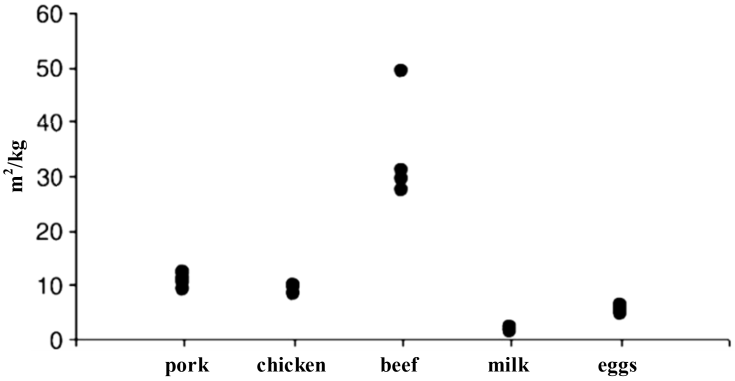

Figure 5 Land use for livestock products (in m^2/kg of products), (Source: **de Vries and de Boer, 2010**).

WATER FOOTPRINT

Due to climate change and population growth, the protection of water resources from overexploitation is another very timely subject. However, pathways for reducing the water footprint of food production chains are increasingly sought, but poorly understood. Agricultural production accounted for about 90% of global freshwater consumption during the past century **(Shiklomanov, 2000)** and even without negative climate change effects; the water consumption for food production will increase to meet demands of a 50% larger global population. **Chapagain and Hoekstra (2004)** present a water footprint methodology by linking global consumption to local water resources. The water footprint concept can be used as an indicator of water use that looks at both direct and indirect water footprint of the feed crop cultivation, the livestock farming, a food processor, a retailer or a consumer. The most common way to assess environmental impacts from a product perspective is the life cycle analysis (LCA) **(Drastig *et al.*, 2010)**. In the field of animal husbandry, water is mainly used for the irrigation of cultivated land and the processes of production and processing. In addition to this, we must consider the impact of production activities on water resources, in terms of eutrophication and pollution **(Pulina *et al.*, 2011)**.The working group "Adaptation to Climate Change" at the Leibniz-Institute for Agricultural Engineering Potsdam-Bornim (ATB) has calculated the water footprint for agricultural processes and farms, distinguished into the three components: "blue" water footprint, as water used for irrigation withdrawn from rivers, lakes and aquifers, the "green" water footprint, as water used stemming from precipitation and soil water, and the "grey" water footprint as volume of used and thereby polluted water for each component of a supply chain **(Drastig *et al.*, 2010)**.

The green and blue water demand of a bovine farm plays a pivotal role in the water balance. The drinking water requirements for beef production are calculated from overall stock water needs on the basis of dry matter intake and ambient temperatures from recent studies **(Capper, 2009b; Drastig *et al.*, 2010)**. Preliminary results obtained by **Drastig *et al.* (2010)** for the cow milk production in Brandenburg (Germany) show a decreasing of blue water footprint demand in the dairy production from the year 1999 with 5.98×109 L/yr to a water demand of 5.00×109 L/yr in the year 2008 because of decreasing animal numbers and an improved average milk yield per cow. The authors suggested that improved feeding practices and shifted breeding to greater-volume producing Holstein-Friesian cow allow the production of milk in a more water sustainable way. In practice the mean blue water consumption for the production of 1 kg milk in the time period from 1999 to 2008 was 3.94±0.29 L, it is about one fifth lower than in 1999 (Figure 6). Furthermore, the authors suggested that the main part of the consumed water seems to stem from the indirect used green water for the production of the feed for the cows. Differently, **Hospido *et al.* (2003)** reported a water consumption of 2.7 L for the production of 1 L raw milk in two farms in Galicia (Spain). Additionally, in accordance to the results of **Drastig *et al.* (2010)**, **Capper *et al.* (2009b)** found for the US-American dairy production systems in 1944 and 2007 a decrease of the water consumption from 10.76 L/kg milk to 3.78 L/kg milk in 2007. Regarding the Animal Water footprint of boneless beef, Capper (2010) estimated a value of 3,600 L, which is a very different result from the estimate of 15,400 L made by **Mekonnen and Hoekstra (2010)**. **Hoekstra (2008)** calculated for the beef production a major share of 99% used water for the production of the feed.

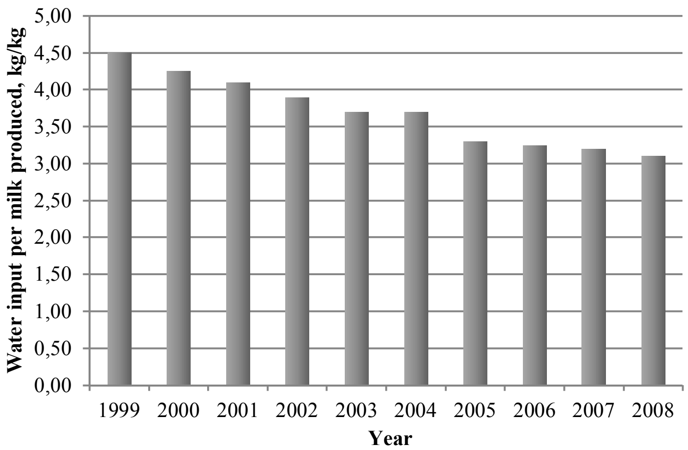

Figure 6 Direct blue water consumption per kilogram of milk from 1999 to 2008 for dairy production systems in Brandenburg state. The blue water footprint per kilogram of milk excludes the indirect water footprint of the feed crop cultivation for the animals. (Source: **Drasting *et al.*, 2010**).

WHAT ARE THE CHALLENGES TO IMPLEMENT A SUSTAINABLE ANIMAL HUSBANDRY?

As reported above, the environmental impact of livestock production has received increasing attention over the last years because it appears to have a major impact on the environment. The livestock sector that increasingly competes for scarce resources (land, water, and energy) has a severe impact on air, water and soil quality because of its emissions. Therefore, a higher production of food of animal origin, necessary to meet growing human needs, that is wholesome and obtained with techniques to protect the environment, poses a number of challenges to implementing a sustainable livestock. These challenges include: i) reducing the use of areas less suitable for agriculture in order to promote biodiversity, ii) an adequate and balanced use between the soil intended for agriculture and alternative activities (e.g. energy, urbanization, industry), iii) the development of more efficient production systems to increase production, mainly in emerging countries.

For a sustainable development, you need to consider all stages of the production chain as related and dependent, thereby taking into account the possible effects that there are upstream and downstream; e.g. studies of environmental sustainability related to livestock production and agronomic, this latter related to the livestock. Using this methodology cannot escape analysis situations in which the reduction of the environmental impact at a certain stage of a given production cycle can result in a growing impact on one of the later stages. In addition, it becomes possible to identify the most critical points of the processes or stages of production, and, therefore the most effective mitigation measures. In this context, the study of factors influencing animal footprint and the development of appropriate technologies to reduce animal footprint will be among the main topics of research in the field of animal sciences and biotechnologies.

Innovation is crucial for such a transition. Indeed, a variety of new technologies will be needed to meet the sustainability challenges, of course, in the various agricultural subsectors. The technological change, however, will not be enough. Nevertheless, the transition to sustainable agrofood systems will not be an easy or straightforward one. One of the reasons for this is the extremely complicated nature of the required long term societal changes. Therefore, the enormous challenges ahead will also require new regulations, new behaviour (e.g. of consumers - a training and nutrition education and health - farmers as well as many other stakeholders), cultural change, institutional change, and institutional 'hybridity' **(Allaire and Wolf, 2004)** as well as new forms of planning, monitoring and evaluation **(van Mierlo *et al.*, 2010)**. A joint effort between European researchers, policy makers and strategic actors of the agrofood sector is of crucial importance to reflect, compare and design elements of the roadmap towards sustainable livestock production and sustainable agriculture in general.

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