KU LEUVEN
ARENBERG DOCTORAL SCHOOL
FACULTY OF BIOSCIENCE ENGINEERING

How to feed and not to eat our world?

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Supervisors:
Prof. Dr. Ir. Eddy Decuypere
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Dissertation presented in partial fulfilment of the requirements for the degree of PhD in Bioscience Engineering

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Uitgegeven in eigen beheer, Ruben Boonen, Geel.

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Summary

Within the finite boundaries of planet Earth, agriculture plays an essential role in the production of renewable resources for the desires and needs of the growing human population. As production inputs such as soil, water and nutrients are limited, choosing between different functions for agriculture results in moral discussions. To analyse the ethical debate, Aerts *et al.* (2009b) developed the 6F-framework, assigning six different functions to agriculture: Food, Feed, Fuel, Fibre, Flower and Fun. In their framework, Flower comprises both ornamental plant production and nature. Because ornamental plant production is also Fun and since humanity not only expects agriculture to take care of nature as such, but also to maintain other ecosystem services and keep agricultural land in good condition for future generations, it seems more adequate to adapt the framework by replacing Flower by Foster, stressing the caring role of agriculture for its environment and for the present and future generations.

During the last decades, agricultural production strongly increased, as shown in chapter one. Nevertheless, more than 800 million people still suffer from hunger. With a global population that will increase up to 9 billion people by 2050, focussing on increasing food production alone will not solve the hunger problem. As discussed in Boonen *et al.* (2012a), animal production can play an essential role in producing food on 'useless' land or by converting 'useless' energy or proteins. Nevertheless, chapter two shows that the role of animal production can change, with e.g. an increasing interest in aquaculture production. Some new ethical discussions will probably occur during the next decades, e.g. the globally increasing population of carnivorous pets that demands for larger numbers of animals raised and killed to feed them. When reconsidering the role of animal production within sustainable agricultural production, several traditional parameters are likely to change: the species used (e.g. insects), the use of new by-products (e.g. from algae production) and animal welfare norms.

Searching for a more sustainable agriculture, 'sustainability' as such is discussed in chapter three. Several definitions are used and depending on one's worldview, priorities are different between people, planet and profit. Furthermore, one has to question if the fulfilment of the desires of a rather small group justifies that the needs of many are compromised. In the consumer society, overconsumption and waste are a way to feel that we are alive (Baudrillard, 1998). Since consumption focuses narrowly on 'having' within the framework of human needs from Max-Neef (1992), it cannot lead to true happiness. Therefore, agricultural production should focus on needs in the first place, before fulfilling desires. Searching for these needs, one has to be aware of a possible inversion of goals and means. The production of a certain crop or animal product as such is not the goal, but only a means. If other means are more sustainable to reach the goal, a rethinking of the agricultural production system can help to reach a sustainable equilibrium within the 6F-framework, with respect for the boundaries of the ecosystem Earth.

Animals play a pivotal role in the 6F-framework. Current animal production uses a large area, often competing with other functions. Animal production is under ethical scrutiny, not only from an animal welfare point of view, but some consider it as competing with human food production. This discussion is not new: in 1975, van Es calculated the efficiency of several types of animal production, comparing the amount of energy and proteins that humans get from the animal products with the amount of energy and proteins that could be available by direct human consumption of the feed ration. Due to improvements in animal production during the last forty years, the efficiency ratios were in need of recalculation. As shown in chapter four, an increase in protein efficiency can be found in almost all types of animal production, although this strongly depends in how 'edible' is defined. Barley for example is not eaten in Western diets, although it is suitable for human consumption. When it is considered 'inedible', cattle production by Belgian blue changes from inefficient to a conversion that more than doubles protein availability for humans. Although progress in efficiency is made in animal production, one could question if one is looking for the desired or for the needed efficiency gain. The main focus is on increasing the efficiency of the most used species like pig, chicken and cow, while poikilothermic species are more efficient. A shift in used species therefore could lead to a large increase in protein efficiency, making it possible to produce more with less.

Samenvatting

Binnen de grenzen van de Aarde speelt landbouw een essentiële rol in de productie van hernieuwbare grondstoffen voor de wensen en noden van de groeiende wereldbevolking. Aangezien productiemiddelen zoals grond, water en nutriënten beperkt zijn, leidt het kiezen tussen verschillende functies voor de landbouw tot morele discussies. Om het ethisch debat te analyseren, ontwikkelden Aerts *et al.* (2009b) het 6F-denkkader met zes verschillende functies voor de landbouw: Food, Feed, Fuel, Fibre, Flower en Fun. Hier omvatte Flower zowel sierteelt als natuurbeheer. Omdat sierteeltproductie ook onder Fun valt en omdat de maatschappij verwacht dat landbouw naast natuurbeheer ook ecosysteemdiensten verzorgt en landbouwgrond in goede conditie houdt voor de volgende generaties, leek het gepast om het 6F-kader aan te passen en Flower te vervangen door Foster, wat de zorgende rol van landbouw voor de omgeving en voor de huidige en toekomstige generaties benadrukt.

Hoewel landbouwproductie de voorbije decennia sterk steeg, lijden meer dan 800 miljoen mensen nog steeds honger. Aangezien de wereldbevolking zal toenemen tot 9 miljard mensen tegen 2050, lost stijgende voedselproductie alleen het hongerprobleem niet op. Zoals besproken in Boonen *et al.* (2012a) speelt dierlijke productie een essentiële rol in voedselproductie op basis van 'onbruikbaar' land of door het omzetten van 'onbruikbare' energie en eiwitten. Toch kan de rol van dierlijke productie veranderen, bijvoorbeeld door een verhoogde interesse in aquacultuur. Nieuwe ethische discussies zullen de volgende decennia opduiken, zoals over de wereldwijd toenemende populatie carnivore huisdieren waarvoor een groeiend aantal dieren geproduceerd en gedood wordt. Wanneer men de rol van dierlijke productie binnen een duurzame landbouw analyseert en beschouwt, zullen verschillende traditionele parameters vermoedelijk veranderen: de gebruikte diersoort (o.a. insecten), de gebruikte bijproducten (o.a. van de algenteelt) en dierenwelzijnsnormen.

In de zoektocht naar een meer duurzame landbouw, wordt in hoofdstuk 3 besproken wat 'duurzaam' is. Verschillende definities kunnen gebruikt worden en afhankelijk van iemands wereldbeeld verschillen de prioriteiten tussen maatschappij (people), milieu (planet) en de markt (profit). Meer nog, men moet zich de vraag stellen of het vervullen van wensen van een eerder kleine groep rechtvaardigt dat de noden van vele anderen beperkt worden. In de

consumptiemaatschappij is overconsumptie en verspilling een manier “om te voelen dat we leven” (Baudrillard, 1998). Aangezien consumptie enkel focust op ‘hebben’ binnen het denkkader van menselijke noden van Max-Neef (1992), leidt het niet tot werkelijk geluk. Daarom moet landbouwproductie in de eerste plaats focussen op de noden, voor het de wensen vervult. Op zoek naar deze noden moet men zich bewust zijn van een mogelijke inversie tussen doelen en middelen. De productie van een bepaald gewas of dier op zich is niet het doel, maar enkel het middel. Als er andere middelen duurzamer zijn om hetzelfde doel te bereiken, helpt het herdenken van de landbouw om een duurzaam evenwicht te bereiken binnen het 6F-denkkader, met respect voor de grenzen van het ecosysteem Aarde.

Dieren spelen een centrale rol in het 6F-denkkader. De hedendaagse dierlijke productie gebruikt een grote oppervlakte, vaak in competitie met andere functies. Dierlijke productie ligt ethisch vaak onder vuur, niet alleen omwille van dierenwelzijn, maar ook omdat sommigen het beschouwen als concurrentie voor de voedselproductie voor de mens. Deze discussie is niet nieuw: in 1975 berekende van Es de efficiëntie van verschillende vormen van dierlijke productie. Hier werd gekeken hoeveel energie en eiwit de mens uit het dierlijke product haalt, in vergelijking met hoeveel energie en eiwit de mens zou kunnen benutten uit directe consumptie van het diervoeder. Door verbeteringen tijdens de voorbije veertig jaar, dienden de efficiëntieratio’s herrekend te worden. Zoals getoond in hoofdstuk vier, is er een toename in eiwitefficiënte voor bijna alle types dierlijke productie, al hangt het er sterk van af hoe ‘eetbaar’ gedefinieerd wordt. Gerst wordt bijvoorbeeld niet gegeten in Westerse diëten, hoewel het wel geschikt is voor menselijke consumptie. Wanneer het als ‘niet eetbaar’ beschouwd wordt, verandert rundveeproductie met Belgisch witblauw van ‘inefficiënt’ naar meer dan een verdubbeling van het voor de mens beschikbare eiwit. Ondanks de vooruitgang op vlak van efficiëntie in de dierlijke productie, kan men zich afvragen of men kijkt naar de gewenste of naar de noodzakelijke efficiëntietoename. De hoofdfocus ligt op een efficiëntietoename bij de meest gebruikte diersoorten zoals varkens, kippen en koeien, terwijl koudbloedige soorten efficiënter zijn. Een omschakeling van gebruikte diersoort kan leiden tot een grote toename in eiwitefficiëntie, waardoor het mogelijk wordt om meer met minder te produceren.

List of abbreviations

6Fs	6 functions
DDGS	distillers' dried grains with solubles
GHG	greenhouse gas
ha	hectare
MBM	meat-and-bone meal
Mt	million metric tonnes = teragram
Mtoe	million tonnes of oil equivalent
nes	not elsewhere specified

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Context and aim

The growing human population leads to an increasing demand for food, animal products, energy and raw materials. Although awareness is rising about taking care for our planet, increasing wealth makes it possible to not only fulfil our needs, but also encourages consumers to create unnecessary but desired demands. How can this all be produced on our finite planet Earth? An alternative for fossil fuels has to be found, the future has to be renewable. Searching for an alternative renewable source, agriculture can play an important role as producer of biomass. At the same time, agriculture is more than food production alone; other functions are gaining importance. The next decades are challenging for humanity, since not only policy makers but also citizens and their choices as consumers will influence in which direction agriculture and society will evolve.

Several ethical questions rise when discussing a sustainable future for agriculture and humanity. This thesis gives an overview of current evolutions in agricultural production and discusses ethical dilemmas linked to this subject. In the first chapter, the framework of the six different functions (Food, Feed, Fuel, Fibre, Foster and Fun) is explained. By discussing the evolution of the past decades for each function, one can try to predict how each of them will evolve in the future, if no other choices are made. The second chapter deals in detail with food, feed and fuel and related major ethical discussions, since these three factors are dominant in the societal debates nowadays, although this does not imply that discussions on the other functions are not important. In the third chapter, sustainability is discussed from different points of view. It will be shown that even a simple definition can be interpreted in many ways and that different worldviews lead to different views on what 'sustainable' is. The fourth chapter focuses on efficiency in animal production. Animal production is a keystone in the whole discussion, since it is strongly linked with all other functions.

Chapter 1

Agriculture, society and the 6F-framework

Introduction

Agriculture played – and still plays – a very important role in the history and evolution of humanity. In a world of hunter-gatherers only about 500 million people could be fed (Mayozer and Roudart, 2006) but agriculture made it possible to change the ecological equilibrium between the human species and the system it relies on, allowing the human population to grow to more than 7.3 billion people and still increasing (U.S. Census Bureau, 2015a; Worldometers, 2015). Agriculture did not only influence the number of people, it also changed their way of living. Humans started to live sedentary and this urged the need for social and moral rules organising social behaviour and interaction. Even now, agriculture is still a keystone of society, not only in small-scale rural communities where agricultural practices are part of everyday life, but also in our Western world. In a society like ours, where agriculture seems almost separated from the rest of society, one might forget that more than half of the human population is working in agriculture (Mayozer and Roudart, 2006). Even though many people in so-called developed countries are no longer aware of this crucial role, since only a small percentage of them still works in agriculture, this minority of farmers produces food and other agricultural products, allowing the rest of society to generate other goods and services without bothering about their daily bread.

Although food production was the main goal – and still is the most important one – humans started to develop agricultural practices, they experienced that biomass (i.e. plants and animals) could be used for other purposes than only food production. Aerts *et al.* (2009b) listed up six different functions: Food, Feed, Fuel, Fibre, Flower and Fun, the so-called 6 Fs of agriculture, that are defined by Aerts (2012, p. 193) as follows:

- Food: "any agricultural produce aimed at direct human consumption. A stricter interpretation could exclude products such as wine and beer and other non-essential food products (sweets, chips, etc.)."
- Feed: "basic agricultural commodities produced to feed animals (directly or indirectly). For example grains, soy, but also grass."

- Fuel: "agricultural products destined for energy generation, directly or indirectly. Includes the typical biofuels of different generations, but also includes solid biofuels, vegetable oils, etc. and possibly even firewood."
- Fibre: "here we include the classic natural fibres (cotton, line), but also the basic commodities for the 'green chemistry' that produces bioplastics. Wood as a building material could also fit under this topic."
- Flower: "this category includes in general all non-edible horticultural production (flowers, shrubs) and – in order to limit the number of Fs – also the protection of wild nature, special habitats (national parks, reserves, etc.)."
- Fun: "again, this includes two types of 'production': recreational activities in the 'open' area, and the drug-related production types. These are not only drugs in the 'strict' sense (e.g. coca), but also tobacco and maybe even the grapes and cereals used in alcohol production."

The framework of Aerts *et al.* (2009b) defined Flower as both production of ornamental plants and conservation of landscapes and nature. Since ornamental plants are produced for Fun and since this thesis focuses on the goals (i.e. fun) and not on the means (i.e. flower production), plant production will be not seen as a separate function. Furthermore, nature and landscape conservation is more than Flower alone. Therefore, Flower is here substituted by Foster, stressing the importance of the caring role of agriculture for its environment. Agriculture does not only depend on the fauna and the flora (i.e. biodiversity), but also soils, nutrients, water, a healthy environment and other important resources that have to be looked after and maintained for future generations.

Therefore, the 6 Fs can be synthesised as:

- Food: production of food for humans
- Feed: production of fodders for animals
- Fuel: production of energy for both movement and heat
- Fibre: production of raw materials for industry
- Foster: conserving natural resources
- Fun: providing recreation, stimulants and luxury goods, both edible (e.g. alcoholic beverages, chocolate…) and non-edible (e.g. flowers, pets…)

The 6 Fs cannot be seen as separate entities, since they rely on the same means of production, i.e. land, water and nutrients, which are limited within de boundaries of the ecosystem Earth. Therefore, the balance between the 6 Fs can be seen as an equation (Aerts, 2012). The total biomass produced is the sum of the biomass produced for each F. Since none of these functions is intrinsically 'wrong', the six different functions as such do not cause ethical problems. It is the competition between them that causes ethical dilemmas, since an increase of one function automatically affects the other five functions.

There is no perfect solution for the question how the 6 Fs have to be balanced, since this strongly depends on personal values, desires and needs, influenced by one's socio-cultural background and worldview. This will be discussed more in detail in paragraph 3.4. Even if one would know what the theoretically perfect balance in a specific situation is, this will never be reached because of the international differences regarding economics, ethics or socio-cultural behaviour. International trade treaties for example will make the 6F-balance evolve to a compromise on a world scale, leading to probably suboptimal balances on a local scale. Since the best solution for each of the Fs will probably never be reached, a pragmatic approach is needed to find the best possible 6F-equilibrium.

Although the six different functions seem well defined, the boundaries between them are not that sharp. Because of the functional approach of comparing the final destination of the biomass used, one cannot discuss a species as such. For several crops, the final destination is not known when sown. Wheat for example can be used for all 6 Fs: as food or feed source, as raw material for biofuel or biobased chemistry, but also to help wild birds through winter or to brew beer. Furthermore, multiple functions can be combined in one species: rapeseed produces both fuel and feed and sheep kept for meat and wool can be fed in the winter with feed, but can be used in the summer as a means for nature conservation and their manure can be used to increase crop production, so they contribute to the functions food, feed, fibre and foster.

This thesis will not focus on the suitability of every species as such, although some of them are more efficient than others in producing one specific function. We are more interested in the balance between and within the different functions and the ethical problems that are linked with it. Therefore, in this chapter, each of the six functions as described by Aerts *et al.* (2009b) will be discussed and recent numbers about productions and evolutions will be given. This makes it possible to compare the global impact of the different functions. By describing what “is”, an objective starting base will inform further ethical discussions in chapter 2 about what “ought”.

1.1 Food

1.1.1 Defining 'Food'

When defining the function 'Food', only the production of biomass directly consumed by humans is considered. Although animals produce edible products too (i.e. meat, blood, milk and eggs), animal husbandry as a whole will be discussed under 'Feed', since the amount of animal products is directly related to the amount of feed produced. Two types of animal products could rather be seen as 'Food' since no 'Feed' is needed to produce it: game meat and wild fish. These sources of animal proteins are taken straight out of nature, so its production does not rely on agricultural production inputs (i.e. land, water, nutrients). One could argue that this places them outside the 6F-discussion, since they do not compete with the other functions. Even though this is correct, they both deliver a valuable addition to the menu, especially in regions where animal products from husbandry systems are scarce, and thus cannot be neglected since they are a very important food source for local communities. Furthermore, both game meat and wild fish are indirectly connected with the 6F-discussion. If these sources of animal proteins were not available, more human-controlled food production would be needed. This is especially clear when one focuses on wild fish. Due to the large demand for fish, aquaculture as an alternative for fishery is rapidly growing (FAOSTAT, 2014d; FAO, 2014a), involving an increasing demand for fish feed and thus coming into competition with the other Fs (and in competition with other animal species). Aquaculture will therefore be discussed under 'Feed', while fishery will be briefly discussed here.

In the next paragraphs the evolution of the most important crops will be discussed. Since the beginning of agricultural activities, crop production was mainly focussed on two groups of food crops, although the used plant species differ from region to region (Mayozer and Roudart, 2006): cereals for the provision of carbohydrates as nutritional energy source, and legumes for the provision of vegetable proteins. In Africa and South America, starchy roots were an important additional energy source and since the importation in Europe in the 16th century, potatoes gained in popularity and became one of the most important crops. Fruits and vegetables were of course also produced, but the species used depends on local conditions, both agricultural and cultural. Therefore, in the following paragraphs only the largest productions will be discussed. Since game meat production is about 1.99 Mt or 0.66% of total meat production (FAOSTAT, 2014a), this will not be discussed. Regarding quantities, wild fish is much more important. This will also be discussed briefly because of the connection with aquaculture.

1.1.2 Cereals

Discussing the evolution and production of cereal species here stresses that these plant species were first domesticated for human food production because of their nutritional value. Due to economical or political forces, part of this production is used for other purposes (e.g. Feed, Fuel, Fibre...), but this is always in competition with global food production. The ethical debate on this competition will be held in chapter 2.

Figure 1.1 shows the evolution in cereal production for different species worldwide, based on data from FAOSTAT (2014b) and ranked by volumes produced in 2013. The production of most cereal species has remained approximately the same during the last fifty years, although these species are less important on a global scale. The three most important species (wheat, rice and maize) account for almost 90% base of total cereal production mass and their importance is still increasing: while the global production of each of them was about 200 Mt in the 1960's, their production has more than tripled, leading to a global production of 1017 Mt of maize, 746 Mt of rice and 713 Mt of wheat in 2013.

Although rice comes at the second place in total production on a mass base, it is the most important staple food crop on earth. IRRI (2014) states that 78% of total rice production is used for human consumption, compared with 64% of wheat production and 14% of maize production. Furthermore, IRRI (2014) estimates that more than 3.5 billion people eat rice every day and for more than half a billion poor people, rice is responsible for more than half of the caloric intake, especially in Asia, where the annual per capita consumption exceeds 100 kg.

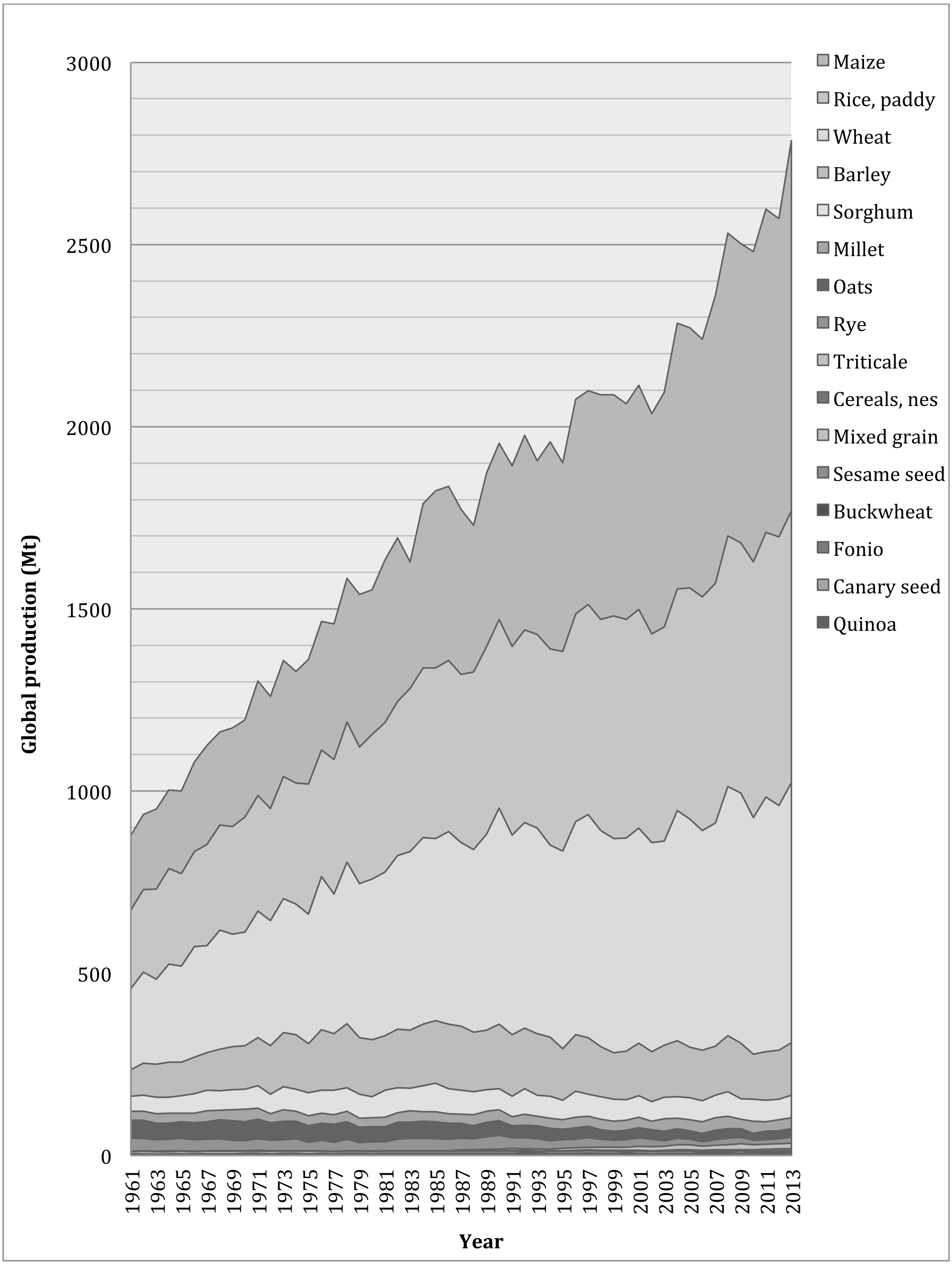


Figure 1.1: Evolution of the global cereal production in million metric tons.

Based on: FAOSTAT (2014b)

1.1.3 Starchy roots

Starchy roots are an important food energy source. As shown in figure 1.2, potatoes are the most important species within this group with a global production of 368.1 Mt in 2013 (FAOSTAT, 2014b), followed by cassava (276.7 Mt) and sweet potatoes (110.7 Mt). Although this is not as impressive as the global production numbers of the top-three cereal species, potato still is one of the three most important species for global food supply, next to rice and wheat (FAOSTAT, 2014c). As discussed in paragraph 1.1.2, maize accounts for the largest global production on a mass base, but only 14% is used for human consumption.

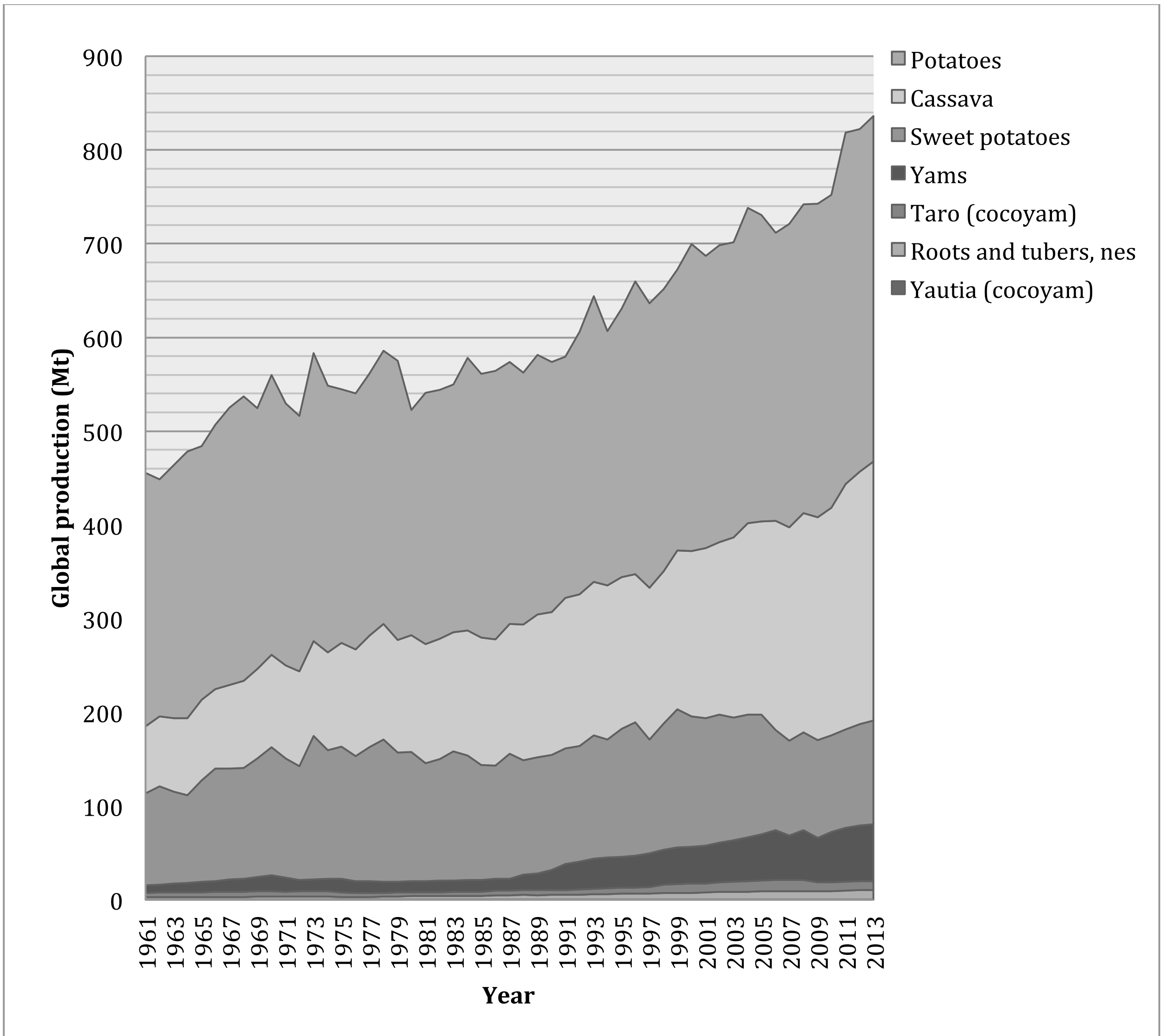


Figure 1.2: Evolution of the global starchy roots production in million metric tons. Based on FAOSTAT (2014b)

1.1.4 Leguminous plants

Compared with the global cereal production, the world pulses production is rather small. Although FAOSTAT (2014b) does not include soybeans in what they call “pulses”, it also is included in figure 1.3 to compare the pulses global perspective. One immediately notices soybean production increased tremendously during the last fifty years: from a production of about 27 Mt in the 1960’s to about 276 Mt in 2013. Of course, soybean is also used to a large extent as animal feed (see later), but as with maize and wheat, it could be and is human food, although only 13% of the global soybean production is used for direct human consumption (Potts *et al.*, 2014).

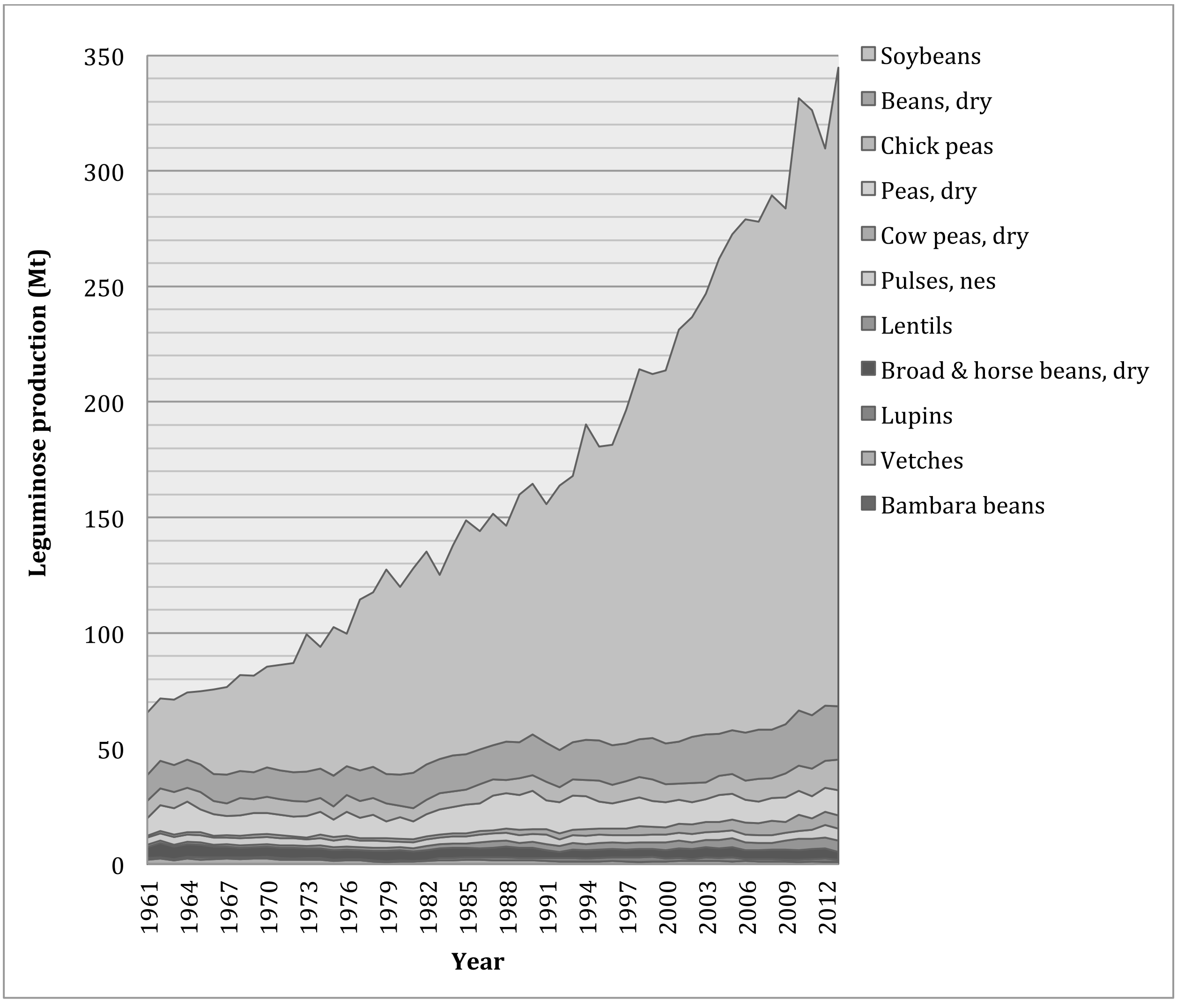


Figure 1.3: Evolution of global leguminous plants production in million metric tons.

Based on: FAOSTAT (2014b)

1.1.5 Fruits and vegetables

FAOSTAT (2014b) estimated that the total production of vegetables (including melons) grew from 223 Mt in 1961 to 1106 Mt in 2012. The group of the “vegetables fresh, not elsewhere specified” contributes for about 25% and is the largest group within the FAOSTAT-vegetable data. Therefore, caution is needed when interpreting the following volumes and percentages as the general category may also contain the species mentioned. The most important vegetable species is tomato, which represents 15% of global vegetable production (161.8 Mt in 2012, compared with 27.6 Mt in 1961), followed by watermelons (105.4 Mt or 9.53% of global vegetable production), onions (82.9 Mt or 7.49%), cabbages (70.1 Mt or 6.34%) and cucumbers (65.1 Mt or 5.89%); other defined species represent less than 5%.

The global fruit production rose from 175 Mt to 637 Mt in the same period. Here, the diversity of species is much larger: 35 different (groups of) species are included in the dataset. The most important species is banana, with a global production in 2012 of 102 Mt or about 16% of all fruit produced, followed by apples, oranges and grapes, each accounting for about 10 to 12%. The other (groups of) species have 5% or less, again indicating how diversified this group is.

1.1.6 Fishery

The global yearly production amounts to more than 158 Mt of aquatic products in 2012 (FAO, 2014a). About 91 Mt or 58% on a mass base is wild caught. The total amount of caught fish remained stable during the last five years. In 2012, about 79,7 Mt is caught in marine fishing areas and 11.6 Mt is caught inland. FAOSTAT (2014d) divides the amount of marine caught fish in 65.5 Mt marine fish, 6.6 Mt molluscs, 5.8 Mt crustaceans and some diadromous and freshwater fish. Although inland fishing only represents 11.6 Mt, it is important for local fishermen in Asia and Africa, where almost 92% of the inland production is caught. From the inland production, 10.3 Mt is freshwater fish, followed by 0.5 Mt crustaceans, 0.4 Mt molluscs and some small quantities of diadromous and marine fishes. FAO (2014a) estimates that by 2022 the total amount of caught fish will increase up to 95.5 Mt.

1.2 Feed

1.2.1 Historical overview

Next to different crop species, humans also domesticated several animal species. For centuries, both humans and animals lived in a symbiosis, where humans took care of animals, feeding and protecting them, and making use of them in order to meet human needs. Animals were and still are used for many reasons: as tractive power, for the production of wool and leather for clothing and as a standing food source for the production of eggs, milk and meat. Moreover, their manure is used as fertilizer and energy source. This can be observed all around the world, although the animal species used differs from continent to continent. Although the species differ, one also could see similarities: smaller monogastric animals were kept near the houses, while larger herbivores were kept further away (Steinfeld *et al.*, 2006). This phenomenon can be explained by the fact that grasslands are usually situated at longer distances, so larger herbivorous species are more useful because they are able to move further and they are able to convert feed sources which are indigestible for humans. Near the houses, smaller animals (e.g. chickens, turkeys and pigeons on land or nearby forests, duck and geese on ponds) were kept as collectors of small particles like seeds, weeds and insects or as converters of waste and surplus production. Pigs were literally piggy banks: besides what they found scavenging around the farm, they were fed with the surplus production of the farm and with table waste, and slaughtered in winter to regain the proteins and energy 'invested' during the year.

In Ancient Egypt already, farmers produced specific feed crops like clover and vetch as part of rotational land use (Mayozer and Roudart, 2006), since these leguminoses also brought nitrogen in the soil, serving as natural fertilizers. For a long time, the availability of fodder during the winter was the limiting factor for herd size. Since only a small number of breeding animals could be fed, most of the youngborn animals and unfit animals were slaughtered in autumn. This way of animal production was very inefficient, since large pastures were needed to feed the maximal herd size during summer, but the rest of the year the pastures were not optimally used. The idea of harvesting grass and storing it as hay to feed animals during the winter, directed to larger herd sizes. The introduction of seeded pastures in rotation systems, a Flemish system developed in the 15th century, produced more than pastures and meadows together (Mayozer and Roudart, 2006), which made fallowing unnecessary and allowed the animal population to grow. This increase in animal production also resulted in an increase in crop production due to more manure that, in combination with less leaching and more organic matter in the soil, resulted in higher crop yields.

1.2.2 Defining 'Feed'

In this thesis, 'feed' is defined as all biomass fed to animals and – as a result – the amount of animal products. This differs from the approach from Aerts *et al.* (2009b; 2012), where animal products are seen as Food, since they can be "directly consumed by humans" (cfr. *supra*). Although feed is mostly divided into roughages and concentrates, here the framework as discussed in Boonen *et al.* (2012) will be used, where the biomass for animal feed is divided into three groups, depending on the feeding strategy: feed production – and thus animal production – based on 'useless' land, feed production based on 'residues', and feed production based on 'surpluses'. While the division between roughages and concentrates is rather an agricultural-technical issue, our division stresses the fact that the used feeding strategy also influences the 6F discussion and therefore also the ethical questions at stake. For example, animal production based on 'surpluses', influences human food availability, while production based on 'useless land', will compete with biofuel.

1.2.3 Production on 'useless' land

Global land area is estimated on 13.0 billion hectares (FAOSTAT, 2014e), or one third of our planet. FAOSTAT (2014e) estimates global agricultural area on 4.92 billion hectares (or about one third of total land area) of which about 3.36 billion hectares are used as permanent pastures and meadows and 1.40 billion hectares as arable land (or about one third of total agricultural land). Therefore, permanent pastures represent 26% of the total land area or 68% of all land used for agricultural production.

Figure 1.4 gives an impression of the global landuse for agriculture. Figure 1.5 shows how many millions of hectares are used per continent as permanent pastures and meadows. As can be seen in table 1.1, there are large differences between the continents and even between the regions (nomenclature and division taken over from FAOSTAT, 2014e) in the same continent.

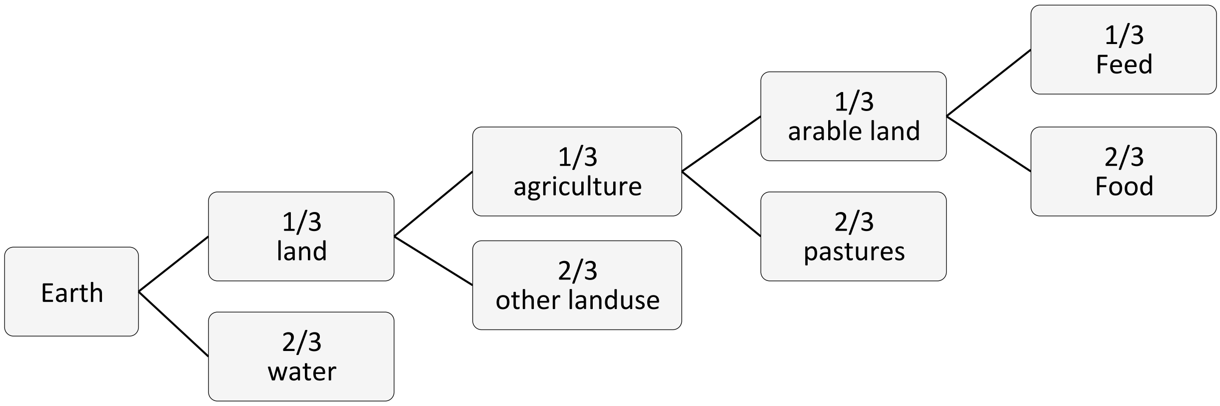


Figure 1.4: Impression of global landuse for agriculture.

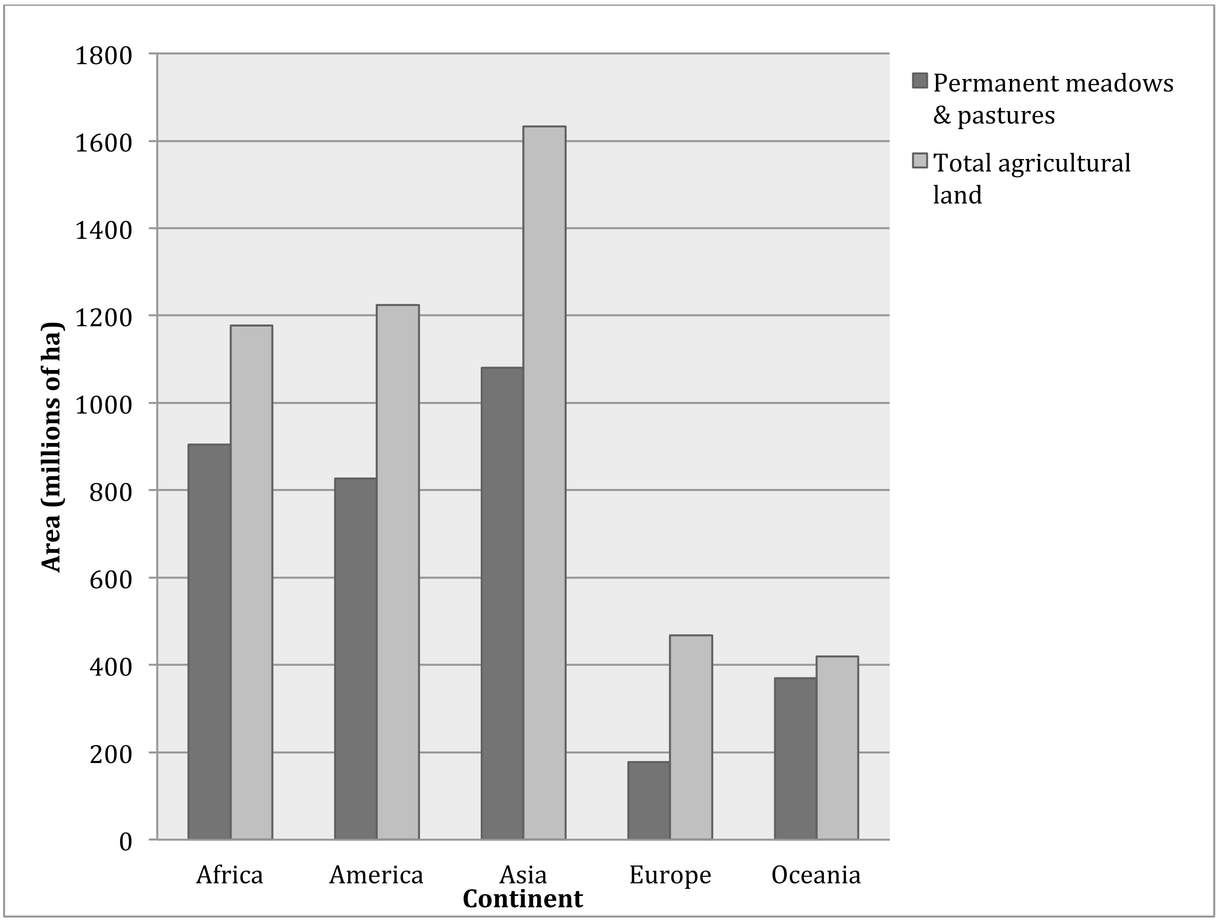


Figure 1.5: Agricultural land (in millions of hectares) and the use for permanent meadows and pastures on a continental scale.

Based on: FAOSTAT (2014e)

Table 1.1: Percentage of agricultural land for permanent pastures and meadows.

Africa	**76.76%**	**Asia**	**66.18%**
Eastern Africa	77.18%	Central Asia	88.73%
Middle Africa	82.60%	Eastern Asia	79.30%
Northern Africa	77.11%	Southern Asia	25.18%
Southern Africa	91.50%	South-Eastern Asia	13.05%
Western Africa	64.14%	Westerns Asia	84.21%
America	**67.58%**	**Europe**	**38.06%**
Northern America	56.05%	Eastern Europe	37.21%
Central America	72.94%	Northern Europe	48.25%
Caribbean	42.43%	Southern Europe	39.20%
South America	75.88%	Western Europe	34.37%
Oceania	**88.11%**		
Australia & New-Zealand	88.45%		
Melanesia	28.16%		
Micronesia	17.82%		
Polynesia	22.76%		

Own calculations, based on FAOSTAT (2014e)

This can be explained by the fact that most of these areas are not suitable for crop production due to climate or soil conditions. In arid regions, where vegetation is scattered and scarce, animal production is the most efficient way to collect vegetal proteins and energy in order to convert them into something useful for humans. About 60% of all pastures or more than 50% of the land used for animal production is extensive grassland (Steinfeld *et al.*, 2006), only suitable for herbivores. In contrast with the large area, the meat output of extensive grassland is only 8% of the total meat production (Steinfeld *et al.*, 2006), due to the very extensive way of animal husbandry, the low quality feed and the traditional breeds with a low feed conversion ratio because of different selection parameters. Nevertheless, this way of animal production could be considered as a necessity for the local people to survive in these harsh conditions. Here, animal production can be viewed as stewardship at its best: taking care for living beings and using their products in a well-balanced way. In industrialised countries, ruminants are also kept on marginal lands, permanent pastures or in rotation in a three-field system. From the 3.9 billion hectares used for animal production, 1.4 billion hectares or 36% is relatively intensive grassland (Steinfeld *et al.*, 2006), a large area that is mainly used by animals, although it also could be used as biomass for renewable energy.

1.2.4 Conversion of 'useless' proteins and energy

Another historical role of animals is to convert products that are unsuitable and unwanted for human consumption. Many useful feed products are by-products of food production processes like sugar extraction, vegetable oil production, brewing, milling and the industrial vegetable industry. In Europe (FEFAC, 2011), about 40% from the basic feed materials are by-products of which cakes and meals are the largest group (27%), followed by co-products from food industry (12%). In the group of by-products, soybean meal has a very debatable position. Some argue that it is not a real by-product and that it is explicitly produced to feed the soybean meal to animals. This will be further discussed in paragraph 2.3.

In any case, since approximately 87% of the global soybean production is processed to meal and oil (Potts *et al.*, 2014), soybean meal is by far the most popular by-product in animal feeds worldwide, accounting for nearly 69% of all proteins used in animal feed (Cromwell, 2012). Figure 1.6 compares production and consumption in the most important soy regions. The total production is about 180 million metric tons of soybean meal in 2010-2011 (Cromwell, 2012). As can be seen, China is the most important producer, but they need as much as they produce. Also the USA uses about 75% of its own production. Brazil and especially Argentina are very important exporters of soymeal, while the EU needs three times as much soy as its own production.

By-products are mainly converted by monogastric species. Cromwell (2012) states that approximately 48% of the soybean meal is fed to poultry, followed by 26% for pigs. Beef cattle and dairy cattle use respectively 12% and 9% of the soybean meal production and only a small fraction is used for fish (3%) and petfood (2%).

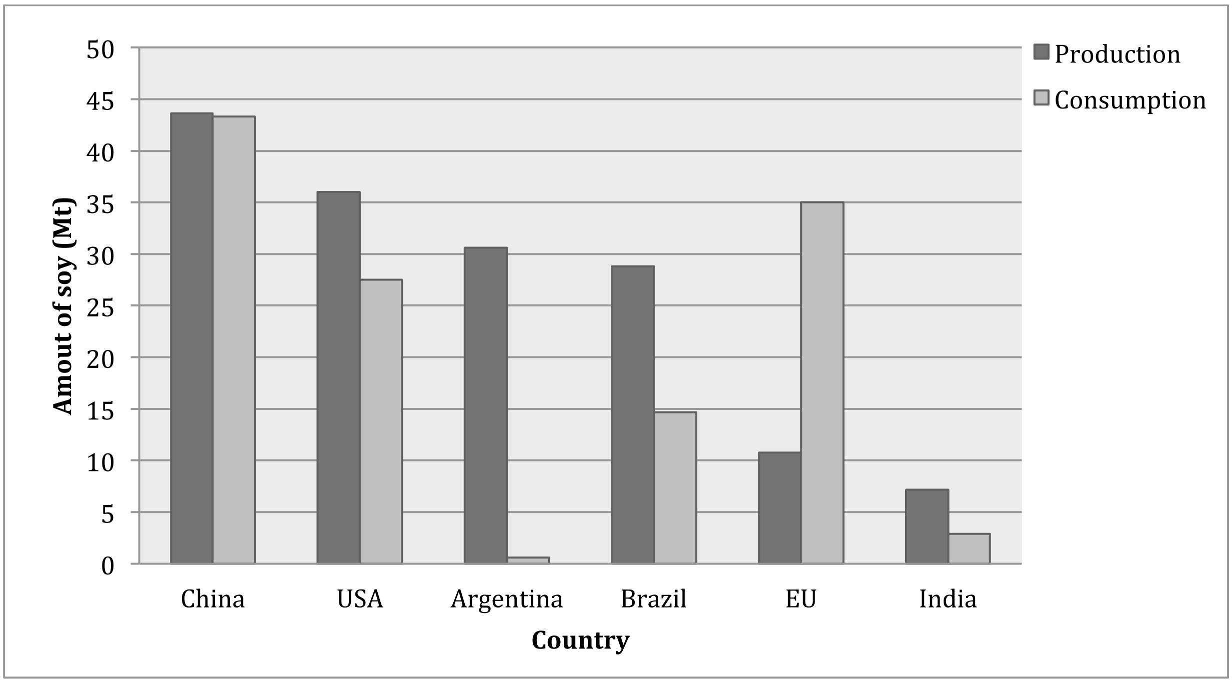


Figure 1.6: Production and consumption of soymeal (Mt) in 2010-2011.

Based on: Cromwell (2012)

Next to vegetal by-products also animal by-products have been used until the European government banned animal meals in the wake of the BSE crisis (EC, 2002). As a result of this regulation, an annual 3.5 million tons of meat-and-bone meal (MBM) produced in Europe (Coutand *et al.*, 2008) has to be used as an energy source (combustion) and at a smaller scale as fertilizer, also in organic farming (Mondini *et al.*, 2008), or in pet food. Since MBM was used in animal feed, it was replaced by other sources of proteins, predominantly soy meal. Steinfeld *et al.* (2006) state that 1 ton of MBM has the same protein value as 1.16 tonnes of soy meal or 1.48 tonnes of soybeans. Replacing the total production of MBM means an import of about 4 million tonnes of soy meal or more than 5 million tonnes of soybeans or the yield of about 1.5 million hectares. Adapting the rules for prevention, control and eradication of certain transmissible spongiform encephalopathies, making it possible to use processed animal proteins as feed source for non-ruminants (European Union, 2010) or in aquaculture (EC, 2013), would certainly decrease the need for cropland for animals. Since the different by-products vary in nutritional value, the rations often have to be supplemented with grains and other additives to balance energy, protein and amino acid content. Animal production on residu-based feed alone seems only possible when there is a low demand for meat (Keyzer *et al.*, 2005).

1.2.5 Surplus based meat production

Where in the past the number of heads (i.e. living animals) was a function of the feed available, feed is now produced to feed the number of heads produced to meet the increasing demand for animal products. Grain-feeding started in the beginning of the 20th century (Steinfeld *et al.*, 2006) and its importance increased strongly from the 1950s onwards. About 33% of all cropland is used for animal feed production (Steinfeld *et al.*, 2006) and 35% (on a mass base) of the total crop production is used as animal feed (Foley *et al.*, 2011). It is estimated that total meat demand will double from 229 million tonnes in 2000 to 465 million tonnes in 2050 (Steinfeld *et al.*, 2006). Since most of this will be produced by monogastrics (see further), a strong demand for cereals will lead to an increase in cropland for feed production, although efficiency gains in both feed and animal production will slow this increase.

1.2.6 Evolution of animal production

Not only the human population increased during the last decades. As can be seen in table 1.2, the number of heads for most domesticated (groups of) species increased between 2014 and 1961 (FAOSTAT, 2014a). Especially smaller animals experienced a markedly increase: chickens and other poultry species quintupled (geese and ducks increased almost tenfold) and small herbivores (i.e. rabbits and rodents) increased eightfold. Small ruminants (i.e. sheep and goats) almost doubled because the number of goats tripled, where the number of sheep remained more or less the same. Also the number of equines (i.e. horses, asses and mules) stayed more or less the same due to increasing mechanisation.

The absolute numbers of animals seems rather impressive and are therefore often used by animal activists as proof that too many animals are produced in large-scale “factory” farms. The picture changes when comparing the numbers of animals per person. With exception of the smallest species (i.e. chickens, other poultry and small herbivores), the number of animals per person worldwide stayed more or less the same or even decreased during the last 50 years. The increase in numbers of animals kept by humans worldwide is more or less parallel with the growth of the human population. When comparing the European Union with the rest of the world, one can see that, except for small herbivores and for pigs, the average number of animals per person in Europe is much lower than the global average. For every 5 European citizens, there is 1 goat or sheep, 1 cow, 1 rabbit, 1.5 pig, 1.5 duck (or goose or turkey) and 13 chickens. Since these numbers are taken from a certain moment in time, they are more or less correct for larger species, but not for broilers, other poultry and small herbivores, where several rounds per year are raised and slaughtered. Therefore the number at a certain moment in time is much smaller than the total amount of e.g. broilers raised during one year. Nevertheless it gives an indication that the amount of animals on European farms is not as impressive as it seems at first sight. There are as many animals per person as fifty years ago, but the animals are now concentrated on fewer and larger farms.

Table 1.2: Evolution of number of living animals

	Number of heads (millions)				**Animals per capita**			
	World		**Europe**		**World**		**Europe**	
	1961	**2013**	**1961**	**2013**	**1961**	**2013**	**1961**	**2013**
Chickens	3907	21 744	818	1300	1.267	3.063	2.019	2.566
Other poultry	448	2217	51	149	0.145	0.312	0.127	0.296
Small herbivores	119	944	65	98	0.039	0.133	0.161	0.193
Small ruminants	1343	2178	132	110	0.435	0.307	0,325	0.217
Cattle	942	1494	103	88	0.306	0.211	0.254	0.174
Buffaloes	88	200	0.27	0.42	0.029	0.028	0.001	0.001
Camelids	18	36	0	0	0.006	0.005	0	0
Pigs	406	977	96	147	0.132	0.138	0.236	0.290
Equines	110	112	15	4	0.036	0.016	0.036	0.009

Own calculations, based on FAOSTAT (2014a), U.S. Census Bureau (2015a) and Eurostat (2014).

The increasing numbers of animals, combined with strong increases in production per animal resulted in a strong animal production growth. Figure 1.7 shows the evolution of different types of meat over the last fifty years. Compared with 1961, the total meat production worldwide more than quadrupled up to about 302 Mt in 2012 (FAOSTAT, 2014a).

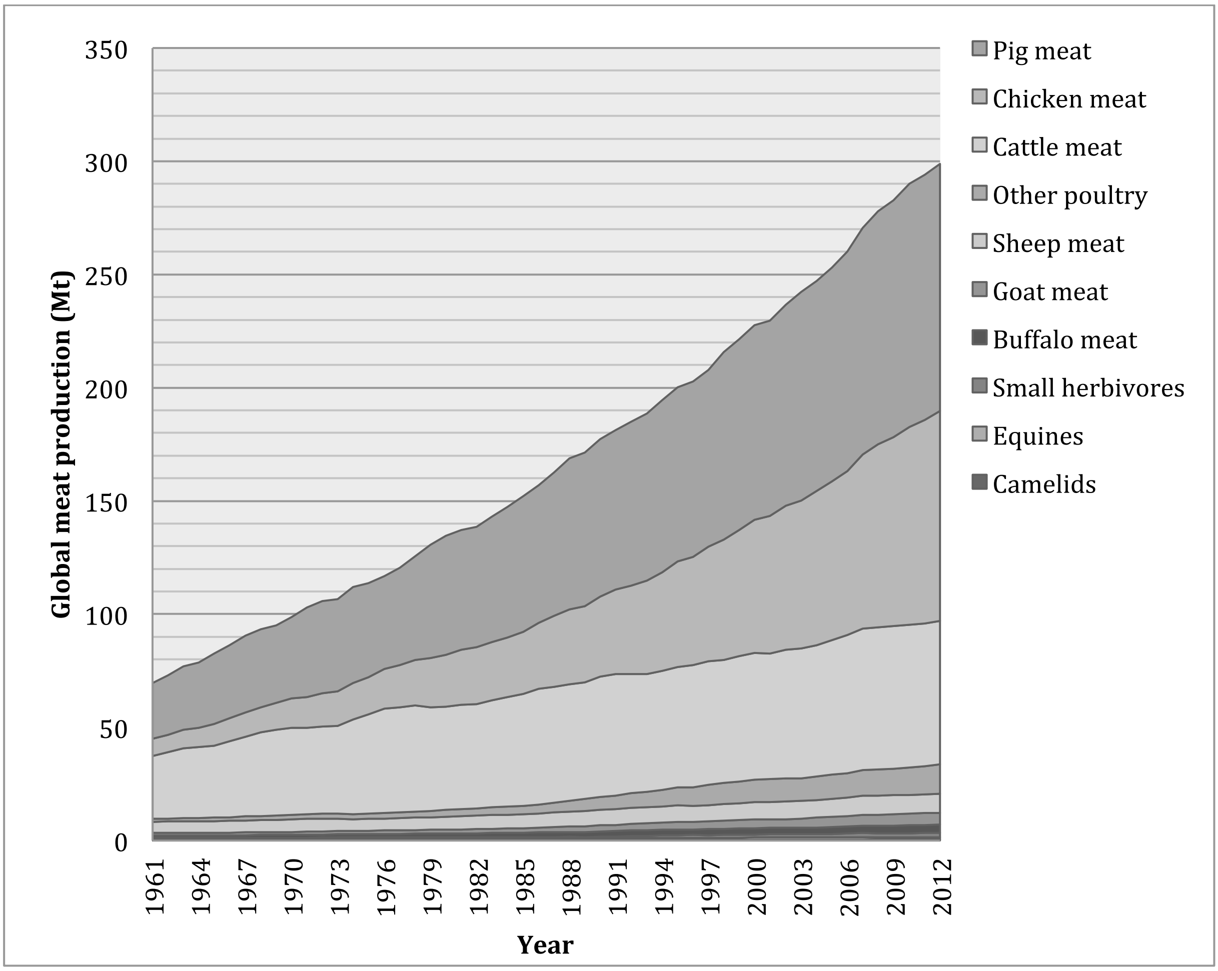


Figure 1.7: Evolution of global meat production from 1961 to 2012.
Based on FAOSTAT (2014a)

Although pig meat is still the most important and the total volume more than quadrupled compared with 1961, a stunning increase can be found in chicken meat production, likely due to both agricultural (small body-size, fast reproduction…) and cultural (lean meat, accepted by most religions…) advantages. It is not only the number of animals that is responsible for the total amount of meat produced. Although the number of chickens quintupled during the last fifty years, chicken meat production increased more than eleven times in the same period, showing that intensive selection on body size and meat percentage cannot be neglected. Cattle and sheep meat production more or less doubled, while goat meat also quadrupled, what can be explained to a great extent by the increasing number of goats. Although not shown in figure 1.7 because of the relative small production, the largest increase can be found in snail production, where the production of 0.017 Mt in 2012 is more than 33 times higher than in 1987 (no earlier data).

With a total production of almost 754 Mt in 2012 (FAOSTAT, 2014a), more than a doubling compared to 1961, milk is on a mass base the most important animal product. With 626 Mt or 83% on a mass base, cow milk has the largest share, followed by buffalo milk (12.9%), goat milk (2.4%), sheep milk (1.3%) and camel milk (0.4%). The strongest increase in production can be found in buffalo milk, which more than quintupled since 1961.

The world egg production is 72 Mt, or almost 5 times more than in 1961. More than 92% are chicken eggs, but egg production from other species is increasing.

1.2.7 Evolution of aquaculture

With an increase from 32.4 Mt in 2000 (FAO, 2014a) to 66.6 Mt in 2012 (FAOSTAT, 2014d; FAO 2014a) one could say that aquaculture is growing very fast. Freshwater production, which grew from 21.8 Mt to 41.9 Mt, is much larger than marine aquaculture, which grew from 12.8 Mt to 24.7 Mt (FAOSTAT, 2014d). Since China accounts for more than 65% of the global aquaculture production, Asia is the most important continent with 88% of the total production and more than 65% is freshwater aquaculture (FAO, 2014b). The most important categories in Asia are finfishes (64.6%), molluscs (24.2%) and crustaceans (9.7%) of which 35% are non-fed species. Contrary to Europe, where the production in brackish and marine waters is the most important due to cage production of a.o. salmon, freshwater fishes are responsible for more than half of the global aquaculture production, followed by crustaceans (almost 10%). Worldwide, the amount of non-fed aquaculture declined to 20.5 Mt or 30.8% on mass base in 2012 (FAO 2014b), although it is still common for carps (7.1 Mt filter-feeding) and bivalves (13.4 Mt). Due to increasing consumer demand for higher trophic-level species, this percentage is expected to decrease further (FAO, 2014a).

About 600 aquatic species are used in aquaculture. Freshwater fish are the most important group (38.6 Mt), followed by molluscs (15.2 Mt), crustaceans (6.5 Mt), mariculture fish (5.6 Mt) and other aquatic species (0.9 Mt). The most important freshwater fish species are the low-trophic level species carps, tilapias and *Pangasius* catfishes, while carnivorous freshwater species only count for 2.6%. More detailed information can be found in FAO (2014a) and FAOSTAT (2014d).

1.3 Fuel

For centuries, both animals and plants are used as energy sources, although they served for different purposes. Animals were mostly used as a means of transport before the industrial revolution. Plants on the other hand were mainly used for other forms of energy: heat for both cooking and warming, and light (e.g. oil lamps). Furthermore, at the end of the 19th century and the beginning of the 20th century, bio-ethanol was used in the industry in Europe and the U.S. (Balat & Balat, 2009). Around 1900, petroleum became widely available (FAO, 2008) and after the Second World War its price was lower than that of bio-ethanol (Balat & Balat, 2009). Therefore, petroleum-based fuels became the most important energy source, especially as transportation fuels. During the last decades, political decisions for both economical (increasing fossil fuel prices and dependence from other countries) and ecological reasons (renewable, possibly less greenhouse gas emissions) increased the attention to this function of agriculture, which seemed ‘forgotten’ in Western society.

When mentioning ‘biofuel’, one is inclined to think about plant-based energy production alone. The large numbers of equines, camelids and buffalos (as has been shown in table 1.2) illustrates that animal power is still very important in developing societies. As the energy produced by physical activity of animals is only a small fraction of global energy consumption and since it is not very likely that the importance of animal power will increase significantly in the future, only plant-based biofuels will be discussed in what follows.

Since the first global oil crisis in 1975, Brazil started to focus on biofuel production based on ethanol production from sugar cane (Balat and Balat, 2009). It has a major role in total South-American biofuel production (more than 84% in 2013 according to BP, 2014). This contrasts with the rather low production in other parts of the world (figure 1.8). From 2000 onwards, biofuel production in the U.S. increased strongly and in 2006 it became the number one producer worldwide. In 2013 the U.S. was responsible for 28.4 million tonnes of oil equivalents (Mtoe) or 43.5% of the global biofuel production (BP, 2013), followed by Brasil with 15.8 Mtoe (24.2%), Europe and Eurasia with 11 Mtoe (16.8%) and Asia Pacific with 6.1 Mtoe (9.3%). Biofuel production in the Middle East is almost unexisting (0.004 Mtoe) and with 0.03 Mtoe also the African biofuel production can be more or less neglected.

On a global scale, biomass accounts for more than 10% of primary energy supply, with an average annual growth rate of 1.4% (REN21, 2012).

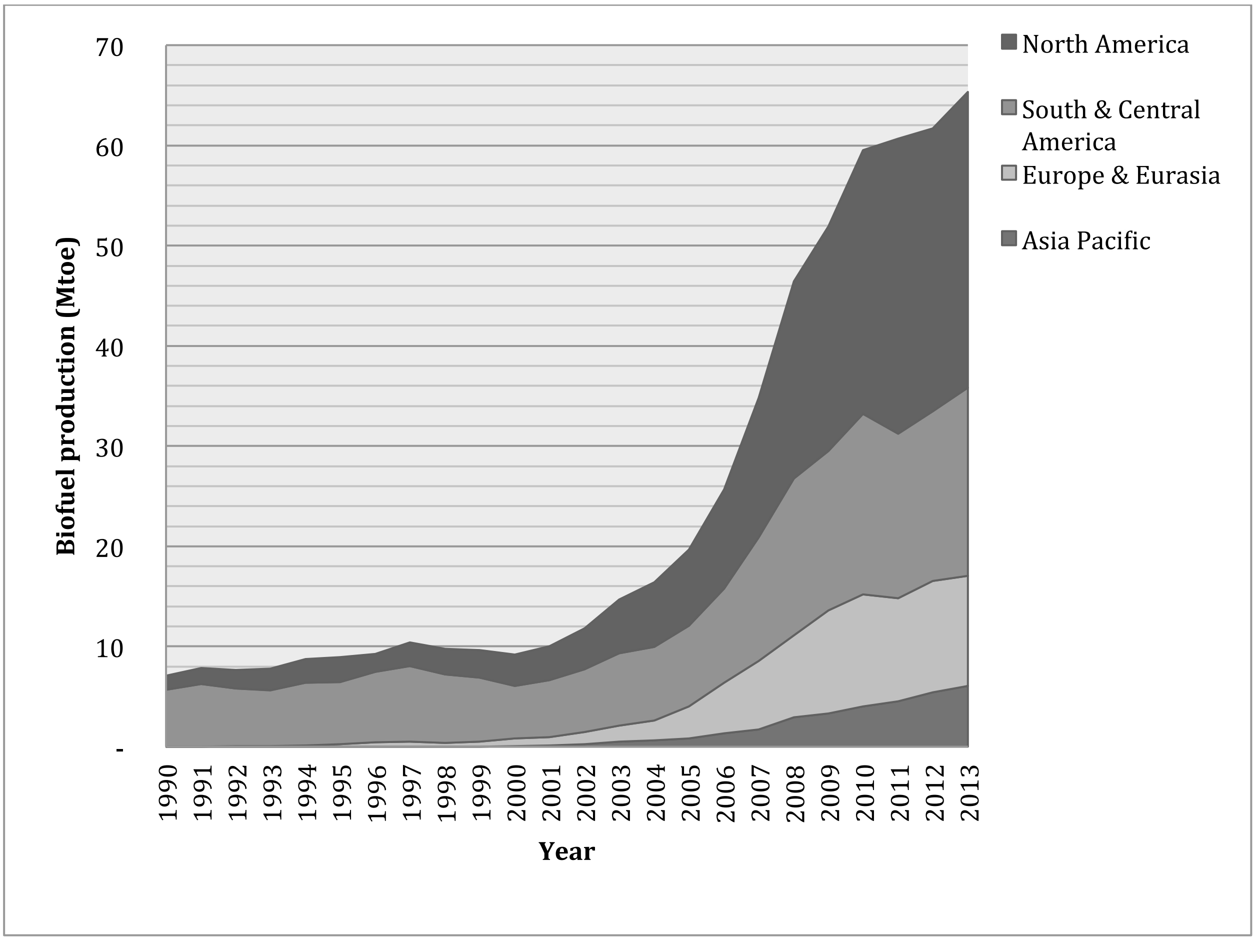


Figure 1.8: Evolution of biofuel production per continent.
Based on: BP (2014)

When discussing biofuels as such, often a distinction is made between three different 'generations', based on the kind of biomass they are produced with. Where the first generation produces energy out of edible crops produced on fertile land, the second generation uses non-edible biomass. Since for both generations of biofuel (and thus biomass production) land is required, a third generation is distinguished, where oil is produced by algae and thus no arable land is needed. A short overview of each of these generations will be given in what follows. More technical details about the different processes can be found in Demirbas (2010) and Naik *et al.* (2010).

1.3.1 First generation biofuels

Biofuels from the first generation can be divided in two groups. On the one hand, as an alternative for fossil diesel, biodiesel is produced by the transesterification of vegetable oils (e.g. soybean oil in the U.S., rapeseed oil in Europe or palm oil in Malaysia) and – although of minor importance – animal fats in a catalysed reaction with an alcohol. The process leads to interesting by-products as protein-rich cakes from the extraction of oil from the oil seeds, and glycerol as a by-product from the transesterification (Naik *et al.*, 2010). Compared to 2010, global production increased by 16% to 21.4 billion litres (REN21, 2012), mostly caused by an increase in production in the U.S. of 159%. With a total production of nearly 3.2 billion litres, it became the number one biodiesel producer worldwide, passing the 2010 leaders Germany (3.2 billion litres), Argentina (2.8 billion litres), Brazil (2.7 billion litres) and France (1.9 billion litres) (REN21, 2012).

On the other hand, sugars and starch, which is enzymatically treated to release the sugars from the starch-polymer (Naik *et al.*, 2010), are fermented in order to produce bio-ethanol, an alternative for gasoline. As can be seen in figure 1.9, bio-ethanol production is the most important worldwide, since both the U.S. and Brazil, the two most important producers (respectively 63% and 24% of global bio-ethanol production; REN21, 2012) use respectively corn and sugar cane for their biofuel production. In 2011, the global bio-ethanol production decreased for the first time since 2000 (REN21, 2012). Of the total production of 86.1 billion litres, more than 54 billion litres were produced from corn (REN21, 2012). Compared to 2010, the Brazilian production decreased by 18%, leading to a production of 21 billion litres, because of declining investments, poor sugarcane harvests and high world sugar prices (REN21, 2012). The U.S. and Brazil are followed by China (2.1 billion litres), Canada (1.8 billion litres), France (1.1 billion litres) and Germany (0.8 billion litres) (REN21, 2012).

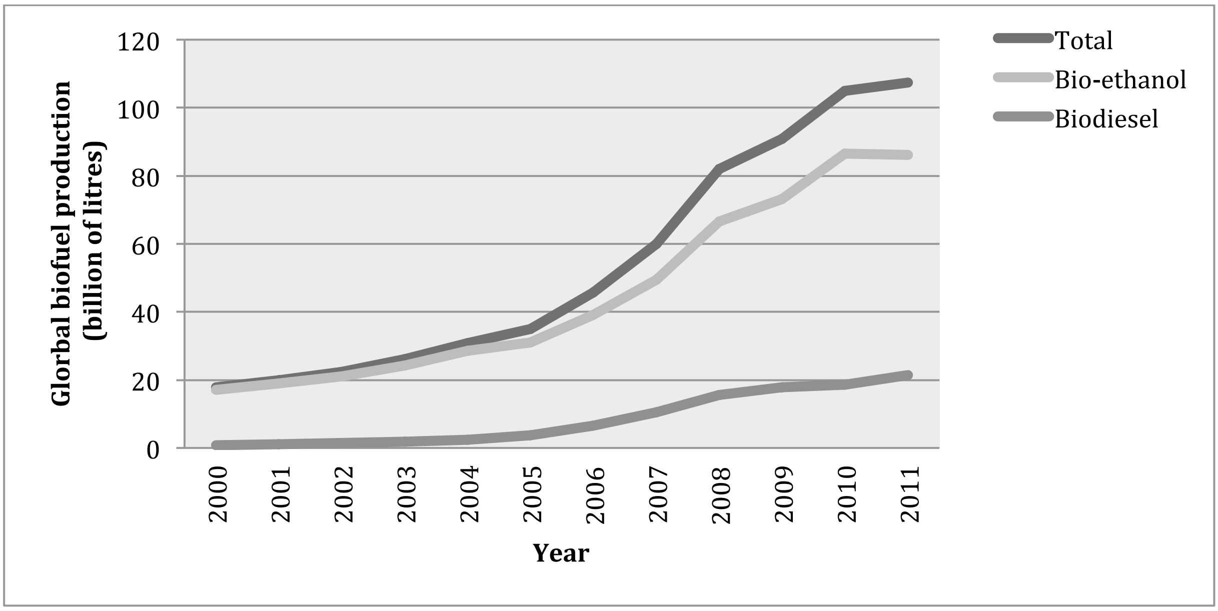


Figure 1.9: Evolution of global production of biodiesel and bio-ethanol.
Based on: REN21 (2012).

1.3.2 Second generation biofuels

Shortly after the booming interest in first generation biofuels, ethical questions rose (see paragraph 2.4) about using food crops for fuel. This led to an increasing interest in producing energy from non-food biomass. Compared with the abundance in which lignocellulosic materials as wood and agricultural residues are available, these materials are rather underutilized, especially in the developed world. For several millennia, wood has been a very important energy source for humans and it still is the case in developing regions, which consume more than 90% of global woodfuel production and consider it as the traditional biomass for cooking and heating. The burning of woodfuels, agricultural by-products and dung is estimated on about 8.5% of total final energy used worldwide (REN21, 2010). Although burning wood might sound like something for underdeveloped societies, it is regaining importance globally (FAO, 2008). The simple process of burning wood can be very efficient: FAO (2008) mentions a conversion efficiency of about 80% for wood pellet stoves, comparable with combined heat and power plants. Global pellet production increases with 25% every year, reaching 18 252 tonnes in 2011 (REN21, 2012) of which more than 60% is produced in Europe (REN21, 2012), followed by North America (about one third). In other regions, pellet production is not that important, also because of the importance of burning non-pelleted wood.

Since most engines for transport are not able to use fuelwood as an energy source, also liquid biofuels of the second generation are developed. For the production of biodiesel, non-edible crops are planted to produce vegetable oil. Bio-ethanol on the other hand is produced from fermenting sugars available after the biochemical breakdown of the lignocellulosic structures. Both the oil and the ethanol are treated analogous to first generation biofuels. Since waste from wood industry and agriculture are not enough to cover the increasing demand for biofuels, specific non-food energy crops are planted: short rotation forestry crops (e.g. eucalyptus, poplar and willow) and perennial grasses like *Panicum* and *Miscanthus* (FAO, 2008) for the production of lignocellulosic material, and species like *Jatropha* for vegetable oil production.

Next to solid biofuel (fuelwood) and liquid biofuel (ethanol from lignocellulosic materials), also gaseous biofuel can be produced from organic waste, which can be fermented to produce biogas. Anaerobic digestion of biomass creates a mixture of both methane (CH_4) and carbon dioxide (CO_2) that is known as landfill gas (Naik *et al.*, 2010). Although contaminants in the gas mixture need to be removed for commercial use, energy production based on waste can produce a lot of energy. Biogas production is very suitable for small-scale production, for example biogas-installations on farms where manure is fermented in combination with other organic materials. The largest growth in biogas production can be found in Europe with an increase of more than 31% in 2010 (REN21, 2012) of which Germany produces about two third. In Sweden even cars on biogas are used (REN21, 2012).

1.3.3 Third generation biofuels

Since energy crops of the second generation still use land and the total arable area is limited, energy production by algae can be seen as a solution for producing renewable oil on 'useless' land or in water. The idea to use microalgae for biofuel production is rather new: only at the end of the 1970's, the U.S. department of energy invested in microalgae research (Hu *et al.*, 2008; Knoshaug & Darzins, 2011), primarily for wastewater treatment, although it was suggested that the algae could be fermented to CH_4 as an energy source (see historical overview in Vandamme, 2013). Algae convert water, CO_2, nutrients and sunlight into oils, which can be used for energy production. Because these micro-organisms have high growth rates in varying conditions, also in high saline water and waste water from e.g. food industry

(Verberkt, 2012), their usability seems very high. They can be produced in both open ponds or in more expensive photobioreactors, each with their own pros and cons, or even in hybrid systems (Knoshaug & Darzins, 2011; Zhu *et al.* 2014). There are about 40 000 species of algae, classified in multiple major groupings, (for an overview, see a.o. Hu *et al.*, 2008; Gosch *et al.*, 2012; Rashid *et al.*, 2014; Allen *et al.*, 2015) and the oil content of some species is more than 80% of the dry cell weight (Hu *et al.*, 2008; Naik *et al.*, 2010), although this is only reached in optimal laboratory circumstances (Vandamme, 2015; personal communication). To extract the oil from the algal cells, the microalgae need to be harvested and dewatered, two very energy-intensive steps since these micro-organisms are only 1 to 20 µm and on a dry weight base only 1 to 2 grams of microalgae can be found in one litre of culture. In contrast with their small size and concentration, the oil production is very high. Based on 50% cell oil and only sun energy (no extra light, no heterotrophic production) a theoretical maximum production of about 354 000 litres of oil per hectare is possible (Weyer *et al.*, 2009), although in practice yields between 40 000 and 60 000 litres of oil per hectare are more realistic (Weyer *et al.*, 2009; Naik *et al.*, 2010), which is still about ten times more than e.g. palm oil yields (Naik *et al.*, 2010). Due to the high costs, algal oil is mostly used for specialty oil production and not for biofuel production (Hu *et al.*, 2008), although this might change in the future.

Microalgae are seen as a very efficient way to produce biomass (Chisti, 2007 and 2008): they can double in biomass within 24 hours and are an alternative to replace fossil transport fuels. Chisti calculated that to replace all transport fuels in de US, only 3% of the cropland is needed when using microalgae, while 61% of the cropland is necessary when oil palm, the plant with the highest oil yield per hectare, is used. Microalgae are more efficient in their photosynthesis, since different species can capture more different wavelengths of the light than terrestrial plants (Nalley *et al.*, 2014). Since microalgae do not need structural compounds as roots or stems, they have a higher percentage of lipids and proteins compared with terrestrial plants (Vandamme, 2013).

In practice, there are some constraints to effective production of enough microalgal biofuel. Klein-Marcuschamer *et al.* (2013) give an overview of ‘details’ that make a difference between microalgal biofuel as a theoretical solution and reality because of site-specific characteristics. For example: microalgal growth requires a CO_2-concentration at least 100 times higher than in the ambient atmosphere. Therefore, a nearby large CO_2-producer (e.g. powerplant) is needed. Furthermore, the production site has to be built in a suitable climate (both temperature and sunlight) with enough water and enough space available (Klein-Marcuschamer *et al.*, 2013).

Biofuel production from microalgae is not yet economically feasible (Zhu, 2015). While a lot of research is done on photobioreactor design, selection of species and strains and genetic engineering, less progress is made on downstream processing (Vandamme *et al.*, 2012), although this knowledge is essential to move from a laboratory and pilot scale to commercial production sites. Especially harvesting costs are high and count for up to 30% of total biodiesel production cost (Rashid *et al.*, 2014). Different techniques can be used for harvesting: centrifugation, filtration, flotation, flocculation, harvesting by polymers or ultrasound (Rashid *et al.*, 2014). Since centrifugation is energy-intensive, reducing the amount of water reduces the costs. If flocculation, followed by sedimentation could decrease the amount of water up to 100 times, costs could be reduced to bulk production levels (Vandamme *et al.*, 2012; Vandamme, 2013).

Zhu *et al.* (2014) state that both energetic and economic efficiency can increase by using combined biorefineries, where the algal lipids are converted into biodiesel, the carbohydrates into ethanol and the leftovers into methane. Since microalgae also contain high value products like poly-unsaturated fatty acids and others that are of interest for the pharmaceutical and cosmetic industry, Zhu (2015) suggests that energy alone is not an option and that research should not focus on oil production alone, but on increasing the cost-effectiveness of these refineries. Others claim that if microalgae are produced for fuel alone, an ecosystem with a complementary, trait-based mix of different species in open-pond systems is the most economically sound option, although further research is still needed to cope with several problems within the microalgal community ecology like predation, contamination, pathogens and so on (Shurin *et al.*, 2013; Nalley *et al.*, 2014).

Although it was believed that macroalgae (seaweeds) are not suitable for oil extraction, Gosch *et al.* (2012) have found lipid contents of 10% and more on dry weight base, which is higher than many species of microalgae, and they believe that higher yields are possible when optimising culture conditions and selection for high-yield strains. Furthermore, seaweeds could also be used for third generation gaseous biofuels after fermentation to biomethane (Allen *et al.*, 2015). Due to their high solid content, thickening before digestion is not needed and harvesting is rather easy. Furthermore, they could be used near fish farms to decrease the nutrients released in the environment. Brown seaweeds are more suitable than green species, since their C:N ratio is better, reducing unwanted ammonia-production.

1.4 Fibre

Already in the Neolithicum, fibre crop production for textile was found in each of the three large expanding centres of the human agrarian population (Mayozer and Roudart, 2006). Although it fluctuated during the last decades, the global fibre crop production area is estimated on 38.3 million hectares in 2012 (FAO, 2014b). This is comparable to the global sorghum production area (38.2 million ha). Of those 38.3 million hectares, seed cotton is by far the most important with about 35 million hectares (about 92%). This importance in production area is readily translated in production quantities, as can be seen in figure 1.10.

With a global production of more than 78 Mt of cotton seed and 26 Mt of cotton lint in 2012 (FAOSTAT, 2014b), cotton accounts for more than 95% of global fibre crop production, followed by jute with 3.5 Mt. All other fibre crops account for less than 0.5%, both on area and on mass base. For some crops, the total production decreased a lot: the 2012 production of hemp is less than 20% of the production in 1960 and also flax is about one third, compared with the production in 1960. Cotton production on the other hand almost tripled in the same period.

Next to the typical fibre crops, also wood delivers raw materials for the industry. Wood can be used as a whole (e.g. timber and planks) or as fibres for building materials (e.g. plywood and veneer) or the paper industry. Global demand for wood and wood products is still increasing: global paper production e.g. more than quintupled compared with 1961 to a total production of 397 Mt in 2014 (FAOSTAT, 2014f) of which more than 29 Mt was for newsprinting alone. Because natural forests cannot produce enough wood for this increasing demand, wood production will be produced – like other agricultural crops – in plantations where *Eucalyptus* is the most important species (Stape *et al.*, 2004). Although forestry is often not seen as 'agriculture', there is only a thin line between them, since both systems produce biomass under human control. Attention increases to mixed production in so-called agro-forestry.

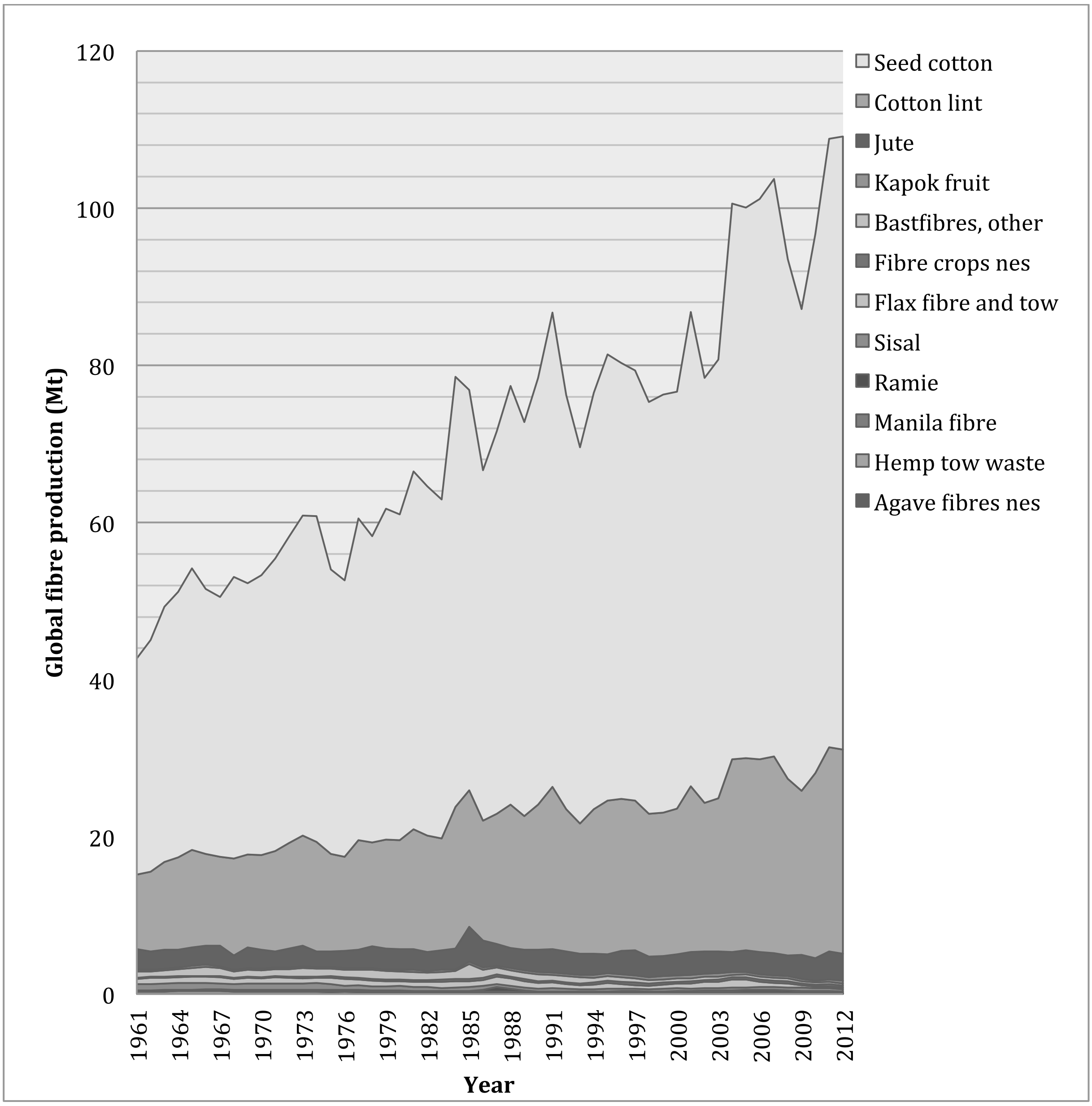


Figure 1.10: World fibre crop production.

Based on: FAOSTAT (2014b)

Not only plants deliver raw materials for the industry, animals do too. Since the total number of animals increased since 1961 (see table 1.2), also the production of hides increased, as can be seen in figure 1.11, although wool production in 2012 was only 79% of the production in 1961 (FAOSTAT, 2014a).

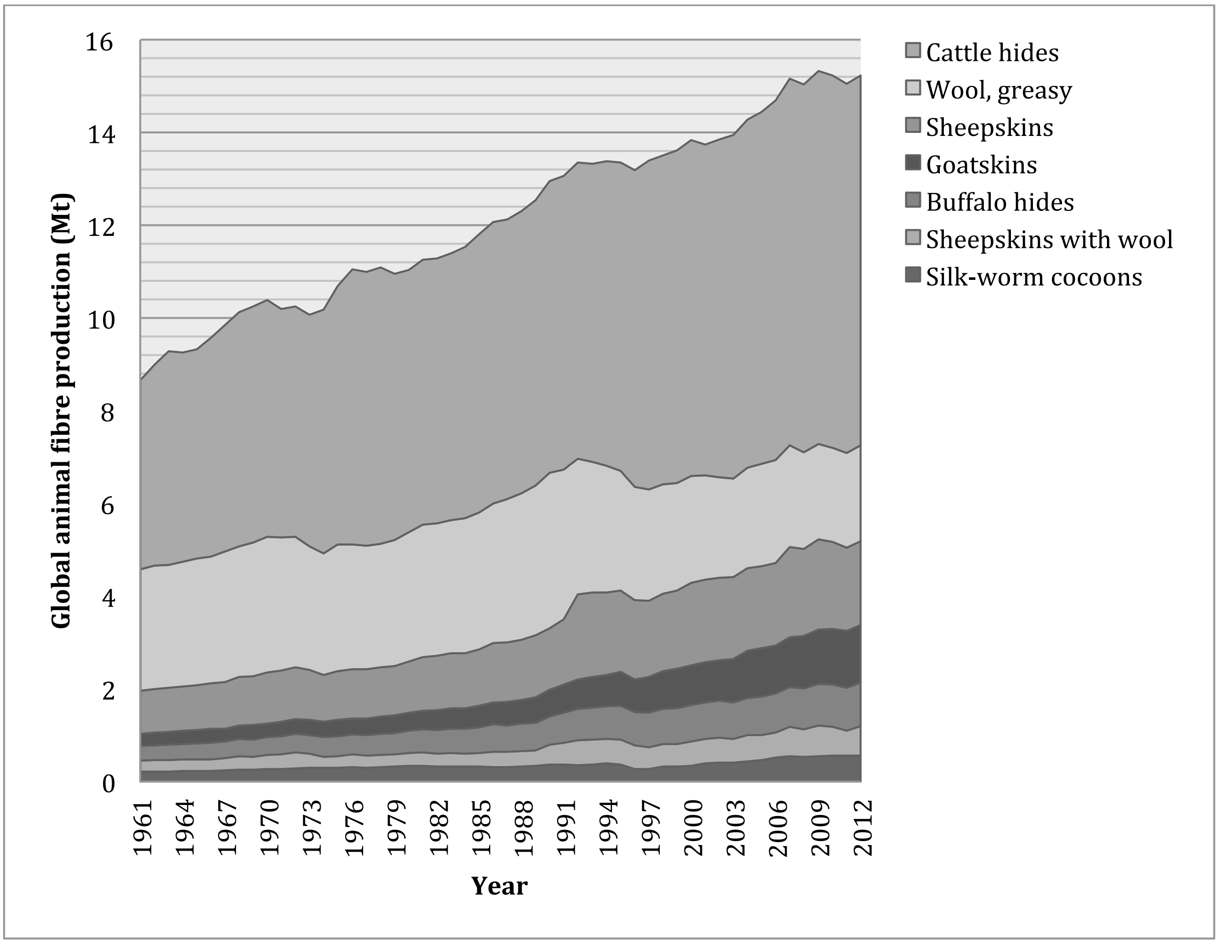


Figure 1.11: Evolution of global production of animal material production.
Based on: FAOSTAT (2014a)

For most animal species, the animal products can be seen as a by-product from meat or milk production, although they are of high value and used as luxury products like leather. Also other parts of slaughtered animals are used, like bones for gelatine-production. Some animal species like mink and fox are kept for fur production only and this comprises more than 85% of total fur sold today (We are fur, 2014). Fur production is very important in Europe, since 30 million pelts or 64% of global production of mink fur and 2.1 million pelts or 56% of global production of fox fur are produced on European farms, especially in Denmark, Finland and the Netherlands (EFBA, 2012).

Agricultural products can also be used in the petrochemical industry to replace fossil fuels. Bio-oil is a complex mixture and contains many reactive types of molecules, which are extracted from biomass in so-called bio-refineries (Demirbas, 2010). Fermentation of biomass, e.g. starch, is not only used to produce ethanol for biofuel, but also lactic acid for the production of bioplastics and enzymes for different industrial applications can be obtained. While the transportation sector uses more than 60% of fossil oils (IEA, 2011), the use of fossil oils for plastics is only 4 or 5 per cent (Queiroz & Collarez-Queiroz, 2009). Global bioplastic production is estimated at 1,4 Mt or less than one per cent of the global plastic production of about 290 Mt, although European Bioplastics (2014) predicts that global bioplastic production will increase to more than 6 Mt by 2017. Often bioplastics and biodegradable plastics are confused: there are biodegradable plastics that are totally composed of petrochemical polymers (Queiroz & Collarez-Queiroz, 2009), while plastics made from vegetable materials are not necessary biodegradable.

Furthermore, plants and animals can be used to produce complex molecules. Pharmaceutical firms are looking for medicinal plants to extract interesting, often unknown molecules; animals are genetically modified in order to produce specific proteins in their milk.

1.5 Foster

Agriculture's relation with nature is very ambiguous. At first, agriculture was seen as a means to manage nature in such a way that nature serves different functions. Although higher yields were possible by several techniques, production was strongly connected with nature, closing nutrient cycles. Starting in the 19th century, but especially after the Second World War, agriculture became more rationalised, efficient and industrialised to meet the desired increase of food production. Since decisions were made on a national and European level, the way in which individual farmers looked at their relationship with nature was of minor importance. The aim became to produce enough safe food at the lowest possible cost. Economic considerations received a central position and other aspects of agriculture were strongly decreased or even externalized. Therefore, "the morality of the market became central and farmers got used to speaking and counting in market terms only. They still had moral beliefs beyond the economic considerations, but these were mainly held as private opinions" (Meijboom, 2009: 238).

A few decades later, the focus in the European agricultural policy is no longer on producing more, but on producing more sustainably. Citizens expect farmers to produce in an environmentally friendly way, with respect for animal welfare, closed nutrient cycles, agro-biodiversity and sustainable water and soil management.

After the Second World War, the autonomy of farmers decreased with regard to technical matters in favour of an increased production, making many small farmers to quit. At the end of the 20th century, farmers' autonomy further decreased, but this time by moral matters (Stafleu and Meijboom, 2009). Intensive farming was no longer seen as the solution but as a threat and the production methods of farmers were criticized for ethical reasons.

As a result, an increasing interest in organic farming occurred. Although one could claim that an organic farmer produces just like any other farmer, in practice it is more than that. Indeed, food (or feed, fuel, fibre or fun) is the result, but also a soil with more organic matter. By this, the farmer produces living soils that are resilient, capture CO_2, have a good water household… The farmer gets paid for the final product, but the by-products of the production system are also what – at least some part of – society expects: agricultural production with respect for the intrinsic value of living objects and nature, an expression of justice towards the environment (Peeters *et al.*, 2012). Farmers have the responsibility to take care of the land and other production resources in order to maintain fertile agricultural land in a way that does not compromise the needs of the future generations, leading to a sustainable agricultural production (see paragraph 3.1). Therefore, fostering the agricultural ecosystem is at least as important as the agricultural production itself.

But it goes farther than only respecting the agricultural ecosystem. For centuries, natural habitats have been seen as 'unlimited' resources of land and large areas of nature have been transformed to pastures or cropland in order to meet the increasing demand for agricultural products (Steinfeld *et al.*, 2006). Nowadays, this transformation can still be seen in Southern countries where tropical rainforests are cut down to create extra agricultural area. In this way, one can say that nature competes with the other Fs since one has to decide if a certain piece of land will be used to produce agricultural products for one or more functions, or if it will remain wild nature and thus generating specific ecosystem services for future generations and ourselves. The debate between agriculture and wild nature is not only discussed in countries with large areas of nature such as Brazil, but also in densely populated areas like Flanders, where increasing interest in nature and ecosystem services leads to reversion of the fertile agricultural land (e.g. polders) back to nature.

Ecosystem services are not only produced by wild nature, but also by agricultural land. The European Commission of Agriculture and Rural Development (2014) encourages farmers to integrate environmental concerns into their management by using agri-environmental measures to protect and enhance the environment on their farmland. In return of payments, farmers engage themselves to adopt environment-friendly farming techniques that go beyond legal obligations for at least five years. By this, farmers choose for techniques that are not the best choice in view of profitability, but for techniques that meet society's demand for fostering nature by agriculture. Introduced in the late 1980s as optional, it became compulsory in 1992 for the Member States in their rural development plans. In the period 2007-2013, nearly 20 billion EUR was invested in agri-environmental measures (European Commission on Agriculture and Rural Development, 2014).

In Flanders, almost one out of three farmers committed to at least one agri-environmental measure (Maertens, 2011) and almost half of them would commit to the same agri-environmental measure even if he/she would not receive financial support. However, there are large differences between different measures: 80% would continue with green cover crops, while only 10% would continue with measures for botanical management of meadows or measures for bird species that typically live in fields or meadows. Farmers are willing to integrate environmental practices in their management thanks to the financial support (56% of the respondents), concerns about the environment (48%), profitability (35%) or the imago of their farm (29%). The most popular measures in Flanders (in 2009) were: green cover crops, papilionaceous flowers, protection of water quality, small landscape elements, parcel border management, mechanical weeding and erosion prevention (Maertens, 2011).

1.6 Fun

Agricultural resources are also used to produce several kinds of ‘fun’ products. They can be divided in two major groups: agricultural fun products that are consumed by humans directly, like stimulants and luxury foods, and agriculture as a source of pleasure. As discussed earlier, floriculture is – in contrast with the framework of Aerts *et al.* (2009b) – also categorised as Fun, since they are produced for their aesthetical and cultural value only.

1.6.1 Non-edible consumable Fun crops

Some crops are consumable without being edible. Well-known examples here are *Nicotiana* production for tobacco, but also more illegal crops like *Papaver* for opioids production (e.g. heroin), *Coca* for cocaine production and *Cannabis* for marijuana and hashish production. Although also other plant species are used for hallucinogenic purposes, only these four major crops will be discussed. One has to be aware that except tobacco production and a small part of poppy production, which is used for morphine (UNODC, 2012), all other crops are illegal and global production can only be estimated with large uncertainties.

Cannabis is the most important illegal drug worldwide and UNODC (2012) estimates that 2.6 to 5 per cent of the adult world population use it, although large differences can be seen, varying between about 1% in Asia up to almost 15% in Oceania. Global cannabis production for 2008 is estimated between 13 000 and 66 100 tons, although it is produced for two different purposes: resin production for hashish and herb production for marijuana. Resin production is mostly found in Morocco and Afghanistan. Here, total cannabis resin production area is estimated between 9 000 and 29 000 ha with an average yield of 128 kg of resin per hectare in Afghanistan, which is much higher than the average yield of about 40 kg per hectare in Morocco (UNODC, 2012). Herb production can be found all over the globe and is more small-scale, although also large plantations are found. Because of increased knowledge about indoor hydroponic breeding and the availability to purchase different breeds and necessary equipment online, indoor or even home-grown cannabis production increases in developed countries. In this way, competition with other agricultural products is rather small.

The second important illegal drug is opium. In 2011, global opium production was 7 000 tons (UNODC, 2012), which is still less than in 2008, but more than the 2010 production of 4 700 tons, recovering from a disease in Afghan poppy production. The total poppy cultivation area increased from 191 000 ha in 2010 to 207 000 ha in 2011 (UNODC, 2012). Myanmar was the most important illicit opium producer worldwide until the 1990s, when Afghanistan became the top producer. Nowadays, Afghanistan (88%) and Myanmar (6%) account for almost 95% of global opium production (UNODC, 2012). Also in Central and South America, mainly Mexico and Colombia, poppy production can be found. UNODC (2012) estimates that between 0.6 and 0.8 per cent of the global adult population use opioids. This type of drugs is mainly used in developed countries, but an increasing demand in upcoming countries can be observed.

Of the global adult population, an estimated 0.3 to 0.4 per cent uses cocaine, mainly in North America, but also in other developed countries (UNODC, 2012). The most important producing countries are Bolivia, Colombia and Peru. Although the production area increased in both Bolivia (from 19 900 ha in 2001 to 31 000 ha in 2010) and Peru (from 46 200 ha in 2001 to 61 200 ha in 2010), the decrease in Colombia from 144 800 ha in 2001 to 57 000 ha in 2010 resulted in an overall decrease of coca bush production (UNODC, 2012). Because of improved yields and techniques, global cocaine production is still increasing, despite the decrease in production area.

Compared with an estimated illicit drug use of 5% of the global adult population, the past-month prevalence of tobacco of 25% of the global adult population is quite high (UNODC, 2012). Not only the global tobacco production area increased from 3.40 million hectares in 1961 up to 4.29 million hectares in 2012, also the yield increased, leading to almost a doubling of the global production from 3.57 Mt in 1961 to 7.49 Mt in 2012 (FAOSTAT, 2014b). With a production of 3.2 Mt in 2012, China is the most important producing country, followed by India (0.88 Mt), Brazil (0.81 Mt) and the U.S. (0.35 Mt). Also, more than half of the production area can be found in Asia (FAOSTAT, 2014b).

1.6.2 Edible Fun crops

Some crops are not grown for their nutritional value, but for specific fun use only. Here, we will discuss cacao, coffee and thee, because of their large production and their importance as export crops in developing countries. One could argue that also sugar production from sugar beet and sugar cane can be seen as fun crop production, but because of the historical use as a means to conserve perishable foods like fruit and because of the new function as energy crop, it will not be discussed here.

The total cacao production area was about 9.93 million hectares in 2012, more than a doubling compared with 4.40 million hectares in 1961 (FAOSTAT, 2014b). Because of increasing yields during the past decades, total cacao bean production more than quadrupled to 5.00 Mt in 2012. Although *Theobroma cacao*, of which the seeds are used for cocoa production, originally grows in the tropical regions of America, 66% of all cacao is now produced in Africa. With a production area of 2.50 million hectares and a production of 1.65 Mt or almost 33% of global production, Côte d'Ivoire is the most important cacao producing country, followed by Indonesia (0.94 Mt or 18.7%), Ghana (17.6%), Nigeria (7.7%), Cameroon (5.1%) and Brazil (5.1%) (FAOSTAT, 2014b).

During the last decades, the production area of coffee stayed more or less the same with 10.0 million hectares in 2012, good for a global production of 8.83 Mt of green coffee, which is almost a doubling compared with 1961 (FAOSTAT, 2014b). The different *Coffea* species of which the seeds are used since the 15th century or earlier (ICO, 2012) to produce various types of coffee are indigenous to (Eastern) Africa, which now only accounts for 11.3% of global coffee production (FAOSTAT, 2014b). Almost 60% of the coffee is now produced in America, mainly due to the importance of Brazil, which covers 34.4% of total production and 21.1% of total production area. Other important coffee producing countries are Vietnam (14.6% of green coffee produced), Indonesia (7.4%), while Ethiopia, the native country of coffee (ICO, 2012), only accounts for 3.1% (FAOSTAT, 2014b).

As the scientific name *Camellia sinensis* suggests, tea was first found in China. Still 35% of all tea is produced there on more than 45% of the global tea producing area. Especially because of China and India (producing 21% of global tea production on 18% of global tea area), Asia is the main tea-producing continent since 88.9% of all plantations and 85.2% of all production is found here (FAOSTAT, 2014b). Africa accounts for about 9.7%, making tea the only crop where the main production did not move to another continent. While total production area more than doubled to 3.28 million hectares, global tea production increased to 4.82 Mt, which is almost five times more than in the 1960’s (FAOSTAT, 2014b).

1.6.3 Edible Fun products from food crops

Some regular crops can be converted into Fun products, often with higher economic value. A well-know example here is the production of alcoholic beverages from edible crops like fruits, cereals or even potatoes. About 42% of all adults drink alcohol every year (UNODC, 2012). Drinking alcohol can be found in almost all cultures and is thus nearly universal in both time and space and among all layers of society (SIRC, 1998).

Of all alcoholic beverages, beer is not only the most popular, but also the oldest. There is evidence that beer, or at least beverages based on natural fermentation by yeasts, was already brewed more than 7000 years ago (Bai *et al.*, 2011) and there is even evidence that the cultivation of grain for beer was as important as cultivating grain for bread in the development of agriculture (SIRC, 1998). All layers of society consumed beer, while wine gained importance in the upper classes due to the influence of the Greeks and the Romans (Poelmans & Swinnen, 2011). In the Middle Ages, demand for beer increased, not only due to economic prosperity but also because increasing water pollution made people choose beer, since boiled water was used in the brewing process, resulting in a lower bacterial content (Poelmans & Swinnen, 2011). All kinds of crops can be used for beer production: the Native Americans used maize and during and short after the World Wars, even peas, beets and beans were used (Poelmans & Swinnen, 2011). Nevertheless, barley-based production is the most important. Global beer production in 2012 is estimated on 190 Mt (FAOSTAT, 2014g) of which 34.3% is brewed in Asia (26.9% in China alone), followed by Europe (27.8%), North America (13.1%) and South America (11.7%) (FAOSTAT, 2014g).

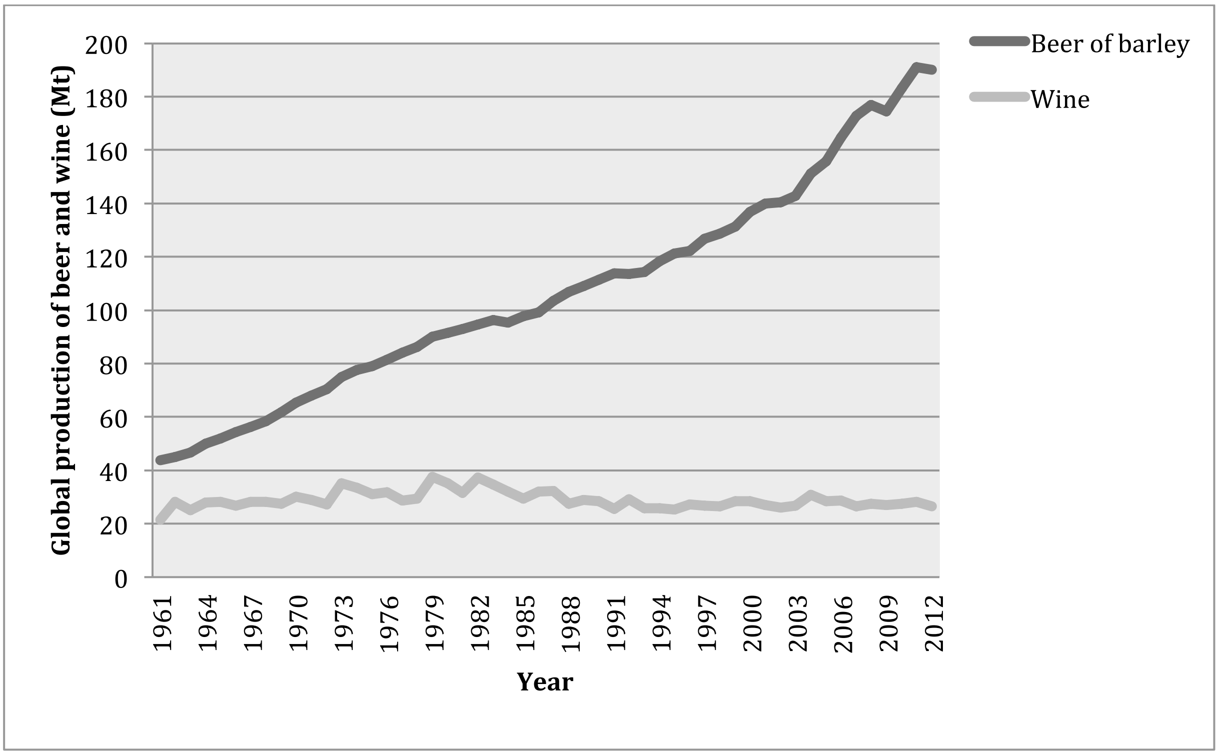


Figure 1.12: Global production of wine and beer (Mt).

Based on FAOSTAT 2014g

While beer production more than quadrupled during the last decades, as can be seen in figure 1.12, global wine production stayed more or less the same (FAOSTAT, 2014g) and is estimated on 25.72 billion litres (Wine Institute, 2014a) produced on a total vineyard area of 7.01 million hectares (Wine Institute, 2014b). With more than 61% of the global production, Europe is still the most important wine-producing region thanks to France (20.0%), Italy (15.5%), and Spain (11.9%) (FAOSTAT, 2014g). The North-American wines account for 10.9%, followed by South-America (10.4%), Asia (7.5%), Oceania (5.3%) and Africa (4.3%) (FAOSTAT, 2014g). Wine is mostly consumed in Western countries: U.S. (3.27 billion litres), France (2.90 billion litres), Italy (2.30 billion litres) and Germany (1.95 billion litres) are the largest consumers(Wine Institute, 2014c).

Of all alcohol beverages, spirits like whiskey, vodka, rum... take the largest part of all alcohol produced. Based on pure alcohol levels, spirits account for more than 45%, while beer accounts for 36% (WHO, 2011). However, the yearly per capita consumption of spirits is decreasing since the 1990’s, reaching about 1.7 litres (pure alcohol base), a little bit more than the per capita beer consumption which is rising slowly (WHO, 2011).

1.6.4 Ornamental plant and flower production

Some non-edible crops are not grown because of their halocinogenic characteristics, but just because they are decorative. The International Association of Horticultural Producers estimates the global production area for flowers and pot plants on 620 000 ha (AIPH, 2014) of which 73.5% is situated in Asia/Pacific, followed by Europe (10.0%), Central + South America (7.4%), North America (5.0%), Africa (3.0%) and the Middle East (0.7%). Despite the global economic crisis, total annual consumption of ornamental plants is estimated between 40 and 60 billion dollars, of which about 80% is consumed in only six countries: Germany, US, UK, France, the Netherlands and Switzerland (Sarkar, 2012). While in the past production was mainly found in developed countries (especially the Netherlands), it is now increasing in other countries. India accounts for 242 000 ha or almost 40% of the global floriculture production area (AIPH, 2014) followed by China with 169 081 ha (or 27%) and the U.S. (29 407 ha or almost 5%).

Because of climatological characteristics and cheap human labour combined with (foreign) investments in transport of the very delicate and perishable flowers (Whitaker & Kolavalli, 2006; Sarkar, 2012), floriculture production for export is increasing in developing countries. African countries like Kenya are producing for the European market (Whitaker & Kolavalli, 2006), whereas Southern American countries such as Colombia and Ecuador produce for the U.S. (Sarkar, 2012). In some countries, like Kenya, floriculture is one of the most important export industries and with about 60% of the African flower trade in 2006 (Whitaker & Kolavalli, 2006), Kenya is the most important African producer. Although there are many small-scale farmers, about 75% of the export is produced by medium- to large-scale farmers. Especially rose production is very important, contributing for about 75% of export volume and 70 to 90 per cent of total export value (Whitaker & Kolavalli, 2006). It is estimated that about 1300 hectares were used in 2006 for rose production (Whitaker & Kolavalli, 2006).

Global export accounts for about 25 billion dollars and still is increasing with 10.3% each year (Sarkar, 2012). Because of the increasing cheaper production in developing countries, the Netherlands shifted their focus from production to distribution and marketing. The Dutch auctions play an important role in European flower trade: 54% of global cut flower production is exported by the Netherlands, followed by Columbia (16%), Ecuador (6%) and

Kenya (6%) (Baris & Uslu, 2009). The Dutch market is very important for Kenyan flower producers: about 66% of all Kenyan flowers go to the Netherlands and more than half of it is sold at auction (Whitaker & Kolavalli, 2006).

1.6.5 Farms as sources of recreation

Indirectly, agriculture also creates fun, not only because of the maintenance of landscapes which can be used for walking, biking, skiing and other forms of recreation, but more and more farmers are broadening their working domain. Some farmers start to produce specific products on their farms, which give the consumers an extra dimension of authenticity. Others open guesthouses or camping areas on their farms, they organise specific farm games (e.g. a labyrinth in maize) or even organise cuddling cows seminars.

Non-production activities can also be seen in a more broadened context. Since a few years, there is an increased interest in farms as a place where people with both mental and physical problems get the chance to work in a normal environment with living organisms and a caring farmer's family. This gives them the possibility to regain self-confidence, responsibility and fun in life. In Belgium, "Steunpunt Groene Zorg", which can be translated as "Foundation for Green Care", was founded in 2004 and expanded to 774 care farms at the end of 2013 (Steunpunt Groene Zorg, 2013). In the Netherlands, 777 registered care farms are registered (Federatie Landbouw en Zorg, 2015).

1.6.6 Animals for fun

With increasing wealth, people have less contact with production animals but have an increasing interest in companion animals, which they treat as members of the family (Lips, 2004; Lips *et al.*, 2004). This evolution was first observed in the Western countries after the Second World War and can now be seen in upcoming countries in Asia and Southern America (Leenstra & Vellinga, 2011). Compared with the global average, the number of pets per person in Western countries is still much higher. For the Netherlands, Leenstra and Vellinga (2011) state that the number of cats per person is more than six times higher, the number of dogs almost four times higher and the number of horses almost three times higher than the global average. More than half of the families in the Netherlands have pets and of the families with children almost 75% have pets (Leenstra & Vellinga, 2011). Although also fish (14.8 million aquaria), birds (54.0 million) and small mammals like rabbits and hamsters (28.6 million) are popular, dogs (75.3 million) and cats (89.8 million) are the most popular pet species in Europe, resulting in one out of four households in Europe having a dog and the same percentage having a cat (FEDIAF, 2012a).

Where in the past, these animals collected their food themselves, and especially in the case of cats the catching of rodents was an important reason why they were kept, there is now a whole pet food industry, growing two per cent every year (FEDIAF, 2012a). In the food for carnivorous pets (dogs and cats, but also fish), animal by-products are used in combination with vegetable materials like cereals and legumes (FEDIAF, 2012b). However, it is estimated that in rich countries more animal products are needed to feed carnivorous pets than is available as animal by-products from slaughtering for human consumption, leading to the use of animal products for pet foods that are normally suitable for human consumption too. On average, the global dog and cat population has the same nutritional needs as 80 million people (Leenstra & Vellinga, 2011).

Since the willingness to pay for medical treatment or more expensive feed is much higher for pets than for production animals (Lips, 2004; Lips *et al.*, 2004), it is clear that although the number of companion animals is much lower, the pet industry is economically very important. A comparison of the economic value of different animal sectors in the Netherlands reveals that the pet industry has a value of 2.1 billion euro, which is almost as important as total pig industry (2.8 billion euro) and almost the double of the poultry industry (1.1 billion euro) (Leenstra & Vellinga, 2011). The total European pet food industry produces 8.5 Mt with a turnover value of 13.8 billion euro in 2012 (FEDIAF, 2012). Leenstra and Vellinga (2011) estimate the global pet food production on 13.5 Mt or about 50 billion dollar in 2011. Alltech (2014) estimates global pet food production on 20.7 Mt, but since the European production is underestimated with 5 Mt, it might be that global production is larger than 21 Mt of pet food.

Next to pets that are kept in the houses, also an increase in horses for leisure can be found. After a decline in the population due to disinterest for horses as draught power in developed countries (e.g. number of draught horses in Belgium declined from 300 000 in 1945 to 15 000 in 1980; Lips, 2004), numbers of registered horses are increasing (Bomans *et al.*, 2009), although the interest in draught horses still remains low. While the number of horses increases in developed countries, the number of horses slaughtered decreases (Leenstra & Vellinga, 2011), stressing the fact that horses are not merely seen as working animals. As a result of this increase in horses, the area used for feeding them also increases. It is estimated that in Flanders about 70 000 ha or about one third of all pastures is used for horses (Bomans *et al.*, 2009). Next to roughage, more and more horses are also fed with concentrates, containing cereals and other vegetable products that can be eaten by humans or production animals. In Flanders, about 75 000 tons of horse feed is produced (PCR, 2008), while the global equine feed production is estimated at 12.4 Mt of compound feed (Alltech, 2014). As with other pets, also horses are economically very interesting: the value of the horse industry in the Netherlands is estimated on 1.2 billion euro (Leenstra & Vellinga, 2011).

1.7 Conclusion

The previous paragraphs show that agriculture is much more than food production alone. Figure 1.13 describes the evolution of the different groups discussed earlier in this chapter. As already mentioned, cereals are by far the most important crops on a mass base, also because they are used for both food, feed and fuel. Although starchy roots were the second largest group about 50 years ago, both vegetables and 'milk & eggs' are more important now and it seems that their increase will still continue. Also fruit production has grown strongly during the last decades. Pulses and meat production are growing slower but both increase more or less at the same speed. The importance of 'Fibre' is rather small, compared with the others. These differences in production volume can also be seen in figure 1.14, where the relative importance within total global production is mentioned.

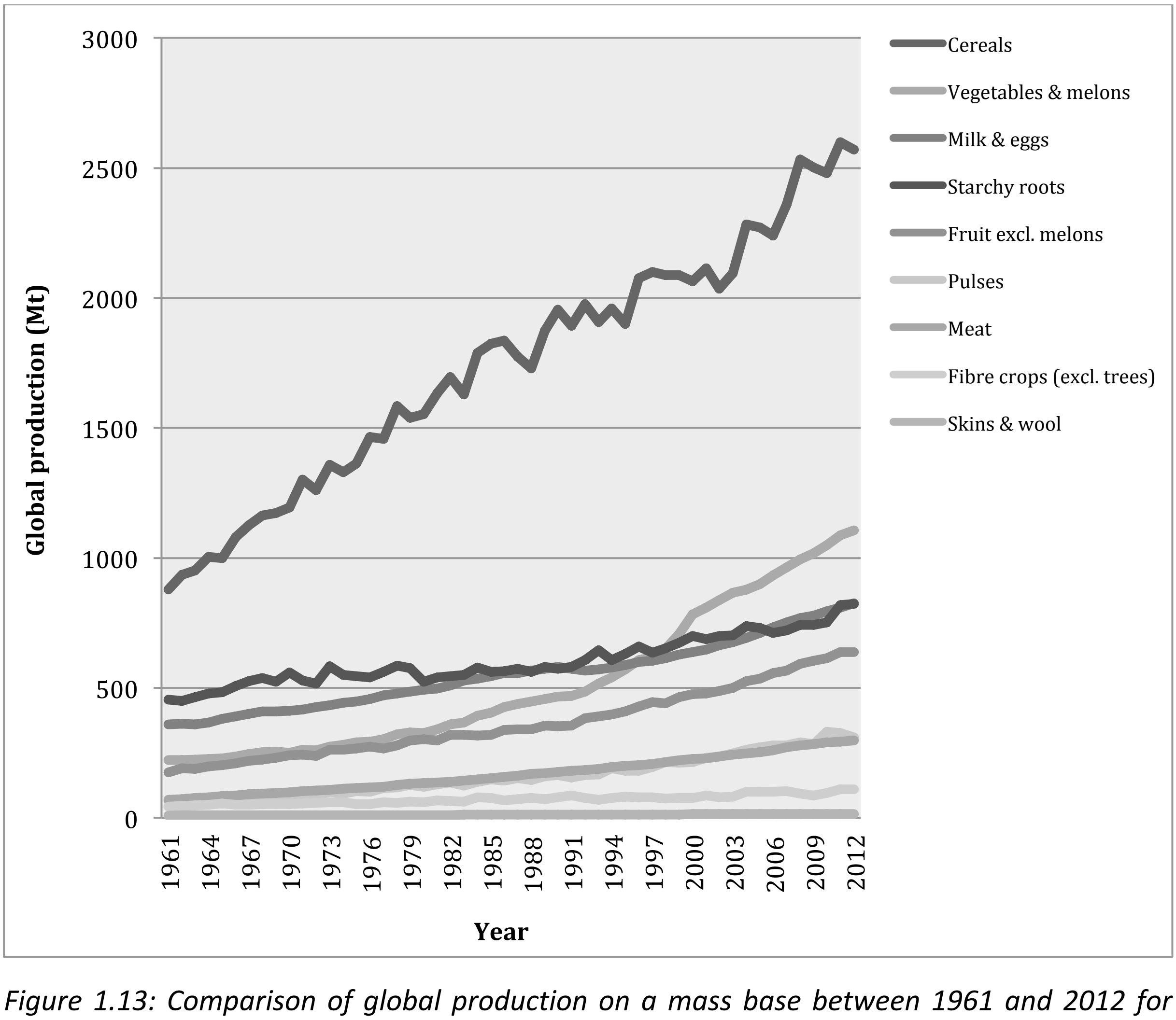


Figure 1.13: Comparison of global production on a mass base between 1961 and 2012 for different product groups.

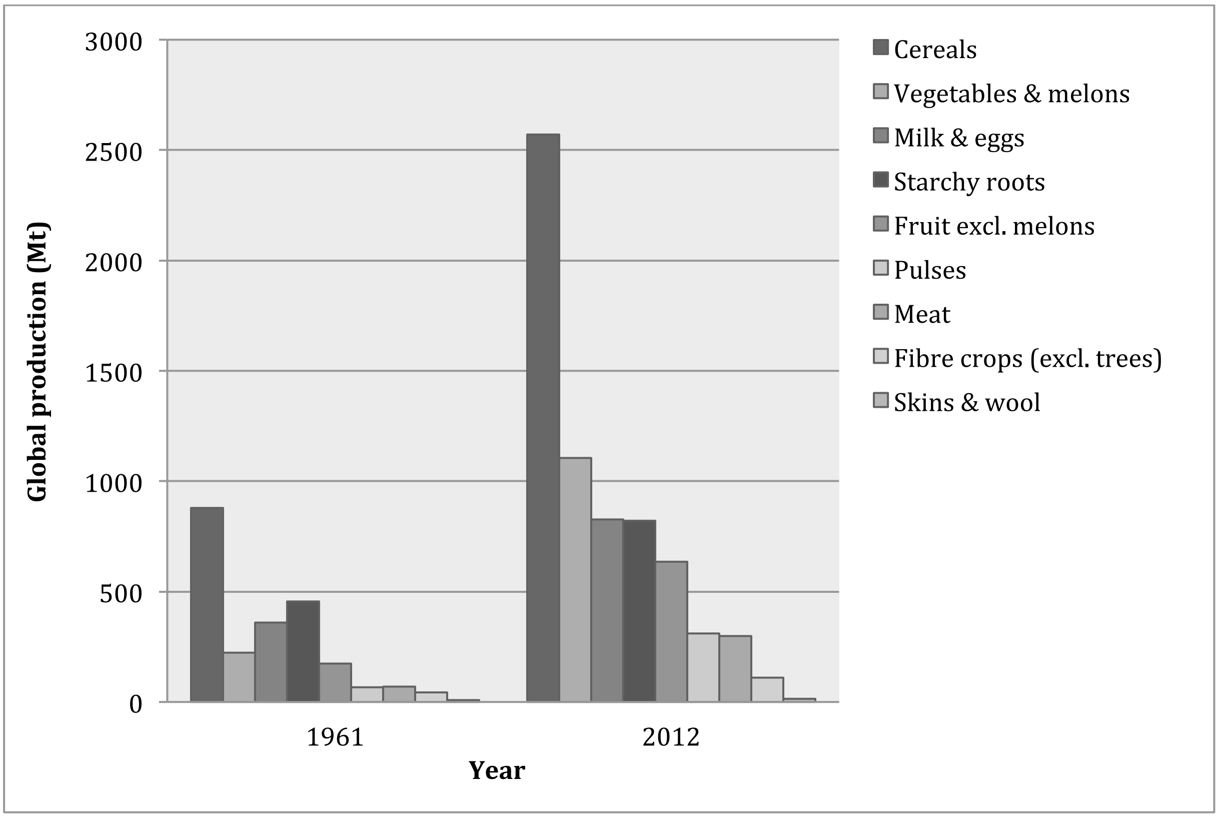


Figure 1.14: Relative importance of the different product groups: a comparison between 1961 and 2012.

Appendix 1 gives an overview of the 50 most important products on a mass base. Maize accounts for the largest tonnage, followed by milk, rice, wheat and potatoes. Since only 14% of the maize production is used for human consumption (IRRI, 2014), one could say that milk is the largest food source on Earth. Furthermore, one can see that tomato production is in the top ten, which is much higher than pig meat (ranked no. 11) or chicken meat (ranked on place 15).

The previous was mainly focused on production on a mass base, i.e. the evolution of the different volumes during the last decades until now. These volumes do not always represent the spatial impact. It is not because maize has the largest production on a mass base that it also uses the largest portion of agricultural land. Animal production uses about 75% of all land used for agriculture (Foley *et al.*, 2011), of which 350 million hectares are cropland and 3.38 billion hectares are permanent pastures (FAOSTAT, 2014e). Compared with this area, the importance of herbivores for global food production is rather small: cattle meat is ranked on place 24 with a global production of 63.29 Mt (which is less than the 66.6 Mt produced in aquaculture, both marine and fresh water), whereas sheep meat, goat meat and buffalo meat (respectively ranked on place 63, 73 and 83) are even less important than plums or taro. Milk is also produced by herbivores, but the largest part of the milk production is not produced on useless land. One could question if it is acceptable that such large areas are used for animal production with such a low yield per hectare. Indeed, some areas are not suitable for agricultural production, but it can be questioned if land use change from agriculture/pastoralism to nature (i.e. Food versus Foster) would not be better. Such questions will be discussed in the following chapters.

Chapter 2

Future needs and ethical discussions on the 6 Fs

2.1 Evolution of the human population

When discussing how the demand for the six different functions will or should evolve in the next decades, the role of humans needs to be discussed. This discussion is only important for humans now and in the near future, since humans are both producers and consumers of Food, Feed, Fuel, Fibre, Foster and Fun. Every non-human process that would alter the preferred balance will be prevented, or at least reduced, in order to maintain man's needs and desires for the six different functions. These depend on both population growth and changes in wealth.

Since the origin of genus *Homo* about 2 million years ago, the human(oid) population was – as any other living organism on the planet – regulated by a natural equilibrium between life and death and the average life expectancy was very low (Lee, 2003). Human population grew rather slow from 1 million in 10 000 B.C. to 1 billion people at the beginning of 19th century (U.S. Census Bureau, 2015b), but an increase in agricultural and medical knowledge (Lee, 2003; Barrett, 2010) allowed the human population to grow exponentially: on 11 July 1987, the world celebrated "the day of 5 billion", in 1998 the human population grew to 6 billion and on 31 October 2011 (UNFPA, 2011) there were 7 billion people on Earth. Several demographic transition theories (Dudley, 1996) suggest that after a population growth due to declining death rates, fertility rates are declining too, resulting in a stabilized population size at the end of this century with an 88% chance (Lutz *et al.*, 2008). Even though fertility rates are declining in most of the countries (except Sub-Saharan Africa) for a few decades (Bongaarts & Watkins, 1996), population is still growing due to a very large group of women who are at reproductive age. Although it is accepted that population growth decreases with increasing economic and social development (National Academy of Sciences, 2000; Lee, 2003), Myrskylä *et al.* (2009) found that at a certain point of development, population growth in developed countries increases again, although fertility rates will remain under replacement level.

One cannot know for sure how many people there will be at a certain point in time, since it depends on many factors that are influenced by man and nature. To know this, the answer of Notestein (1950, p. 335) on the question how many people there would be in the year 2000 still stands: “the only way I know of finding the answer to this question is to keep alive until that date”.

In the past, the UNDESA made three different variants to estimate the world population, where the difference between “low”, “medium” and “high” is 0.5 child in fertility rate. Since the probability that either the “high” or the “low” fertility assumption will occur in all countries of the world is beyond the 95% probability range, UNDESA (2013) adapted the range between the “high” and “low” variant. With a probability of 80%, global human population will increase by 2.3 to 3.0 billion people up to 2050, resulting in a world population between 9.7 and 12.5 billion people in 2100. This increase is a result of the fact that more than half of the people live in intermediate- or even high-fertility countries, where women have one or more daughters, which will reach reproductive age. Only in the low-fertility countries, like most European countries, not every woman is replaced by a daughter and a decrease in total population is possible. It is assumed that after 2100 only the high-fertility countries will still have an increasing population; the population of the others would be declining.

Due to lower fertility and longer life expectancy, the ratio between groups of different ages also changes. Lee (2003) states that in 2100 the ratio of elders over children will increase tenfold, which might cause social problems. It is estimated by Lutz *et al.* (2001) that in 2100 around 34% of the human population will be above the age of 60. The median age will probably increase from 26.6 years in 2000 to 37.3 years in 2050 and to 45.6 years in 2100, although there are large differences between different regions, since the largest increases will happen in developing countries because of reduced child mortality (Lutz *et al.*, 2008).

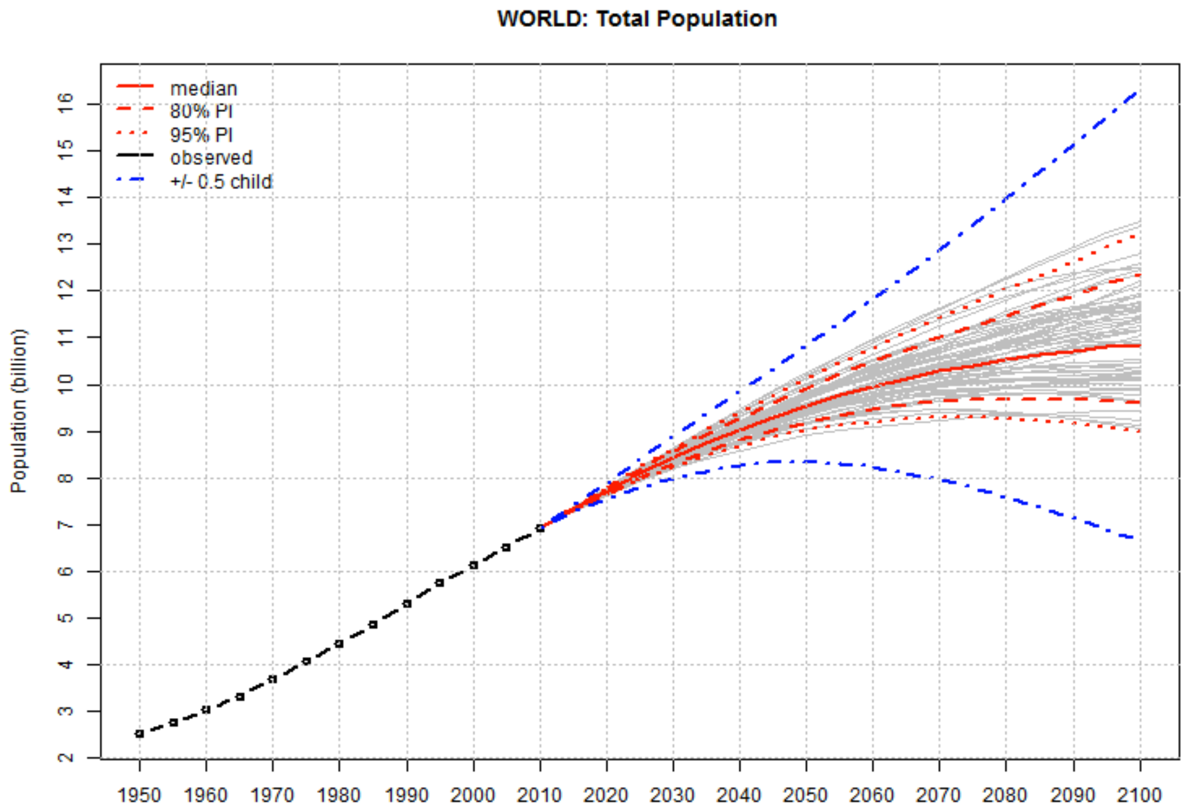


Figure 2.1: Evolution of the global human population.

Source: UNDESA (2013)

Although there are many uncertainties about predicting human population growth, estimating economical evolution is even more difficult. While human population growth mainly depends on the number of women at reproductive age, economical evolutions depends on many other, more unpredictable factors. For 2050, Dadus and Stancil (2010) estimated that economic balances will shift rapidly with China taking over the role of the U.S. (estimated to happen in 2032) as the world's largest economic power. Similarly, India will become one of the most important economies. It is believed that there will be a big shift from the G7 to emerging countries such as the BRIC-countries (Brasil, Russia, India and China). New is that due to the large number of people in these upcoming countries, the per capita income will not grow as fast as the economy, leading to a different type of demand. Since the traditional Western powers will lose economic strength because of higher wages and a declining working population, protectionist pressures may occur, shifting international relations in an unpredictable way. Also other things will have an unpredictable impact, e.g. climate change can cause 5 to 20 per cent reduction in consumption (Dadus & Stancil, 2010).

The above makes clear that estimating the evolution of the human population, both in numbers and age classes and in changing desires and needs is quite difficult. With the increasing world population, also the need for biomass from agriculture will increase. Because the largest group will have a rather low to medium income (Dadus & Stancil, 2010), an increase in demand for basic needs as food, energy and fiber, can be expected. How it will affect the other functions is less clear. In what follows, we will discuss what the future estimations are for each F and what ethical issues this might entail.

2.2 Food

During the last forty years, while the world population almost doubled during that period (U.S. Census Bureau, 2015a), the average number of hungry people in the world is about 805 million people or one in nine of the world's human population (FAO, 2014b). Although the number of hungry people increased in 2008 due to high food prices, there are nowadays about 100 million less hungry people than a decade ago (FAO, 2014b). One of the Millennium Development Goals of the United Nations is to halve the number of hungry people by 2015 (UN, 2012), which is within reach or is even already reached in 63 countries (FAO, 2014b). The global hunger index, based on the percentage of undernourished people, child underweight and child mortality, is decreasing, although there are large differences between regions and countries: hunger can be mostly found in poor regions as South Asia and Sub-Saharan Africa, especially in the Democratic Republic of Congo, where 70% is undernourished (von Grebmer *et al.*, 2011).

Since it is estimated that by 2050 – or within less than forty years – human population will increase with another two billion people (UNDESA, 2014), mostly in poor and developing countries, one could question if these extra people can be fed properly if one is not able to feed everyone today. Furthermore, Lappé *et al.* (2013) question if the estimations of the FAO on global hunger are correct. They argue that the global number of hungry might be as high as 1.33 billion, depending on how hunger is measured. FAO starts from the necessary caloric intake for a sedentary lifestyle, but poor people rely much more on human power and thus need more calories for their activities. Also, FAO only takes into account chronic undernourishment, while short-term hunger periods also have an impact, not only during the famine, but also afterwards. Third, FAO focuses on caloric intake only, while also diet quality matters. Therefore, Lappé *et al.* (2013, p. 258) "encourage the FAO both to develop and communicate a wider conceptualization of hunger and food insecurity in its indicators and to promote the full range of policies that have proven essential to end hunger."

'Hunger' is a very complex issue, depending on many different parameters. Food availability – or better: the lack hereof – is not the major cause why there is still hunger in the world. In 2002, FAO (2002, p. 9) calculated that "agriculture produces 17% more calories per person than it did 30 years ago, despite a 70% population increase". With an average increase in demand of 1.1% each year, Alexandratos and Bruinsma (2012) estimated that by 2050 an increase of 60% in agricultural production is needed to meet future needs, but no problems are expected as long as necessary investments are made and without large changes in policies (e.g. no unexpected extra rise in biofuel demand). Between different types of food products, the increase might differ because of changes in dietary patterns or political decisions. For example, it is estimated that there will be a large increase in cereal production, but that more than half of the cereals will not be used for food purposes, but for feeding animals and especially for biofuel production (figure 2.2). If humanity wants to meet this increase in demand, more production is needed, but the growth of crop yields has slowed down considerably, because of higher stress on the scarce production resources as land and water in combination with for example climate change (Alexandratos & Bruinsma, 2012).

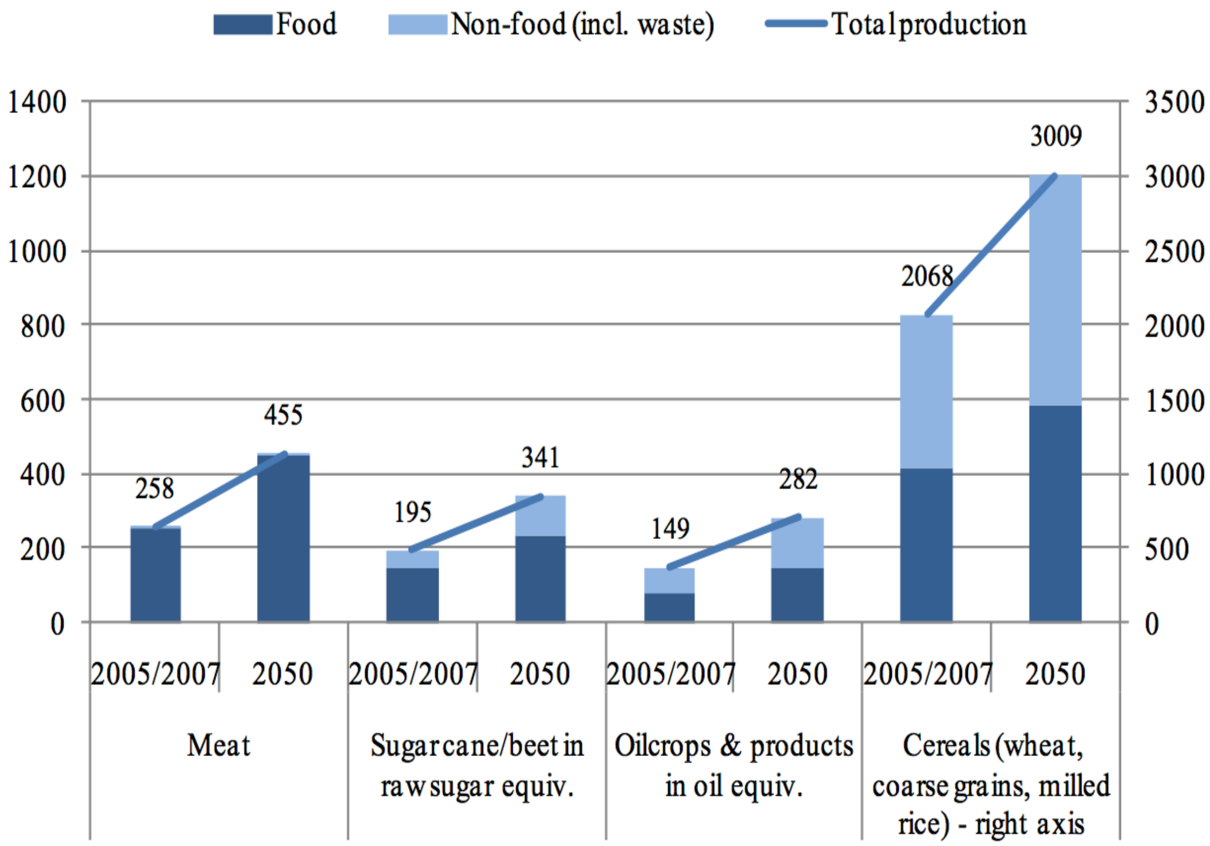


Figure 2.2: Evolution of global agricultural production and use by 2050 (Mt).

Source: Alexandratos and Bruinsma (2012, p.8)

A major issue is the fact that this production will not be equally distributed among countries, leading to an increasing global trade in agricultural products. Myskja (2012) states that global food trade is morally problematic because of environmental issues and injustice within the system, since small farmers and their families are put under large pressure. In a global market, food prices are also more volatile, which has serious implications for poor people. From the three most important reasons for volatility, two of them are linked with globalisation: the increasing demand for food crops for biofuels and the increased volumes traded on the commodity stock market (von Grebmer *et al.*, 2011). This effect is boosted by the historically low grain reserves, the dependence of many importing countries on a few exporters, and overreaction to the given information (e.g. export stops even if there is enough available). It is very likely that in the future, these fluctuations will increase because of fluctuating harvests due to climate change (von Grebmer *et al.*, 2011).

Next to an increase in agricultural production during the last decades (see chapter 1), also the increasing number of overweight people, which is estimated at more than 1.4 billion adults (WHO, 2012), suggests that there is no global lack of food, especially if one takes into account that a large part of agricultural production is also used as animal feed or as source for biofuels, which can be theoretically used for human consumption. Furthermore, in a report on global food losses and wastes, the FAO (2011a) estimated that 1.3 billion tons – or about one third of food produced for human consumption – is lost or wasted during production, storage, processing, distribution or consumption. While in developing countries more than 40% of the losses occur after harvest and during processing, the same percentage is wasted in industrialized countries at retail and consumer levels (FAO, 2011a). Even more: the food waste at consumer level in industrialized countries is almost as high as the total net food production of Sub-Saharan Africa, both being about 230 Mt (FAO, 2011a). This makes clear that next to technological improvements or changes in legislation (a list of this can be found in FAO, 2011a) also public awareness in industrialized countries is a very important factor to reduce spillage and the use of scarce production resources as land, water, energy and other inputs.

Food waste is also directly connected with the 6F-discussion. For example, carrots which are not straight are unwanted by certain retailers because they are more difficult to peel by consumers, so they are sorted out and used as animal feed (FAO, 2011a). Food waste also can be used to produce energy and some retailers already use methane from the fermentation of organic waste as an energy source (Colruyt Group, 2012). Although in both ways biomass is reoriented and thus not lost, one could question if this is ethically correct. Due to abundance, Western consumers have the freedom to choose between different formed carrots. By this, the food product is merely reduced to measurable parameters as its energy content or the time needed to peel, and more intrinsic values as "source of life" or "fruit of farmer's labour" are forgotten, resulting in a decreasing respect for food. Food is more than amino acids, energy and micro-nutrients in a well-shaped packing. It also plays a significant role in self-understanding and self-expression (Myskja, 2012). This increase in alienation from food and how it is produced will continue, since it is estimated that by 2050 nearly 70% of the world population will live in cities (OECD, 2012), thus being dependent on others for their daily food intake.

It is clear that agricultural production itself is most likely not to be the restrictive factor to feed every human being on Earth. Alexandratos and Bruinsma (2012) calculated that there are 2770 kcal per person per day available right now (corrected for waste, animal feed and non-food issues), but 2.3 billion people have less than 2500 kcal and 0.5 billion even less than 2000 kcal. Figure 2.3 shows that food energy intake differs a lot between different macroregions. Both Sub-Saharan Africa and South Asia, where now most hunger can be found, will experience a strong increase in average energy intake by 2050, but still will be below other parts of the world. Even though caloric intake in the developed world is already too high, leading to obesity, still an increase in food energy consumption is expected.

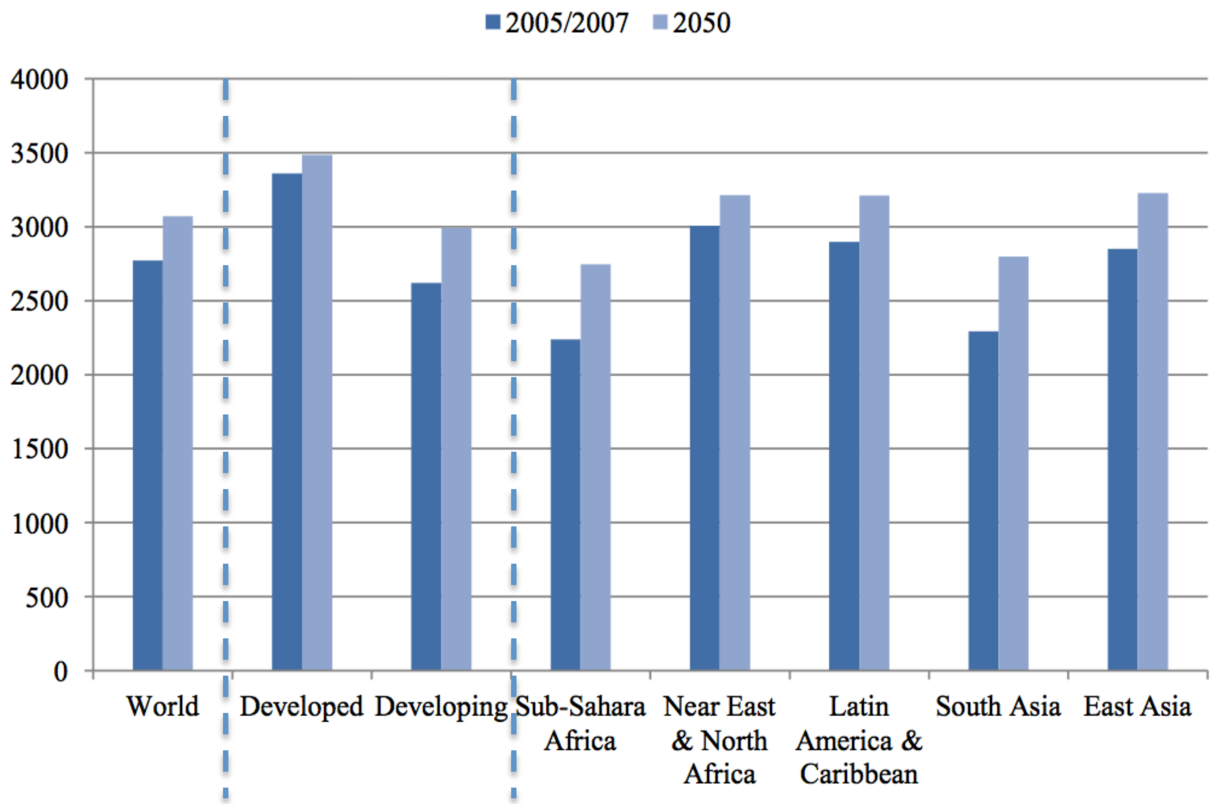


Figure 2.3: Per capita food consumption (kcal/person/day).

Source: Alexandratos and Bruinsma (2012, p. 4)

There are two types of hunger: transitory hunger is mostly caused by conflict or weather-related problems and affects about 5 to 10 per cent of the poor (CFS, 2005). Chronic hunger is caused by low or no acces to food, mostly because of poverty (FAO, 2011a; FAO 2011c). The increase to 850 million hungry people, as a result of the food price peaks in 2008, demonstrates that food prices and hunger are strongly connected (FAO 2011b). Since population growth will be the most pronounced in South Asia and Sub Saharan Africa, where most of the poor countries are situated and where poor people sometimes spend more than 70% of their income to food (FAO, 2011b), one could question how the problem of hunger has to be solved. Von Grebmer *et al.* (2011) suggest that global policy, especially on biofuel and financial activity, needs to be balanced in order to make sure that food prices stay stable on a level at which everyone can effort nutritious food. Also global willingness to invest in adaptation and mitigation strategies to reduce the impact of climate change on food production is essential to stabilise food markets and for building up food reserves. Westhoek *et al.* (2011) claim that an increase in food production alone will not improve food security and stress that a pro-poor approach based on local conditions is necessary to reduce hunger and malnutrition. The "Fome Zero" program in Brazil shows that investments in family farming to increase local food availability, combined with investments in education so that youngsters can escape poverty, can reduce hunger within only a few years (Graziano da Silva *et al.*, 2011).

Solving hunger is only possible if there is enough water for food production. About 80% of all agriculture is rainfed, affecting more than 1.1 billion people (Rockström & Karlberg, 2009) and contributing for about 58% of global food production (Wani *et al.* 2009), although its importance varies between regions: rainfed agriculture is very important in sub-Saharan Africa (more than 95% of the farmed land), Latin America (90%), North Africa (70%), East Asia (65%) and South Asia (60%) (Wani *et al.*, 2009), which are all regions with an expanding human population. Rainfed regions often have to deal with water scarcity, land degradation due to erosion, low rainwater use efficiency and poor infrastructure, leading to low agricultural yields. Since in China and India, two countries with the largest numbers of inhabitants, 57% of the agricultural lands are degraded (Wani *et al.*, 2009), it is clear that a large part of the global population depends on fragile rainfed agriculture. Due to future climate change, rainfall is expected to alter: shorter rainy seasons with intensive rainfall during a shorter period of time. It will be challenging to optimally collect and distribute this water, in order to produce enough food in those regions. Both soil and water management (rain-, ground- and surface water) therefore will be of major importance for a sustainable food production in densely populated developing regions. Wani *et al.* (2009) describe many best cases showing that small investments can lead to large production increases and better water management.

Food imports could be seen as a theoretical solution to feed regions with less productive agriculture. In practice, these are often remote regions with poor infrastructure, making it very expensive to get the food at its final destination. By this, even if the food gets where it is needed, people cannot afford it. Also from a political point of view, food imports are often not desired, since it increases political dependence from other countries. Therefore, it is preferable to invest both money and knowledge in local agriculture, empowering local farmers to produce in a more sustainable way.

2.3 Feed

2.3.1 Projections of future animal production

There is a strong relationship between increasing income and increasing demand for animal products (FAO 2011c). Since population growth will almost entirely occur in cities in developing countries and since city dwellers usually have higher incomes, an increasing demand in animal products is expected, especially in developing regions. During the last forty years, the production of animal proteins (both meat and milk) doubled and it is expected that by 2050 global demand will double again and even triple, if all humans would use animal proteins following Western consumption levels (Westhoek *et al.*, 2011). While the global increase in meat production is estimated at 1.8% each year (which is higher than the 1.1% in global food, cfr. *supra*), the increase in meat production in OECD-countries will be only 1% (OECD/FAO, 2010). The largest increase will thus occur in developing countries, where dairy and poultry meat production is even estimated to increase with almost 40% during the next decade (OECD/FAO, 2010). There will also be a strong increase in pig production, especially in China (Alexandratos & Bruinsma, 2012), but the global production will not be as large as milk or poultry production, since pork is not eaten by Muslims. As poultry and pigs have shorter production circles than beef, these types of meat production are cheaper and will easier meet the increasing meat demand. Although most meat production in developing countries will be for their own markets, some upcoming countries (especially Brazil) also play an important role in meat export (OECD/FAO, 2010).

In developed regions, animal production and consumption is already very high and often is an economically very important sector within agriculture: the total value of the EU livestock sector is estimated on 140 billion euro (Westhoek *et al.*, 2011) of which milk (35%), beef, poultry and pig meat (each around 20%) are the most important. Although production differs between countries, the EU as such is more or less self-sufficient for livestock products. While an intensification of animal husbandry can be seen in developing countries, within developed countries, especially in Europe, increasing interest in animal welfare creates niche markets for more animal friendly production (FAO, 2011c ; Westhoek *et al.*, 2011). These niche markets sometimes need different breeds that produce less, have a higher feed demand, and more greenhouse gas (GHG) emissions per kilo of product.

Westhoek *et al.* (2011) estimated that this improve in welfare would lead to an additional feed use of 10% for pigs and laying hens and 25% for broilers, and in case of organic production, this could even be higher. This increase in animal feeds causes ethical questions and should be compensated by innovative solutions or by a decreasing demand for animal products. Nevertheless, FAO (2011c, p.94) states "there are no technically or economically viable alternatives to intensive production for providing the bulk of the livestock food supply for growing cities." It is estimated that intensive animal husbandry is the major producer of poultry meat (67%), eggs (50%) and pork (42%) (Blackmore & Keeley, 2009; In: FAO, 2011c). For these intensive types of production, the challenge will be to maintain high production levels within given environmental limits. Furthermore, an increase of intensive animal farms is expected, especially in South America and Asia. In China, for example, the percentage of pigs kept in large farms more than tripled (from 20 to 64%) in only twenty years (FAO, 2011c).

It is clear that an increase in demand for animal products cannot be reached by just increasing the number of animals, not only because of the feed needed, but also because of the ecological impact of a doubling in production. In developing countries, a lot of progress can be made by investing in animal health (since every dead animal is spilled feed), feed production (since organic waste from cities or (semi-)industrial processing is not always available for farmers), post-harvest losses (since a lot of milk or meat is lost due to bad conservation) and feed efficiency by selection. This is especially important in poor countries where most people are fed by small- or medium-scale farms (FAO, 2011c).

2.3.2 Necessary conversion or needless spillage?

As already stated in paragraph 1.2.3, production on useless land by grazing animals is an important source of protein production, especially for the 120 million (semi-)pastoralists (FAO 2011c) that strongly rely on their herds for survival. Since the total amount of land available for grazing is limited and overgrazing is already a problem (Steinfeld *et al.*, 2006), it is unlikely that the increase in animal production can be met by milk and meat produced by grazers which are kept on 'useless land'. The FAO (2011c) states that rain fed grazing systems provide about 19% of the world's meat production and about 12% of the world's milk production, and Westhoek *et al.* (2011) estimated that in the EU only 4% of dairy production and 20% of beef production is produced on natural grasslands. So, although this type of animal production results in a net protein gain and it surely plays an important local role in human nutrition, it is doubtful that this kind of production will strongly increase by 2050 and play a major role in global production. On the other hand, extensive livestock production plays an important role in maintaining specific landscapes with a corresponding high biodiversity (e.g. alpine meadows).

The largest group of animals gets at least some cereals or by-products in their rations. Especially the 'landless animal production', which accounts for 45% of the global meat production and 61% of the global egg production (FAO, 2011c), is strongly dependent on cereals and oil cakes: of the 500 million tonnes of animal feed used in the EU each year, about 28% are cereals, which is 60% of the total European cereal production (Westhoek *et al.*, 2011). The feeding of cereals to livestock in the EU (about 280 kg per citizen per year or less than 800 grams per citizen per day) is necessary to maintain the high levels of production: when only fed with grasses and by-products, less than half of the EU livestock could be fed (Westhoek *et al.*, 2011).

Of all by-products fed to animals, almost 70% are meals from vegetable oil production (FEFAC, 2011). Especially soybean-meal plays a major role in feed rations of pigs and poultry, since the amino-acid composition strongly matches the needs of the animals. Since the growing conditions in the EU are not so suitable, about 35 million tons of soybean-meal equivalents are imported each year, making the EU import-dependent for more than 75% of the protein-rich feed materials needed in the feed industry (Westhoek *et al.*, 2011). Since the total arable land area in Europe is about 120 million hectares, the production of soy on about 12 million hectares outside Europe cannot be neglected and makes intensive animal production less "landless" than it seems. Furthermore, two thirds of the agricultural land in the EU is related to livestock production, which is about 65 to 70 million hectares of grassland and more or less the same area of arable land for cereals and forage such as maize silage (Westhoek *et al.*, 2011).

There is a lot of discussion about using edible components in animal rations. Some state that using cereals for feeding animals competes with the needs of the hungry people in the world. FAO (2011c) states that reducing the amount of cereals fed to livestock will not ensure that the access to food increases, because this might reduce the prices for those commodities, making it less interesting to grow. Especially large farms will change to another so-called “cash crop” rather than producing food for local people. Also, intensive animal husbandry – strongly depending on cereals – profits from economical scale advantages, resulting in cheaper meat and making it more accessible for the growing urban populations.

Also the use of soybean-meal in animal feeds is controversial: some state that the meal is a by-product of the oil-industry (e.g. FEFAC, 2011), while others state that soybeans are grown to produce soybean-meal for feeding animals and that the oil is the secondary product. Westhoek *et al.* (2011) for example argue that soybean-meal is not a by-product since the economical value of the meal (60%) is larger than that of the oil (40%), which is not unexpected since soybeans deliver about 18% oil and 80% meal (American Soybean Association, 2008). The example of soybean illustrates very well that making a distinction between the different functions is often very difficult. Next to the meal used as animal feed, the oil is used for human consumption, biofuel production and other industrial processes as e.g. lubricant or solvent (American Soybean Association, 2008) and the importance of the different functions can differ within time. While one could claim that soybean-meal is currently more important than soy oil and thus conclude that soybean-meal is not a by-product, an increasing interest in biofuels makes it possible that fuel will become more important than feed or food. In the U.S., for example, about 80% of biodiesel was produced from soybean-oil in 2007 (American Soybean Association, 2008) and its production has increased strongly (REN21, 2012). Of course, soybean-meal will still be used as feed component because of the nutritional qualities and the expected increase in demand for animal products, but changes in economic importance of oil versus meal are likely to occur. This possible change in function (from feed to fuel) has also implications for the discussions about livestock’s GHG-emissions: land use change, especially in the Amazon region, is usually largely accounted to livestock production. When the same area of arable land will be used to produce soy oil (or another crop) for biodiesel production, the allocation of the emissions needs to be reassigned.

2.3.3 Necessary part of the diet?

As already mentioned, in some conditions, animals are an inevitable means to produce food on useless land or convert useless proteins and energy. Furthermore, animal products are very nutritious and a very important source of many vitamins and other micronutrients. Meat is an important source of vitamins B1, B2, B3, B6 and especially B12, since this is hardly found in vegetal food sources (Šebek & Temme, 2009). It further provides vitamin A and D and is an important source of zinc and iron, the latter also being more available than in plant products, since it is provided in haem-form (Šebek & Temme, 2009 ; Tijhuis *et al.*, 2011). Fish contains less iron and zinc than meat, but provides iodine, selenium, vitamin B3, B5, B6, B12 and is also rich in the omega-3 fatty acids eicosapentaenoic acid and docosahexaenoic acid (Šebek & Temme, 2009). Dairy also provides vitamins B2, B12 and A, next to calcium, phosphorus and zinc (Šebek & Temme, 2009 ; Tijhuis *et al.*, 2011). Animal products account for 93% of all vitamin B12 (of which 47% from meat alone) and 60 – 65% of all calcium (dairy) (Westhoek *et al.*, 2011).

Nowadays, many substitutes for animal products can be found. Meat can be replaced by tahoe/tofu, tempé, seitan, quorn, tahin, hummus, falafel, nuts, seeds and legumes (Tijhuis *et al.*, 2011), which are all good protein sources, but often lack one or more micronutrients, especially the vegan alternatives (Tijhuis *et al.*, 2011). Vegetable alternatives lack vitamin B12 and also iron is present in a less available form, although soy-based products (tahoe/tofu, tempé) have comparable iron content and nuts even contain twice as much iron as meat (Šebek & Temme, 2009). Meat replacers based on mycoproteins from *Fusarium venenatum* (quorn, e.g.) contain as much vitamin B12 as meat, but have low iron-levels (Šebek & Temme, 2009). Also the amino acid composition differs from meat: grains are rather low in lysine, legumes in methionine and cysteine, and nuts and seeds are rather low in lysine, but high in methionine and cysteine (Tijhuis *et al.*, 2011).

When one wants to replace dietary animal products, enough knowledge about human nutrition is needed to combine the different alternatives in order to avoid deficiencies for one or more micronutrients. Since plant resources have lower digestibility, protein requirements for vegetarians and vegans are 1.2 to 1.3 times higher (Tijhuis *et al.*, 2011). Adding animal products to one’s diet is a simple way in composing a healthy, well-balanced diet. Especially in developing countries, adding meat to the diet has a positive influence on people's health (UNSCN, 2010). In developed countries on the other hand, often too much meat is eaten. In the EU, for example, the per capita animal protein intake is much higher than the global average: meat consumption is twice as high (52 kg of meat or 85 kg carcass weight), milk consumption is even three times as high, while fish consumption is only 30% higher (Westhoek *et al.*, 2011). A daily intake between 55 and 60 grams of proteins per adult per day is recommended (Šebek & Temme, 2009 ; FAO, 2011c). European protein consumption is twice as high and the recommended amount of protein is met by animal protein alone. Although animal products are healthy in a well-balanced diet, a positive association is found between consumption of red and processed meat and colorectal cancer (Willett *et al.*, 1990; Chao *et al.*, 2005; Norat *et al.,* 2005; Cross *et al.,* 2010; Chan *et al.,* 2011). The exact reason is still unknown: Willett *et al.* (1990) found that animal fat consumption increases the risk of colon cancer, while Cross *et al.* (2010) concluded that it may be explained by heme iron, nitrate/nitrite and heterocyclic amines. Additionally, an increased intake of saturated fat can cause cardiovascular diseases (FAO, 2011c). While red meat consumption is twice the recommended amount, fish consumption is only half of it (FAO 2011c), so a decrease in red meat consumption and an increase in consumption of fish would be beneficial from a human health point of view (Westhoek *et al.*, 2011).

2.3.4 Aquaculture

As global marine fish populations have declined since 1950 with 24% and about 80% is fully exploited or overexploited (Westhoek *et al.*, 2011), aquaculture is needed to meet the increasing demand for fish. Compared with other parts of the world, European aquaculture grows more slowly and is mainly focused on predatory finfishes (Westhoek *et al.*, 2011), while elsewhere herbivorous species are more important (FAO 2014a). Carnivorous species are fed with large amounts of wild-caught forage fish: almost 17 Mt or 20% of all fish caught is used for fish feed (Tacon & Metian, 2008). Due to improvements by selection, management and different feeding strategies, less fish products are needed in aquaculture. It is expected that this will further decrease in the future due to decreasing availability from catch, rising prices of fishmeal and fish oil, and upcoming alternatives from plant and animal protein and lipid sources (Tacon & Metian, 2008). Within a decade, these decreases are the strongest in the rations of carnivorous species, although still a lot of fish as well as feed is needed: from 7.5 kg to 4.9 kg of feed fish for one kilo of salmon, from 6.0 kg to 3.4 kg for trout, from 5.2 kg to 3.5 kg for eel, from 3.0 kg to 2.2 kg for marine fish and from 1.9 kg to 1.4 kg for shrimp in 2008 (Tacon & Metian, 2008). Further decrease still occurs: herbivorous species like catfish, tilapia and carp are fed with less than five per cent of fishmeal and oil (Jobling, 2010), leading to a positive fish balance. Since these species are globally more important, the overall fish-in fish-out ratio is 0.44 and this is expected to decrease to 0.2 by 2020, together with the ratios per species, where salmon still will be the highest with 1.5 (Tacon & Metian, 2008). Tacon *et al.* (2011) expect global fishmeal use to decrease from 3.75 Mt in 2008 to 3.49 Mt in 2020 (or 4.9% of total aquafeeds), although fish oil us is expected to increase from 0,78 Mt in 2008 to 0,91 Mt in 2020.

Table 2.1: Evolution of the global use of fishmeal and fish oil in compound aquafeed for different fish species.

Species / species group	**Mean % fishmeal**			**Mean % fish oil**		
	1995	**2008**	**2020***	**1995**	**2008**	**2020***
Fed carps	10	3	1	0	0	0
Tilapias	10	5	1	0	0	0
Catfishes	5	7	2	0	0	0
Miscellaneous freshwater fishes	55	30	8	8	5	2
Salmons	45	25	12	25	14	8
Trouts	40	25	12	20	15	8
Milkfish	15	5	2	3	1	1
Eels	65	48	30	8	5	2
Marine fish	50	29	12	15	8	4
Marine shrimps	28	20	8	2	2	1
Freshwater crustaceans	25	18	8	2	1.5	1

* : Projected

Based on Tacon et al. (2011).

Although replacement of fishmeal and oil by vegetal and animal sources of protein and energy in fish rations is preferable from an ecological point of view, one could question if this is what consumers want. Fish oil is the major source of omega-3 fatty acids. These are not composed by the fish itself, but acquired from aquatic microorganisms they are fed with, or by eating other fish, as is the case for carnivorous species. Meat from fish that are fed with feed where fish oil is replaced by plant oil contains less omega-3 fatty acids (Jobling, 2010). The health claim that fish is healthy because it contains much omega-3 fatty acids is not true for fish raised this way. Research is done on using finishing feeds that contain more omega-3 fatty acids, possibly leading to an overall decrease of fish oil use, without loosing the healthy aspect of the meat (Jobling, 2010). Experiments with juvenile Jade Perch (*Scortum bartoo*) where fish oil is totally replaced with vegetable oils (sunflower oil, linseed oil and a mixture of 75% canola and 25% linseed oil) shows that the fatty acid profile of the vegetable oil influences the fatty acid profile in the fish muscle tissue and that Jade Perch flesh can obtain very high omega-3 fatty acid levels without using fish oil (Van Hoestenberghe *et al.*, 2013).

About 1% of agricultural land is already used to produce feed crops for aquaculture (Westhoek *et al.*, 2011), a 66.6 Mt production sector (FAOSTAT 2014d; FAO, 2014a). With the expected increase in fish production and the attempts to decrease in fishmeal and fish oil use, it is very plausible that the demand for arable land for aquaculture will increase in the future. Furthermore, when feeding plant material to carnivorous fish species, one could question if the integrity of the fish is not harmed, since it is as “unnatural” as feeding animal waste to herbivorous mammals as cows, which was widely discussed after the mad cow disease outbreak. Although herbivorous fish are eaten all over the world, Western consumers prefer the less efficient production of (top-)carnivorous species. Since ‘taste’ is here more important than the nutritional value of the fish meat produced, one could argue that aquaculture production of these species should be categorised under ‘Fun’.

Aquaculture can also be questioned for other reasons. Next to the discussions on fish slaughtering methods, there also are many ecological problems, especially in non-recirculation systems, like eutrophication, spread of diseases to wild fish stocks, escapes of domesticated fish into the wild (about 2 million fishes per year in the North Atlantic;

McGinnity *et al.*, 2003), reducing fitness and possibly leading to the extinction of wild fish populations.

2.3.5 Edible Fun products from animals

Next to animal production for every day use, some animals are also kept for the production of luxury products. The best-known example here is foie gras production, where ducks, geese and mulards are force-fed to produce fat livers as delicacy with “superior taste”, especially popular in France, but strongly discussed in other countries because of animal welfare issues (SCAHAW, 1998). Other animals are slaughtered before their ‘optimal’ slaughtering age is reached, like milk lambs, weaned piglets and veal calves, just because of the taste and consumers’ desire. By doing this, the feed needed to maintain breeding stock is not optimally used, since the optimal production from one breeding female is not reached.

Here, animal production is not seen as a means to convert something useless in edible proteins, nor to produce high quality proteins in an efficient way. They are a means to produce something tasteful, an exclusive product for those who can afford it. This illustrates that economical incentives (higher prices for more exclusive products) can lead to less efficient resource use. Of course, there is a thin line between animal production “as a necessity” or “for fun”. Only from an anthropocentric point of view, where killing animals to feed humans is accepted, eating animal products can be seen as “necessary”. But one might also see eating meat as a certain form of Fun.

2.3.6 Vegetarianism will not solve the problems

Often, vegetarianism is suggested as a solution for the problems resulting from increasing demand for animal products. Indeed, in our Western society, there is enough diversity in food products and enough vegetable protein available to switch from meat to vegetable alternatives (Tijhuis *et al.*, 2011). Because vegetarians still eat eggs and milk, also vitamin B12 deficiency will not occur when the diet is well-balanced. Vegetarians also see their way of life as a solution for the animal welfare problems in modern animal husbandry, although there are still reasons why a vegetarian world will not solve all problems.

While in an omnivorous diet all animals can be used, in a strict vegetarian world only the females are useful. For every laying hen, a male chick is born, which now are all culled as day-old chicks, a practice which causes a lot of discussion, not only from an animal welfare point of view but also because of the instrumentalisation of living creatures (Aerts *et al.*, 2009a). Also in milk production, mainly by cows but also by other species, males cannot be used, with exception of draught animals as oxen, but this practice is not common in the developed world. Since fattening and slaughtering is not an option in a vegetarian world, there are two ways to solve this. On the one hand, one could decide to let all these male animals live, but it is doubtful that a group of roosters or a herd of bulls is free of animal suffering, since they have to deal with fighting and sexual frustration. On the other hand, one could prevent that these males are born, e.g. by sexed sperm or *in-ovo* gender detection, techniques that are not free from ethical questions either, since it causes an act-omission-dilemma (see further).

Although a smaller number of animals will be kept in a vegetarian world, problems will emerge when killing animals is no longer tolerated. Within a short term, the large numbers of males and unproductive females will need a lot of feed and space – even though they are useless from an anthropocentric point of view – when they all stay alive until they die a natural death. One could question if this situation is more preferable than slaughtering these animals and use them as high quality food source. Since about two thirds of European beef meat comes from the dairy herd (Topliff *et al.*, 2009), also in a vegetarian world a large amount of meat could be available. If the amount of meat in our diet will be replaced by vegetarian alternatives, more eggs and milk are needed, leading to an increase in dairy herd and laying hens. One could question if it is morally acceptable to let such a useful food source die 'for nothing'.

Next to the use of animals as human food source, a lot of carnivorous pets, also kept by vegetarians, need to be fed with meat. As already mentioned in 1.6.6, the number of cats and dogs which are kept cannot be fed by animal by-products alone, so even now extra animals need to be killed to feed these carnivorous species. In a vegetarian world where no animals would be slaughtered at all for human consumption, the ambiguous situation will be created that one is not allowed to raise and slaughter animals for human consumption of high quality food, while one needs to raise and slaughter animals to feed dogs and cats. Often, meat eating by humans is seen as ‘Fun’ by vegetarians, because there are enough alternatives in Western society. On the other hand, meat eating by the large numbers of carnivorous animals, which are mostly kept for fun, is not openly discussed by vegetarian organizations, although the ethical problems are the same.

In this discussion, it seems important to distinguish between the killing of the animal as such and what is done with the dead animal. If one has an issue with the killing as such, any form of killing animals by humans cannot be tolerated, except maybe if it is to put it out of its misery (‘mercy killing’). From this point of view, neither killing for own consumption, nor for consumption by carnivorous pets can be justified. Someone who is against the killing of animals therefore cannot keep carnivorous pets, since this implies that several other animals have to be killed in order to feed one’s pet. The fact that the dead animal is used for feeding carnivorous pets cannot justify the act of ending another animal’s life. Most owners of carnivorous pets, also vegetarians and vegans, seem to forget the link between the bag of dry feed or the small tin of feed and the fact that what is in it once lived. Furthermore, if one has no problems with killing animals to feed carnivorous species, one could question why killing animals to feed humans is wrong. From a non-speciesist point of view, where humans and other animal species are considered equal, it is contradictory and even ‘unfair’ that dogs are allowed to eat meat and humans are not. Also for the slaughtered animal there is no difference between ‘being killed for human food’ and ‘being killed for pets’, since it will die either way.

2.3.7 Animals as necessary fertilizers of the soil?

One could suggest that a vegan world would be the solution, since no animals will suffer or be killed. In our Western society, there are enough alternatives to balance a healthy meal without animal products, although it requires sufficient dietary knowledge. However, one might argue that in a world without animal production, problems may occur in soil fertility, since manure still plays an important role in plant production around the world. In the past, animals were used as transporters of nutrients from other parcels to the land where human food is produced. In Roman times, animals were herded in the so-called ‘*saltus*’, savage land that was not suitable for agriculture (Mayozer & Roudart, 2006). During the day, the animals browsed through the bushes, taking up biomass. In the evening, the animals were gathered and their nutrient-rich droppings were collected and used to fertilize the land for food production. Techniques to increase the number of animals, like harvesting hay for feed during winter, made it possible to collect larger quantities of nutrients, leading to higher crop yields. Also the production of leguminoses for animal feed in the rotation system led to a higher nutrient balance, since these plants are able to fix nitrogen in the soil. By this, animals played an important role in human food production and human population growth.

In the middle of the 19th century, the use of mineral fertilizers was discovered (1843 for phosphates in England, 1870 for potassium mines in Germany; Mayozer and Roudart, 2006). In 1900, the demand was still limited: about 4 million tons of fertilizer, since all the rest came from the cultivated ecosystem itself. Fifty years later, the amount used had already quadrupled, at the end of the 1980's it reached 130 million tons (Mayozer and Roudart, 2006). By now, total production is more than 170 million tons (FAOSTAT, 2014h). By using mineral fertilizers, an increase in plant production independent from the increase in animal production was possible. But these sources are finite, just as fossil fuels. For nitrogen and potassium, the situation is not that bad, since air contains about 80% N_2 and also potassium reserves in the soil are large enough for a few centuries. For phosphorus, on the other hand, the reserves are estimated to be sufficient for 50 to 100 years, with the peak-phosphorus expected around the year 2033 (Cordell *et al.*, 2009).

Currently, a lot of phosphorus is lost, not only on the fields but also in manure and human excrements. Optimisation of phosphorus retention by plants (e.g. Vance *et al.*, 2003) and recirculation of phosphorus by using (treated) human excrements on the fields (about 100% of the phosphorus taken up by food is excreted) would strongly decrease phosphorus demand to maintain high levels of plant production. Even an increase in global plant production is possible since on 30 to 40 per cent of the arable land the crop yield is limited by phosphorus availability (Vance *et al.,* 2003). A change in diet could also decrease the phosphorus demand, since a vegetable-based diet requires significantly less phosphorus than a meat-based diet and would lead to a decreasing phosphorus demand of at least 20 to 45 per cent (Cordell *et al.*, 2009). Also overeating leads to high phosphorus demands: if people in Sydney would eat as much as the recommended daily intake per person, the phosphorus demand would decrease with 70% (Cordell *et al.,* 2009). On the other hand, manure contains about five times more phosphate than human waste (Gilbert, 2009) and it is collected purely, in contrast to human excrements that are often mixed with (drinking) water in the sanitary system. As soon as it is economically viable, animal dung will be a useful source to recover phosphorus as ingredient for well-balanced fertilizers.

2.3.8 Conclusion

Animal production played an essential role in human history, not only as a way to produce essential elements (vitamins, amino acids…) on land which is not suitable for agriculture or on inedible feed, but also as fertilizers of the land, making it possible to increase crop yield and let the human population grow. Although a healthy life as a vegetarian or a vegan is possible, especially in our Western world where because of international trading a large diversity in products is available all year long, eating animal products is much easier. One can be sure that by eating some animal products, there is no lack in essential elements in the diet. But what started as an essential part of diet, ended in mass production and overconsumption, leading to problems for human health, environmental consequences and animal welfare problems.

Nevertheless, it is very unlikely that animal production will diminish within the next decades. With increasing incomes in developing countries, millions of people will eat more animal products and it is expected that by 2050 animal production will double, compared to 2010. Due to increasing wealth, more people keep carnivorous pets that also require animals for feed. Since increasing pastoral land is not an option, more intensified animal production is the most obvious way to meet global demand. These animals will be fed with cereals and – preferably – by-products, although it is not always clear what these are, as can be seen from the soybean discussion. On the other hand, one could question if the predicted increase in animal production should be seen as a given. It would be better to decrease per capita meat consumption in Western countries and increase animal efficiency in upcoming countries. This alternative could match global demand for animal products with a stabilised animal production that has less ecological impact.

In order to have a more sustainable animal production, the right balance between different types of animal production needs to be found. Many parameters have to be taken into account and many questions need to be answered:

- Which species produce essential nutritional elements in an efficient way? It is plausible that the most important species today will be at least partially replaced by others (aquaculture, insects …) which are also nutritious, but need less feed or can convert other, non-edible products.

- How will these animals be fed? Until now, the combination of feeding value and price decided if certain feed products were used in rations. Will economy still decide what is acceptable and what is not, or will new parameters also become important in this debate (cfr. responsible soy or new feed stocks like by-products from third generation biofuels by algae or protein production by insects)?

- What is a fair price for animal products? Is it fair that in Western countries, due to cheap feed imports, meat is sold for such a low price that it leads to overconsumption, while in the countries where the feed is produced, the prices are still too high to have access to the necessary amount of animal products?

- What is the optimal balance between animal welfare and efficient production? To what extent are we willing to opt for animal welfare, if certain practices seem to be worse for the environment than intensive animal production?

Surely, there will be more questions to solve and new ones will arise during the process. But it is essential that a new equilibrium in the production and consumption is established. Economics is not able to steer offer and demand in a sustainable way, as otherwise it would not be such a problem. A long-term global policy, based on scientific knowledge, is necessary for farmers, consumers and citizens.

2.4 Fuel

2.4.1 Replacing fossil fuels

As stated in paragraph 1.3, biofuels (bio-ethanol) were already used as an energy source in the 19th century. Due to the lower prices for fossil fuels, biofuels did not become that important worldwide during the 20th century. Since fossil fuels are not renewable (at least not at the speed society needs them), one has to take into account that one day these energy sources will no longer be available. A decrease in availability combined with the same or an increased demand will raise fossil fuel prices to a level that makes it unaffordable for everyday energy demand. BP (2014) estimates the world's total proven reserves on 238.2 billion tons or 53.3 years of global production of oil, 185.7 trillion cubic meters or 55.1 years of global production of natural gas and 891.5 billion tons or 113 years of global production of coal. Even though energy consumption in OECD-countries declined, global energy consumption increased with 2.3% because of industrial development in other countries, China accounting for almost half of this growth (BP, 2014). Of our global energy consumption of 12 730.4 Mtoe in 2014, 86.66% comes from fossil fuels (BP, 2014), compared with 4.42% from nuclear energy and 8.9% from renewable energy sources. More than half of these renewables are traditional biomass (e.g. wood, dried manure…) used in developing countries, where 2.7 billion people depend on them for cooking (IPCC, 2011).

Although fossil oil has the smallest reserve, it accounts for about one third of global energy consumption (BP, 2014). Since 60% of the world's oil production goes to transportation fuels (REN21, 2012), especially in this sector there is a lot of interest in biofuels. The big question is if it is sustainable to invest in biofuel production, while it will not be sufficient to replace fossil fuels within global energy demand. Nowadays, its use is only 0.7% of global energy consumption and only 3% of global road transport fuels (IPCC, 2011; REN21, 2012), which is rather small, especially when evaluated in the framework of the discussions in the food-versus-fuel-debate. IEA (2006) estimated that in 2006 about 1% of arable land was used for biofuel production and predicts an increase up to 2.5 or even 3.8% of arable land in 2030. For the U.S., Hill *et al.* (2006) calculated that if the total 2005 corn and soybean production would be used for biofuel production, it could only replace 16% of gasoline and 6% of diesel demand. Taking into account that global energy demand will probably increase with 50% for power generation and 20% for transport energy (FAO, 2008), one can easily see that using all arable land for biofuel production would even not be enough to meet global energy demand. Therefore, decarbonisation seems the only sustainable alternative for fossil fuels. Even though it is known that biofuels are not the solution for replacing fossil fuels, the research and discussion about them are still going on.

Production of energy as such cannot be seen as ethically problematic, since it is a necessary means for humans in all kinds of societies. For decades, only little importance was given in the developed world to the energy-discussion since fossil fuels seemed endless and were available at affordable prices, even though most countries were dependent on energy imports. The increase in scientific knowledge has provoked an increasing awareness, not only of the finiteness of our most important energy resources, but also of the consequences of our large energy use, like GHG-emissions and other types of pollution (air pollution, oil leaks…), leading to climate change and altering the viability of the Earth. New ways of energy production are needed and biofuels seemed a good solution: they are renewable and a part of the emitted CO_2 is recycled, so that the net carbon output is lower than that of fossil fuels (Hill *et al.*, 2006).

As said, the first generation biofuels is based on food crops. This has many advantages, such as a fast implementation, since these crops were already grown and the end products (biofuel and bioethanol) have similar characteristics as fossil fuels. This makes it possible to continue the use of existing infrastructure of both production (production of crops and refinery of vegetal oil and methane) and consumption (combustion motors) (IPCC, 2011). In contrast with the technical advantages, many ethical arguments were formulated against first generation biofuels. Jean Ziegler, UN Special Rapporteur for the Right to Food, even called it “a crime against humanity to convert agricultural productive soil into soil which produces food stuff that will be burned into biofuel” (UN, 2007). Ziegler continued that biofuels lead to more hunger because the increase in demand will lead to higher food prices. These arguments are very common themes in the ethical debate on biofuels, but are they valid?

2.4.2 Is it wrong to use food as an energy (re)source?

Several arguments can be given why it is not implicitly wrong to use food crops as an energy source. First of all, “food crop” is a human definition. Corn and wheat e.g. are only food crops because humans say they are. From a biological point of view, cereals are not made by plants “to be eaten by humans”, but are the reproductive stage of the plants. Its main reason of existence is not to feed humans, but to make sure its own species will survive. A change in destiny from “food” to “fuel” is not intrinsically wrong, since using it as food already implies a change in the *telos* of the edible particles. The nutritious qualities of these plant species do not imply that they should be eaten: dogs and cats are full of nutrients too, although these are not seen as “food” in most cultural traditions. It is not because it can be eaten that it should be eaten.

Also, as already shown in table 1.2, millions of animals are used as a means of transportation and are therefore fed with biomass. Although most people would not mind feeding biomass to horses, they have problems with feeding biomass to horsepower of a car. Why is one type of conversion from biomass to transport more acceptable than the other? Is it because horses and other animals are also living creatures and that it feels more natural to give “food” to something living than to something mechanical? But is this an ethical ground to reject food for fuel?

In biofuel debates, the fact that more than 800 million people are living in hunger is often given as an argument against the use of first generation biofuels, where food crops are used for energy production. One could say that it is immoral to burn food as long as there is hunger in the world. But one could make a long list of things that are immoral as long as there is hunger in the world, like food spillage (about one third of global food production, as we have seen before) or feeding pets. Even tolerating obesity is morally doubtful from that point of view: is it acceptable that one out of five person eats too much, even leading to major health problems for the subject (for example increased diabetes levels; Diamond, 2011), while one out of seven has not enough to eat? As we have seen, hunger is more a problem of accessibility than of availability. Everything that is spilled, fed to animals or eaten too much, is not accessible for the hungry or it is too expensive to transport it to regions with famines. Therefore, the use of locally available food surplus as a local energy source will not alter global food accessibility for the hungry. Even an increase in food price is not necessary since the global balance between supply and demand of food is not altered.

2.4.3 Are second generation biofuels better?

First generation biofuels imply that edible crops are grown to a larger extent. Indeed, they are used for energy production, but they are still edible and could be harvested to feed the hungry too if one would decide so. The fact that these crops are used for energy is merely a result of political and/or economical decisions. Second generation biofuels use productive agricultural land to produce biomass that is not edible. One could question if it is worse to produce and harvest food and use it as an energy source, compared to producing e.g. *Miscanthus* on the same piece of arable land. In the case of second generation biofuels, there is no choice: the biomass produced can only be used for fuel. First generation biofuels still gives the opportunity to choose what the final destination of the biomass will be: man, animal or machine. One could argue that second generation biofuels is only ethically acceptable if it occurs on land that is not suitable for food production.

The most important consequence of the renewed interest in biofuels is that the huge amounts of energy used became more apparent. Where biomass production for energy is encouraged because of energy security, climate change mitigation and rural development and is seen by policy-makers as a sustainable solution (Shortall and Millar, 2012), it also showed, once more, the ambiguity of the consumer: he has less problems with using biomass from the past – because this is what fossil fuels are – than with using biomass from the present. Harvesting crops, both edible and non-edible, showed that energy use has an impact, since it became visible and spatially embedded. Unlike fossil fuels, the amount of energy needed is no longer hidden under the surface, but visible on the fields, as the result of natural resources combined with human effort, time and energy. By this, it contributed to the awareness that humans depend on what nature gives, that we are connected with and relying on our environment. Even more, the visualization of our energy consumption, especially the food-based ones, appeal to our feeling for intragenerational justice: is it fair that I use food as an energy source while others have troubles that could be solved by using this product? An extra dimension is given to the discussion when the energy crops are imported from developing regions. It feels morally wrong. As long as the biomass is pumped from underground oil or gas reservoirs in the same regions, its use for energy seems more accepted than growing new biomass for the same purpose.

With second generation biofuels, the feeling of guilt is probably smaller since one is not using someone else's food for one's insatiable desire for energy. The use of non-edible energy sources seems to have no direct impact on world hunger and is therefore more acceptable. But this does not imply that second generation biofuels are free from discussion. As Gamborg *et al.* (2009) explain, the discussion between first and second generation biofuel production is an example of the act-omission dilemma, well-known in medical ethics, but also present in agricultural ethics. One could question what is morally more problematic: to do something (act) with known consequences or not to do something (omit), wit the same result. Within the act-omission doctrine, it is seen as morally more problematic to actively do something than to omit (e.g. active or passive euthanasia). From a consequentialist point of view, it is morally the same since the result is the same. Therefore, one could question if it is worse to act – in this case: to produce food and than use it for fuel so that it cannot be eaten – than to omit, in this case to produce inedible biomass that cannot be eaten at all. The latter leaves us no choice, except using it as biofuel, while first generation biofuels do not compromise the final destination of the crop: there is still a choice of using them for Food or for Fuel. Therefore, in the case of biofuel, it seems worse to omit than to act.

Even if second generation biofuels are not depending on production of non-edible crops but on using by-products and waste, competition still occurs. Low quality biomass and manure, also used for energy production, are important to maintain soil quality. When biomass is removed, this has consequences for the carbon sequestration in soils. Therefore, biofuel production does not only compete with Food/Feed, but also with Foster, i.e. our responsibility to maintain agricultural land and its environment in good condition for present and future generations. In contrast with biofuel production, there is no direct short-term economic gain when using biomass to ameliorate soil quality. As long as externalities like carbon content of the soil are not internalized and made economically measurable, it is very plausible that Fuel versus Foster will not be debated, although it is at least as important from an intergenerational point of view. Again, the decarbonisation of energy production is preferable.

2.5 Fibre, Foster and Fun

For Fibre, the same remarks can be made as for Fuel with regard to fossil fuel use, although it is less controversial. Next to the fact that the volumes needed to replace fossil fuels within the production of Fibre are smaller, there is another important difference. There are several alternatives for energy production that do not need the destruction of biomass that first has to be produced. Solar, wind and other decarbonised alternatives can be used to produce energy. Biomass as such is not necessary: it is the energy within it that is looked for. For Fibre, the biomass itself is what is desired because of its (bio-)chemical or physical characteristics; the biomass is the goal and not the means. This makes it more acceptable and unavoidable to produce biomass for Fibre production.

It is very likely that Foster will gain increased interest during the next decades, in order to make sure that the other functions of agriculture can be sustained for present and future generations. The United Nations declared 2015 as the International Year of Soils. In his opening speech, FAO Director-General José Graziano Da Silva stresses the importance of soils for the future: "We need it for food, feed, fiber, fuel and much more" (FAO, 2015). Carbon sequestration will gain importance, because higher soil organic carbon levels have a positive effect on soil resilience and yields, leading to higher food security in developing regions, and is also a means to mitigate climate change. Lal (2004) states that agricultural and degraded land has a carbon sink capacity between 50 and 66 per cent of historic carbon loss over a short period of 20 to 50 years. Lal (2004) but also Delgado *et al.* (2011) have listed conservation practices to maintain or ameliorate soil quality in many aspects (carbon level, water retention, GHG-emissions…). Since about a quarter of global climate forcing occurs in developing countries through forest clearing and soil degradation or typical agricultural techniques as extensive livestock production, paddy rice cultivation, inefficient manure management or burning as an agricultural practice (Scholes *et al.*, 2014), it is necessary to evolve from an agriculture that is problematic for climate change to an agriculture that offers a solution. A discussion on what type of agriculture is needed to foster agricultural land for present and future generations is too large to be embodied in this thesis, but lengthy explanations can be found in Lal (2004), Godfray *et al.* (2010), Foley *et al.* (2011), FAO (2015) and others.

As already shown *supra*, the increasing interest in Fun (e.g. alcoholic beverages, pets, floriculture…) will probably continue, since people in upcoming economies adapt their lifestyle to the Western 'role model'. The importance of consumption as a source of fun and the difference between needs and desires will be discussed on a more abstract level in the next chapter.

Chapter 3

Towards a sustainable biomass use

3.1 What is 'sustainability'?

Since the report "Our Common Future" of the Brundtland-Commission (WCED, 1987), in all kinds of discussions - from biodiversity to responsible food consumption - the themes of sustainable development and sustainability became very prominent. Although afterwards, different definitions of sustainable development have been presented, the WCED-definition is still the best-known and the most widely used: "Humanity has the ability to make development sustainable to ensure that it meets the needs of the present without compromising the ability of future generations to meet their own needs." (no. 27) The document further states "sustainable development is not a fixed state of harmony, but rather a process of change in which the exploitation of resources, the direction of investments, the orientation of technological development, and institutional changes are made consistent with future as well as present needs." (WCED, 1987: no. 30) and it clearly mentions that sustainability is never achieved. Something can always become more sustainable, which implies that the discussion about sustainability will never stop. Just like for 'health' and 'happiness', constant efforts for 'sustainability' are desirable (Van Latesteijn and Andeweg, 2011). Sustainability has become a leading principle and a societal ideal for a large variety of activities. Even though its manifold use in communication gives the impression that 'sustainability' is well-defined, worldwide discussions show that there is no consensus at all. In what follows, the WCED-definition will be analysed. Discussing "humanity", "needs", "future generations" and "sustainable" will show that even a simple sentence, used as definition, opens the gates for disagreement.

3.2 Humanity: whose responsibility is it?

Although one might overlook the first word, 'humanity' plays a key-role, since it "has the ability to make development sustainable" (WCED, 1987: no. 27). Humanity can be interpreted in two ways: as the total population of all human beings or 'mankind' (in Dutch: 'mensheid'), and as 'being/acting human' (in Dutch: 'menselijkheid'), the quality that is ascribed to humans distinguishing us from other animals by our cognitive capabilities and ability for ethically sound behaviour. While the first meaning of 'humanity' implies that humans as a group have the ability to create a sustainable future, humanity as a quality rather stresses the fact that 'acting humanely' is the way to develop sustainable. This implies that any human being should know the difference between 'good' and 'bad', between 'what is' and 'what ought'. Although this probably will never be achieved, it is nevertheless a good guidance for every individual to let mankind develop in a sustainable way.

In what follows, humanity will be discussed as the total human population, now more than 7 billion and increasing. Since 'a sustainable future' is of common interest, one can question why it is so hard to achieve. This can be explained by Olson's paradox (1965), which states that larger groups are less successful in reaching their common interest because of the free-rider problem. Olson (1965) states that if a good is undividable (the number of users does not affect the availability of the good for others) and unexcludable (if the good is available, one cannot be excluded from its benefits), collective rationality (if one cannot be excluded from the good and if one's use does not prevent others from using it, why should one pay for it?) leads to collective irrationality: there is no money to maintain the good, although it would be advantageous for all. Although this is a rather economical approach, it can be seen broader than this: changing one's lifestyle is also a certain payment, albeit not monetary but in effort (e.g. less meat, less air flights on holidays… effort that does not cost but saves money). But it seems that paying effort is even more difficult to achieve than the monetary payment. Therefore, the free-rider problem also occurs in sustainable development: one thinks that its own behaviour does not affect the availability for others (cfr. 'undividable') and that if one does not pay any effort himself, there still will be a sustainable future. Acting as a free-rider, i.e. paying no effort for a sustainable future, seems rational behaviour and although everyone wants a 'sustainable future' – whatever this might be, see further – in the end, most of us will act as a free-rider, paying no or maybe little effort to really achieve this. Already in 1962, Hardin described this as the "tragedy of the commons".

Furthermore, especially in a consumer-based society, those who do pay effort and adapt their lifestyle – hoping that it will lead to a better world – are often considered as 'strange'. Although vegetarians and vegans are more accepted than a decade ago, people without cars or having almost no electric devices are still scarce in developed countries. Although these people try to adapt their lifestyle to a more sustainable way of living (maybe not always in the most efficient way), they are even stigmatised as 'undeveloped'. Combining the free-rider problem with the possibility that one would get a social stigma, it asks for a lot of courage to change one's habits. Therefore, other incentives are needed to accelerate sustainable development.

3.3 Development: the battle between present desires and future needs

3.3.1 Desires or needs in the consumer society

The Brundtland definition (WCED, 1987) states that development is about 'needs' of both present and future generations. Therefore, making a difference between 'needs' and 'desires' is necessary. Needs like good health or enough affordable and healthy food, are universal among all humans and can be satisfied (Baudrillard, 1998). Desires, on the other hand, are merely individual and vary in time and space and are very culturally dependent. They are insatiable and therefore the driving force behind economy in the Western "consumer society" (Baudrillard, 1998). Where at first the focus was merely on production, this changes in the golden 1960's and 1970's, when the "heroes of production" had to give way to the "heroes of consumption" (Baudrillard, 1998). Researchers, entrepreneurs, large-scale producers and other heroes of production experienced a decreasing status as source of inspiration for others, in favour of large-scale consumers. Baudrillard (1998) mentions movie stars as idols of consumption: the focus is no longer on the hard work, the skills or the sacrifices that have to be made to reach this (cfr. self-made production heroes), but on the "useless and inordinate expenditure" of these "great wastrels".

Waste is not new: already in ancient societies, it was part of many rituals to increase one's social status, since wasting implies abundance and hence wealth. It is also important from a psychosocial point of view: Baudrillard (1998) states that "it is in the consumption of a surplus, of a superfluity that the individuals – and society – feel not merely that they exist, but that they are alive". While surplus consumption in the past occurred rather occasionally and was something that only the happy few could afford, in the contemporary consumer society surplus consumption and waste are omnipresent. Despite the increasing importance of wasting commodities, the created feeling of abundance is false. In 1986, Andrew Simms introduced “Earth Overshoot Day” (Earth Overshoot Day, 2015): the day that humanity has used all natural resources that can be reproduced during one year. About 30 years already, humanity uses more than the earth can regenerate, at an increasing pace. Several resources that are the fundamentals of our society (fossil fuels, but also phosphorus; see earlier) are decreasing. And although humanity is aware of this, production, consumption and spillage still increase. As Hardin (1968) pointed out: a real tragedy of the commons.

This is caused by a changed view of wealth. In primitive societies, wealth was based on human exchange (Baudrillard, 1998). This type of wealth is unlimited and hard to quantify. In modern societies, wealth is linked to individual property and can be quantified by the number and type of objects one possesses. This quantification of wealth also has an impact on happiness in the consumer society. After the industrial revolution, egalitarianism gained increasing interest in politics and sociology (Baudrillard, 1998). In the consumer society, this implies that consumers want to have the same things as others to have the feeling that they are treated equally. If one does not have an object others have, one often feels disadvantaged or at least tries to find an explanation for the “unfairness”. In the consumer society, one can only be happy if one possesses the same objects, or even better: something more exclusive that the others do not have. This form of happiness can never be reached according to Max-Neef (1992). He divides human needs in two categories: the needs according to existential categories (Being, Having, Doing and Interacting) and the needs according to axiological categories (Subsistence, Protection, Affection, Understanding, Participation, Creation, Leisure, Identity and Freedom). These human needs are fundamental: they are finite, few and classifiable and are the same in all cultures and in all historical periods. The only thing that changes over time and through cultures is the ‘satisfiers’. In a consumer capitalism society, human needs are narrowly focused on ‘Having’, a point of view that is fundamentally unfulfilling for human needs and therefore true happiness cannot be reached.

Also the way in which people look at objects changed. Where in the past commodities were mostly bought for their use, objects are now rather seen as a manner to differentiate oneself from the others. Objects are no longer bought for their usability only, but rather become the embodiment of signs, used to create a social status (Baudrillard, 1998). In the consumer society, individual consumers (have to) know the code to translate the signs behind the products. Therefore, products became also a way to differentiate from others. By combining products, we combine codes and thus create and express our identity – not only who we are, but also who we want to be – to our fellow-beings.

3.3.2 Present or future generations

Intergenerational responsibility is a key element in the Brundtland definition (WCED, 1987). It states that one should also take the future generations into account and not only the needs of the present generation. Before that, some authors – for example De George (1979) and Macklin (1981) – argued that future generations cannot have rights since they do not exist yet. De Tavernier (2008) synthesises the arguments pro and contra and concludes that rights can be predicated to future generations because of possible future interests, or 'anticipatory rights' as Nash (1991) calls it. One could question if the discussions in the past on 'generations that are not here now' were a correct base for the ethical debate. With nowadays' life expectancies, some part of the human population of the 22nd century is already born. The future generation is thus already present. Making decisions for the future is not something abstract for unknown individuals, as some might think, but has important consequences for the life of our younger fellow-human beings.

Although the Brundtland definition has a strong focus on intergenerational responsibility, also a balance with intragenerational solidarity is important. One could question if it is for example fair to focus on sustainable food production in the future, while today's food production and distribution system is not capable to feed the present generations, with about 805 million hungry people as a consequence. Furthermore, to meet the desires of some present generations, the ability to meet the needs of other present generations is already compromised. If we are not even able to develop in such a way that our fellow-generations are not compromised, how can we make sure that future generations still will be able to meet their own needs?

Defining the needs of the future generations is not that simple. On a more abstract level, general aspects as 'food' or 'good health' will be mentioned, but it gets more difficult when discussing the tools, techniques or knowledge needed to achieve this, since the boundary conditions are unknown or at least disputable. Since the present is the past of the future, one could look at the evolutions between the past and the present in order to try to understand what the evolution towards the future might be. Knowing that the future generations are our grandchildren, one could return back into time and imagine if our grandparents, when they had our age, would be able to predict what our present needs would be. They definitely would not mention the internet, genetic engineering or 3D-printing; technologies that nowadays are very important in e.g. health care, leading to truly better lives. Are the present generations capable to know what the needs of the future are? Or will they extrapolate their own needs and techniques, aspiring to predict the needs of the future generations? But what if they are wrong? Some techniques that are nowadays contested might become important to solve certain problems, while seemingly promising techniques will fade out. Policy makers face the challenge to implement the precautionary principle to protect humanity against unknown disadvantages, with the danger to inhibit new solutions for both known and unknown challenges.

3.4 Sustainability: which sustainability suits you?

As discussed in Boonen *et al.* (2012b), the triple-P-concept (People, Planet, Profit) is very often used when talking about sustainability. 'People' refers to the social costs and benefits, influencing public opinion and the values, perception and interests of citizens. The goals for sustainability "should be about opportunities, capacities and capabilities to choose, adapt, adjust, improve, and communicate" (Knippenberg *et al.*, 2006). 'Planet' refers to the ecological costs and benefits. The ecological pillar deals with norms and goals regarding 'natural capital' and public environmental goods, asking not to trespass ecological limits (air, water, climate, biodiversity, forests, soil). 'Profit' refers to the economical costs and optimising benefits. Norms and objectives for sustainability in the economic sphere should be about improving this process of optimization.

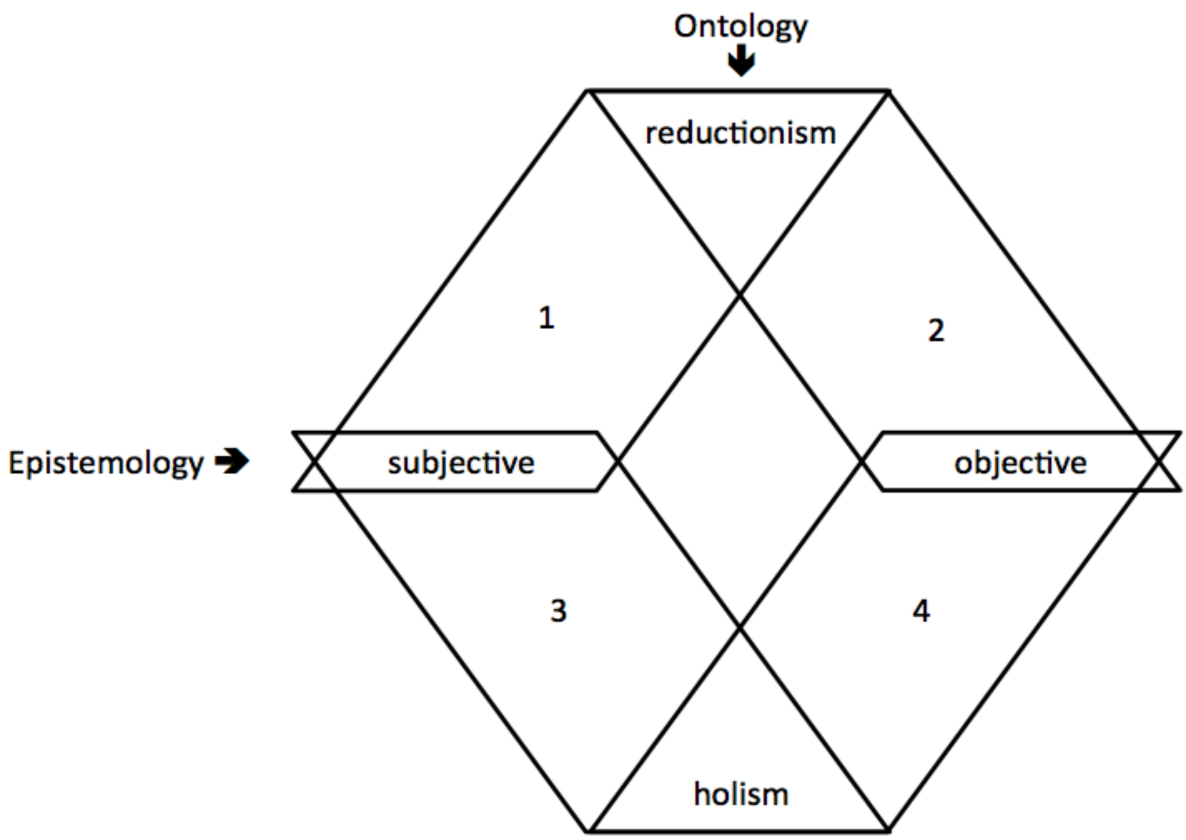
Although these three pillars are told to be of equal value, one often gives much more attention to one of those P's to prove the right of one's view on sustainability or to counter a different opinion. When referring to 'sustainability', sometimes only the ecological balance is sought as is the case in the article 'Broad sustainability contra sustainability' of Hueting and Reijnders (2004). They come to the conclusion: "In view of the arguments mentioned in the previous sections, the designation 'narrow' should be dropped when sustainability refers to an equilibrium relation between human activities and the environment. The indicators for sustainability which also include economic and social elements proposed so far (...) are flawed because they rather generate fog than shed light on the road to a sustainable production level." (Hueting & Reijnders 2004: 259). Since there are measurable criteria indicating the limits of the carrying capacity of the earth as ecosystem, why should we not restrict economic activities and social systems? But as Davidson (2009: 79) proposes, albeit from an anthropocentric point of view: "Our obligations to future generations include the obligation to leave behind not only a healthy environment but also a healthy economy and society, these also being prerequisites for a good life". But again, the question is how we could develop a consensus on defining sustainable development since the method to derive norms or goals also differs in each pillar. Especially the social realm creates a problem. Sometimes it is solved by introducing a stakeholders approach, but could stakeholders be trusted? We are always struggling with the practical problem that we often lack the capacity to take rational decisions about the long-term implications of our actions. In the end, obtaining a coherent view on the kind of obligations we have towards future generations may prove to be very difficult.

Discussing sustainability, we cannot avoid developing meta-criteria. One's worldview does not only influence the sorts of norms and goals used for a sustainability assessment - from an exclusive focus on scientific facts in order to foster the issue of climate change to value commitments in order to foster 'People' - but also the point of view in outweighing tensions between these three P's. Although other ways of evaluating and discussing one's behaviour when talking about sustainability are possible (e.g. Casimir and Dutilh, 2003 four different worldviews are here distinguished, based on ontology and epistemology. Within each of these worldviews, a certain priority among the triple-P-principles is given, explaining why debates about assessment indicators for sustainability are so difficult. The term "world view" stresses that the whole discussion is seen from an anthropocentric point of view, i.e. how humanity looks at the world and discusses sustainable development of this world. For the Earth as an ecosystem, sustainable development and sustainability is not an issue, since a new equilibrium will always be found between the species that survive.

3.4.1 Different worldviews

In order to understand why people act and argue in a certain way when discussing sustainability, two distinct philosophical approaches can be used to distinguish different worldviews: we can look to things from an ontological viewpoint (from a particular belief about what nature is) and from an epistemological viewpoint (from the way we analyse things) (Olesen *et al.*, 2000). From an ontological point of view, one can look at nature in two radically different ways. At one hand there is the extreme reductionist view that holds that nature can be divided into isolated parts (for example a mechanistic study of individual plants or research on sugar beet production) and where the whole equals the sum of all these parts. At the other hand, there is the holistic view where all parts are connected to each other and where altering one part also affects other parts because everything is dependent from one another (f.i. organic agriculture, seeking for an equilibrium).

From an epistemological point of view, our way of analysing things can also be divided in two radically different ways: an objective viewpoint where is believed that we can analyse everything in a detached way since things have objective value. Subjective emotions and personal values do not influence value recognition and decision-making processes. Opposite to this, is a subjective viewpoint where people's evaluation is affected by and even based on personal values and emotions. Combining these two-on-two views gives us four different types of worldview (Sriskandarajah and Bawden, 1994): a personal-egocentric worldview (subjective decision-making + reductionist and fragmented view on nature), a technical worldview (objective decision-making + reductionist and fragmented view on nature), a cultural-social worldview (subjective decision-making + holistic view on nature) and an ecological worldview (objective decision-making + holistic view on nature), as can be seen in figure 3.1.



1. Personal-egocentric worldview
2. Technical worldview
3. Cultural-social worldview
4. Ecological worldview

Figure 3.1: Four different worldviews, based on differences in ontology and epistemology.

3.4.2 Worldviews and sustainability

In these four worldviews, the three Ps (People, Planet and Profit) do not have equal value, as discussed in Boonen *et al.* (2012b) and shown in figure 3.2.

It is obvious that for someone with a personal-egocentric worldview (i.e. subjective and reductionist) his/her own welfare (profit) is more important than interests of both other human beings and the environment. On the other hand, a personal-egocentric person needs society (people as customers) in order to make profit, so in this worldview one will try to convince society that what he/she is doing is right. Due to the increasing interest in green sustainability, green-washing is a very well-known practice of window-dressing: a particular company claims to do efforts in favour of the environment, but in fact uses the Planet as a tool to convince People to buy their 'sustainable' products, in order to make Profit. Here, the three P's are not seen as three equally important pillars, but as building blocks where the underlying blocks are needed in order to get the ultimate goal, *in casu* Profit (see figure 3.2). We call this 'enlightened self-interest', which means that persons who act to promote the interests of others ultimately further their own self-interest.

Somebody with a cultural-social worldview defends a holistic view but is still influenced by subjectivity. One does not act from an individual point of view, but situates oneself within a cultural tradition. This worldview could be (and it often is the case in Western countries) an anthropocentric one, due to the religious past and present, where humanity is placed on top of the 3P-list, but with respect for nature. Since life is transient, the survival of the society is more important than personal gain. Profit here is not a goal but a means to survive and to serve the 'common good'. Even the protection of the environment serves to let humankind survive (anthropocentric environmental concerns). In practice, people who buy Fair Trade and care about the tropical rain forests because of duties towards future generations, are motivated by a cultural-social worldview. Often so much attention is given to human concerns (a sufficient and just income of farmers, job opportunities, etc.) that the environmental concerns are not taken as serious as the human concerns. In this worldview, we only have direct obligations to humans, not to the environment. To the extent that environmental concerns fit into human interests, they will count but even if this is the case, we interpret them as indirect obligations. The three P’s are again building blocks, but the ultimate goal here is saving People.

In a radical ecological worldview, humans are seen as just one of the millions of species on Earth (cfr. the importance of biodiversity), making People only a small subset of the Planet. In order to protect the planet and all living beings dwelling upon it, humans need to be convinced that our habitat (and that of millions of other species) is vulnerable and that humanity has a severe and too big impact on several ecological parameters. Important topics for people with an ecological worldview are climate change, biodiversity, air and water pollution... For people living in a market-economical environment, positive financial incentives are needed to lure people to do the right thing for the Earth, but for those who adopt an ecological worldview Profit is seen only as a subset of society. Negative incentives and even coercion is acceptable.

Since a technical worldview can be described as ‘objective’ and ‘reductionist’, it is characterized by the fact that one is mainly focused on one of the themes. This kind of worldview can often be found in the scientific world because many scientists have a fragmented view on nature due to their methodology.

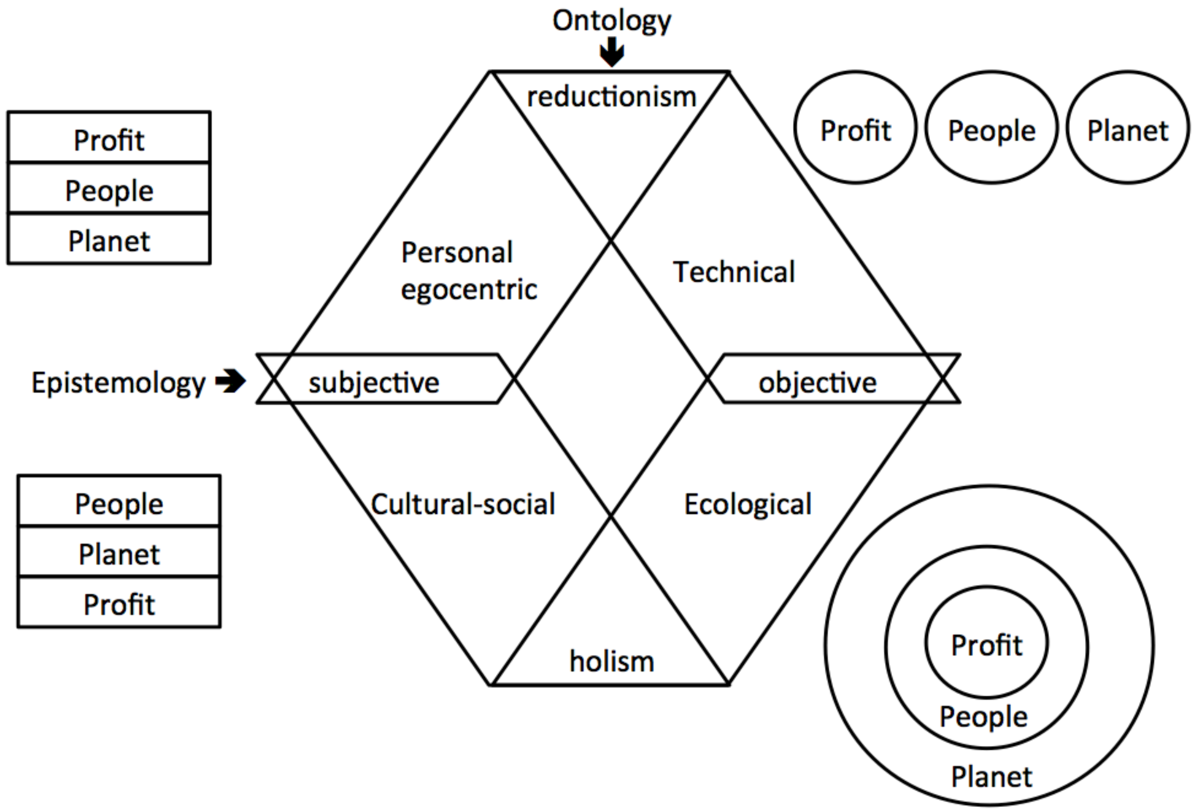


Figure 3.2: Impact of one's worldview on how sustainability is perceived.

3.4.3 Triple-P and principles of sustainability

Is it possible to describe an all-encompassing perspective that avoids undesirable trade-offs between the three perspectives? Could we balance the different interests and claims and work out a fair treatment of all wants, needs and deeds? Knippenberg *et al.* (2006) believe that we need some kind of overall principles. In the literature on sustainable development one sees the principles justice (fairness) for People, resilience for Planet and efficiency for Profit: "It is not difficult to understand this choice. Sustainable development is about fair deliberation, about fair access to opportunities and about the fair distribution of profits and liabilities. This makes justice, defined as fair distribution, a core principle of sustainable development, irrespective of the particular circumstances or particular preferences." (Knippenberg *et al.* 2006: 77). Resilience is the capability of ecosystems to provide ecosystem functions in a normal manner and to cope with stress. Resilience means that a system in process is capable of self-organisation. It also indicates an adapting capacity to resist a severe decline in functioning due to changing circumstances. Efficiency deals with the allocation of limited resources and the fact that we are supposed to make trade-offs between competing goals, while choosing at the same time the suitable means to an end.

How to present these three principles in such a way that they could give guidance to public debates about the three pillars of sustainable development? According to Knippenberg *et al*. (2006) the three overarching principles refer to systemic properties because they characterise a particular quality of the interactions within a particular system: "Justice is about fairness in a societal system. Resilience is about adaptation and regeneration of a system or systems, and efficiency is about the working of a system". (Knippenberg *et al*. 2006: 78). For solving concrete discussions about sustainable practices, they propose a combined approach of these three principles, including the use of certain minimum norms per pillar, and a stakeholder approach. Stakeholders are requested to frame their perspectives by making use of the three principles and searching together for norms and goals in a particular context.

Take for instance, sustainability assessments. They usually use a three-pillars approach within sustainable development, a social one, an ecological one and an economic one. Assessments, using this triple-bottom-line-model, focus on an integrated assessment of these perspectives. But these assessments could not solve the fundamental question at stake, i.e. "what sustainable development should entail" (Knippenberg *et al.*, 2006: 73).

3.4.4 Conclusion

Which sustainability suits you? Boonen *et al.* (2012b) focused on the question if it is possible to develop a consensus on what sustainable development is since the method to derive norms or goals differs in the three pillars (economic, ecological, social). First of all, when debating sustainability, it is necessary to consider meta-criteria. Worldviews do not only provide the kinds of norms and goals used for sustainability assessments but offer also a basis for outweighing tensions between the three P's (People, Planet, Profit). Although other options for classifying worldviews are possible, in this chapter we focused on four different worldviews, divided by an ontology-based and epistemology-based approach. For each of them, we have indicated that within each of these worldviews a certain priority among the triple-P-principles is given, explaining why discussions about assessment indicators for sustainability are difficult to solve. Especially the social pillar creates a huge problem. People might act in an ambiguous way and context- and interest-dependent. Sometimes this problem is solved by introducing a process-based approach, with a firm stakeholders' participation, but can stakeholders be trusted? How to avoid that stakeholders react in an emotional and subjective way and lack the capacity to take rational decisions about the long-term consequences of their acts? So in the end, developing a coherent view on the kind of obligations we have towards future generations by using traditional assessment tools may prove to be very difficult. Those traditional assessment tools are often not sufficiently comprehensive to be labelled as true sustainability assessments. In order to solve this major problem, Knippenberg *et al*. (2006) claims that sustainable development necessitates a triple principle-based framework (justice, resilience, efficiency) to help stakeholders fine-tune their discourses and behaviour - very much influenced by their respective worldviews - in confrontation with existing norms and goals within each of the pillars of sustainable development. This kind of approach is believed not only to reduce complexity but also to strengthen commitment, deliberation and creativity.

3.5 Economics, ethics and the 6 Fs

Although one might have the impression that there is a gap between economics and ethics, Graafland (2007) argues that this is not the case. He states “whereas economics is a social science that engages in a *descriptive* study of the economy that attempts to describe or explain the economy without reaching conclusions about what ought to be done, ethics is a *normative* study that attempts to reach normative conclusions about what things are good or bad” (Graafland, 2007: p.7). The disconnection with ethics occurred at the end of the 19th century, with the rise of the neoclassical view on economics. As an example of this neoclassical view, Graafland (2007) uses Robbins’ view on economy that can be summarized as the study of human behaviour in order to reach different goals by using scarce means with multiple uses (Robbins, 1932). In order to let one behave economically, it is important that there are different goals, since if there is only one goal – or “end” as Robbins calls it – it becomes merely a technical problem of finding out what the optimal use of the different means is to reach this single end. Also scarcity is important, since if means – not only material, but also immaterial like ‘time’ – are abundant, the individual will not have to behave economically since all goals can be reached. Robbins (1932) stresses this by stating: “The external world does not offer full opportunities for their complete achievement. Life is short. Nature is niggardly” (Robbins, 1932: p. 13). The fact that the means have multiple uses is essential to allow economic decision-making. If they cannot be exchanged, “they may be scarce but cannot be economized” (Robbins, 1932: p.13). Following Robbins (1932), one could argue that the discussion on how the 6 Fs should be balanced can be seen as an economic question: the means are scarce (i.e. biomass production is limited) and have multiple uses, and there are different goals, *in casu* the six functions.

On the other hand, this neoclassical view has lost connection with ethics in several ways. With the ambition to become a neutral science, economics focuses more on objectively describing the relations between the scarce means and the ends, and the decisions that are made by rational agents. This is the reason why economics became more and more a mathematical science (Weintraub, 2002). This made economics lose its connection with ethics on several fronts (Graafland, 2007). Neoclassical economists take the different goals – whether good or bad – as a given. Value judgements are not made with respect to the personal preferences of the economic agents. The means are only valued in their capacity to meet human wants and even if the mean or goal itself is socially or ethically discussable and even unacceptable, the neoclassical economist will only look at the instrumental value for fulfilling human ends. This contrasts with Baudrillard’s view on desires and needs (Baudrillard, 1998) and our discussion on this subject earlier. From an intergenerational and intragenerational point of view, humanity first has to give priority to fulfilling the needs of others in a sustainable way before focussing on maintaining desires. Here, ethical sound decisions have to be made by policy makers, leading to choices that are good for the whole human society and not only for individuals or groups that can afford it.

This discussion is not new. Already in ancient Greece, Aristotle (350 B.C.) mentioned in his book ‘Politics’ the difference between *oikonomia* and *chrèmatistikè*. While economy stands for the rules (*nomia*) for the good management of the household (*oikos*), chrematistics focuses on how goods (*chrèmata*) can be acquired. Both chrematistics and economics are linked: agriculture is a way to obtain goods and thus belongs to the domain of chrematistics, while the right use and distribution of it belongs to the domain of economics. Goods can also be exchanged in order to correct shortages or surpluses, both on a household as on a community level, and done from a virtuous attitude. Money can be used as medium to facilitate exchange, since this was the primary use of money. But money also gives the opportunity to gain wealth without limits. For Aristotle, this limitless pursuit and accumulation of wealth cannot be the goal of the household, since wealth as such is not what we are seeking, but is only a useful means to obtain ‘the good life’ for the household and/or the community. Nevertheless, an inversion of goals and means occurred: profit became the goal and ‘human desires’ the instrument.

For a neoclassical economist, there is also no accountability of the economic agents. Graafland (2007) illustrates this by the example of an increase in unemployment, where neoclassical economists will explain ‘what’ has caused it, and not ‘who’. Since the Brundtland definition states that “humanity has the ability to make development sustainable”, one cannot allow that only the market will decide how the six functions are balanced. Markets are not perfect, behaviour is not always rational and fierce competition can persuade companies to lessen their moral standards.

Chapter 4

Animal efficiency as keystone in the 6F-discussion

Introduction

Animals play a pivotal role in the 6F-discussion. They are an important food source, not only because of their high nutritional value, as discussed earlier, but also because animals can increase global food production by using land that is not suitable for crop production, or feed stocks that are inedible for humans. Feed production for animals is ambiguous: feed crop production often competes with food production, although the feed crops are interesting for crop rotation. Animals are often fed with by-products from vegetable oil extraction, needed for food oil, biofuel or bioplastic production. Animals convert biomass that also could be used for energy production by fermentation. Also in Foster, animals play an important role: they maintain landscapes and ecosystems by grazing and spreading seeds by their droppings. But animal production has also a negative impact on Foster: it is responsible for deforestation, desertification, GHG-emissions, eutrophication and other environmental hazards. Furthermore, animals are also used for fun, not only as pets or for leisure (e.g. horses), but also when they are eaten just because of their taste and not as a necessary part of the human diet. Therefore, one could say that animal production plays an important role within the 6F-equilibrium. Future choices in animal production will affect the 6F-discussion in several ways. Therefore, in this chapter we will focus on efficiency in animal production.

4.1 Another view on animal efficiency

In 1975, van Es estimated energy and protein efficiency in animal production. He made a distinction between apparent digestible energy and apparent and true metabolisable energy. Apparent digestible energy is the difference between the gross energy of the feed consumed by the animal and the excreted faecal energy. The ratio between the apparent digestible energy and gross energy is the (apparent) digestibility coefficient, and indicates the efficiency with which the gross energy is retained by the body and hence not excreted in the faeces. Next, the apparent metabolisable energy is the apparent digestible energy corrected for energy losses in gasses (mainly CH_4 due to fermentation) and urine. Urine contains energy-rich compounds such as urea, uric acid and other metabolites, but these compounds are lost from the organism. Fermentation energy is the energy that is produced by the microbiota in the digestive tract, especially in animals living in symbiosis with cellulose-degrading bacteria. This energy can be used by the animal in a cold environment for thermoregulatory purposes, but most of the time, it cannot be used and hence is lost. Fermentation energy is estimated as a 10% loss for cows, 5% for horses and is negligible for monogastrics. Finally, the true metabolisable energy is the apparent metabolisable energy corrected for the fraction of endogenous energy in faeces (e.g. digestive enzymes, enterocytes) and in urine (e.g. metabolites for protein turnover).

4.1.1 Use of metabolisable energy

There are some differences between monogastric species and ruminants in the utilisation of metabolisable energy. First of all, monogastric animals are able to resorb a larger part of the carbohydrates, which is useful, because more ATP can be formed from this than from other chemical compounds. Second of all, ruminants need more metabolisable energy for fat synthesis, since the organic compounds resorbed are mostly amino acids and volatile fatty acids. For the formation of fats, the efficiency from amino acids and volatile fatty acids is lower than from carbohydrates. Third, the metabolisable energy in ruminants includes 10% of heat energy and 5% in monogastric animals. Lastly, ruminants have a larger need of metabolisable energy if the feed is less concentrated, because of the heat losses during bacterial digestion and higher need for energy for transport through the digestion tract. From that point of view, monogastric animals seem to have an advantage, but ruminants are able to get more metabolisable energy from cellulose- and lignine-rich feed.

To explain the energy utilisation in production animals, van Es used following equation (van Es, 1975, p. 119):

$$NE = a\,(ME - b\,W^{0,75})$$

NE = net energy used for meat and/or milk production (kcal/day)

ME = metabolisable energy (kcal/day)

$W^{0,75}$ = metabolic body weight (kg)

a = utilisation coefficient

b = maintenance coefficient

The maintenance coefficient b is defined as the amount of metabolisable energy needed for maintenance per unit of metabolic weight.

This equation only applies on homeothermic species, because these need a lot of energy to maintain their body temperature. Therefore they have a totally different energy need for maintenance compared with poikilothermic species.

The part of the equation between brackets is the metabolisable energy that can be used for the synthesis of tissue, milk, eggs and other products. The utilisation coefficient 'a' indicates to which extent the available energy is actually used.

The equation above could also be written as:

$$\frac{NE}{W^{0,75}} = a\,\frac{ME}{W^{0,75}} - ab = a\left(\frac{ME}{W^{0,75}} - b\right)$$

The graphical representation of this formula, with all values from the same animal, is:

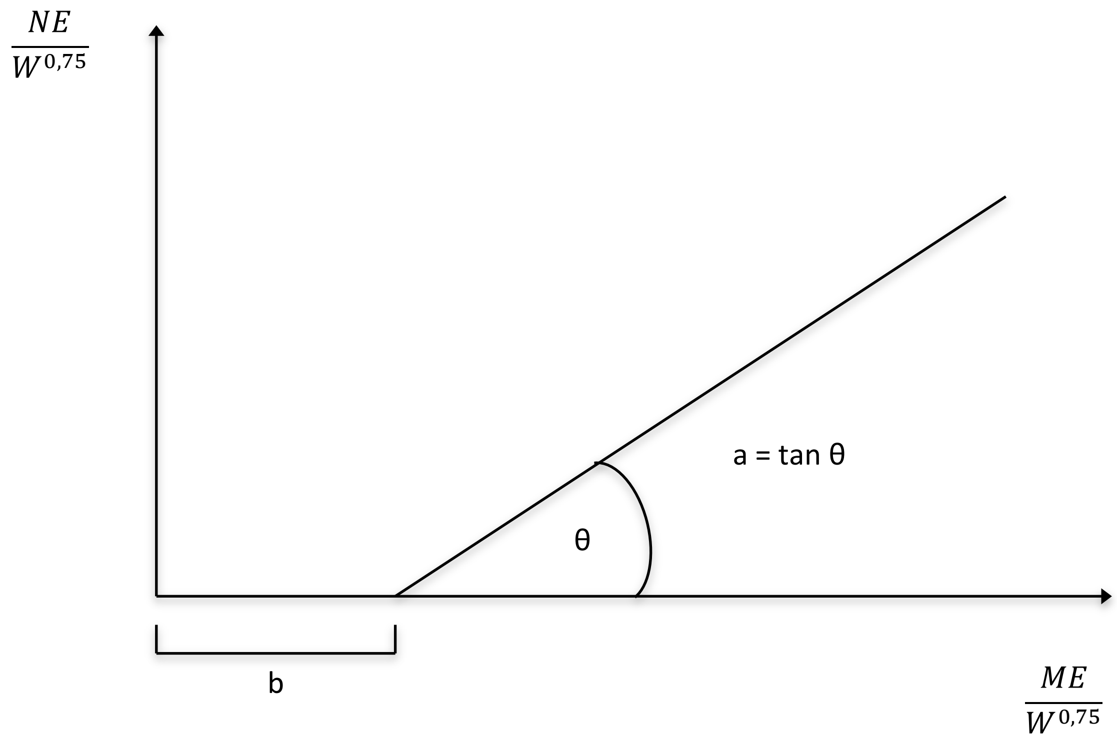


Figure 4.1: Relation between metabolisable energy and net energy used for production. Source: van Es (1975).

Van Es' first remark on figure 4.1 is that the measurements for composing the graph depend on the growth or production stadium of the animal. Animals in a growth, lactation or laying period have a rather low ME-intake per metabolic weight. Periods of low production have a higher ratio of ME over metabolic weight. Therefore, van Es suggests eliminating this correlation by varying measurements of high and low feed levels for growing animals. Even with this adjustment, the model will probably not give the correct values for coefficients 'a' and 'b'. The animal will first use its reserves to maintain production level, followed by changes in behaviour (e.g. less movement) in order to try to minimize its ME-need. The difference in activity is also correlated with age.

According to van Es (1975, specifically the utilisation coefficient 'a' for growing animals will be lower in practice than in theory. The protein synthesis during growth uses more ME, because of the shorter half-life of proteins in tissues for a larger ratio of protein growth per metabolic weight. Normally, this will alter the maintenance coefficient, but in this model, the maintenance coefficient is independent from production, leading to a lower utilisation coefficient.

4.1.2 Animal efficiency by van Es (1975)

In his research, van Es (1975) questioned what the efficiency would be of turning plants into animal products. He imagined huge energy losses and wanted to find out to which extent humans could use feed themselves instead of feeding it to animals and eating the animal products.

To determine the amount of feed needed for an animal, van Es started from average feed use and average production during the life of an animal, also taking into account the feed for maintenance and production during gestation and lactation of the mother animal. For this, van Es made a few assumptions:

- Humans cannot use roughage like grass, hay, straw etc. as source of ME and they do not want it either.
- Humans can and want to use calves' milk for 100%, concentrate for poultry and pigs for 75% and concentrate for cattle for 50% as source of ME.

- Humans have approximately the same digestion coefficients as pigs and therefore pig digestibility coefficients are used.

- Concentrates for ruminants are partially composed of by-products from the food industry (brans, pulp, oil cakes…), which are cellulose-rich and therefore less attractive for humans.

- During food shortage, humans are willing to eat feed products that they otherwise would not eat.

Van Es defines the efficiency coefficients as follows:

$$Energy\ efficiency = \frac{ME\ available\ for\ humans\ in\ animal\ products}{ME\ for\ humans\ in\ animal\ feeds}$$

$$Protein\ efficiency = \frac{Protein\ available\ for\ humans\ in\ animal\ products}{Protein\ for\ humans\ in\ animal\ feeds}$$

The results of his calculations can be found in table 4.1.

Table 4.1: Energy and protein efficiency in periods of food abundance as calculated by van Es (1975, p. 137).

Species	**Energy efficiency**	**Protein efficiency**
Broiler	0.29	0.43
Laying hen	0.23	0.40
Pig	0.40	0.34
Meat calf	0.28	0.33
Cattle, extensive	1.3	2.7
Cattle, intensive	0.41	0.94
Dairy cow	2.4	2.7

Efficiency coefficients close to one indicate that eating animal products is almost as efficient as eating the animal feed itself. Dairy cows show coefficients larger than one, indicating that there is an upgrading of the feed because of the large amount of roughage in the ration, which is not digestible by humans. On first sight, the efficiency coefficients of the other animal species are rather low, but one has to interpret these coefficients correctly. They only inform about the ME and proteins (on N-basis). They do not imply anything about the digestibility of the proteins, nor the vitamins and minerals which are often more available in animal products compared to vegetable products (cfr. supra). Furthermore, by-products from the food industry can be converted into a high-quality product.

Since these coefficients are from 1975 and both genetics of the animals and feed rations are strongly adapted, a recalculation was needed. In this chapter, we focus on the Belgian situation.

4.2 Recalculation of animal efficiency as defined by van Es (1975)

4.2.1 Rebuilding the model

Our model starts from the same underlying thoughts: how much energy or proteins are available for humans in animal products compared with the availability for humans in the direct consumption of animal feeds. This could be seen as follows:

$$\frac{[Feed \rightarrow animal \rightarrow human]}{[Feed \rightarrow human]} \gtreqless 1$$

If it is more efficient to feed the animals and eat the animal products, the equation will be larger than one. If the equation is smaller than one, it is more efficient to eat the feed itself.

For the numerator, the total amount of animal products on a population level will be taken into account to calculate the amount of energy and proteins in animal products that are available for humans. For the model, a population of 1000 breeding females and their offspring will be taken as starting point. Due to intensification, especially for species where artificial insemination is common, the number of breeding males in the population is very small and therefore will be neglected in this model (we will justify it later). The total amount of animal products for each population depends on several characteristics:

- Type of animal: some are only kept for meat, while others are mainly kept for other products (milk, eggs) but are slaughtered after production.
- Number of animals: not every animal species has the same number of offspring per breeding female. Also some animals die before they could be slaughtered.
- Slaughtering weight: each species has his own preferred slaughter weight. Also within the species different slaughtering weights occur. Meat pigs, for example, are slaughtered not fully grown-up at 110 kg in Belgium, while breeding sows are slaughtered as adults at about 190 kg.
- Meat percentage: some parts of the animals, like skin, feathers, intestines, bones … are not eaten.
- Energy and protein content: milk, eggs and meat have a different energy and protein content.

To know how much energy or protein is available for humans, starting from a breeding population of 1000 females, the digestibility of each animal product (i.e. milk, eggs or meat) has to be taken into account. The amount of energy or proteins that is available for humans, when feeding and eating animals, could be calculated as follows:

$$[Feed \rightarrow animal \rightarrow human] = \sum V_{ap} \cdot EP_{ap} \cdot DC_{ap\_h}$$

$[Feed \rightarrow animal \rightarrow human]$= energy or protein available for humans from animal products

V_{ap} = volume of a specific animal product on population level

EP_{ap} = energy or protein value of the specific animal product

DC_{ap_h} = digestibility coefficient for humans for the specific animal product

For the denominator, we start from the amount of feed needed to produce the amount of animal products as calculated earlier. Since animals of different ages or production stages differ in their nutritional needs to obtain optimal production or growth, multiphase feeding is a common practice within intensive agriculture. In the model, the total amount of feed for the population is calculated by making the sum of the feed taken up by the animals in each phase. Where van Es (1975) used an overall-percentage, here the specific feed components of the ration for each phase are taken into account. The ration compositions were obtained from feed companies and experts in the field. The total volume of each component for the whole population can thus be calculated. Since the digestibility of the components differs between animal species and humans, the energy and protein available for humans can be obtained as follows:

$$[Feed \rightarrow human] = \sum V_{fc} \cdot EP_{fc} \cdot DC_{fc\_h}$$

$[Feed \rightarrow human]$ = energy or protein available for humans when directly consuming the feed

V_{fc} = volume of a certain feed component in the animal ration on population level

EP_{fc} = energy or protein value of food component

DC_{fc_h} = digestibility coefficient for humans for a certain feed component

The global formula could be rewritten as:

$$\frac{[Feed \rightarrow animal \rightarrow human]}{[Feed \rightarrow human]} = \frac{\sum V_{ap} \cdot EP_{ap} \cdot DC_{ap\_h}}{\sum V_{fc} \cdot EP_{fc} \cdot DC_{fc\_h}} \gtreqless 1$$

The digestibility coefficients for the different components are taken from Perez *et al.* (2004) or older articles (Piccioni, 1965; Fonnesbeck *et al.*, 1984; Blum *et al.*, 1986) when necessary.

4.2.2 Pigs

The starting population of 1000 sows will farrow eight times with a litter size of 12 piglets, leading to a meat pig population of 96 000. To calculate the amount of energy and proteins available for humans out of this population, certain characteristics have to be taken into account. These characteristics can differ from farmer to farmer or country to country. Therefore, this cannot be projected on e.g. extensive pig production. The used population parameters, obtained from practical experts in the field, can be found in table 4.2, together with the calculated energy and protein availability.

Table 4.2: Pigs: population characteristics and energy and protein available for humans from animal products.

	Sows	**Meat pigs**	**Total**
Number of animals	1000	96 000	
Falling-out percentage	5%	9%	
Animals slaughtered	950	87 360	88 310
Slaughtering weight	190 kg	110 kg	
Meat percentage	45%	48%	
Total amount of meat	81 225 kg	4 612 608 kg	4 693 833 kg
Energy content of meat	7988 kJ/kg	6732 kJ/kg	
Utilisation coefficient humans	84.1%	84.1%	
Energy available for humans	**$5.46 \cdot 10^8$ kJ**	**$2.61 \cdot 10^{10}$ kJ**	**$2.67 \cdot 10^{10}$ kJ**
Protein content of meat	19.62%	19.88%	
Utilisation coefficient humans	90%	90%	
Protein available for humans	**$1.43 \cdot 10^4$ kg**	**$8.25 \cdot 10^5$ kg**	**$8.40 \cdot 10^5$ kg**

The energy and protein content of the meat are estimated on data from Nubel (2013), taking 60% of lean meat and 40% of fat meat for the meat pigs and 40% lean meat and 60% fat meat for the sows.

To calculate the denominator, the total amount of feed has to be taken into account. In pig production, multiphase feeding is common. The amount of feed can be found in table 4.3.

Table 4.3: Energy and protein intake by pigs.

Phase	**Feed intake per animal (kg)**	**ME/kg feed (kJ/kg)**	**Total ME (kJ)**	**Digestible protein/kg feed (%)**	**Total digestible protein (kg)**
Sow: raise	462	$1.12 \cdot 10^{4}$	$5.18 \cdot 10^{9}$	11.05	$5.11 \cdot 10^{4}$
Sow: gestation	2530	$1.07 \cdot 10^{4}$	$2.69 \cdot 10^{10}$	8.94	$2.26 \cdot 10^{5}$
Sow: lactation	1250	$1.10 \cdot 10^{4}$	$1.26 \cdot 10^{10}$	10.66	$1.23 \cdot 10^{5}$
Meat pig: 7 – 20 kg	25	$1.24 \cdot 10^{4}$	$2.97 \cdot 10^{10}$	12.21	$2.93 \cdot 10^{5}$
Meat pig: 20 – 40 kg	60	$1.13 \cdot 10^{4}$	$6.51 \cdot 10^{10}$	11.32	$6.52 \cdot 10^{5}$
Meat pig: 40 – 80 kg	100	$1.13 \cdot 10^{4}$	$1.09 \cdot 10^{11}$	10.48	$1.01 \cdot 10^{6}$
Meat pig: 80 – 110 kg	100	$9.78 \cdot 10^{3}$	$9.39 \cdot 10^{10}$	7.77	$7.46 \cdot 10^{5}$
Total			$\mathbf{3.42 \cdot 10^{11}}$		$\mathbf{3.10 \cdot 10^{6}}$

Since humans cannot digest or do not want to eat certain feed components, the amount of energy and proteins has to be adapted. Here, by-products from oil extraction (soy, rapeseed, coleseed, sunflower), sugar production (beet mash, molasse) and other feed industries (cookie meal, wheat gluten, draff, whey, glycerol…) are given a digestibility of zero. These components account for about 20% (young sows and pigs < 20 kg), 30% (meat pigs and lactating sows) and 40% (sows during gestation) of the total ration. The adapted calculations can be found in table 4.4.

Table 4.4: Energy and protein availability to humans from the pig ration.

Phase	**ME/kg feed (kJ/kg)**	**Total ME (kJ)**	**Digestible protein/kg feed (%)**	**Total digestible protein (kg)**
Sow: raise	$9.12\cdot10^{3}$	$4.21\cdot10^{9}$	5.32	$2.46\cdot10^{4}$
Sow: gestation	$6.53\cdot10^{3}$	$1.65.\ \cdot0^{10}$	4.51	$1.14\cdot10^{5}$
Sow: lactation	$8.07\cdot10^{3}$	$9.29\cdot10^{9}$	5.99	$6.89\cdot10^{4}$
Meat pig: 7 – 20 kg	$9.47\cdot10^{3}$	$2.27\cdot10^{10}$	7.96	$1.91\cdot10^{5}$
Meat pig: 20 – 40 kg	$7.16\cdot10^{3}$	$4.12\cdot10^{10}$	4.43	$2.55\cdot10^{5}$
Meat pig: 40 – 80 kg	$7.95\cdot10^{3}$	$7.63\cdot10^{10}$	4.92	$4.73\cdot10^{5}$
Meat pig: 80 – 110 kg	$6.67\cdot10^{3}$	$6.40\cdot10^{10}$	4.44	$4.27\cdot10^{5}$
Total		$\mathbf{2.34\cdot10^{11}}$		$\mathbf{1.55\cdot10^{6}}$

The energy efficiency for humans is then calculated as follows:

$$\frac{[Feed \rightarrow animal \rightarrow human]}{[Feed \rightarrow human]} = \frac{\mathbf{2.67 \cdot 10^{10}\ kJ}}{\mathbf{2.34 \cdot 10^{11}\ kJ}} = 0.1138 = 11.38\%$$

The protein efficiency for humans is then calculated as follows:

$$\frac{[Feed \rightarrow animal \rightarrow human]}{[Feed \rightarrow human]} = \frac{\mathbf{8.40 \cdot 10^{5}\ kg}}{\mathbf{1.55 \cdot 10^{6}\ kg}} = 0.5389 = 53.89\%$$

4.2.3 Broilers

Also for broilers, we start from a population of 1000 broiler breeders. Each broiler breeder lays about 182 eggs, with a hatching percentage of 80%, leading to a broiler population of 145 600. As in pig production, species-specific characteristics are needed to calculate the energy and protein available from the meat for humans. The population characteristics used in table 4.5 are obtained from practical experts in the field. The energy and protein content of the meat are from Nubel (2013).

Table 4.5: Broilers: population characteristics and energy and protein available to humans from animal products.

	Broiler breeder	**Broiler**	**Total**
Number of animals	1000	145 600	
Falling-out percentage	12%	3%	
Animals slaughtered	880	141 232	142 112
Slaughtering weight	4.1 kg	2.7 kg	
Meat percentage	65%	62%	
Total amount of meat	2345 kg	236 422 kg	238 767kg
Energy content of meat	10 320 kJ/kg	6710 kJ/kg	
Utilisation coefficient humans	84,1%	84,1%	
Energy available for humans	**$2.04 \cdot 10^7$ kJ**	**$1.33 \cdot 10^9$ kJ**	**$1.35 \cdot 10^9$ kJ**
Protein content of meat	19.00%	19.20%	
Utilisation coefficient humans	90%	90%	
Protein available for humans	**401 kg**	**$4{,}09.10^4$ kg**	**$4.13 \cdot 10^4$ kg**

To calculate the denominator, the total amount of feed has to be taken into account. Also in boiler production, multiphase feeding is common. The amount of feed can be found in table 4.6.

Table 4.6: Energy and protein intake by broilers.

Phase	Feed intake per animal (kg)	ME/kg feed (kJ/kg)	Total ME (kJ)	Digestible protein/kg feed (%)	Total digestible protein (kg)
Broiler: 0-4 weeks	2.22	$1.08 \cdot 10^{4}$	$3.50 \cdot 10^{9}$	16.62	$5.37 \cdot 10^{4}$
Broiler: 5-6 weeks	2.85	$1.09 \cdot 10^{4}$	$4.54 \cdot 10^{9}$	13.03	$5.41 \cdot 10^{4}$
Broiler breeder: 0-6 weeks	1.55	$9.11 \cdot 10^{3}$	$1.42 \cdot 10^{7}$	18.11	281
Broiler breeder: 7-24 weeks	9.69	$1.00 \cdot 10^{4}$	$9.68 \cdot 10^{7}$	14.56	$1.41 \cdot 10^{3}$
Broiler breeder: laying (25-64 weeks)	44.72	$9.96 \cdot 10^{3}$	$4.45 \cdot 10^{8}$	9.71	$1.00 \cdot 10^{3}$
Total			$\mathbf{8.59 \cdot 10^{9}}$		$\mathbf{1.14 \cdot 10^{5}}$

Also in the ration of broilers and broiler breeders, certain feed components are not eaten by humans. Especially soybean meal is important in the different rations: from 10% to more than one third of the ration. Furthermore also animal products, like feather meal, are used. The adapted values can be found in table 4.7.

Table 4.7: Energy and protein availability to humans from the broiler ration.

Phase	ME/kg feed (kJ/kg)	Total ME (kJ)	Digestible protein/kg feed (%)	Total digestible protein (kg)
Broiler: 0-4 weeks	8058	$2.60 \cdot 10^{9}$	3.93	$1.27 \cdot 10^{4}$
Broiler: 5-6 weeks	10000	$4.17 \cdot 10^{9}$	6.00	$2.49 \cdot 10^{4}$
Broiler breeder: 0-6 weeks	6793	$1.06 \cdot 10^{7}$	8.57	133
Broiler breeder: 7-24 weeks	8012	$7.76 \cdot 10^{7}$	8.99	871
Broiler breeder: laying (25-64 weeks)	2097	$9.38 \cdot 10^{7}$	5.41	2420
Total		$\mathbf{6.96 \cdot 10^{9}}$		$\mathbf{4.11 \cdot 10^{4}}$

The energy efficiency for humans is then calculated as follows:

$$\frac{[Feed \rightarrow animal \rightarrow human]}{[Feed \rightarrow human]} = \frac{\mathbf{1.35 \cdot 10^9\ kJ}}{\mathbf{6.96 \cdot 10^9\ kJ}} = 0.1947 = 19.47\%$$

The protein efficiency for humans is then calculated as follows:

$$\frac{[Feed \rightarrow animal \rightarrow human]}{[Feed \rightarrow human]} = \frac{\mathbf{4.13 \cdot 10^4\ kg}}{\mathbf{4.11 \cdot 10^4\ kg}} = 1.0048 = 100.48\%$$

4.2.4 Laying hens

The breeding population will produce 245 chicks per breeder, half of which will be hens. Total laying hen population thus will be 122 500 animals. The males are culled as day-old-chicks and will not be taken into account in these calculations, since they are not used for human purposes. After egg production, both breeders and layers are slaughtered. All characteristics in table 4.8 are obtained from practical experts in the field. The energy and protein content are from Nubel (2013).

Table 4.8: Laying hens: population characteristics and energy and protein available for humans.

	Breeders	**Layers**	**Eggs**	**Total**
Number of eggs			48 599 425	
Average egg weight			62.9 g	
Number of animals	1000	122 500		
Falling-out percentage	4%	6%		
Animals slaughtered	960	115 150		
Slaughtering weight	1.7 kg	1.7 kg		
Meat percentage	63%	63%		
Total amount of animal product	1028 kg	123 326 kg	3 056 904 kg	
Energy content	10 320 kJ/kg	10 320 kJ/kg	6440 kJ/kg	
Utilisation coefficient humans	84.1%	84.1%	84.1%	
Energy available for humans	**$8.92 \cdot 10^6$ kJ**	**$1.07 \cdot 10^9$ kJ**	**$1.66 \cdot 10^{10}$ kJ**	**$1.76 \cdot 10^{10}$ kJ**
Protein content	19.00%	19.00%	12.6%	
Utilisation coefficient humans	90%	90%	100%	
Protein available for humans	**176 kg**	**$2.11 \cdot 10^4$ kg**	**$3.85 \cdot 10^5$ kg**	**$4.06 \cdot 10^5$ kg**

Each layer hen will produce 409 eggs with an average weight of 62.9 grams during 72 weeks. Since 6% of the layers will die before the end of their productive period, total egg production of the population here discussed is estimated as the number of eggs layed by the number of animals slaughtered, augmented with half of the number of eggs of the 6% that do not finish their productive period.

To calculate the denominator, the total amount of feed from all different phases has to be taken into account. The amount of feed can be found in table 4.9.

Table 4.9: Energy and protein intake by layers.

Phase	**Feed intake per animal (kg)**	**ME/kg feed (kJ/kg)**	**Total ME (kJ)**	**Digestible protein/kg feed (%)**	**Total digestible protein (kg)**
Breeder: 0 – 18 weeks	6.94	$9.95 \cdot 10^3$	$6.91 \cdot 10^7$	13.02	904
Breeder: 17 – 70 weeks	35.36	$9.95 \cdot 10^3$	$3.52 \cdot 10^8$	13.87	$4.90 \cdot 10^3$
Layer: 0 – 18 weeks	6.60	$9.88 \cdot 10^3$	$7.99 \cdot 10^9$	18.11	$9.14 \cdot 10^4$
Layer: 19 weeks – 50% laying	1.62	$9.73 \cdot 10^3$	$1.93 \cdot 10^9$	11.34	$2.25 \cdot 10^4$
Layer: 50% laying – 50 weeks	23.07	$1.02 \cdot 10^4$	$2.89 \cdot 10^{10}$	10.92	$3.09 \cdot 10^5$
Layer: 50 – 90 weeks	31.64	$1.01 \cdot 10^4$	$3.90 \cdot 10^{10}$	10.61	$4.11 \cdot 10^5$
Total			$\mathbf{7.82 \cdot 10^{10}}$		$\mathbf{8.40 \cdot 10^5}$

Again, certain feed components are not eaten by humans. In layer rations, by-products from oil extraction (soy and sunflower) are used, next to minor percentages from feed industry (e.g. wheat draff) and alfalfa pellets. The percentage increases from about 24% for young laying pullets up to about 45% for breeders. The amount of energy and protein available for humans can be found in table 4.10.

Table 4.10: Energy and protein availability to humans from the layer ration.

Phase	ME/kg feed (kJ/kg)	Total ME (kJ)	Digestible protein/kg feed (%)	Total digestible protein (kg)
Breeder: 0-18 weeks	$8.16.10^3$	$5.66\cdot10^7$	4.66	324
Breeder: 17-70 weeks	$6.40.10^3$	$2.26\cdot10^8$	3.47	$1.23\cdot10^3$
Layer: 0-18 weeks	$8.74.\ 10^3$	$7.07\cdot10^9$	5.10	$4.12\cdot10^4$
Layer: 19 weeks – 50% laying	$8.59.10^3$	$1.70\cdot10^9$	5.10	$1.01\cdot10^4$
Layer: 50% laying – 50 weeks	$7.63.10^3$	$2.16\cdot10^{10}$	4.03	$1.14\cdot10^5$
Layer: 50-90 weeks	$7.52.10^3$	$2.92\cdot10^{10}$	3.95	$1.53\cdot10^5$
Total		$\mathbf{5.98\cdot10^{10}}$		$\mathbf{3.20\cdot10^5}$

The energy efficiency for humans is as follows:

$$\frac{[Feed \rightarrow animal \rightarrow human]}{[Feed \rightarrow human]} = \frac{\mathbf{1.76 \cdot 10^{10}\ kJ}}{\mathbf{5.98 \cdot 10^{10}\ kJ}} = 0.2950 = 29.50\%$$

The protein efficiency for humans is as follows:

$$\frac{[Feed \rightarrow animal \rightarrow human]}{[Feed \rightarrow human]} = \frac{\mathbf{4.06 \cdot 10^{5}\ kg}}{\mathbf{3.20 \cdot 10^{5}\ kg}} = 1.2695 = 126.95\%$$

4.2.5 Dairy cattle

Dairy cows only produce milk after giving birth to a calf. Since cows only have one calf a year, the daughters are used to replace the mothers. Therefore, unlike pigs and chickens, cows are both breeders and production animals. The male calves are fattened for veal production. In this model, we will not consider these males and focus on milk production alone. Bull calves from dairy cows are not the most efficient way to produce cow meat, influencing the efficiency of milk in a negative way, and the impact would be rather small: one cow gives birth to two calves for veal production, each resulting in about 160 kg of meat or $9.15 \cdot 10^5$ kJ and 32,8 kg of proteins. Compared with total energy and protein production by the dairy cows, veal calves only add for 2.71% and therefore can be neglected. With sexed sperm, it is theoretically possible to produce no bull calves at all. The used population parameters, obtained from practical experts in the field, can be found in table 4.11.

Table 4.11: Dairy cows: population characteristics and energy and protein available for humans from animal products.

	Cows	Milk	Total
Total milk production		$2.89 \cdot 10^7$ kg	
Number of animals	1000		
Falling-out percentage	7.5%		
Animals slaughtered	925		
Slaughtering weight	600 kg		
Meat percentage	45%		
Total amount of meat	249 750 kg		
Energy content	8400 kJ/kg	2710 kJ/kg	
Utilisation coefficient humans	84.1%	84.1%	
Energy available for humans	**$1.76 \cdot 10^9$ kJ**	**$6.58 \cdot 10^{10}$ kJ**	**$6.76 \cdot 10^{10}$ kJ**
Protein content	19.2%	3.3%	
Utilisation coefficient humans	90%	100%	
Protein available for humans	**$4.32 \cdot 10^4$ kg**	**$9.53 \cdot 10^5$ kg**	**$9.96 \cdot 10^5$ kg**

The energy and protein content of the meat is derived from Nubel (2013), taking 40% lean meat and 60% fat meat. As for laying hens, total milk production is based on the production of the animals slaughtered (average life production of 30 000 kilo milk) and half of the milk of those that die early. The amount of energy and proteins available in the total amount of feed available for animals can be found in table 4.12. For the rations with grass and maize silage, the feed intake per animal is expressed in kilogram dry matter.

Table 4.12: Energy and protein intake by dairy cows.

Phase	**Feed intake per animal (kg)**	**ME/kg feed (kJ/kg)**	**Total ME (kJ)**	**Digestible protein/kg feed (%)**	**Total digestible protein (kg)**
Calf: pre-weaning	303	$1.94 \cdot 10^4$	$5.86 \cdot 10^9$	20.17	$6.11 \cdot 10^4$
Calf: post-weaning	391	$1.06 \cdot 10^4$	$4.14 \cdot 10^9$	15.45	$6.04 \cdot 10^4$
Pre-lactation	5191	$1.15 \cdot 10^4$	$5.97 \cdot 10^{10}$	11.40	$5.92 \cdot 10^5$
Lactation	$3.10.10^7$	$1.02 \cdot 10^4$	$3.16 \cdot 10^{11}$	7.27	$2.25 \cdot 10^6$
Total			**$3.86 \cdot 10^{11}$**		**$2.97 \cdot 10^6$**

Because they are ruminants, dairy cows can convert many inedible feed products. Not only roughages are unwanted by humans, also a large part of the concentrates exists of by-products from the feed industry like sugar beet pulp and rapeseed meal. Therefore, more than 85 per cent of the ration is not usable for humans, leading to the results in table 4.13.

Table 4.13: Energy and protein availability to humans from the dairy cow ration.

Phase	ME/kg feed (kJ/kg)	Total ME (kJ)	Digestible protein/kg feed (%)	Total digestible protein (kg)
Calf: pre-weaning	$1.70 \cdot 10^4$	$5.14 \cdot 10^9$	15.27	$4.62 \cdot 10^4$
Calf: post-weaning	$3.70 \cdot 10^3$	$1.45 \cdot 10^9$	2.35	$9.20 \cdot 10^3$
Prelactation	$1.36 \cdot 10^3$	$7.05 \cdot 10^9$	0.69	$3.61 \cdot 10^4$
Lactation	0	0	0	0
Total		$\mathbf{1.36 \cdot 10^{10}}$		$\mathbf{9.15 \cdot 10^4}$

The energy efficiency for humans:

$$\frac{[Feed \rightarrow animal \rightarrow human]}{[Feed \rightarrow human]} = \frac{\mathbf{6.76 \cdot 10^{10}\ kJ}}{\mathbf{1.36 \cdot 10^{10}\ kJ}} = 4.9550 = 495.50\%$$

The protein efficiency for humans:

$$\frac{[Feed \rightarrow animal \rightarrow human]}{[Feed \rightarrow human]} = \frac{\mathbf{9.96 \cdot 10^{5}\ kg}}{\mathbf{9.15 \cdot 10^{4}\ kg}} = 10.8855 = 1088.55\%$$

4.2.6 Cattle: Belgian blue

For cattle meat production, the calculations are based on intensive meat production with Belgian blue cattle. During its life, an average meat cow will give birth to three calves. Two of them will be slaughtered, the third one will replace the mother in the next generation. Therefore, the population here exists of 1000 breeding animals and 2000 slaughter animals. The population parameters, obtained from practical experts in the field, can be found in table 4.14. The energy and protein content of the meat estimated on data from Nubel (2013), taking 60% of lean meat and 40% of fat meat.

Table 4.14: Cattle: population characteristics and energy and protein available for humans from animal products.

	Breeders	**Slaughter**	**Total**
Number of animals	1000	2000	
Falling-out percentage	6.3%	15%	
Animals slaughtered	937	1700	2637
Slaughtering weight	650 kg	700 kg	
Meat percentage	55%	60%	
Total amount of meat	334 978 kg	714 000 kg	1 048 979 kg
Energy content of meat	7100 kJ/kg	7100 kJ/kg	
Utilisation coefficient humans	84.1%	84.1%	
Energy available for humans	**$2.00 \cdot 10^9$ kJ**	**$4.26 \cdot 10^9$ kJ**	**$6.26 \cdot 10^9$ kJ**
Protein content of meat	19.8%	19.8%	
Utilisation coefficient humans	90%	90%	
Protein available for humans	**$5.97 \cdot 10^4$ kg**	**$1.27 \cdot 10^5$ kg**	**$1.87 \cdot 10^5$ kg**

The amount of energy and proteins available for animals in the total amount of feed can be found in table 4.15. The milk consumed by the calves is not taken into account, since most calves are kept with the mother. The energy available on a population level stays the same, since the energy in the mother's milk is a result of the energy from the mother's ration. In case of separation in intensive systems, the artificial milk (about 30-35 kg of milk powder) should also be taken into account. Due to the large volumes of other feeds, the impact of this will be rather small on the total amount of energy and protein available in the ration for animals. For the rations with grass and maize silage, the feed intake per animal is expressed in kilogram dry matter. Since a cow has three calves, total feed intake during gestation and lactation is for three cycli.

Table 4.15: Energy and protein intake by Belgian blue.

Phase	**Feed intake per animal (kg)**	**ME/kg feed (kJ/kg)**	**Total ME (kJ)**	**Digestible protein/kg feed (%)**	**Total digestible protein (kg)**
Breeding cows					
3 – 21 days	3.6	572	$2.06 \cdot 10^{6}$	0.87	31.36
4 – 8 weeks	52.5	$4.44 \cdot 10^{3}$	$2.33 \cdot 10^{8}$	3.49	$1.82 \cdot 10^{3}$
9 – 12 weeks	68	$7.33 \cdot 10^{3}$	$4.99 \cdot 10^{8}$	5.93	$4.04 \cdot 10^{3}$
13 – 25 weeks	133	$1.14 \cdot 10^{4}$	$1.53 \cdot 10^{9}$	10.92	$1.46 \cdot 10^{4}$
Until insemination (16 months)	1830	$9.46 \cdot 10^{3}$	$1.73 \cdot 10^{10}$	5.97	$1.09 \cdot 10^{5}$
Gestation: 1 – 220 days	5490	$9.41 \cdot 10^{3}$	$5.59 \cdot 10^{10}$	4.98	$2.96 \cdot 10^{5}$
Gestation: 220 – 282 days	1860	$1.03 \cdot 10^{4}$	$1.91 \cdot 10^{10}$	7.9	$1.47 \cdot 10^{5}$
Lactation	2520	$1.15 \cdot 10^{4}$	$2.90 \cdot 10^{10}$	10.65	$2.68 \cdot 10^{5}$
Fattening reform cow	1000	$1.01 \cdot 10^{4}$	$1.01 \cdot 10^{10}$	7.65	$7.65 \cdot 10^{4}$

Phase	Feed intake per animal (kg)	ME/kg feed (kJ/kg)	Total ME (kJ)	Digestible protein/kg feed (%)	Total digestible protein (kg)
Slaughter population					
3 – 21 days	3.6	572	$4.12 \cdot 10^{6}$	0.87	62.71
4 – 8 weeks	52.5	$4.44 \cdot 10^{3}$	$4.68 \cdot 10^{8}$	3.49	$3.67 \cdot 10^{3}$
9 – 12 weeks	68	$7.33 \cdot 10^{3}$	$9.98 \cdot 10^{8}$	5.93	$8.07 \cdot 10^{3}$
13 – 25 weeks	133	$1.14 \cdot 10^{4}$	$3.05 \cdot 10^{9}$	10.92	$2.91 \cdot 10^{4}$
180 – 407 kg	2790	$9.62 \cdot 10^{3}$	$5.93 \cdot 10^{10}$	5.93	$3.31 \cdot 10^{5}$
407 kg – 700 kg	4071	$8.00 \cdot 10^{3}$	$6.51 \cdot 10^{10}$	5.44	$4.43 \cdot 10^{5}$
Total (breeding + slaughter)			$\mathbf{2.57 \cdot 10^{11}}$		$\mathbf{1.73 \cdot 10^{6}}$

Continuation of table 4.15

Table 4.16 shows the energy and proteins available for humans from the ration. In the Belgian blue ration, the use of concentrates is necessary to have an optimal growth. The rations can differ between farms: some use potatoes or bulk grains, others use composed pellets. The composition of the ration has a large influence on the calculated efficiency, since both edible and non-edible compounds can be used. In the following calculations, a concentrate based on barley, maize, colza meal, DDGS and molasses is used. About 60% of the concentrate is edible (considering barley as edible; see further). Since especially in the last phase of the slaughter population a large amount of concentrates (about half of the dry-matter-based ration) is fed, this has a large impact on total efficiency.

Table 4.16: Energy and protein availability humans from the Belgian blue ration.

Phase	ME/kg feed (kJ/kg)	Total ME (kJ)	Digestible protein/kg feed (%)	Total digestible protein (kg)
Slaughter population				
3 – 21 days	293	$2.11 \cdot 10^{6}$	0.19	13.45
4 – 8 weeks	$3.21 \cdot 10^{3}$	$3.37 \cdot 10^{8}$	1.56	$1.64 \cdot 10^{3}$
9 – 12 weeks	$5.35 \cdot 10^{3}$	$7.28 \cdot 10^{8}$	2.75	$3.74 \cdot 10^{3}$
13 – 25 weeks	$8.10 \cdot 10^{3}$	$2.16 \cdot 10^{9}$	4.66	$1.24 \cdot 10^{4}$
180 – 407 kg	$1.20 \cdot 10^{3}$	$6.68 \cdot 10^{9}$	0.69	$3.87 \cdot 10^{4}$
407 kg – 700 kg	$3.92 \cdot 10^{3}$	$3.20. \cdot 0^{10}$	2.27	$1.85 \cdot 10^{5}$
Breeding cows				
3 – 21 days	293	$1.06 \cdot 10^{6}$	0.19	6.73
4 – 8 weeks	$3.21 \cdot 10^{3}$	$1.69 \cdot 10^{8}$	1.56	820
9 – 12 weeks	$5.35 \cdot 10^{3}$	$3.64 \cdot 10^{8}$	2.75	$1.87 \cdot 10^{3}$
13 – 25 weeks	$8.09 \cdot 10^{3}$	$1.08 \cdot 10^{9}$	5.17	$6.89 \cdot 10^{3}$
Until insemination (16 months)	496	$9.09 \cdot 10^{8}$	0.29	$5.27 \cdot 10^{3}$
Gestation: 1 – 220 days	0	0	0	0
Gestation: 220 – 282 days	0	0	0	0
Lactation	0	0	0	0
Fattening reform cow	526	$5.26 \cdot 10^{8}$	0.31	$3.13 \cdot 10^{3}$
Total		$\mathbf{4.49 \cdot 10^{10}}$		$\mathbf{2.60 \cdot 10^{5}}$

The energy efficiency for humans:

$$\frac{[Feed \rightarrow animal \rightarrow human]}{[Feed \rightarrow human]} = \frac{\mathbf{6.26 \cdot 10^{9}\ kJ}}{\mathbf{4.49 \cdot 10^{10}\ kJ}} = 0.1395 = 13.95\%$$

The protein efficiency for humans:

$$\frac{[Feed \rightarrow animal \rightarrow human]}{[Feed \rightarrow human]} = \frac{\mathbf{1.87 \cdot 10^{5}\ kg}}{\mathbf{2.60 \cdot 10^{5}\ kg}} = 0.7199 = 71.99\%$$

4.3 Discussing animal efficiency

4.3.1 Comparison with van Es (1975)

Table 4.17 compares the results from van Es (see table 4.1) with the new calculated efficiencies for the different animal species.

Table 4.17: Comparing animal energy and protein efficiencies with the earlier results of van Es (1975).

	Energy efficiency		Protein efficiency	
	van Es (1975)	**Boonen**	**van Es (1975)**	**Boonen**
Pig	0.40	0.11	0.34	0.54
Broiler	0.29	0.19	0.43	1.00
Layer	0.23	0.29	0.40	1.27
Dairy cow	2.4	4.95	2.7	10.89
Cattle, intensive	0.41	0.14	0.94	0.72

Like the results of van Es (1975), the energy efficiency is still smaller than one, except for dairy cows. Although some might use this to prove animal production is energy inefficient, these results are rather logic: animal products are produced because of their high-value proteins and vitamins, not for their energy content.

The differences with van Es (1975) are the result of several factors. For energy efficiency of pigs for example, the large difference is caused by the fact that in van Es' calculations a pig of 105 kg delivers more than 1173 MJ, or an energy content of more than 11 000 kJ/kg. In reality, not the whole pig can be consumed (cfr. table 4.2: meat percentage of 45-50%) and the energy content of pig meat is now lower (about 6750 kJ/kg) due to selection for lean meat. Furthermore, not only the number of piglets per sow increased, also a larger part of the ration is edible for humans (68.5% compared with the 60% of van Es in 1975). Therefore, the energy efficiency nowadays is almost four times lower than in van Es' calculations forty years ago. For cattle, van Es also starts from 450 kg with an energy content of 8659 kJ/kg, while in our calculations the energy content is only 7100 kJ/kg. Furthermore, van Es estimates that about half of the cattle ration would be eaten by humans, while in current feeding strategies more inedible by-products are used. For layers and dairy cows, the increase is a result of an increase in production. Especially milk production per cow more than doubled during this period.

For proteins, an increase in efficiency can be found for almost all animal species (except intensive cattle; see further). This can be partially explained by better feed conversion. Furthermore, the percentage of "inedible" feed products is nowadays larger than in the time of van Es (1975). For pigs, the difference is not that large, but for poultry, the percentage is 50% rather than the 25% in van Es (1975) because of the large amount of soybean meal used in current rations. For ruminants, van Es (1975) estimated that 50% of the concentrates would be edible for humans. Nowadays, many by-products from the food and oil industry are used in dairy cow ration, decreasing its edibility to almost zero. For the Belgian blue, the protein efficiency is about 3.32 for the breeding females, while the slaughtered animals have a protein efficiency of about 0.65 due to the large volume of concentrates that is fed during the finishing phase. From the 6 kg of concentrates that is fed daily, about 60% of the ration used in the calculation are cereals and thus can be consumed by humans. As will be shown further, defining 'edible' has a strong impact on protein efficiency of Belgian blue cattle.

4.3.2 Importance of breeders for total population

In this model, breeding males were not taken into account. Table 4.18 shows the influence of the breeders for certain population characteristics. The first column shows the percentage of the number of breeders compared to the total population (both breeders and production animals; neglecting falling-out percentage); the second column shows the percentage of the total amount of feed that is used for the breeders; the third column shows the percentage of meat from the breeders. Due to the high number of progeny per breeder, the number of breeders for pigs and poultry is 1% or less of the total population. This can also be seen in the percentage of meat, although these percentages are slightly higher, due to lower falling-out. For feed, pig and poultry breeders score higher due to longer life expectancies than the slaughter generation. For dairy cows and Belgian blue, the number of breeders is higher, because they are both breeder and producer.

In poultry production, it is common to use one rooster for every ten hens or about 10% of the breeding population. Since breeders in poultry production only account for less than one per cent of the total population, males can be neglected. In pig and dairy cow production, artificial insemination is common practice. One male could fertilise hundreds of females, even up to more than one million for some famous dairy bulls. Also here, males account for less than one per cent of total population and thus can be neglected.

Table 4.18: Importance of breeders for total population.

	% breeders in number of animals	**% feed for breeders**	**% of meat from breeders**
Pig	1.03	13.15	1.76
Broiler	0.68	7.04	0.98
Layer	0.81	0.55	0.83
Dairy cow	100	100	100
Cattle	33.33	48.50	31.93

Table 4.18 also shows that when one wants to increase the feed efficiency of the total population, only minor returns are achievable by adjusting the ration of sows or poultry breeders. On the other hand, altering the ration of dairy cows and especially cattle will have major consequences on the efficiency ratio.

4.3.3 Influence of defining 'edible'

In the calculations, feed components are labelled by "edible by humans" or "inedible". For some feed components (e.g. grass silage or feather meal) this is quite obvious, but for others, it is more difficult. One could say, for example, that maize silage cannot be seen as something "inedible for humans": instead of silaging the whole plant, the kernels could be harvested and consumed by humans. The maize kernels in silage account for about 26% dry matter, so for the total amount of maize silage taken up by a dairy cow population of 1000 animals, this leads to $4.72 \cdot 10^{10}$ kJ of ME and 241 tons of digestible proteins extra for humans. The efficiency of dairy cows e.g. would decrease from 495.50% to 111.13% for energy and from 1088.55% to 299.15% for protein. On the other hand, one could question if this amount of maize kernels, when not eaten by cows, would be used as food. The dairy ration would deliver about 126 grams of maize kernels for each kilo of milk. Would a Western consumer prefer to eat this volume of maize or rather feed the kernels to the cows and eat the animal product?

Some feed components are considered “edible”, although they are not eaten in modern Western diets. Barley was important for humans in ancient times (Mayozer & Roudart, 2006), but is nowadays used for alcohol production (beer and distilled beverages like whiskey) and as animal feed. One could argue that since modern Western consumers do not eat it, it should be given a digestibility of zero. Since in broiler rations no barley is used, they are not included in table 4.19. Giving barley a digestibility of zero changes the efficiencies for the other species as follows:

Table 4.19: The effect on efficiency, considering if barley is edible or not.

	Energy efficiency (%)		**Protein efficiency (%)**	
	Edible	**Not edible**	**Edible**	**Not edible**
Pigs	11.38	13.88	53.89	62.45
Layers	29.50	31.62	126.95	137.82
Dairy cows	495.50	560.21	1088.55	1222.46
Cattle	13.95	36.26	71.99	222.43

As can be seen, there is a large increase of efficiency, especially for cattle where its status changes from “not efficient” to very efficient. Excluding edible feed components as barley that could be, but are not eaten by humans, is positive for the calculated animal efficiency. One could also argue that feeding cereals of minor quality are not in competition with humans, since the baking industry is not interested in it. The line between “competition” and “using unwanted products” can be thin.

4.3.4 Are we eating soy?

As discussed before, the status of soybean meal as a by-product is disputed. In our calculations, soybean meal was given a digestibility coefficient of zero, since the meal is not used for human consumption. Due to its high nutritional values and because the meal is cheaper than the whole beans (FAO, 2014c), soybean meal is mainly used in animal rations. Table 4.20 shows how much soybean meal is used per kilo of animal product based on the amount of soybean meal eaten by the entire population. For layers and dairy cows, only the amount per kilo of eggs or milk is given.

Table 4.20: Relation between animal product and soybean use.

	Soybean meal per kilo animal product	**Conversion to whole soybeans**
Pork	0.5451 kg	0.6814 kg
Chicken	0.7669 kg	0.9586 kg
Eggs	0.1892 kg	0.2365 kg
Milk	0.0683 kg	0.0853 kg
Beef	0.6222 kg	0.7778 kg

These numbers are higher than the percentage of soybean meal in the feed, since also feed conversion and meat percentage are taken into account. As can be seen, a lot of soybean meal is used for meat production in these rations, since muscle growth requires high quality proteins. Layer rations are rather low in soybean meal, but contain 50 – 60% of cereals (wheat and corn). In dairy production, other by-products can be used, since ruminants digest products that are not digestible by monogastrics.

Since 1 kg of soybean delivers 0.8 kg soybean meal (American Soybean Association, 2008; Potts *et al.*, 2014), the necessary amount of soybeans can be calculated. The results are also shown in table 4.20. These are even more impressive, especially for broilers, where one kilogram of meat is produced with about one kilogram of soybeans. Those who are against soy imports or animal husbandry as such will gladly use these numbers as proof that eating meat is eating soy. However, the same numbers could also be interpreted in another way…

As stated earlier (see 2.3.3.), the recommended daily protein intake for adults is between 55 and 60 grams (Šebek & Temme, 2009; FAO, 2011c), half of it coming from animal products. Due to the protein content of meat, an amount of 100 to 150 grams of meat a day is enough to cover dietary needs. Instead of looking at one kilogram of animal product, the numbers from table 4.20 could be expressed in function of daily intake advice. These results can be found in table 4.21. Here, also the amount of soy oil (17% of soy bean; American Soybean Association, 2008; Potts *et al.*, 2014) that can be produced with the given amount of soybeans is displayed.

Table 4.21: Soybean use per portion of animal product.

	Portion of 100 grams			Portion of 150 grams		
	Soybean meal (g)	Conversion to whole soybeans (g)	Conversion to oil (g)	Soybean meal (g)	Conversion to whole soybeans (g)	Conversion to oil (g)
Pork	55	68	12	82	102	18
Chicken	77	96	17	115	144	26
Eggs	19	24	4	28	35	6
Milk	7	9	2	10	13	2
Beef	62	78	14	93	117	21

Although starting from exactly the same data, an alternative representation gives a totally different connotation. While table 4.20 almost suggests that you are eating soybeans instead of chicken, table 4.21 shows that the by-products of about 20 grams of soy oil production are enough to produce the daily advised amount of chicken meat. For the other animal species, the numbers are even lower. One could even say that the amount of soy-based butter-alternative used for baking (which contain 75% vegetable oil of which 75% soy oil; Alpro Soya, 2014) is responsible for more or less as much soybean meal as needed to produce the meat baked. From large transports of soy for feeding chickens, the picture changes to feeding humans in a well-balanced diet, where both soybean oil and soybean meal are eaten, the last one after being converted by an animal.

As seen in paragraph 2.3.3, many substitutes for animal products can be found. Tahoe/tofu and tempé are derived from soybeans, the first being curdled soymilk, the latter soybean cake inoculated with fungus. Seitan is made from wheat gluten and it is more efficient to directly consume it than to feed wheat to animals. It is obvious that it is more efficient to directly consume the soy or cereal products than to feed it to animals and then eat the animal product. Quorn is made from *Fusarium venenatum*, a fungus that is grown on glucose. It converts cheap carbohydrates in high quality proteins and it is obvious that fungi are more efficient in this conversion, since higher animals – as mammals or birds – are not able to do this. Other meat alternatives are tahin (a paste of sesame seeds), hummus (mashed chickpeas) and falafel (balls of chickpeas and/or beans) are processed plant products. These products are not common in animal rations, but nevertheless it is also more efficient to consume it directly. One can conclude that substitutes are more efficient than animal products, when it comes to protein production. As discussed in paragraph 2.3.3, the substitutes are less suitable for other microelements.

4.3.5 Efficiency in aquaculture

As shown earlier, aquaculture is an important part of animal production and is still increasing. Since many species are used in aquaculture and feed rations are changing, the discussion here will not be on a species level. Nevertheless, lessons can be learned for aquaculture and other types of animal production (e.g. invertebrates as insects, snails…). Poikilothermic species have low metabolic rates, up to 15 to 20 per cent of the metabolic rate of mammals of the same size due to low maintenance requirements (Jobling, 2010). By this, fish can use 50 to 60 per cent of the feed nutrients into growth. On the other hand, the homeothermic species used in agriculture (mainly pig, cow and chicken) are herbivores or omnivores that can be fed with cheap carbohydrates, while many fish species used in aquaculture are mostly carnivores that require more expensive high-protein feeds, often from fishmeal because of the better amino acid composition. A shift from animal proteins (i.c. fish meal) to plant proteins ameliorates the fish-in-fish-out-ratio. But next to the fact that several plants are deficient for nutrients that are essential for fish, also research has to be done on anti-nutritional factors from plant feeds for fish (Jobling, 2010). As discussed in paragraph 2.3.4, changing from fish oil to plant oil also has consequences on the amount of omega-3 fatty acids in fish meat, making it less suitable as 'healthy food'. Attempts to make aquaculture 'more efficient' (i.e. less fish oil and animal proteins) do not always lead to the desired result.

Furthermore, it has been shown that animal efficiency, as defined by van Es (1975), strongly depends on the difference between what is defined as 'edible' for humans or not. As stated earlier, about 20% of all caught fish is used to produce fishmeal and fish oil (Tacon & Metian, 2008). Although commercially not interesting fish species are used, this does not mean that humans cannot eat these species. Especially in the case of carnivorous species, where fish-in-fish-out-ratios can be larger than one, it might be more efficient from a nutritional point of view to eat the 'fish in' instead of the 'fish out'. Also here, the discussion on soybean meal is of importance, since its part in several fish feeds is increasing (in some rations to more than half of it; see a.o. Davis & Arnold, 2004; Davis *et al.*, 2005; Lazo *et al.*, 2010; Silva-Carillo *et al.*, 2012) to replace fishmeal. Also soybean oil is used in fish feed: Jobling *et al*. (2010) mention that replacement of 50% of fish oil with soybean oil in the ration of salmonids is widely accepted. Tacon *et al.* (2011) mention that the use of fishmeal and fish oil will decrease because of increasing prices, caused by an increasing demand combined with decreasing supplies as a result of tighter quota setting and more controls on unregulated fishing. In non-European countries, meals and oils from terrestrial animals, like hydrolysed feather meal, blood meal and MBM, are used as more cost-effective replacers: from 5 to 10% in carp feed and up to 30% and more in salmon feeds (Tacon *et al.*, 2011). Also plant protein meals and oils are gaining interest, especially in lower trophic level fish species or in Europe, due to regulations of the use of animal by-products. Soybean meal is the most common vegetable feed (up to 45% or more), but also other by-products from vegetable oil production (rapeseed, sunflower…) are frequently used. Taking into account that poikilothermic species have lower maintenance levels, animal protein production by fish seems more efficient than by mammals or birds.

4.4 Conclusion

Compared with van Es (1975), the efficiency of protein production by animals increased during the last decades, not only because of increasing production per animal, but also because of changing feed strategies. As shown, defining 'edible' has a large impact on efficiency. Ruminants compete less with humans since they are able to convert roughages and are therefore more efficient. Belgian blue is often fed with grains during the last months before slaughter, decreasing its efficiency from a human-animal-competition point of view. Monogastric species are not that efficient. Indeed, when soybean meal is seen as inedible, broilers and layers have an efficiency ratio of more than one, but soybean can be consumed by humans too. Pigs are the least efficient way to produce animal products.

On the other hand, due to increased demand for vegetable oil for both Food and Fuel, large amounts of meals are available. Animal production here is a useful way to convert these byproducts into something edible. This alters the view on animal production, as shown in table 4.21: animals convert the inedible byproducts from vegetable oil production into the daily advised amount of edible animal product. Nevertheless, increasing the efficiency of animal production is still possible, not only by increasing the percentage of unedible or undesirable feedstocks in the ration, but also by using poikilothermic species like fish.

Chapter 5

General discussion and conclusion

5.1 Feeding our world by closing yield gaps

Global agricultural production strongly increased during the last decades. Since human population is likely to increase to more than 9 billion people in 2050, food production needs also to increase. Further expansion in land use meant for agriculture is not an option (Foley *et al.*, 2011) due to the negative environmental impacts on the ecosystem Earth. The challenge thus will be to close the yield gap on a global scale (Godfray *et al.,* 2010; Foley *et al.,* 2011). Many regions in the world do not produce as much as they could, because of lack of education or investments in both production (e.g. water management) and infrastructure (e.g. post-harvest loss). Even if global yields would be 75 per cent of its potentials, this would mean that global production would increase with more than 1100 Mt or +28% (Foley *et al.*, 2011). Furthermore, about one third of the food produced is wasted and there are more obese than hungry people. Enough food is produced to feed all humans (Alexandratos & Bruinsma, 2012), so if humanity chooses to invest in closing the yield gap and organizing a more fair distribution of food, it seems plausible that making use of nowadays technologies and the present yet available agricultural land, it will be possible to feed the human population by 2050.

Throughout history, animals play a key role in global agriculture. This is the case from the poorest people that depend on their herds to have at least some proteins in their diets, to the people living nowadays in the developed world, where too much animal products are eaten. Therefore, the main focus in this thesis was animal production, its relation with the other functions, some ethical questions that rise, and the efficiency of animal products and its competition with human food. Furthermore, developing sustainable animal protein production chains is one of the greatest challenges (Fresco, 2008, p. 384). Reducing animal products in the Western diet is necessary (Foley *et al.*, 2011), not only because of our own health, but also for the health of our planet. Indeed, animal products have a high nutritional value and are important in human diet, but overproduction and -consumption has a worldwide impact. Current global animal production is already able to feed the present human population of 7.3 billion people every day with about 115 grams of meat, half an egg, 300 grams of milk and 60 grams from fishery/aquaculture (calculations based on FAOSTAT, 2014) or more than is needed from a nutritional point of view. If also yield gaps in animal production are closed, it seems plausible that even with current technologies and the present number of animals, it will be possible to provide enough animal products for the human population in 2050.

This gives hope to the future generations: it is possible to produce enough food for everyone by 2050, even with existing technologies and on already cultivated land. Scientific and technological innovations during the next decades will make it easier. But as Godfray *et al.* (2010, p. 817) state: “We are hopeful about scientific and technological innovation in the food system, but not as an excuse to delay difficult decisions today”. A shift within current agricultural paradigm could make it possible to produce more with less. This creates opportunities for the future, but it will not be easy to implement, since it is not only a matter of production, but also of socio-cultural preferences. Tansey (2013, p. 3) states that “projections are easier to make in terms of the physical Earth system, and how the environment will respond to changing energy inputs linked to greenhouse gas levels in the atmosphere than we are in saying how our social and political entities will cope with future stress and strains”. The major challenge therefore will be to convince producers, consumers and policy makers of the benefits, in order to make them willing to adapt a new agricultural paradigm.

5.2 How not to eat our world?

5.2.1 Smart sustainable animal production

Economic viability is essential for a sustainable animal production. If there is overproduction, markets will get saturated, leading to decreasing prices and thus decreasing income for the producer. If markets are saturated, one could try to explore new markets (export) or to add value to the cheap product. In the past, imports from the U.S. led to lower cereal prices. It caused problems for cereal producers in Western Europe, but gave a boost to farmers to switch from cereal production to animal production. Therefore, one could argue that "much meat and dairy can be seen as 'value-added grains and pulses' " (Tansey, 2013, p. 6). A century later, animal product markets seem almost saturated. The milk market can choose to add value through processing cheap milk into more expensive dairy products as cheese or yoghurts. For the meat market, alternatives are more difficult, since the next step would be feeding cheap herbivorous or omnivorous meat to a carnivorous species and eat it, but this is – with exception of fish – not done in most societies. This could explain why pig production in Europe suffers from low prices during the last years: there seems to be no way forward (i.e. no possibility to process cheap meat to add extra value) and no way back (e.g. because of large investments that require large numbers of pigs on one farm). Discouraging overproduction in animal husbandry could therefore be more sustainable, not only ecologically, but also economically.

Even if animal production stabilizes or even declines, efficiency improvements will remain important during the next decades. There are many ways to discuss the efficiency of animal products. Chapter 4 discussed animal efficiency as defined by van Es (1975) by focusing on the discussion if animals compete with humans or deliver an addition to global food status. As discussed in paragraph 1.2.3, animals are able to produce food on 'useless land'. Some regions are not suitable for agriculture and using animals is often the only way to produce food. On the other hand, one could question if it is acceptable that such large areas are used for food production with such a low yield per hectare. It might be better to use those areas for Foster, increasing biodiversity, reducing desertification and so on. Furthermore, it depends on how one defines 'useless'. In Western countries, some parcels are used for animal production since they are told to be unsuitable for crop production. Often it is possible to produce crops on these parcels, but not in the given economical environment. For example, a parcel can be 'useless' because it is too wet for heavy machines, but would be 'top quality' if it was in another region where it would be worked by humans or animal traction.

Animals are also able to convert 'useless' proteins or energy by using ingredients that cannot be eaten by humans. As has been shown in chapter 4, the definition of 'inedible' is of major importance and has a great influence on animal efficiency as defined by van Es (1975). Barley is now not eaten by humans, just as large amounts of maize or soybean. But this does not mean that these products cannot be eaten, it is only not desired by some present generations of humans. To produce these crops that are not consumed by humans in so-called developed societies, good quality arable land is needed. Even if the output is not seen as 'edible' in these societies, another crop could have been produced with the same input.

Today's reality is a result of historical evolutions, but things can be different and humanity can learn from its history and adapt to new insights. One could try to rethink/reinvent animal production, based on historical motives (e.g. convert useless biomass into something edible), but adapted to new desires. From this, one can decide whether the species used now are still the best way to produce the desired result. Because poikylothermic species are more efficient, it seems plausible that it would be better to produce animal products using herbivorous fish or insects, even if this means that production of other animal species needs to be strongly reduced. As shown in 4.3, pig production is – from a human-animal-competition point of view – the least efficient way to produce animal products. While in the past they were used as piggy banks to convert surplus production, an inversion of goals and means occurred: animal production became the goal and no longer a means. During the last decades, a majority of research is done on increasing the efficiency of the most common species (i.e. cow, pig and chicken) without asking if these species are the most efficient means to reach the goal. A smart shift to new species to produce animal products with a maximum use of inedible feeds will restore the role of animals as converters of inedible products into something useful. If not, we are eating our world, since "using highly productive croplands to produce animal feed, no matter how efficiently, represents a net drain to the world's potential food supply" (Foley *et al.,* 2011, p.338).

5.2.2 Biofuels burn our world

The same can be said about land-based biofuel production, both first and second generation: if it is produced on highly productive croplands, we are eating (or in this case: burning) our world. Although global biofuel production increases every year, it is not a sustainable alternative for fossil fuels. In the short term, it might be economically interesting, since it offers a new market for certain crops, like maize, wheat, rapeseed, soy and other crops of which the markets became more or less saturated, or it offers possibilities for new crops like *Miscanthus*. Although the first generation biofuels is often seen as worse because it uses food for fuel, paragraph 2.4 reveals that the second generation is not better, because of the act-omission-dilemma. Furthermore, in fibre production, one is interested in the biomass itself because of its (bio-)chemical and physical characteristics and the biomass is the goal. In biofuel production, the biomass is only a means to convert and harvest solar energy. There are more efficient alternatives to convert solar energy that do not require land and have higher yields. These alternatives can be technological (i.e. photovoltaic cells), but also algae production can be used. For the latter, a lot of research and development is and has to be done to make it economically interesting, but it has great potential, albeit more as a producer of high quality products and thus more suitable for Fibre than for Fuel production.

5.2.3 Agriculture needs to foster

In this thesis, the concept of 'Foster' is introduced into the 6F-framework. Aerts *et al.* (2009) defined 'flower' as both production of ornamental plants, and conservation of landscapes and nature. But ornamental plants production is merely fun and agriculture has more responsibilities than only conserving landscapes and nature, like e.g. maintaining the soil in good agricultural quality, but also reduce negative impact on water (quality and availability), air (smell, dust, greenhouse gasses…) and biodiversity. In the future, 'Foster' will become more important, since awareness of the subject is increasing, not only from an ecological point of view, but it is also a means to internalize externalities, what gives the farmer an extra income. Sustainable agriculture without Foster is not possible.

5.2.4 Feeding our needs without overconsumption due to desires

Global agricultural production for Fun is also increasing. As has been shown in paragraph 1.6, many types of fun production can be found: from stimulants over ornamental plants to the pet industry. The pets and equines (those that are fed with processed feed are almost all kept for fun) are responsible for about 35 Mt of feed production (Alltech, 2014), which is almost as much as the 40 Mt of aquaculture feed production. While the last one adds to global food security and is an efficient way to produce animal proteins (and even is more healthy than meat, when fed correctly; see chapter 2.3.4), pets and horses have no further importance than fun.

Although Fun has several links with the matrix of human needs of Max-Neef (1992), one could question if it is acceptable that such large volumes of feed are used for pet animals that are often kept in at least as unnatural conditions as in large-scale animal production. If human consumption of meat and animal products has to be reduced, one could question if the increasing population of millions of carnivorous pets (cats, dogs, ferrets…) is acceptable. Even nowadays, animal by-products alone are not enough to feed them and animals have to be killed to feed animals that are kept just for fun. A shift from carnivorous pets to omnivorous (e.g. mini-pigs or fancy chickens) or even herbivorous (e.g. rabbits or cavies) pets can lower the impact on our planet.

5.3 Food for thought

There are many ways to discuss sustainability and efficiency, not only in terms of animal production or agriculture, but also of humanity and the ecosystem Earth as a whole. We have shown that different worldviews have an influence on ethical discussions and explains why it is so hard to reach 'what ought'. Theorists often discuss top-down sustainability, i.e. in which direction humanity (or agriculture) should evolve. In the field – metaphorically, but in case of the discussions in this thesis also literally – sustainability is more bottom-up and often comes down to 'surviving': a farmer wants a sustainable farm with a sustainable income (= 'what is'), while society wants a sustainable agriculture with a sustainable future (= 'what ought'). As long as there is no willingness to listen to and understand 'the others', no bridges can be made between the bottom-up and top-down approach and the transition to a more sustainable agriculture then remains merely a discussion than a reality. Therefore, understanding and acceptance of the other's point of view is necessary.

Depending of one's worldview, many 'solutions' for the same problem can be given and there are always facts and figures that support each of them in an attempt to prove one's right. Although a holistic approach is the only correct way to understand what reality looks like, a reductionistic approach is often used, since this is easier to take only a few parameters into account. Increasing knowledge on several subjects reveals that even if one thinks that his or her view is holistic, it is only an extended reductionistic attempt to understand what reality is. Therefore, there is no truth, not even an inconvenient one. There are only facts that can be used as building blocks in an attempt to understand how reality evolves and as tools in order to make – or at least try to make – the right decisions for ourselves and the future generations.

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Appendix 1: Comparison of global production on a product level

	Species	Global production in 1961 (Mt)	Global production in 2012 (Mt)
1	Maize	205,03	872,79
2	Milk	344,18	753,93
3	Rice, paddy	215,65	738,19
4	Wheat	222,36	671,50
5	Potatoes	270,55	365,37
6	Vegetables, fresh nes	62,31	269,85
7	Cassava	71,26	269,13
8	Soybeans	26,88	241,14
9	Tomatoes	27,62	161,79
10	Barley	72,41	133,51
11	Pig meat	24,75	109,12
12	Sweet potatoes	98,19	108,00
13	Watermelons	17,85	105,37
14	Bananas	21,49	101,99
15	Chicken meat	7,56	92,81
16	Onions, dry	14,26	82,85
17	Seed cotton	27,48	78,00
18	Apples	17,05	76,38
19	Eggs	15,11	71,92
20	Cabbages and other brassicas	23,40	70,10
21	Oranges	15,98	68,22
22	Grapes	42,99	67,07
23	Cucumbers and gherkins	9,55	65,13
24	Cattle meat	27,68	63,29
25	Coconuts	23,84	62,14
26	Yams	8,32	59,52
27	Sorghum	40,93	57,03
28	Eggplants (aubergines)	7,03	48,42
29	Mangoes, mangosteens, guavas	10,90	42,14
30	Carrots and turnips	5,84	36,92
31	Melons, other (inc.cantaloupes)	6,99	31,93
32	Melons, other (inc.cantaloupes)	6,99	31,93
33	Fruit, fresh nes	6,57	31,45
34	Chillies and peppers, green	5,91	31,17
35	Millet	25,71	30,20
36	Tangerines, mandarins, clementines, satsumas	2,84	27,06
37	Cotton lint	9,46	25,96
38	Lettuce and chicory	6,62	24,95
39	Garlic	4,30	24,84
40	Pumpkins, squash and gourds	6,65	24,62

41	Beans, dry	11,23	23,92
42	Pears	5,20	23,58
43	Pineapples	3,83	23,33
44	Spinach	2,96	21,66
45	Oats	49,59	21,31
46	Cauliflowers and broccoli	3,39	21,27
47	Peaches and nectarines	5,17	21,08
48	Beans, green	2,63	20,74
49	Fruit, tropical fresh nes	5,16	20,42
50	Peas, green	3,79	18,49