Worldwide Alternatives to Animal Derived Foods – Overview and Evaluation Models

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Solutions to Global Problems caused by Livestock

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WORLDWIDE ALTERNATIVES TO ANIMAL DERIVED FOODS – OVERVIEW AND EVALUATION MODELS

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Preface and Dedication

This doctoral thesis is dedicated to all the people who put their efforts into solving the current and future problems that humans, animals and the environment are confronted with. And to all the people who chose to go a part of the way through this life together with me, voluntarily or as family members.

I am indebted and obliged to Prof. Helmut Mayer for giving me, as a geophysician, the opportunity to write this doctoral thesis in special food sciences based on the ideas of my project "Future Food". But to make it clear, this was not handed to me on a plate: It was necessary to pass various final exams in food science, especially the big food technology and the big food chemistry exams to name but two of them.
I also want to thank the English native speaker Paula Stibbe for her very valuable linguistic support.

Vienna, February 2012

Kurt Schmidinger

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Glossary & Abbreviations

CAFO	Concentrated animal feeding operation. The term is primarily used in the US and has been coined by the US Environmental Protection Agency. CAFO is defined as a facility with more than 1000 animal units confined on a site for more than 45 days. Animal equivalents for 1000 Animal Units are: beef – 1000 head; dairy – 700 head; swine – 2500 pigs weighing more than 55 lbs; poultry – 125,000 broilers or 82,000 laying hens or pullets (EPA).
CHD	Coronary heart disease.
CI	Confidence interval, statistical standard measure of an interval estimate of a population parameter.
CIWF	Compassion in World Farming, an NGO for welfare of farm animals.
EF – Ecological Footprint	A measure of human demand on the earth's ecosystems. It compares human demand with planet earth's ecological capacity to regenerate (also see chapter 2.3).
EFSA	European Food Safety Authority
FAO	Food and Agriculture Organization of the United Nations
GHG	Abbreviation for greenhouse gas.
GMO	Genetically modified organism whose genetic material has been altered using genetic engineering techniques.
GWP	Global warming potential, the GWP is defined as the

	cumulative radiative forcing between the present and some chosen time in the future (per definition 100 years) caused by a unit mass of gas emitted now relative to the effect of the same mass of CO_2 over the same time period. CO_2 is assigned a GWP of 1 by definition. Methane (CH_4) has a GWP of 21, thus being a 21 times more potent GHG compared to the same mass of CO_2. Nitrous oxide (N_2O) has a GWP of 310.
H5N1	A subtype of the Influenza A virus. A bird-adapted strain of H5N1, called HPAI A(H5N1) for "*highly pathogenic avian influenza virus of type A of subtype H5N1*". It is the causative agent of H5N1 flu, commonly known as "*avian influenza*" or "*bird flu*".
HPAI	Highly pathogenic avian influenza
LCA	Life Cycle Assessment, a technique to assess all (environmental) impact associated with every stage of a process from cradle-to-grave. See chapter 2.2.
MRSA	Methicillin-resistant *Staphylococcus aureus*, or also: Multidrug-resistant *Staphylococcus aureus*. MRSA is a bacterium responsible for several difficult-to-treat infections in humans.
NASA	National Aeronautics and Space Administration of the United States government, responsible for the nation's space programs and research.
OIE	Office International des Epizooties, World Organisation for Animal Health.

PDCAAS	Protein Digestibility Corrected Amino Acid Score (PDCAAS) is a method of evaluating the protein quality based on both the amino acid requirements of humans and their ability to digest it (see chapter 7.5.2).
Prospective cohort studies	An analysis of risk factors which is done by following groups of people (cohorts). A cohort is a group of individuals that share a common behaviour, characteristic or experience within a defined period (e.g. diet patterns). A prospective cohort study monitors several cohorts who differ with respect to the factors under study over a certain period of time. The goal is to find out how these factors influence the rates of a certain issue under investigation (e.g. the effect of diet patterns on certain forms of cancer).
SCP	Single Cell Protein. SCP is protein that has been extracted from pure or mixed cultures of yeasts, fungi, bacteria or algae. SCP is commonly grown on wastes from agriculture or food production. SCP can be used as protein supplement for human and animal nutrition. Quorn is an example of a SCP (see chapter 9.1.6).
Vegan diets	Vegan diets are often defined as exclusively plant based diets. Given the artificially produced or mineral food ingredients, a more exact definition of a vegan diet is the leaving out all animal products in nutrition, including meat and meat products, milk and dairy products, egg and egg-products, gelatine, honey and so on.

Vegetarian diet	In this dissertation, the term "*vegetarian*" is used for all kind of diets that leave out products from dead animals, such as meat, meat products, fish or gelatine. The consumption of milk and dairy products, egg and egg products or honey is possible, but optional. A vegan diet is a special form of such a vegetarian diet, other forms are ovo-lacto vegetarian diets (including eggs and dairy products) or lacto-vegetarian diets (including dairy products, but not eggs).
WHO	World Health Organization, an agency of the United Nations specialized on public health issues.

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CHAPTER 1

Introduction

At the beginning of 2010, an estimated 27 billion animals were being kept as livestock globally, with 66 billions slaughtered each year around the globe (Schlatzer, 2010). This exceeds the number of human inhabitants on the globe almost by an order of magnitude.

Global meat production has doubled between 1980 and 2007 from 136.7 to 285.7 million tons, egg production rose by 150 percent from 27.4 to 67.8 million tons, and milk production has risen from 465 to 671.3 million tons (FAO, 2009b). Pork accounts for 40 percent of the global meat production, poultry for 30 percent and beef for 22 percent, and 55 percent of the global pig production, 61 percent of the global egg production and 72 percent of the global poultry meat production takes place in industrial systems (FAO, 2009b), where feed production often occurs far away from the livestock facilities.

If no provisions are undertaken to avoid further growth in the livestock sector, meat production is forecasted to rise to 465 million tons by 2050 and milk production to 1043 million tons (Steinfeld et al., 2006), due to a growth of global population as well as a forecasted increase of per capita consumption of meat and milk. Nutritional transitions in developing countries and especially emerging markets, such as China towards much higher intakes of animal derived foods (Popkin, 2001; Popkin, 2004) aggravate the global problems associated with these increases in the demand for livestock products.

This present dissertation can be separated into 3 main sections

- The chapters 2 to 5 summarize the huge negative effect of the mass production of animal products and the breeding of more than 65 billion animals annually on the environment, on human health, on world nutrition and on the animals themselves.

- In chapter 6 ethical evaluation methods for foods are summarized and also adapted and refined to be applied to the alternatives to livestock products that are presented in the last chapters. Chapter 7 presents major success criteria for such new alternative foods and based on this, chapter 8 presents economical evaluation methods for foods with further elaboration done on existing models for applying them to alternatives to livestock products.
- Chapters 9 to 11 give an overview of the wide variety of existing alternatives to meat, egg products and dairy products globally, with some of them evaluated by applying the methods elaborated on in the preceding chapters. Chapter 12 invites the reader to journey to a possible future by presenting the status quo of the plans to produce actual meat in vitro without the use of animals (and not "just" products which are copies of meat). These final chapters, 9 to 12, have a journalistic touch, presenting a global overview of remarkable developments and trends in the market and in science

Before we start to explore the effects of livestock on the world and their alternatives, Table 1.1 gives an overview of world production figures of various food categories. It is important to note that livestock affects many categories, e.g. a third of the global cereal production (FAO, 2008b) or approximately 85 percent of the global soy production (Pachauri, 2008; WWF, 2008) is consumed by livestock animals and not by humans directly. In this case, the calories are converted by the animals to meat-, milk- or egg-calories, and due to the natural conversion losses within the metabolism of each animal, a big share of calories is lost for human nutrition when cereals, soy or other plant products are fed to animals and not to humans directly. The total expenses for feed, including cereals, pulses, bran, fish meal and oils, made up around 1300 million tons by 2008 (FAO, 2009b).

	Global annual production	Main exponents of this category	Animal feed share
Cereals	**2 182** (USDA, 2011)	**Maize: 826** **Wheat: 683** **Rice: 686** all (FAOSTAT, 2009)	**overall 754** (FAO, 2008b)
Oilseeds	**447** (USDA, 2011)	**Soya: 231** (FAOSTAT, 2009) **Rapeseed: 59** **Peanuts: 35** **Sunflowerseed: 31** all (USDA, 2011)	Very relevant, especially for soya, where approx. 85 % is used for animal feed (WWF, 2008)
Vegetables	**~ 900** (Fruit-Inform-Project, 2007)	**Potatoes: 325** **Tomatoes: 136** all (FAOSTAT, 2009)	
Fruits (incl. nuts)	**~ 500** (Fruit-Inform-Project, 2007)	**Apples: 70** **Grapes: 67** all (FAOSTAT, 2009)	
Meat (products)	**> 261** (FAOSTAT, 2010), B10+B11	**Pig meat: 106** **Chicken meat: 80** **Cattle meat: 62** **Sheep and goat: 13** all (FAOSTAT, 2010), B10+B11	Parts reused as animal feed (meat and bone meal)
Fish/sea food	**142** (FAOSTAT, 2010), B14	**Fish total: 110** **Molluscs: 16** **Crustaceans: 11** all (FAOSTAT, 2010), B14	Parts (re)used as animal feed (fish meal)
Cow + buffalo milk and dairy products made from these	**668** (FAOSTAT, 2009)	**Cow milk: 579** **Buffalo milk: 89** all (FAOSTAT, 2009)	
Hen eggs	**61** (FAOSTAT, 2009)		

Tab 1.1: Global production figures of agricultural products (in million tons).

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CHAPTER 2

Meat Production (Livestock) and the Environment

2.1 Overview

The production of meat, milk and eggs through the use of animals puts far more strain on the environment than other kinds of food production, as the use of animals to produce food is rather inefficient. Due to the fact that most feed for livestock is used up by the animal's metabolic processes as well as for bone growth and so on, only a small proportion of the feed is transformed into muscle tissue i.e. meat, and respectively eggs or milk. This leads to a much higher demand for land to produce the same amount of e.g. beef calories when compared to e.g. soy-calories for direct human consumption.

The Worldwatch Institute points out the following environmental problems caused by livestock (Worldwatch-Institute, 2004):

- deforestation,
- grassland destruction,
- fresh water usage,
- waste (excrement) disposal and water pollution,
- high energy consumption,
- global warming and
- biodiversity loss and threat of extinction.

Other papers, e.g. (Steinfeld, Gerber et al., 2006) add the following to this list:

- land degradation and loss of fertile land generally and
- air pollution generally.

The Intergovernmental Panel on Climate Change IPCC also mentions nitrous oxide (N_2O) not only as a greenhouse gas, but also as a contributor to the ozone destruction in the stratosphere (IPCC, 2001). Jungbluth (2000) adds problems like the turnout of pesticides, over-fertilization with nitrogen, phosphor or potassium (more details in (Taylor, 2000) and acidification, with

Bouwman et al. (2006) emphasizing that terrestrial and marine biodiversity is threatened by over-fertilization and turnouts of toxic substances.

Jungbluth (2000) also adds the enormous land use by livestock to the list of the most serious issues. Deforestation due to livestock or feed production is especially dominant in the valuable Latin American rainforests and contributes significantly to the global GHG-emissions (Smith et al., 2007; Greenpeace-International, 2009; McAlpine et al., 2009)

The United Nations Environment Programme (UNEP) concluded in 2010 that "*impacts from agriculture are expected to increase substantially due to population growth, increasing consumption of animal products. Unlike fossil fuels, it is difficult to look for alternatives: people have to eat. A substantial reduction of impacts would only be possible with a substantial worldwide diet change, away from animal products*" (Hertwich et al., 2010). Other papers come to a similar conclusion, that "*reining in growth of the livestock sector should be prioritized in environmental governance*" (Pelletier, 2010). According to Dutch investigations, the global food system covers three future priority areas: Food, water and energy, it consumes 30 percent of all ice-free land, 70 percent of available freshwater and 20 percent of energy, with animal protein production having a disproportionate impact as the conversion of plant nutrients to animal food wastes 85 percent of proteins (Aiking, 2011).

As of 2000, the livestock sector is estimated to have contributed 63 percent of reactive nitrogen mobilization (Pelletier, 2010) and has consumed 58 percent of directly used human-appropriated biomass generally (Krausmann et al., 2008).

The following chapters highlight some of these aspects in detail. Figure 2.1 shows the significant contribution of animal products on the so called Environmentally weighted Material Consumption (see description in van der Voet et al. (2005)), especially due to its outstanding land use share, but also its significant contribution to global warming.

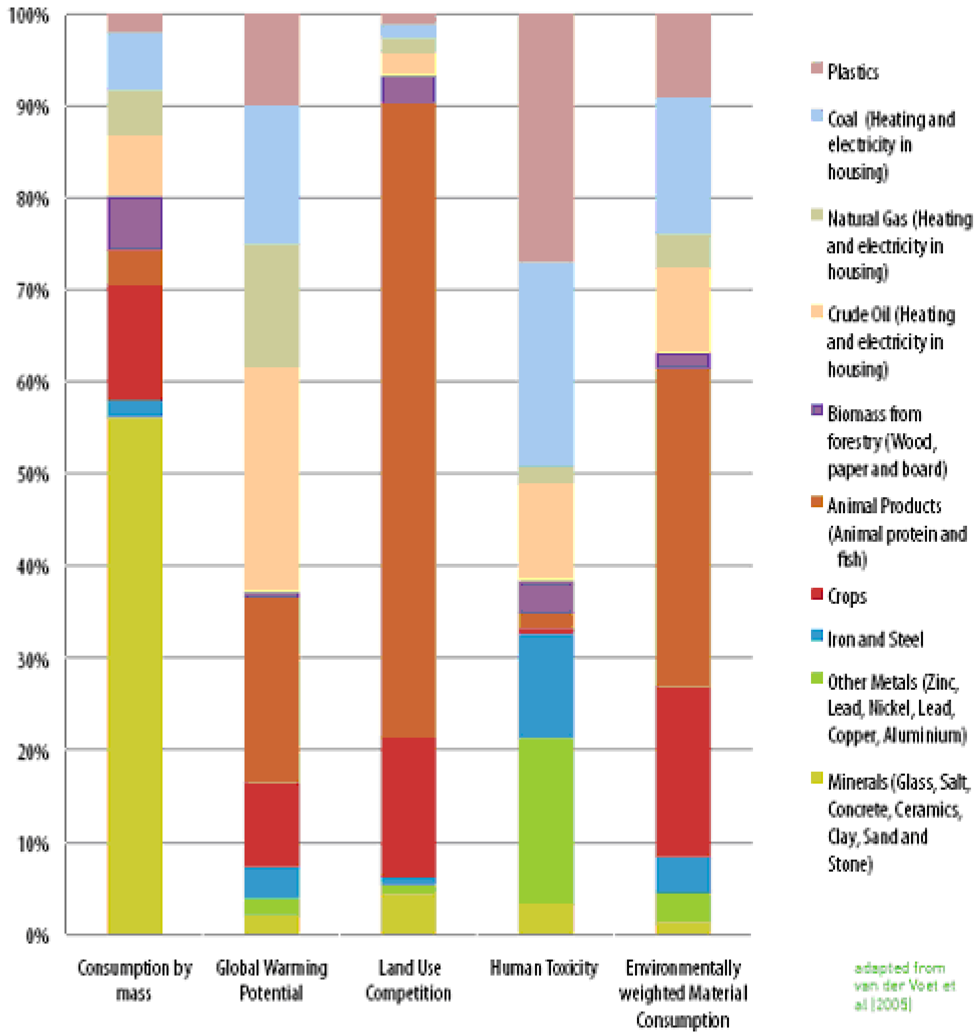

Fig. 2.1: Relative contribution of groups of finished materials to total environmental problems (total of 10 material groups set at 100 %). The analysis was commissioned by the European Commission, DG Environment for the EU-27 plus Turkey in 2000. Source: van der Voet, van Oers et al (2005) resp. Hertwich, van der Voet et al (2010).
The leading role of animal products in global land use and global warming and thus in the integrated measurement "*Environmentally weighted Material Consumption*" becomes apparent.

2.2 Life Cycle Assessment methodology

Life Cycle Assessment (LCA) is a methodology focusing on the complete life cycle of a product, starting with resource extraction or raw material acquisition, followed by steps such as transformations, transports, distribution and use and finally by recycling, incineration or landfilling steps. An LCA quantifies these steps with regard to aspects such as climate change impacts of the product, energy or water consumption, eutrophication and so on. To make these effects for different products comparable, the effects have to be expressed in connection with a certain amount of end product, the so called functional unit, e.g. 1 kg of beef or 1 kg of beef protein. Product losses should also be taken into account in a LCA, e.g. some of the milk produced will be lost in supermarkets or with the end-consumer due to passed expiration dates.

Another difficulty with LCAs is assigning the environmental effects to a product at a certain stage of production, when this production stage supplies other products too, and not just the one examined in our LCA. For example, a formula must be found to divide the environmental effects of a dairy cow farm between the various end products like milk and dairy, beef or leather.

In the following chapters 2.3 to 2.6, the LCA methodology is often used, although sometimes not mentioned explicitly by the quoted authors. More detailed definitions and standards for LCAs can be found in various publications (Curran, 1993; Hendrickson et al., 1998; Guinee et al., 2002; International Dairy Federation, 2009). LCAs are the leading method for the environmental impact of systems or products (Fritsche and Eberle, 2007) and can assist in finding ways to improve the environmental performance of products throughout their lifespan. The LCA approach has even been standardized by the International Organization for Standardization (ISO 14040 and 14044, see ISO (2006)).

2.3 Land usage / Ecological Footprint

Globally, 38 percent of total land area can be used for agriculture, almost 5 billion ha totally. Approximately 69 percent of this land, 3.4 billion ha, is used as grazing land (pasture) whereas 1.4 billion ha (28 percent of total) is cropland and 0.138 billion ha is used for permanent crop (e.g. apples, grapes, some sort of nuts). Eighty percent of the total agricultural area is used for livestock, in addition to pasture, one third of cropland is also used for this purpose. This 80 percent of area usage is accompanied by a share of only 17 percent of calories, that animal products contributed in 2003 to global food supply (FAOSTAT, 2008; Ramankutty et al., 2008). The 38 percent of total land used for agriculture is by far the largest use of land on the planet and much of the rest is unsuitable land for agriculture as it is covered by deserts, ice, mountains, tundra or cities (Ellis et al., 2010).

Table 2.1 shows the area demand of various food products for New York State. Animal derived foods require much more land to produce a certain amount of food energy than plant based foods (Peters et al., 2007).

	Area demand (m^2/1000 kcal)
Animal products	
Beef	31.2
Poultry	9.0
Pork	7.3
Eggs	6.0
Whole milk	5.0
Plant based products	
Oleiferous fruit	3.2
Fruit	2.3
Pulses	2.2
Vegetables	1.7
Cereals	1.1

Tab 2.1: Area demand of various food categories to deliver 1000 kcal of dietary energy per year, based on crop yields in New York State, USA. Cropland and pastures are included in the figures for animal products. Source: Peters, Wilkins et al (2007).

Table 2.2 shows further results of area requirements calculated by De Vries and De Boer (2010), who compared 16 studies. Table 2.3 shows area requirements for various products as determined by Blonk et al. (2008).

Product	Area demand (m^2/kg product)	Area demand (m^2/kg protein in product)
Beef	27 - 49	144 - 258
Pork	8.9 – 12.1	47 - 64
Poultry	8.1 – 9.9	42 - 52
Milk	1.1 – 2.0	33 - 59
Eggs	4.5 – 6.2	35 - 48

Tab 2.2: Area demand for producing 1 kg of various animal products per year. Survey of 16 studies, summarized by De Vries and De Boer (2010). The right hand column shows the adjustments of the area demands to 1 kg of protein in the product, where all animal products show very similar area requirements, only beef being an outlier.

	Total area (m^2/kg)	Pasture (m^2/kg)	Cropland (m^2/kg)
Animal products			
Beef Brazil	420.2	420.2	0
Beef Ireland	60.3	54.6	5.7
Beef Cattle NL	14.7	1.4	13.3
Dairy Cattle NL	7.3	4.7	2.6
Pork NL	7.7	0	7.7
Broiler Brazil	7.3	0	7.3
Broiler NL	4.6	0	4.6
Milk NL	0.9	0.6	0.3
Eggs NL	3.8	0	3.8
Plant based products			
Soy milk NL	0.6	0	0.6
Tofu NL	3.0	0	3.0
Tempeh NL	2.3	0	2.3
Quorn	1.2	0	1.2

Tab 2.3: Area demand of various food categories to produce 1 kg of product annually. For comparison, some plant based meat and dairy alternatives are shown (chapters 9 and 11 present more details about these products). For all products, the distribution of areas to pasture and cropland is shown. Source: Blonk, Kool et al. (2008).

If merely cropland (in contrast to pasture land/grassland) is surveyed, a switch from ruminant meat to vegetarian meat alternatives like tofu or Quorn can increase the need for (arable, not overall) land. On the other hand, substituting milk with dairy analogues not only reduces overall area demand substantially, but also the demand for arable(-forage) land. These scenarios were modelled for the UK in Audsley et al. (2009).

Fig. 2.2: The Ecological Footprint and its schematic distribution into various fields. With credits to Joe Ravetz, University of Manchester.

A tool for an extended measurement of the effects of consumption on the capacity of the earth is the so called Ecological Footprint (EF), first published by Rees and Wackernagel (Rees, 1992; Wackernagel, 1994). The Ecological Footprint is a measure of human demand on the earth's ecosystems. It compares the human requirements for resources with the regenerative ecological capacity of the earth. It represents the amount of biologically productive land and sea area needed to regenerate the resources a human individual or the population consumes on the one hand, and the area required to absorb and render innocuous the accumulating waste on the other hand. By using this model, it is possible to calculate how much of the earth (or "how many earths") it would take to fulfil the needs of humans if everybody lived a lifestyle under investigation. The methodology for the EF-calculations has been refined perpetually over the years, a detailed description of the theoretical basics used for the calculations in 2008 can be found in Ewing et al.

(2008) and Kitzes et al. (2008). Currently, humans produce an average EF of 2.2 global hectares per person annually. The sustainable value for the EF would be an average of 1.8 gha per person. People in different world regions produce strongly disproportionate values for the EF, as seen in Figure 2.3.

A case study for the town of Cardiff in Wales showed that nutrition is responsible for 25 percent of total EF, with animal products being responsible for 61 percent of this footprint (Collins and Fairchild, 2007).

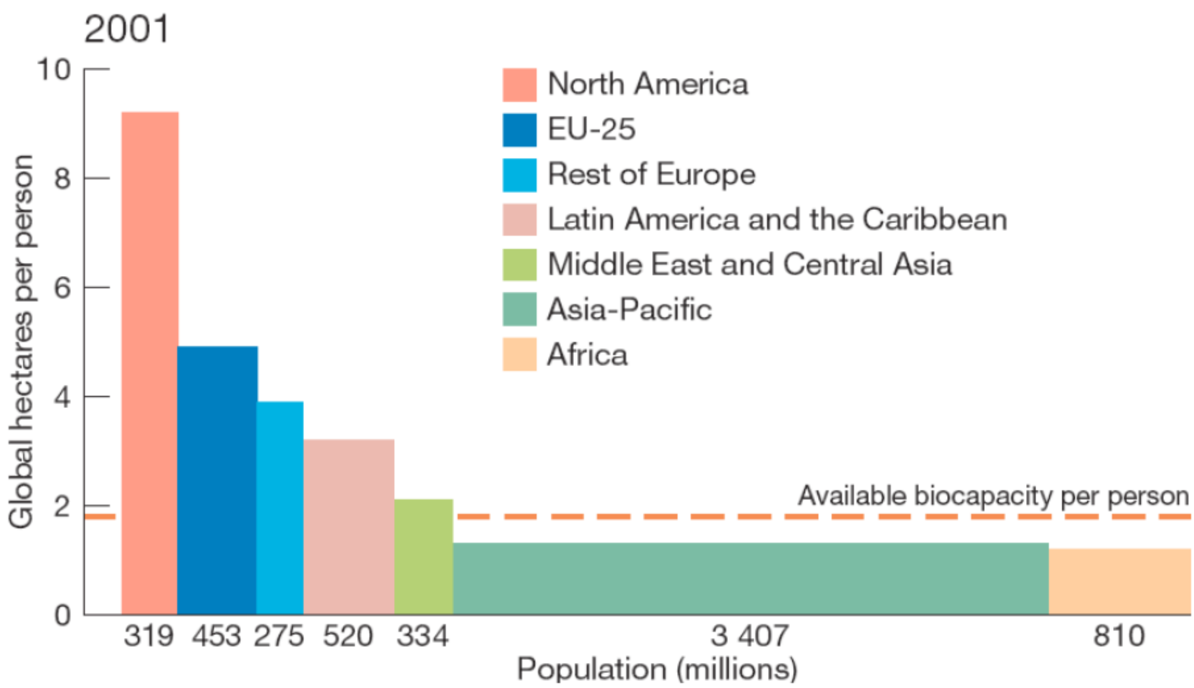

Fig. 2.3: Ecological Footprint (EF) per person in different regions of the world in global hectares. The available biocapacity per person shows the ecologically compliant value which is currently 1.8 gha. Source: WWF (2005) and von Koerber et al.(2008).

Comparing the whole production chain of 1000 kg of pork protein with 1000 kg of protein of a vegetarian meat product based on peas, and converting the results to land- and water-usage shows the inefficiency of the pork chain. The pork chain requires 12.4 ha land, the pea based vegetarian meat chain only 1.3 ha (Aiking, Helms et al., 2006).

2.4 Energy usage for the production of various foods

Measuring the energy input to produce 1 kg of protein of different foods is another approach used for comparing their environmental impact. Fig. 2.4 shows results of such an approach (Seiler, 2006).

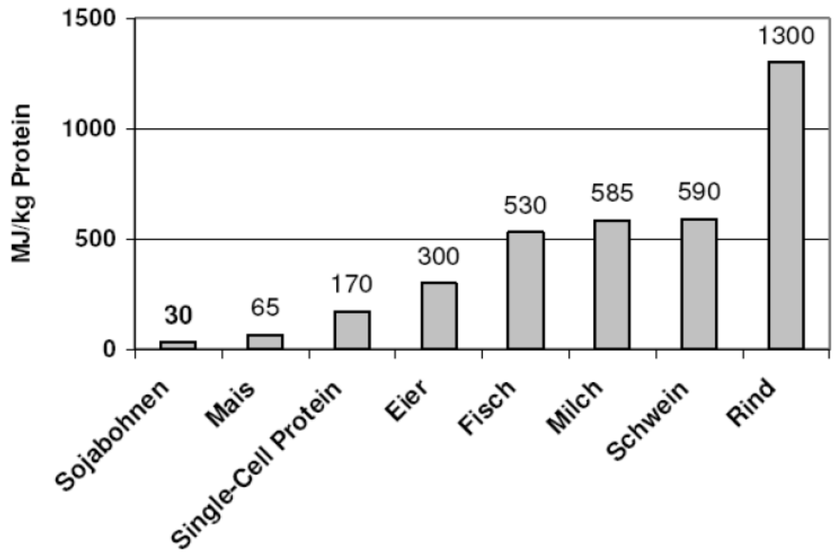

Fig. 2.4: Energy input in MJ to produce 1 kg of protein, for soy beans, maize, SCP, eggs, fish, milk, pork and beef. Source: Seiler (2006).

The International Dairy Federation found that the production of 1 kilogram of cheese requires 41 MJ and 1 kilogram milk requires 8 MJ (International Dairy Federation (2009), see Fig. 2.5). As milk contains approximately 3.5 percent protein, this results in roughly 230 MJ per kilogram milk protein and is much lower than the 585 MJ per kilogram milk protein found by Seiler (2006).

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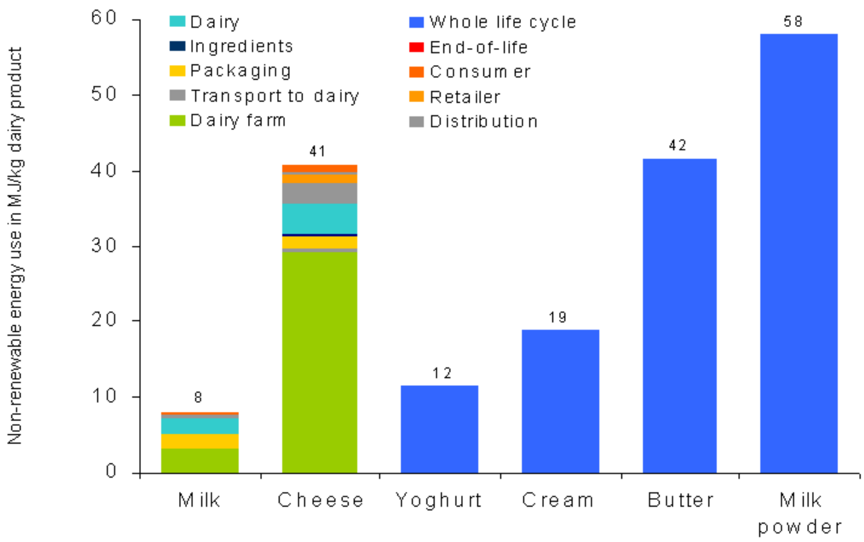

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Fig. 2.5: Energy input in MJ to produce 1 kg of milk, cheese, yoghurt, cream, butter and milk powder. Totals of energy consumption are also broken down into the contributions of the various life cycle steps for milk and cheese. Source: International Dairy Federation (2009).

De Vries and De Boer (2010) compared 16 studies, and found energy demands for beef ranging between 34 and 52 MJ/kg, for pork between 18 and 45 MJ/kg and for poultry between 15 and 29 MJ/kg.

2.5 Climate impact of food production / livestock

2.5.1 The Global Warming Potential definition

A definition of the Global Warming Potential (GWP) can be found in IPCC (2001), a summary of which is as follows: GWPs are relative index based factors based upon the radiative properties of different GHGs to estimate the integrated future climate impacts of emissions of these GHGs in a relative sense.

The GWP has been defined as "*the ratio of the time-integrated radiative forcing from the instantaneous release of 1 kg of a trace substance relative to that of 1 kg of a reference gas*" (IPCC, 2001):

$$\mathrm{GWP}(x) = \frac{\int_0^{TH} a_x \bullet [x(t)]\, dt}{\int_0^{TH} a_r \bullet [r(t)]\, dt}$$

with

TH *time horizon to be considered (e.g. 100 years)*

a_x *radiative efficiency due to a unit increase in atmospheric abundance of the substance in question (in $Wm^{-2}\ kg^{-1}$)*

[x(t)] time-dependent decay in abundance of the instantaneous release of the substance

the corresponding quantities for the reference gas are in the denominator (IPCC, 2001).

Table 2.4 shows the global warming potential of the main greenhouse gases emitted by livestock enterprises, CO_2 (carbon dioxide), CH_4 (methane) and N_2O (nitrous oxide).

Gas	GWP for 20 years time horizon	GWP for 100 years time horizon
CO_2	1	1
CH_4	72	25
N_2O	289	298

Tab 2.4: Global warming potential (GWP) of the 3 relevant greenhouse gases (GHGs) in agriculture. The GWP is defined as the cumulative radiative forcing between the present and some chosen time in the future (20 years and 100 years) caused by a unit mass of gas emitted now relative to the effect of the same mass of CO_2 over the same time period. CO_2 is assigned a GWP of 1 by definition. Methane (CH_4) has a GWP of 25 on a 100 years scale, thus being a 25 times more potent GHG over this period compared to the same mass of CO_2, nitrous oxide (N_2O) has a GWP of 298 over a 100 years period. The GWP is used to convert the contributions of various GHGs into CO_2-euqivalents. Source: Forster and Ramaswamy.

2.5.2 Livestock's climate impact

Agriculture and livestock in particular also contribute significantly to the anthropogenic greenhouse gas effect due to emissions of greenhouse gases (GHGs), mainly carbon dioxide (CO_2), methane (CH_4) and nitrous oxide (N_2O). The increasing levels of these greenhouse gases in the atmosphere due to anthropogenic activities raise global surface temperatures, a fact which is now commonly accepted and seen as one of the major threats for the future of humanity, although the models of how much temperatures will rise in the following decades in various areas differ significantly.
This chapter summarizes the contribution of livestock to the anthropogenic portion of the greenhouse effect.

Many papers refer to the extensive investigation carried out by the FAO and presented as a report entitled "*Livestock's long shadow*": When emissions from land use and land use change are included, the livestock sector accounts for 9 percent of CO_2, for 65 percent of human-related nitrous oxide, and for respectively 37 percent of all human-induced CH_4. Applying a 100 year time horizon to the GWP-conversions to CO_2-equivalents, livestock accounts for 18 percent of the total human related greenhouse gas emissions globally. In absolute numbers these are annual global GHG-emissions of 7.1 billion tons of CO_2-equivalents including emissions from land use and land use change or 4.6 billion tons of CO_2-equivalents excluding these emissions (Steinfeld, Gerber et al., 2006). The different shares of various sectors on the global GHG emissions are shown in Figure 2.7. Land use changes (especially destruction of rainforests) are the primary source of livestock related CO_2-emissions, fertilizers the primary source of N_2O-emissions, ruminant digestion the primary source of CH_4 and manure another important CH_4 and N_2O-source (see Figure 2.6). Livestock is responsible for almost 80 percent of the total emissions from the global agricultural sector (Steinfeld, Gerber et al., 2006; McMichael et al., 2007).

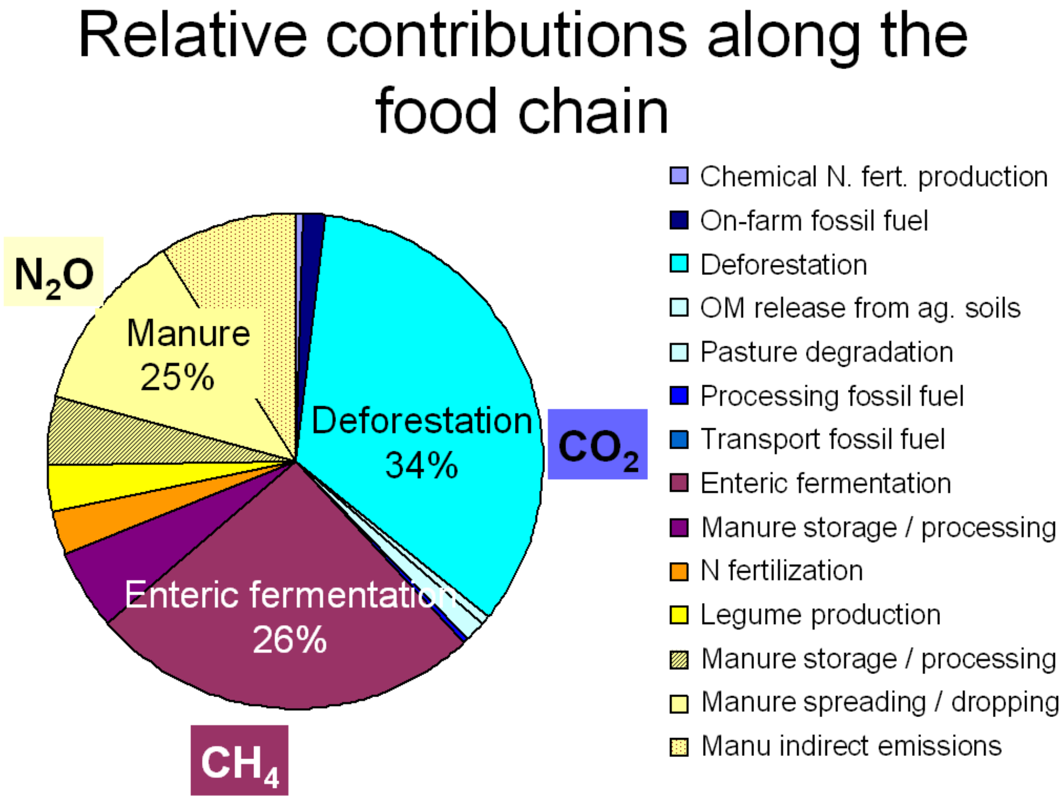

Fig. 2.6: Relative contributions along the food chain of animal based foods to GHG emissions globally, according to the FAO (Steinfeld, Gerber et al., 2006). The biggest contributors are deforestation (primarily emitting CO_2), enteric fermentation (primarily producing CH_4) and manure (primarily contributing N_2O). With credits to Henning Steinfeld, FAO.

In some countries, the agricultural sector is the largest contributor to national GHG emissions, in New Zealand it accounts for about 70 percent of national emissions (International Dairy Federation, 2009). In Germany, the agricultural sector accounts for 13 percent of national GHG-emissions, but some emissions are "exported" when feed is produced elsewhere and imported to Germany, these emissions are not included in the 13 percent (Hirschfeld et al., 2008). In Brazil, the cattle sector is the key driver of deforestation in the Brazilian Amazon, responsible for an estimated 80 percent of all deforestation in the Amazon region (Chomitz and Thomas, 2001; Grieg-Gran, 2006) and thus a key driver in GHG emissions. The cattle sector in the Brazilian Amazon alone is responsible for 14 percent of the world's annual deforestation (Greenpeace-International, 2009).

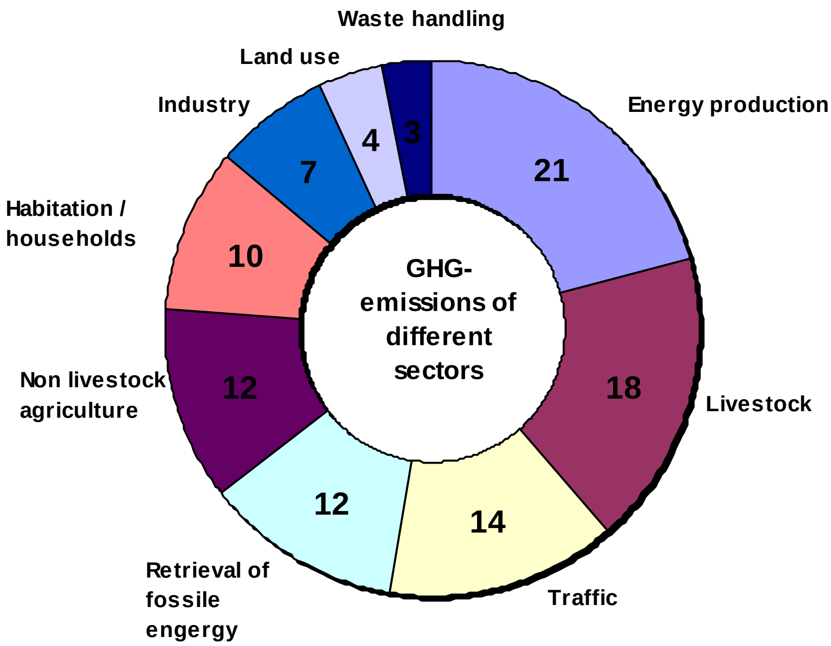

Fig. 2.7: Assignment of global greenhouse gas emissions to sectors in percent. Rounding differences lead to a total of 101 %. Source: Fiala (2009).

The general problem of LCAs is that generalisations of GHG-emission-values for products such as beef are problematic. First of all, a cow is not only used for the production of beef, but also for milk/dairy, leather, gelatine and much more. It is not obvious how the climate impact of the cow has to be split and distributed among these products. An even bigger problem arises from massively varied production methods. Cattle grazing in Austrian alps without much additive feeding and without being fed any imported concentrated feed can have a much more favourable CO_2-balance than those being fed with imported feed, especially from former rainforest areas destroyed for the purpose of feed crop production, although the methane balance might be similar in both cases.

In spite of these pleas that can be raised against generalised CO_2-figures for various foods, such average figures can be found in many publications, e.g. in Pendo Verlag (2007) as shown in Table 2.5

Product Group	Product	CO_2-equ. emissions in g per kg of the product
Meat / sausage	Beef	13300
	Uncooked sausages	8000
	Ham (pork)	4800
	Poultry	3500
	Pork	3250
Other animal products	Butter	23800
	Hard cheese	8500
	Cream	7600
	Eggs	1950
	Curd	1950
	Cream cheese	1950
	Margarine	1350
	Yoghurt	1250
	Milk	950
Fruits and vegetables	Apples	550
	Strawberries	300
	Tomatoes	140-200
	Avg. value for frozen vegetables	400
	Avg. value for tinned vegetables	500
	Brown bread	750
	White bread	650
	Pasta	700-900
	French fries, deep frozen	5700

Tab 2.5: A showcase attempt to quantify CO_2-emissions per kg of various food products. Source: Pendo Verlag (2007).

At least some of these shortcomings can be overcome if LCA is applied to a comparison of foods produced in the same, delimited region. Tables 2.6 and 2.7 show results of an LCA analysis for major production systems in England and Wales according to the proportions of production systems in 2006 there (Williams et al., 2006). Again, in general animal products contribute considerably more to global warming than their plant based counterparts.

Impacts & resources used per t	Bread wheat (0.7%)	Oilseed rape (0%)	Potatoes (1%)	Tomatoes (3.6%)
Primary energy used, GJ	2.5	5.4	1.4	130
GWP_{100}, t CO_2 (1)	0.80	1.7	0.24	9.4
Eutrophication potential, kg PO_4^{3-}	3.1	8.4	1.3	1.5
Acidification potential, kg SO_2	3.2	9.2	2.2	12
Pesticides used, dose-ha	2.0	4.5	0.6	0.5
Abiotic resource used, kg antimony (2)	1.5	2.9	0.9	100
Land use (Grade 3a), ha	0.15	0.33	0.030	0.0030
Irrigation water, m^3			21	39

(1) GWP_{100} uses factors to project global warming potential over 100 years. (2) ARU antimony is the element used to scale disparate entities.

Tab 2.6: The main burdens and resources used for field and protected crops in England and Wales (using LCA).
Note a: To calculate the land use, the yields were calculated for an average classified land of grade 3a (a British measurement for agricultural land classification).
Note b: Abiotic resource use (ARU): Method for aggregating the use of natural resources. Many elements and natural resources are put onto a common scale that is related to the scarcity of the resources. It is quantified in terms of the mass of the element antimony (Sb), which was an arbitrary choice. This data includes most metals, many minerals, fossil fuels and uranium for nuclear power.
Note c: In this model, tomatoes were partly produced in heated greenhouses to extend the growing season.
Source: Williams, Audsley et al. (2006).

Impacts & resources used per t of carcass, per 20,000 eggs (about 1 t) or per 10m³ milk (about 1 t dm)	Beef (0.8%)	Pig meat (0.6%)	Poultry meat (0.5%)	Sheep meat (1%)	Eggs, (1%)	Milk, (1%)
Primary energy used, GJ	28	17	12	23	14	25
GWP_{100}, t CO_2	16	6.4	4.6	17	5.5	10.6
Eutrophication potential, kg PO_4^{3-}	158	100	49	200	77	64
Acidification potential, kg SO_2	471	394	173	380	306	163
Pesticides used, dose ha	7.1	8.8	7.7	3.0	7.7	3.5
Abiotic resource use, kg antimony	36	35	30	27	38	28
Land use (1)						
Grade 2, ha	0.04			0.05		0.22
Grade 3a, ha	0.79	0.74	0.64	0.49	0.67	0.98
Grade 3b, ha	0.83			0.48		
Grade 4, ha	0.67			0.38		

(1): Grazing animals use a combination of land types from hill to lowland. Land use for arable feed crops was normalised at grade 3a.

Tab 2.7: The main burdens and resources used for field and protected crops in England and Wales (using LCA). Also see comments in Table 2.6.

Source: Williams, Audsley et al. (2006).

The following Figures 2.8 to 2.10 show GHG-emissions for 1 kg of different animal foods taken from various investigations in different countries globally.

For poultry meat, Williams, Audsley et al. (2006) calculated 4.58 kg CO_2-eqivalents per kg meat (assuming a meat yield of 70 percent of live weight) and Hirschfeld, Weiß et al. (2008) summarise existing literature showing a range from 1.66 to 4.6 kg CO_2-eqivalents per kg live weight.
The biggest share of energy usage and GHG-emissions occur at the farm level, nevertheless the retail market is responsible for 20 percent of energy usage (instore cooling systems etc.) and 9 percent of GHG-emissions in poultry production (Katajajuuri, 2008).

A few papers have also calculated GHG emissions using LCA for relatively protein rich meat alternatives like tofu, tempeh and Quorn (for definition, see chapter 9.1.6). In the Netherlands and Belgium the production of 1 kilogram of tofu leads to emissions of approximately 2 kg CO_2-eq, for 1 kilogram of tempeh of 1.1 kg CO_2-eq and for 1 kilogram of Quorn (including 4 percent egg white and produced in Great Britain) of 2.6 kg CO_2-eq (Blonk, Kool et al., 2008).

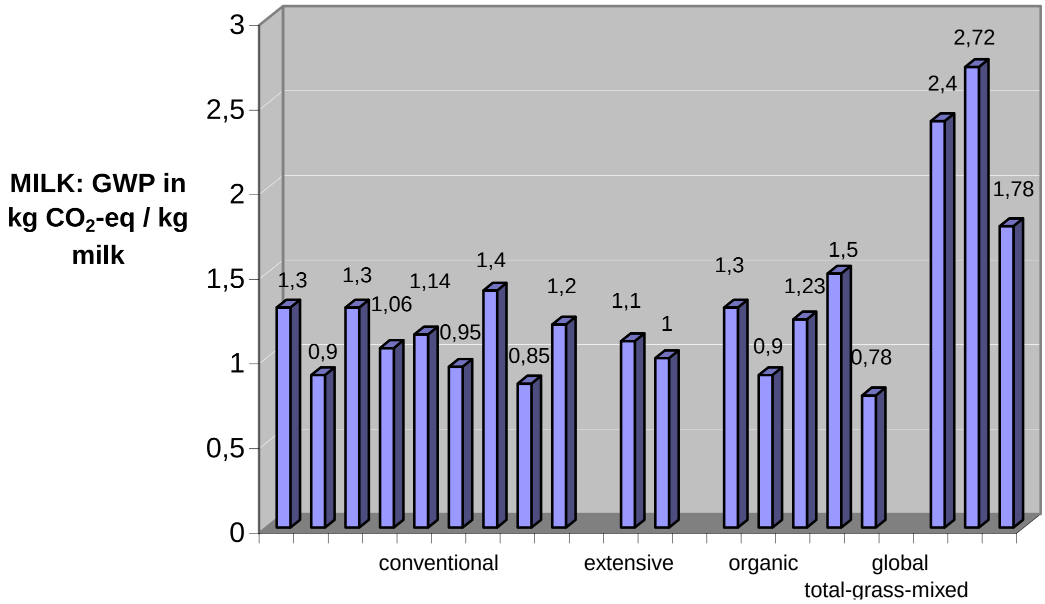

Fig. 2.8: GHG-emissions for 1 kilogram of milk, taken from various papers. The values range from 0.78 to 1.5 kg CO_2-eq/kg milk.

The values (in kg CO_2-eq / kg milk) are taken from the following papers:

Conventional milk production:	
Haas et al. (2001)	1.3
Cederberg (2004)	0.9
Casey and Holden (2005)	1.3
Williams, Audsley et al. (2006)	1.06
Forster et al. (2006)	1.14
Pendo Verlag (2007)	0.95
Thomassen et al. (2007)	1.4
Hirschfeld, Weiß et al.(2008)	0.85
International Dairy Federation (2009)	1.2
Extensive conventional milk production:	
Haas, Wetterich et al. (2001)	1.1
Cederberg (2004)	1.0
Organic milk production:	
Haas, Wetterich et al. (2001)	1.3
Cederberg (2004)	0.9
Williams, Audsley et al. (2006)	1.23
Thomassen, van Calker et al. (2007)	1.5
Hirschfeld, Weiß et al. (2008)	0.78
Global average values by FAO (Gerber et al., 2010)*:	
Global average:	2.4*
Grassland systems global	2.72*
Mixed farming systems	1.78*

* Global average measured per kg of “*fat and protein corrected milk*”, which is milk corrected for its fat and protein content to a standard of 4 % fat and 3.3 % protein. This is a standard used for comparing milk with different fat and protein contents.

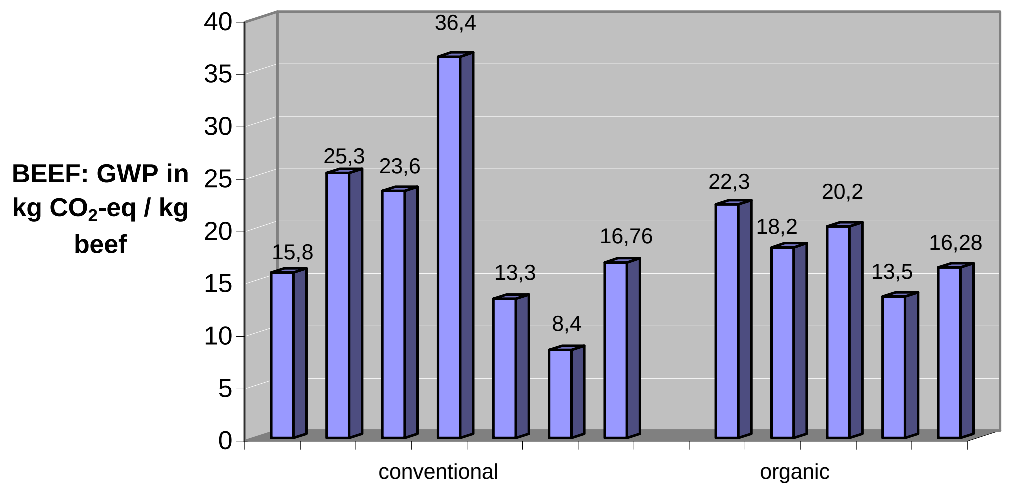

Fig. 2.9: GHG-emissions for 1 kilogram of beef, taken from various papers. The values show a massive range of between 8.40 and 36.4 kg CO_2-eq/kg of beef.

The highest value given by Ogino et al. (2007) can partly be explained by the high share of imported feed in Japan and relatively low assumed meat yield of only 40 % of the live weight of the cattle.

The values (in kg CO_2-eq / kg beef) are taken from the following papers:

Conventional beef production:

Williams, Audsley et al. (2006)	15.8	Bulls from calves out of milk prod. systems
Williams, Audsley et al. (2006)	25.3	Bulls from calves from suckler cows. In the paper, a meat yield of 55 % of the live weight is estimated
Casey and Holden (2006)	23.6	Calculated from 13 kg CO_2-eq/kg live weight assuming 55 % meat yield
Ogino, Orito et al. (2007)	36.4	In the paper, a meat yield of 40 % of the live weight is estimated.
Pendo Verlag (2007)	13.3	The book does not specify the meat yield which is used for calculations.
Hirschfeld, Weiß et al. (2008)	8.4	Bulls from calves out of milk prod. Systems. In the paper, all emissions for cattle/beef are calculated per kg carcass weight,
Hirschfeld, Weiß et al. (2008)	16,76	Bulls from calves from suckler cows

Organic beef production:

Cederberg and Stadig (2003)	22,3	The paper does not specify the meat yield which is used for calculations.
Williams, Audsley et al. (2006)	18,2	In the paper, a meat yield of 40 % of the live weight is estimated.
Casey and Holden (2006)	20,2	Calculated from 11.1 kg CO_2eq/kg live weight assuming 55 % meat yield
Hirschfeld, Weiß et al. (2008)	13,5	Bulls from calves out of milk prod. systems
Hirschfeld, Weiß et al. (2008)	16,28	Bulls from calves from suckler cows

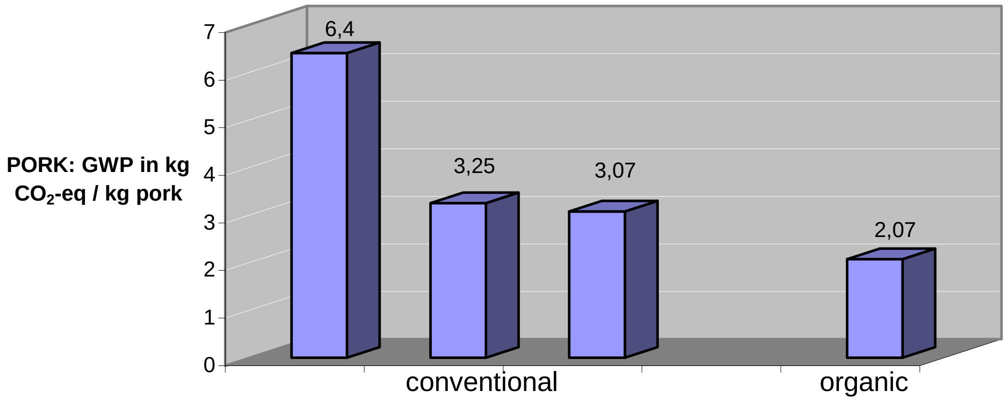

Fig. 2.10: GHG-emissions for 1 kilogram of pork, taken from various papers. The values show a massive range of between 2.07 and 6.4 kg CO_2-eq/kg of pork.
The low values found in Hirschfeld, Weiß et al. (2008) can be explained by the fact that forest clearances for feed production are not included in these figures. And while Williams, Audsley et al. (2006) assign emissions from pig manure to pork production, Hirschfeld, Weiß et al. (2008) assign it to plant products as part of the manuring strategy within plant production.
The values (in kg CO_2-eq / kg pork) are taken from the following papers:

Conventional pork production:		
Williams, Audsley et al. (2006)	6.4	In the paper, a meat yield of 77 % of the live weight is estimated.
Pendo Verlag (2007)	3.25	The book does not specify the meat yield which is used for calculations.
Hirschfeld, Weiß et al. (2008)	3.07	In the paper, a meat yield of 79 % of the live weight is estimated.
Organic pork production:		
Hirschfeld, Weiß et al. (2008)	2.07	In the paper, a meat yield of 79 % of the live weight is estimated.

Fig. 2.11 shows the GHG-emissions of the total lifecycle for 1 kg of various products. By way of comparison the emissions of 1 litre fuel and diesel are also displayed. In a Japanese analysis, the life cycle of 1 kg of beef leads to GHG-emissions of 36.4 kg CO_2-equivalents, equivalent to the use of nearly 14 litres of diesel or nearly 16 litres of fuel or driving an average European car 250 kilometres (Ogino, Orito et al., 2007).

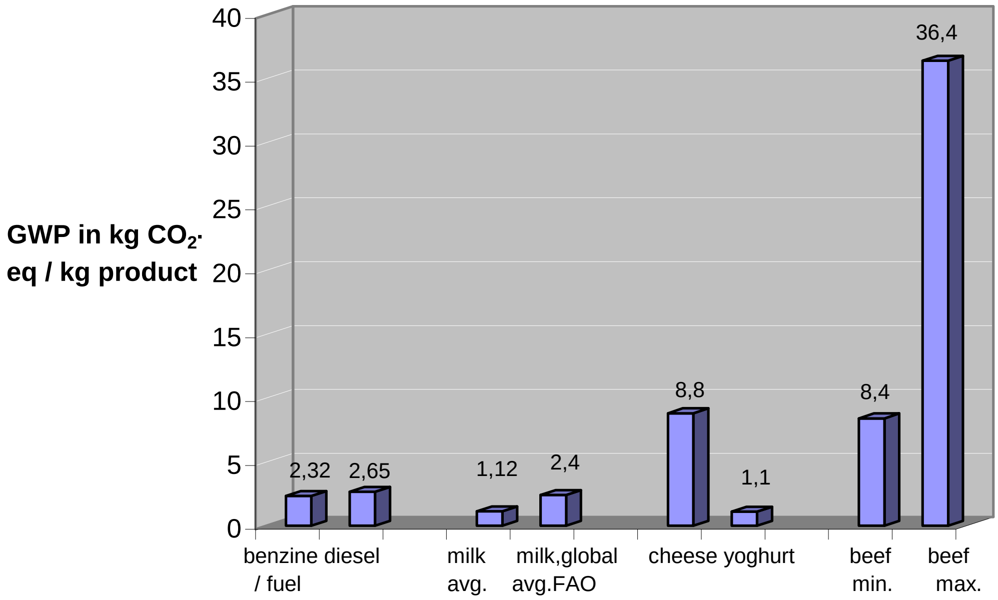

Fig. 2.11: GHG-emissions for 1 kilogram of different food products in CO_2-equivalent. By way of comparison the CO_2-emissions of the burning of 1 litre of fuel and diesel are also displayed. Sources: For milk, an average value for conventional milk from Fig. 2.8 is taken as well as a global average value from the FAO (Gerber, Vellinga et al., 2010), for cheese and yoghurt values are taken from the International Dairy Federation (2009), for beef, a minimum value from Hirschfeld, Weiß et al. (2008) and a maximum value from Ogino, Orito et al. (2007) is shown.

Using LCA methodology, the largest contributor to GHG emissions in dairy production is the dairy farm and feed production with 80 percent of GHG emissions. Dairy end product manufacturing, packaging, retail, transport and usage by the consumer altogether account for just a fifth of the effect (International Dairy Federation, 2009).

2.5.3 *Climate effect of certain diets*

Another shortcoming of many climate impact calculations of foods is that foods are compared simply by their weight in kilograms and not by the much more significant energy of these foods in calories or maybe by other nutritional values such as the protein contents and its biological value.

Based on data from Defra (Williams, Audsley et al., 2006) and FAOSTAT, a British calculation compared a typical UK diet with 30 percent of calories originating from animal products with a UK diet typically found among vegans. The results showed savings of 74 percent in the annual water consumption (535 versus 140 m^3), 67 percent in land use (0.195 versus 0.065 ha), 55 percent in the use of arable land only (0.143 versus 0.065 ha) and of 69 percent in the annual CO_2-eq emissions (1088 versus 332 kg CO_2-eq), based on a 100 year timeframe for GWP conversions of the various greenhouse gases (Walsh, 2009).

An LCA of the average Spanish diet including the impact of human excretion showed that feeding an average Spanish citizen for a year contributes 2.1 tons CO_2-eq to the overall GHG-emissions. This figure is dominated by the food production stage. Highlighted contributions are those by meat products and dairy with 54 percent of the total GWP for food production (Muñoz et al., 2010).

Geophysicians from the University of Chicago state that the average American diet requires the production of an extra ton and a half of carbon dioxide-equivalent annually, in the form of actual carbon dioxide as well as methane and other greenhouse gases compared to a strictly vegetarian diet (Eshel and Martin, 2005). These 1500 kilograms of extra CO_2-equivalents are, by comparison, the same as burning 650 litres of fuels per year.

Carlsson-Kanyama and Gonzalez (2009) compared three meals for their climate effect: The first containing soybeans, apples, wheat and carrots leads to

only 0.42 kg CO_2-eq/kg food. The second consisting of pork, potatoes, beans and oranges, adds up to 1.3 kg CO_2-eq/kg, with pork contributing 0.94 kg CO_2-eq to the result. And the third including beef, tropical fruits, rice and cooked deep-frozen vegetables adds up to 4.7 kg CO_2-eq/kg food, with beef contributing 3 kg CO_2-eq, the tropical fruits 1.1 kg CO_2-eq.
Comparing two "endpoint-scenarios" to achieve the United States Department of Agriculture (USDA) recommendations for kilograms of dietary protein consumption per capita and year shows that the meat/eggs/dairy livestock-scenario produces impacts higher by one or two orders of magnitude compared to the other extreme, a pure soybean-scenario for the following environmental issues: GHG emissions, biomass appropriation and reactive nitrogen mobilization (Pelletier, 2010).
Case studies from Sweden and Spain have shown that diets replacing pork based meals with pea based burger meals can reduce the global warming potential by around 50% as well as the eutrophication potential by more than half. The case studies also showed markedly reduced land use but, similar energy-use for the pea burger meal compared to the pork based meals (Davis et al., 2010).

A multidisciplinary study by the Netherlands Environmental Assessment Agency (PBL) from 2008 investigated the effect of carbon sinks that could be established if croplands and pastures could be abandoned through changes in diet. PBL focussed on livestock in their climate change mitigation models due to it accounting for 18 percent of greenhouse gas emissions and 80 percent of total anthropogenic land use. Up to 2700 Mha of pasture and 100 Mha of cropland could be abandoned if the global population shifted to a low-meat diet – defined as 70 grams of beef and 325 grams of chicken and eggs per week. Vegetation growing on this land would mop up carbon dioxide. Of the climate stabilisation costs that are required to achieve a 450 ppm CO_2 equivalent concentration in the atmosphere by 2050, around 50 percent could be saved by such a low-meat diet model compared to a reference case, that is a saving of no less than US$ 20 trillion or US$ 20000 billion. For the reference case, data from OECD, IEA and the FAO was used. PBL also calculated alternative diet models and their effect on climate stabilisation costs. A "*no animal product*"-model was also calculated, assuming that the global population would switch to a vegan diet containing no animal products at all. Mitigation costs in this model would be reduced by 80 percent by 2050, from a total of US$ 40 trillion (Stehfest et al., 2009). Figure 2.12 shows some of the effects of the different scenarios over the years until 2050.

To illustrate these figures: These climate cost savings of US$ 32 trillion would be enough to build more than 200 million one-family houses at the cost of US$ 150 000 each. Assuming that an average of 4 people lived in such a house, this would be enough to build houses for the whole population of Europe, including the whole of Russia, and in addition, for all inhabitants of Australia and Canada.

The authors accredit these enormous figures mainly to the huge carbon sink achieved by regrowing forest vegetation on parts of the abandoned pastures and croplands and also to the reduced CO_2-, CH_4 and N_2O-emissions achieved by reducing the number of farmed animals globally (Stehfest, Bouwman et al., 2009).

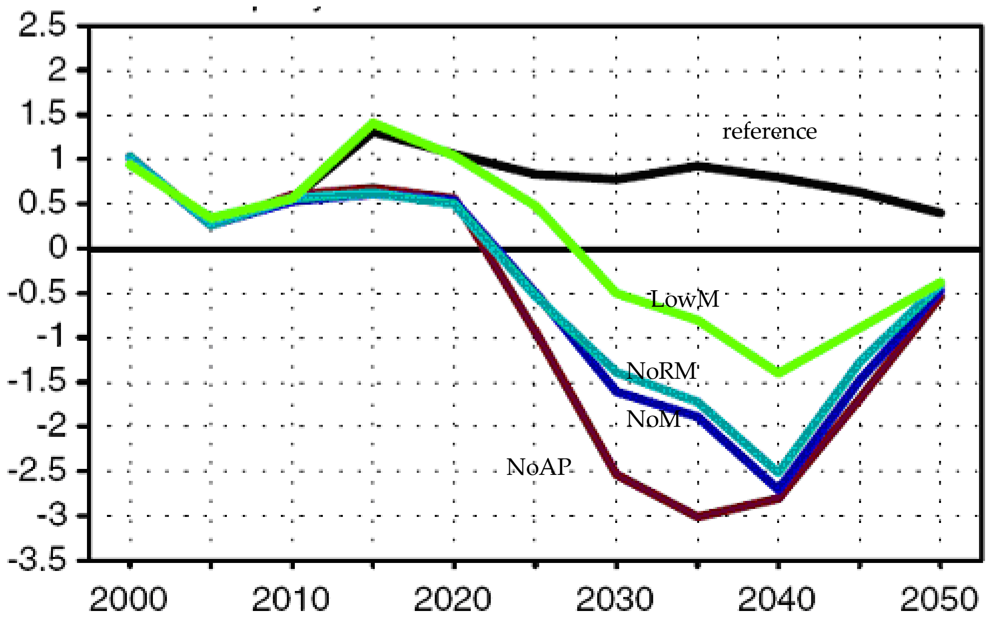

Fig. 2.12: Land use CO_2-emissions in Gtonne C per year. Comparison of 5 scenarios: Reference scenario (predicted animal consumption per capita and predicted population growth), NoRM-scenario (no ruminant meat eaten globally), NoM-scenario (no meat eaten globally), NoAP-scenario (no animal products eaten globally: Vegan diet) and LowM-diet (low meat diet globally which is defined by 70 g beef, 70 g pork and 325 g chicken meat and eggs per week and per capita globally).
The NoRM-, NoM-, NoAP- and LowM-scenarios have been designed in such a way that the shifts in diet start in 2010 and are completed in 2030. The animal products mentioned are replaced by plant proteins in these scenarios.
All scenarios except the reference scenario show the appearance of a huge carbon-sink which could bind CO_2 from the atmosphere. Source: Stehfest, Bouwman et al. (2009).
Note: This effect would bind CO_2 from the atmosphere and mitigate climate stabilisation costs particularly in a period when fossil fuels are still available and their usage producing CO_2. Prognoses for availability of fossil fuels can be found in Bräuninger and Matthies (2005).

Comparing emissions and resource use indicators for pork and pea based vegetarian meat products shows that pork contributes 61 times more to acidification, measured in NH_3 equivalent, 6 times more to eutrophication, measured in N equivalent and 6.4 times more to global warming, measured in CO_2 equivalent (Zhu and Van Ierland, 2003). Another Dutch investigation showed that meat protein requires 6–17 times more land compared to processed protein food based on soybeans. The analogous relative factors for water consumption are 4.4–26, for fossil fuel requirements 6–20 and for the emission of acidifying substances a factor > 7 (Reijnders and Soret, 2003). More recent Dutch investigations show that a totally vegan diet, compared to a classical omnivore diet, in the Netherlands saves per day: 0.46 kg CO_2-eq by replacing dairy products with products based on soy, 0.53 kg CO_2-eq by replacing meat with vegetarian meat alternatives, 0.12 kg CO_2-eq by replacing fish and 0.06 kg CO_2-eq by replacing eggs. The summed daily alimentary emissions are 1.46 kg CO_2-eq for a classical Dutch omnivore diet, 1.06 kg CO_2-eq for a Dutch ovo-lacto vegetarian diet (assuming an increased intake of dairy products to replace the meat) and 0.51 kg CO_2-eq for a Dutch vegan diet (Blonk, Kool et al., 2008).

A calculation of the greenhouse gas emissions within the European Union for consumption, including foods and beverages showed that, of the overall 31.1 percent share that nutrition contributes to greenhouse gas emissions, three quarters are caused by animal products (Tukker et al., 2006, page 111).

2.5.4 General note on CO_2-equivalents

In most of the studies, the GWPs used to convert the effect of CH_4 into CO_2-equivalents are the values for a time horizon of 100 years. When calculating short term climate effects, e.g. for the next 20 years, CH_4 becomes much more influential on global warming as its GWP is about three times higher on the 20 years time scale compared to the commonly used 100 years, leading to a much higher CO_2-equivalent value. As CH_4-emissions are coupled closely with livestock, it can be stated that on a 20 years horizon livestock plays an even larger part in global warming than stated in the research results in chapter 2.5.2.

2.6 Including the "*missed potential carbon sink*" of land occupation to LCAs

In the course of writing this doctoral thesis, a new concept of integrating land occupation as a "*missed potential carbon sink*" into LCAs, leading to the integration of the concepts of LCA and the ecological footprint was formed. This new, more complete LCA concept led to a paper submitted by myself together with the Dutch scientist Elke Stehfest, that has by the beginning of 2012 not yet been released (Schmidinger and Stehfest, submitted). This chapter gives a short overview of this new concept.

As seen in the previous chapters, there are several different approaches to measuring the climate impact of livestock products or products in general, here are three of them:

- The classical LCA, measuring the emissions during the life cycle of a product in kg CO_2-equivalent per kg of a product.
- The approach used by Stehfest, Bouwman et al. (2009) that emphasizes the potential of carbon sinks in climate stabilisation, if areas can be freed up by reducing the production and consumption of animal products globally. These carbon sinks are caused by the regrowth of natural vegetation on these freed up areas. The result is not expressed in kg CO_2-equivalent per kg product, but in reduced climate stabilisation costs (in trillion US$).

In LCAs, land use changes, due to higher feed demands as a result of increased meat production, start to become adopted. The same applies for opportunity costs (Garnett, 2009; Nguyen et al., 2010). But land use change effects have to be differentiated from land occupation effects: Land occupation is independent of recent changes in land use whereas land use change only covers the climate effects of agricultural areas that were just established on land that was covered by natural vegetation until the recent past.

- The Ecological Footprint approach measures the impact of the production in areas, global hectares, or virtual "earths".

More recent papers on LCAs of agricultural products either recognize land use change as a relevant issue, but do not integrate it in the LCA results (Hirschfeld et al., 2008) or they integrate historic changes in land use into LCA (e.g. Gerber et al. (2010) for FAO). But the pure occupation of land for the production of agricultural goods and its consequence of being a missed potential carbon sink, as it prevents natural vegetation from regrowing on this area and by this absorbing CO_2 from the atmosphere, has de facto not yet been addressed.

An exception is a recent paper that presents a general methodology on how to include carbon emissions from land conversion and land occupation into LCAs (Müller-Wenk and Brandão, 2010). The authors suggest a method to calculate a delayed uptake of CO_2 due to land occupation and add this to LCAs. But, it does not provide information of how to add this new summand to the overall LCA result, instead keeping transformation and occupation separated. The CO_2 implications of land transformation for agricultural use in a particular year are described as CO_2 emissions from conversion, which is followed by a carbon uptake of the natural vegetation, which starts to regrow directly in the following year. Thus an average stay of additional CO_2 from land transformation is computed, depending on how fast the regrowth takes place in a certain ecosystem and area. Continued land use (land occupation) leads to a delayed carbon uptake, resulting in an additional 1 year stay of CO_2 in the atmosphere. But as mentioned, the authors do not provide a final formula of how to incorporate these occupation effects into an overall LCA result (Müller-Wenk and Brandão, 2010).

This chapter presents a different model of integrating land occupation or a missed potential carbon sink (in contrast to the "*delayed carbon sink*" in Müller-Wenk and Brandão (2010)) in a Life Cycle Assessment of livestock products to derive total GHG emissions per kg product. It contains the result according to the standard LCA approach, and then adds a further amount of "potential" CO_{2}-eq to the production of 1 kg of a product. This second amount represents the area that the production of this (food) item occupies, the area that therefore cannot fulfil its potential as a carbon sink to mitigate GHG concentrations in the atmosphere. Other influences of land occupation on the climate are not yet part of the new method: Nitrous oxide and methane emissions might be affected by these land conversions or occupations as well as evapotranspiration and the albedo of the land. These effects go beyond the scope of the method presented here.

The result of the new, "enriched" LCA is based on the standard LCA results for a certain food item (the summand is called $GHG_{LCAstandard}$), expressed in kg CO_2-

eq / kg of the product. The innovation is that a second summand called $GHG_{missedPotentialCarbonSink}$ is added. This second summand represents the carbon uptake (carbon sink) that natural vegetation could accomplish if the land that is used for the production of the food item was freed up. Or alternatively, this can be seen as the missed carbon uptake (carbon sink) if the land is further used for the production of the food item.

$$GHG._{total} = GHG_{LCAstaandard} + GHG_{missedPotentialCarbonSinkk}$$

The following steps show a way of calculating the new summand $GHG_{missedPotentialCarbonSink}$ to achieve more comprehensive LCA calculations for future use:

2.6.1 How to calculate the new summand $GHG_{missedPotentialCarbonSink}$

For the calculation of the new summand $GHG_{missedPotentialCarbonSink}$, the following formula is established:

$$GHG._{missedPotentialCarbonSink} = 1/\,\mathrm{timehorizon} * \sum_{l=1,r=1}^{L,R} Area_{l,r} * (CarbonSink_{l,r,t})$$

with Area l,r representing the agricultural area [m^2] of land use l (crop or grassland) in region r, required per unit of product [m^2 / kg product], and CarbonSink l,r is the carbon sink [kg CO_2/m^2] that occurs in region r when land use l (crop or grass) is regrowing to natural vegetation (e.g. forests, or tundra) during t years.

The "region" represents a geographic unit involved in the production process having a characteristic current carbon content and potential carbon sink. The granularity (size) can be selected according to the data quality available, from world regions down to small grid cells. This "region" allocation is very relevant, as the carbon stocks, and thus, potential sinks differ significantly across ecosystems. Furthermore, the potential carbon sink also depends on the initial form of land use, with grassland often already containing more carbon than cropland.

Additionally, the time t during which the carbon uptake is accumulated has to be defined. The CO_2 fixation is higher in the initial phases when the vegetation starts to grow again, and declines when the forests approach maturity. And, on the other hand, the time horizon over which the missed potential carbon uptake is added to the products GHG balance must also be defined. For both these time horizons the same value should be applied, simply called time horizon here. A time horizon of 100 years could be adequate, as by then the regrowing vegetation is approaching its equilibrium state (e.g. Mila i Canals et al. (2007) mention such a relaxation time). For biofuel studies the time horizon used for to apply emissions from land use change to the products is often set to 30 years (IPCC, 2006; Searchinger et al., 2008). Thus, in the pending paper on how to include the missed potential carbon sink to LCAs (Schmidinger and Stehfest, submitted), these time horizons of 30 and 100 years are used for the model calculation examples. Based on area requirements as well as the standard LCA results taken from Blonk, Kool et al. (2008) and on the potential carbon sink data for different regions taken from MNP (2006), sample calculations have been made. For the 100 years time horizon and, even more so, the 30 years time horizon the results show that the missed potential carbon sink for livestock products ($GHG_{missedPotentialCarbonSink}$) is in the same order of magnitude or higher than the standard LCA results $GHG_{LCAStandard}$

(Schmidinger and Stehfest, submitted). This reveals or at least indicates that current LCAs conceal at least half of the climate relevant effects of agricultural production. Some results are shown in Figure 2.13.

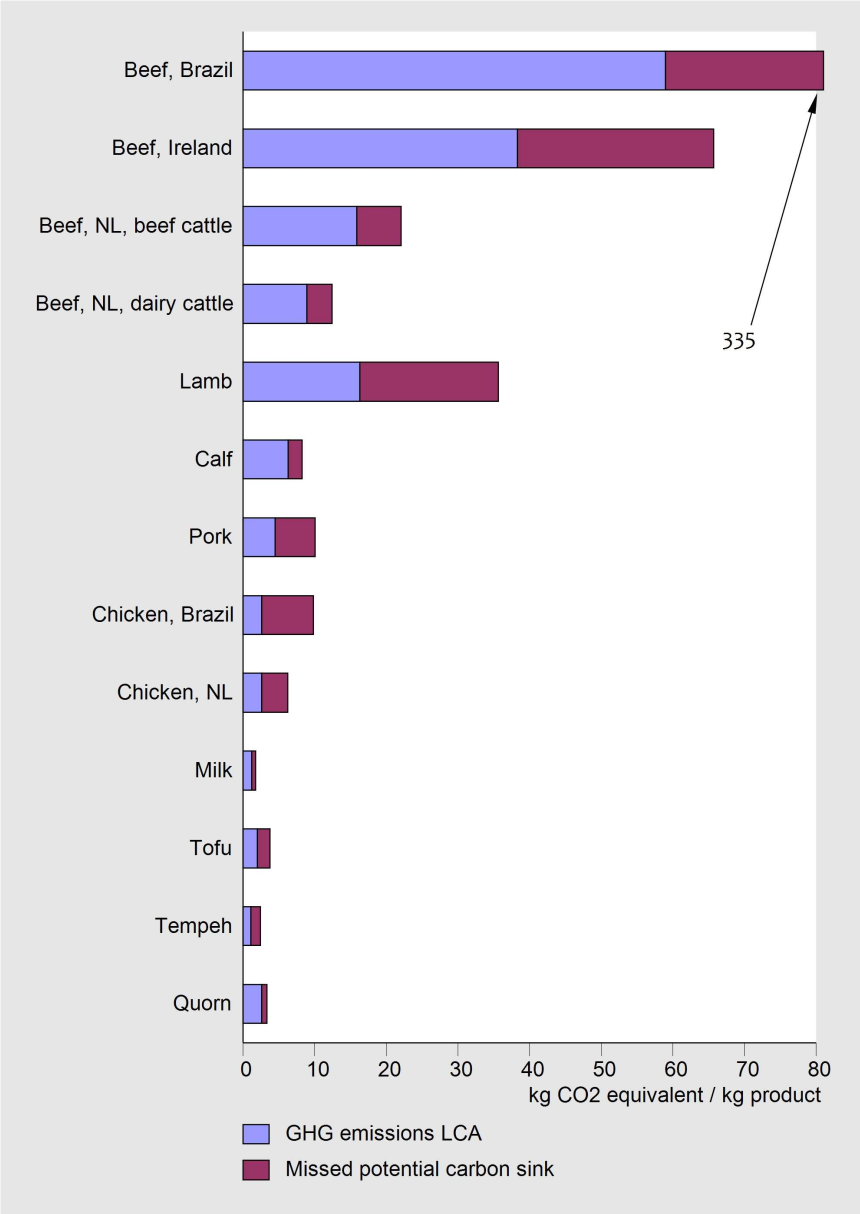

Fig. 2.13: Results of LCA for the various products, using a 30 year time horizon. The chart shows the standard LCA results and the LCA result for the missed potential carbon sink as well as the totals. Source: Schmidinger and Stehfest (submitted).

2.6.2 *Short discussion*

Whether agricultural production requires a lot or little land has major implications for the climate balance of the products, but – unlike emissions – has de facto been ignored in LCAs so far. This reveals a major loophole in hitherto existing LCAs, which is especially relevant for agricultural products, as these consume huge areas (see chapter 2.3). The integration of missed potential carbon sinks due to land occupation to LCAs will lead to a more realistic and holistic climate balance: Products that consume a lot of land for their production will have additional CO_2-eqivalents added to their LCA balance as the occupied land and its related missed potential as a carbon sink is now also taken into account. It might be argued that not only reforestation of abandoned cropland can bind CO_2, but the crops on the cropland as well: The crucial difference here is, that the breathing of humans or animals when fed with the crops on the one hand, and the growth of the crops on the other, form a carbon balance, an equilibrium, a zero sum game. Reforestation contrariwise is a huge net carbon sink, as carbon is stored in the forests and also in produced soil in forests permanently.

2.7 Water usage for the production of various foods

70 percent of the global withdrawals of water from rivers, lakes, and groundwater is used for agriculture, 20 percent for industrial purposes and 10 percent is consumed by municipalities (IWMI, 2007; Hertwich, van der Voet et al., 2010).

The water use for the production of different foods is sometimes hard to estimate, and can differ greatly for different regions or production methods.

Also, the same amount of water used in a very humid region can have a negligible effect on the environment compared to water used in an arid region. Nevertheless, this chapter presents some calculations of water usage for the production of some animal products.

When the whole production chain of 1000 kg of pork protein is compared with the production of 1000 kg of protein of a vegetarian meat product based on peas, the pork chain requires 11345 m^3 water, the pea based vegetarian meat chain only 177 m^3 (Aiking, Helms et al., 2006). The discrepancy in such estimations can be seen in Renault (2003), who estimates the virtual water demands for pork or chicken in Californian production sites as being both slightly above 4 m^3 per kg, and for various plant based products between less than 0.1 and almost 2 m^3 per kg (with rice and wheat showing the highest values, potatoes and tomatoes the lowest).
The International Dairy Federation calculated that 1 kg of milk requires 1000 litres, 1 kg of cheese 5000 litres and 1 kg of milk powder 4600 litres of water (International Dairy Federation, 2009).

The term "*water footprint*" has been introduced by Hoekstra and Chapagain (2006) and has been further specified in Hoekstra et al. (2009). It expresses the personal water usage in relation to consumption. Food consumption patterns, especially the level of meat consumption, are a key driver of the water footprint of a nation.
The amount of water that is used in the process of producing goods, for example food, is called "*virtual water*". While the amount of drinking water consumed per capita and day is between 0.05 and 0.15 m^3, the virtual water for

food consumption is much higher and varies between 1 m^3/capita/day for a survival diet and more than 5m^3/capita/day for a typical US meat based diet. A vegetarian diet requires 2.6 m^3/capita/day of virtual water (Manning, 2008).

2.8 "The smaller evil" – organic or industrial livestock farming?

The previous chapters 2.1 to 2.7 showed, that plant based foods can ecologically outperform animal based foods by far.
But if it is not possible to substitute animal products completely by plant based products in industrial countries, due to general political or societal conditions, then it is still interesting to answer the question of whether organic livestock farming or industrial livestock farming is "the smaller ecological evil", and which one of these antagonists has more potential to at least mitigate the negative effects of the production of animal products on the environment.

Some authors emphasize, that industrial livestock farming is more efficient than traditional livestock practices. Compared to 1944, the US dairy production in 2007 only required 21 percent of animals, 23 percent of feedstuff, 35 percent of water and 10 percent of land for the same amount of milk, according to Capper et al. (2009). Manure has been reduced to 24 percent, CH_4 to 43 percent and N_2O to 56 percent compared with the values from 1944. Average milk yield per cow has increased from 2074 kg/year to 9193 kg/year in this period. Aspects such as animal health are not discussed here, but German Holstein cows in 2006 for example have only an average of 2.9 lactations in their life (Eilers, 2007). Capper et al. (2009) claim that many characteristics of the 1944 livestock system are similar to those of modern organic systems. Nevertheless, Seemüller (2001) claims that only 24 percent more area than is now being used would be required if the total German food demand were to be supplied by organic farming practices. This shows that modern organic farming does not inherit disadvantages of traditional livestock practices, even if both share some characteristics with free range systems.

Eberle and Reuter (2005) emphasize the advantages of organic farming in terms of reduced pollutions, preservation of flora and biodiversity due to the reduced applications of N-fertilizers and the waiving of herbicides and genetically modified seeds

A detailed comparison of the burdens of producing various animal products in organic and conventional systems in England and Wales is shown in Tables 2.8 to 2.11 providing a heterogeneous picture of merits and drawbacks of both systems (Williams, Audsley et al., 2006).

Impacts & resources used	**Non-organic**	**Organic**	**100% suckler**	**Lowland**	**Hill & upland**
Primary energy used, MJ	27,800	18,100	40,700	26,800	29,700
GWP_{100}, kg 100 year CO_2 equiv.	15,800	18,200	25,300	15,600	16,400
EP, kg PO_4^{3-} equiv.	157	326	257	153	169
AP, kg SO_2 equiv.	469	711	708	452	510
Pesticides used, dose ha	7.2	0.0	7.3	6.7	8.0
ARU, kg antimony equiv.	36	31	51	34	41
Land use, ha	2.3	4.21	3.85	2.28	2.41
N losses					
NO_3^--N, kg	147	427	269	146	156
NH_3-N, kg	119	180	178	114	130
N_2O-N, kg	10.9	11.8	15.9	10.7	11.3

Tab 2.8: Comparison burdens of production of some alternative beef systems (per tonne). Source: Williams, Audsley et al. (2006).

Note: EP is eutrophication potential, AP is acidification potential, ARU is abiotic resource use, see comment in table 2.6.

Impacts & resources used	Non-organic	Organic	Heavier finishing	Indoor breeding	Outdoor breeding
Primary energy used, MJ	16,700	14,500	15,500	16,700	16,700
GWP_{100}, kg 100 year CO_2 equiv.	6,360	5,640	6,080	6,420	6,330
EP, kg PO_4^{3-} equiv.	100	57	97	119	95
AP, kg SO_2 equiv.	395	129	391	507	362
Pesticides used, dose ha	8.8	0.0	8.2	8.6	8.8
ARU, kg antimony equiv.	35	33	33	40	33
Land use, ha	0.74	1.28	0.69	0.73	0.75
N losses					
NO_3^--N, kg	48	71	43	40	51
NH_3-N, kg	98	40	98	119	91
N_2O-N, kg	6.4	6.8	5.9	6.1	6.5

Tab 2.9: Comparison burdens of production of some alternative pork systems (per t). Source: Williams, Audsley et al. (2006).

Impacts & resources used	Non-organic	Organic	Free-range (non-organic)
Primary energy used, MJ	12,000	15,800	14,500
GWP_{100}, kg 100 year CO_2 equiv.	4,570	6,680	5,480
EP, kg PO_4^{3-} equiv.	49	86	63
AP, kg SO_2 equiv.	173	264	230
Pesticides used, dose ha	7.7	0.6	8.8
ARU, kg antimony equiv.	29	99	75
Land use, ha	0.64	1.40	0.73
N losses			
NO_3^--N, kg	30	75	37
NH_3-N, kg	40	60	53
N_2O-N, kg	6.3	9.3	7.6

Tab 2.10: Comparison burdens of production of some alternative poultry meat systems (per t). Source: Williams, Audsley et al. (2006).

Impacts & resources used	Non-organic	Organic	More fodder as maize	60% High yielders	20% autumn calving
Primary energy used, MJ	25,200	15,600	23,600	24,200	23,400
GWP_{100}, kg 100 year CO_2 equiv.	10,600	12,300	9,800	10,200	10,300
EP, kg PO_4^{3-} equiv.	63	103	61	60	65
AP, kg SO_2 equiv.	162	264	164	159	159
Pesticides used, dose ha	3.5	0.0	2.8	3.4	2.9
ARU, kg antimony equiv.	28	14	24	27	25
Land use, ha	1.19	1.98	1.18	1.14	1.21
N losses					
NO_3^--N, kg	71	117	65	65	77
NH_3-N, kg	40	63	41	39	39
N_2O-N, kg	7.1	7.6	6.3	6.6	6.6

Tab 2.11: Comparison burdens of production of some alternative milk production systems (per 10,000 l milk). Source: Williams, Audsley et al. (2006).

The extensive German survey conducted by the Institute for Ecological Economy Research (IÖW) investigated climate impacts of food production and also compared organic farming practices with conventional ones. It shows similar, but, overall more favourable results for the organic farming practices. Organic farming benefits from much lower levels of used nitrogenous fertilizers (leading to lower N_2O-emissions), but suffers from a higher area-demand. These advantages of organic products over their conventional counterparts are usually more distinctive with plant based products than with animal products (Hirschfeld, Weiß et al., 2008). Similarly Fritsche and Eberle (2007) report small savings in GHG-emissions for organic pork (5 percent) or beef (15 percent).

Another important aspect is that organic farming often leads to topsoil composition whereas conventional farming to topsoil losses. As topsoil represents carbon storage this would change a climate balance including carbon sink (carbon storage) of soils in favour of organic farming (Hülsbergen and Küstermann, 2007; von Koerber et al., 2007). This sometimes leads to the misunderstanding that grazing livestock would perform as a carbon sink, when organic farmed grazing land is compared by mistake to intensively cultured land instead of natural vegetation when the land use effect of farming is examined in terms of climate balances. This is an example of choosing a totally wrong reference. A comparable fallacy would be when people think that the more they drive in a fuel saving car the more they are protecting the climate, using the rational that the emissions are lower than from driving a conventional car and not being able to see that driving any kind of car produces greenhouse gases. Actually, no form of agricultural land use represents a carbon sink. Instead, agricultural activities represent a missed carbon sink when compared to natural vegetation, showing lower carbon stocks than natural vegetation, which it pushes aside. For extensively or organic farmed areas this missed carbon sink per given area might be smaller, but on the other hand, the required areas are usually much larger. The predominating effect of these two decides whether organic or conventional farming practices are better or worse in terms of land use related GHG balances (also see chapter 2.6 for more information on missed potential carbon sinks).

For cropped soils, there is still potential to mitigate greenhouse gas emissions. Reducing fertilizers results in lower N losses, but also reduced crop yields. Use of techniques like nitrification inhibitors and split fertilizer applications as well as renouncing tillage operations can reduce GHG emissions by 50 percent while slightly increasing crop yields (Del Grosso et al., 2009).

2.9 Ecological aspects of fish production

Two general methods can be distinguished, farmed fish and traditional fishing methods.
Traditional fishing requires high energy inputs and thus leads to relevant GHG emissions. Other problems include overfishing and bycatch, the latter making up over 8 percent of the total catch globally (Ellingsen, 2009).

Farmed fish also require high energy inputs. Escape of farmed fish, the spreading of pathogens or vermin and the usage of antibiotics are among the most relevant ecological considerations involved (Ellingsen, 2009).

Current LCAs do not cover overfishing or other relevant problems with fish production on the ecological system in the sea, as they have been designed for land based systems initially. Nevertheless, there have been a few LCAs in the recent years on the GHG effect of fish: Farmed Norwegian salmon shows results of between 2.3 and 3.0 kg CO_2-eq/kg (Ellingsen, 2009). Pelletier and Tyedmers (2007) calculated between 1.2 and 2.7 kg CO_2-eq/kg for farmed salmon in Canada depending on the feeding strategies, and Ellingsen and Aanondsen (2006) 1.3 kg CO_2-eq/kg for wild caught cod. This means that the GHG emissions from fish production are relevant, even though they are smaller than livestock production on land.

CHAPTER 3

Meat Production (Livestock) and world hunger

3.1 World nutrition – facts and forecasts

World nutrition and world hunger are complex subjects, and the causes of malnutrition and their solutions are highly controversial. According to UNICEF, more than 8000 children die of starvation each day, around 3 million per year (UNICEF, 2007). Low personal incomes, wars and political disturbances are main causes of missing food security for humans (Schmidhuber, 2005), but the rapid growth of the livestock sector is also a factor, because it raises the prices of staple foods by competing for land and other resources (FAO, 2009b). Political stability and education are often seen as main strategies out of malnutrition. Some scientists and industries emphasize genetic engineering in agriculture as a solution while opponents to genetic engineering see the solution in organic farming. In this chapter the frequently emphasized nexus between different livestock methods, consumption of animal products and global nutrition is investigated. Is it true that "*the cattle of the rich eat the bread of the poor*"?

	1969-71*	1999/01*	2015**	2050**
Sub-Sahara Africa	2100	2194	2420	2830
Northern Africa / Middle East	2382	2974	3080	3190
Latin America	2465	2836	2990	3200
Southern Asia	2066	2392	2660	2980
East Asia and Southeast Asia	2012	2872	3110	3230
Transition countries	3323	2900	3020	3270
Industrial countries	3046	3446	3480	3540

Tab. 3.1: Average available food energy in different world regions (in kcal per person and per day). Source: FAO (2006).
* Average values for the time span.
** Estimations

The average availability of food calories has seen improvements in the last decades, as shown in Table 3.1. And the FAO assumptions show a further increase in food availability for all regions globally, but it should be noted, that access to food can be very biased within a society for different social groupings (FAO, 2006).

Advances made in crop genetics, inorganic fertilizers and many other realms have resulted in a corn grain yield increase from 2071 kg/ha to 9484 kg/ha and a soybean yield increase from 1264 kg/ha to 2804 kg/ha between 1944 and 2003 in the USA (USDA/NASS, 2003).

On the other hand, other authors emphasize that soil quality has declined and will continue to decline in the future (Bouma et al., 1998). Organic farming systems could be an alternative approach, reducing this loss of soil: After evaluating 293 studies, Badgley et al. (2007) state that organic farming also has the potential to nourish the global population.

Focusing on the 23 most important food crops in terms of food energy, Balmford et al. (2005) try to project plausible values for 2050 for population size, diet, yield, and trade, and then look at their effect on the area needed to meet demand for the 23 crops, for the developing and developed worlds in turn. The calculations suggest that across developing countries, the area for these crops will need to increase very considerably by 2050 (by 23 percent under intermediate projections). By contrast, cropland area in developed countries is likely to decrease slightly by 2050 (by 4 percent under intermediate projections for these 23 crops), and will be less sensitive to variation in population growth, diet, yield or trade. Generally, the expansion of arable land globally is very limited, as only 11 percent of the land surface is potentially arable (Pimentel et al., 1976).

3.2 Livestock's role in world nutrition – facts and forecasts

Table 3.2 shows historical data and future prognoses from FAO demonstrating a dramatic increase in consumption of animal products. With such anticipated increases in per capita consumption of animal products as well as in global human population and including other factors like loss of fertile soils it is not evident that global food security can be maintained or even improved.

	Meat (kg per person per year)				Dairy products (kg per person and year)			
	1969-71*	1999/01*	2030**	2050**	1969-71*	1999/01*	2030**	2050**
Developing countries	10.7	26.7	38	44	28.6	45.2	67	78
Transition countries	49.5	44.4	59	68	185.7	160.2	179	193
Industrial countries	69.7	90.2	99	103	189.1	214.0	223	227
World Total	**26.1**	**37.4**	**47**	**52**	**75.3**	**78.3**	**92**	**100**

Tab. 3.2: Usage of meat, milk and dairy products in developing countries, transition countries and industrial countries. Source: FAO (2006).
* Average values for the time span.
** Estimations

The principle characteristic of eating meat is that it lengthens the food chain between plants and humans. This way of producing food by adding another "link" to the chain, i.e. animals, represents a loss of nutrients for humans due to the use of a huge portion of the food for the metabolism of animals. The latter makes the animal an inefficient calorie converter, as a big portion of feed calories is converted to excrement, skin, bones, feathers and the like, and only a rather small portion to meat, milk or eggs. Table 3.3 shows typical conversion losses for various livestock species. Protein losses due to the food chain extension in livestock vary between 80 and 96 percent (Smil, 2002). Although animal protein often shows higher biological values than plant protein, this disadvantage of many plant based proteins could be overcome by plant breeding (see chapter 7.5.2) or other measures. Pimentel (2004) states that 1 kg of protein from farm animal meat requires 6 kg of plant based protein.

	Chicken	Pig	Cattle
Feed requirements (kg / kg live weight)	2.5 (1.7-4)	5 (2.4-5.9)	10 (5-13)
Typical yield of edible meat (% of live weight)	55	55	40
Feed requirements (kg / kg edible meat)	4.5	9	25
Energy conversion efficiency (% of input gross energy)	11	9	3
Protein conversion efficiency (%)	20	10	4

Tab. 3.3: Typical feed demands and efficiency of various species in livestock systems in the conversion of feed energy and feed protein (Smil, 2002). The figures show that the extension of the human food chain by eating meat from farm animals is ineffective, with chicken showing the smallest losses in energy and protein.
The numbers in brackets in the feed requirements section per kg live weight (first row) show ranges from different analyses (Caspari et al., 2009; Garnett, 2009).

The WHO showed that one hectare land per year can feed 19 humans on the basis of rice, 22 humans on the basis of potatoes, but only 2 humans on the basis of lamb and 1 human on the basis of beef (WHO, 2008) For more details on area demands for food products also see 2.3. If people in developing countries ate the same amount of meat as those in industrial countries, the global agricultural area demands would increase by two thirds (Naylor et al., 2005). Using a pictorial metaphor, industrial livestock practices resemble "*a* *malignant tumour that selfishly grasps all the nutrients and resources for itself, leaving the rest of the host undernourished, and then driving the entire system to failure*" (Chiu and Lin, 2009).

The exception to the rule of animals being highly inefficient and huge "*calorie annihilators*" can be ruminants grazing on pastures which cannot be used as croplands. In this case, these ruminants, mostly cattle or sheep, can produce edible meat and milk on an area that does not provide food for direct human consumption, acting as "*calorie creators*". Grazing cattle and other ruminants are thus generally capable of producing food for human nutrition on areas not suitable for cropland, albeit less efficiently than if they were kept intensively and fed with cereals or pulses (Galloway et al., 2007). But in the latter scenario they act as a food competitor to humans, making this system problematic for world nutrition as shown in this chapter. In the extensive grazing systems, ruminants do not compete for food with humans. But cattle in extensive grazing systems show the worst climate balance (see chapter 2.5.2), especially if the missed potential carbon sink of the vast grazing areas is taken into account (see chapter 2.6 and Stehfest et al. (2009)), which cannot fulfil climate mitigation tasks. Therefore, and even more so for the limited areas and the rather inefficient production methods, such extensive systems are not expected to expand, their share in global meat production is rather declining (Schlatzer, 2010). Currently, the share of meat from animals that act as food competitors to humans and cannot be used on pastures, i.e. poultry and pigs, is globally 70 percent, and from the remaining share of ruminants, many are also fed with cereals or crops and thus also act as food competitors to humans (Schlatzer, 2010). So, the "*calorie creators*" only produce a smaller fraction of the global meat compared to the "*calorie annihilators*", and this gap is widening.

The "*calorie creator*" model presented above makes it clear that extensive livestock production in developing countries can have positive effects on the nutritional state of people there. Results for Kenya and Egypt (representing developing countries) demonstrate the negligible competition between livestock and people for food resources as only marginal lands and crops are used for livestock feed and forage. Under current, largely extensive livestock production systems, particularly those practised by the poor, livestock can offer an efficient utilization of resources that would otherwise go unexploited, such as the use of organic wastes to feed livestock in urban areas (Randolph et al., 2007). It must be emphasized once again, that this only applies to extensive, small scale livestock methods. The introduction of intensive livestock systems on the other hand would clearly lead to a massive competition between livestock and people for food resources, as can be seen in industrialised countries.

In their comments on agricultural sustainability, Maynard and Nault (2005) state that achievements in the last 20 years remain elusive. The authors emphasize that sustainable future livestock systems have to ensure soil quality, addressing depletion of organic matter and minimising soil erosion or water conservation (Maynard and Nault, 2005). But can these and other measures overcome the problem for world nutrition that arises from the fact that most farm animals act as "*calorie annihilators*", as food competitors to humans? The FAO figures for 2008 show that from 2120 million tons of cereals

produced globally, 754 million tons were used as feed for livestock while "only" 100 million tons of cereals were lost for human nutrition because of the production of biofuels (FAO, 2008b). The latter was blamed for being a major cause of food shortage in that year, whereas the usage for livestock received much less attention from the media, even though approximately 85 percent of the global soy production is used for animal feed (WWF, 2008). The total expenses for feed, including cereals, pulses, bran, fish meal and oils, made up around 1300 million tons by 2008 (FAO, 2009b).
Shifting 16 major crops to 100 percent human food could add over a billion tons to global food production, which is a 28 percent increase, or the equivalent of 3×10^{15} food kilocalories, which is a 49 percent increase. Only one other measure, closing yield gaps by bringing them to within 95 percent of their potential for 16 important food and feed crops, could have a greater potential with 2.3 billion tons of food that could be added to the global supply (Foley et al., 2011). But bringing all global agricultural land to its full yield potential can be accompanied by the negative side-effects already shown by the intensification of agriculture (water usage and pollution, intensive fertilizing, monocultures and loss of biodiversity to name but a few of those negative side-effects detailed in chapter 2), and would require a high economical and market development of the whole world.

To avoid shortages and to meet the demands of livestock production, which is forecast to double again by 2050 if no measures are undertaken to restrict such a growth, the global supply for cereals has to be raised by 50 percent to 3 billion tons – a demand that is not safeguarded (Schlatzer, 2010).

To sum up, extensive livestock production of ruminants on pastures can make sense from a world nutrition point of view, but relevant expansions of such systems are neither expected nor possible due to limited areas. Besides, beef from extensively kept cattle shows the worst climate balances as shown in chapter 2.5. In very small niches, livestock systems with monogastrics (e.g. pigs and chicken) could still make sense in terms of gaining food calories, as long as the animals are fed kitchen slops only. But such practices are currently prohibited in many areas globally, e.g. within the EU (EU, 2002) to avoid hygiene risks. In all other livestock systems - and that is the vast majority in global livestock production - animals act as food competitors to humans, losing food calories on the way between plants and humans to the animals' metabolism, in enormous amounts on a global scale, as shown in this chapter.

CHAPTER 4

Meat Production (Livestock) and Human Health

In chapters 3 and 4 the mainly negative effects of livestock production on the world's ecology as well as on world hunger issues have been shown. The present chapter investigates the effects of livestock production and the consumption of animal products on the health of human individuals.

The International Food Policy Research Institute summarises the benefits and risks of livestock for human health as follows (Catelo, 2006):

- Especially for people in poor countries livestock products offer high quality protein and highly bioavailable micronutrients, such as iron, zinc, vitamin A or calcium.
- Diseases that can be transmitted from livestock to humans, such as salmonellosis, swineherds' disease, BSE and bird flu caused by the H5N1 virus threaten human health.
- Environmental pollution from livestock facilities can harm human health, too. Untreated and ill-disposed hog waste can become airborne and waterborne, leading to health effects such as gastrointestinal diseases, respiratory ailments primarily caused by inhalation of noxious gases such as hydrogen sulfide, methane, and ammonia, skin irritation, blue baby syndrome and cognitive impairments due to the growth of pfiesteria in the air and water at high nitrate concentrations.
- Foodborne diseases and risks are to be considered as well. Several deadly bacteria are associated with the consumption of ill-prepared livestock products, notably *Campylobacter*, *Salmonella*, *E. coli* O157:H7, and *Enterococcus*. Strains of resistant pathogens due to the overuse of antibiotics in industrial livestock facilities are another risk.

- And finally, the excessive consumption of livestock products can lead to obesity, cardiovascular disease, some forms of cancers, diabetes and other health problems. Societies in developing countries adopting the typical western animal based diets high in saturated fats, are experiencing rapid increases in obesity and chronic diseases. Worldwide, 1.6 billion people are overweight or obese, compared to 1 billion people who are undernourished (WHO, 2006; FAO, 2009a).

This overview (Catelo, 2006) allows the assumption that benefits or risks of livestock for human health vary between intensive farming methods and small scale livestock units. Intensive, industrialised livestock methods are responsible for BSE, antibiotic resistance of bacteria (see chapter 4.3) and highly pathogenic strains of Avian Influenza (Greger, 2007). Many surveys and papers show, that the health benefits of consuming animal products are reversed in an affluent society, although they can be substantiated in malnourished humans (see chapter 4.4).

4.1 Diseases transmitted from livestock to humans

The Food and Agriculture Organization of the United Nations (FAO) states that animal diseases endanger human health. With more than 70 percent of all emerging infectious diseases which affect humans originating in the animal kingdom and with global livestock production gradually shifting from North to South and into areas of high human density, animal-related public health risks are being viewed with increasing urgency and importance. This disease emergence is very closely linked to changes in the livestock production environment and in sector structure, including:

- increased animal densities in warm, moist and changing climates,
- increased mobility of people,
- increased movements of animals and animal products,
- and inadequate public investments in services and institutions (FAO, 2008a).

This is in accordance with the findings that three out of four new pathogens affecting humans in the decade before 2001 originated from animal products or animals (Taylor et al., 2001). Almost ten years later, things have hardly changed , as the FAO states in 2009 that 75 percent of newly occurred diseases in the decade preceding 2009 that affected humans have been induced by animals or animal products (FAO, 2009b). The three human influenza pandemics of the last century were caused by new strains of influenza A viruses (Spanish flu 1918, Asian flu 1957 and Hong Kong flu 1968), and all showed an avian origin. Since 2000 there has been a sharp increase in the number of outbreaks of avian influenza in poultry, compared with the previous 40 years (Capua and Alexander, 2006).

Increased specialisation can be found in many livestock sectors, such as using different facilities for pig breeding and pig fattening. This creates new potential paths for disease transmission. High stocking densities of the animals within the pens in industrial livestock systems can also raise the prevalence of various influenza viruses (Maes et al., 2000). The population densities of poultry, pigs and humans, are also likely factors affecting the evolution of these viruses (Webster and Hulse, 2004).

Fig. 4.1 shows the geographic distribution of poultry and pigs globally. It can be seen that – except the absence of pigs in Muslim countries – there is a large coincidence, and there are certain hotspot areas where these animals are concentrated. This has potential consequences for the development and transmission of zoonotic disease agents. Furthermore, confined animals produce large quantities of waste that needs to be disposed of. Most of this waste, that may contain large amounts of pathogens, is disposed of on land, posing an infection risk for wild living animals (Otte et al., 2007).

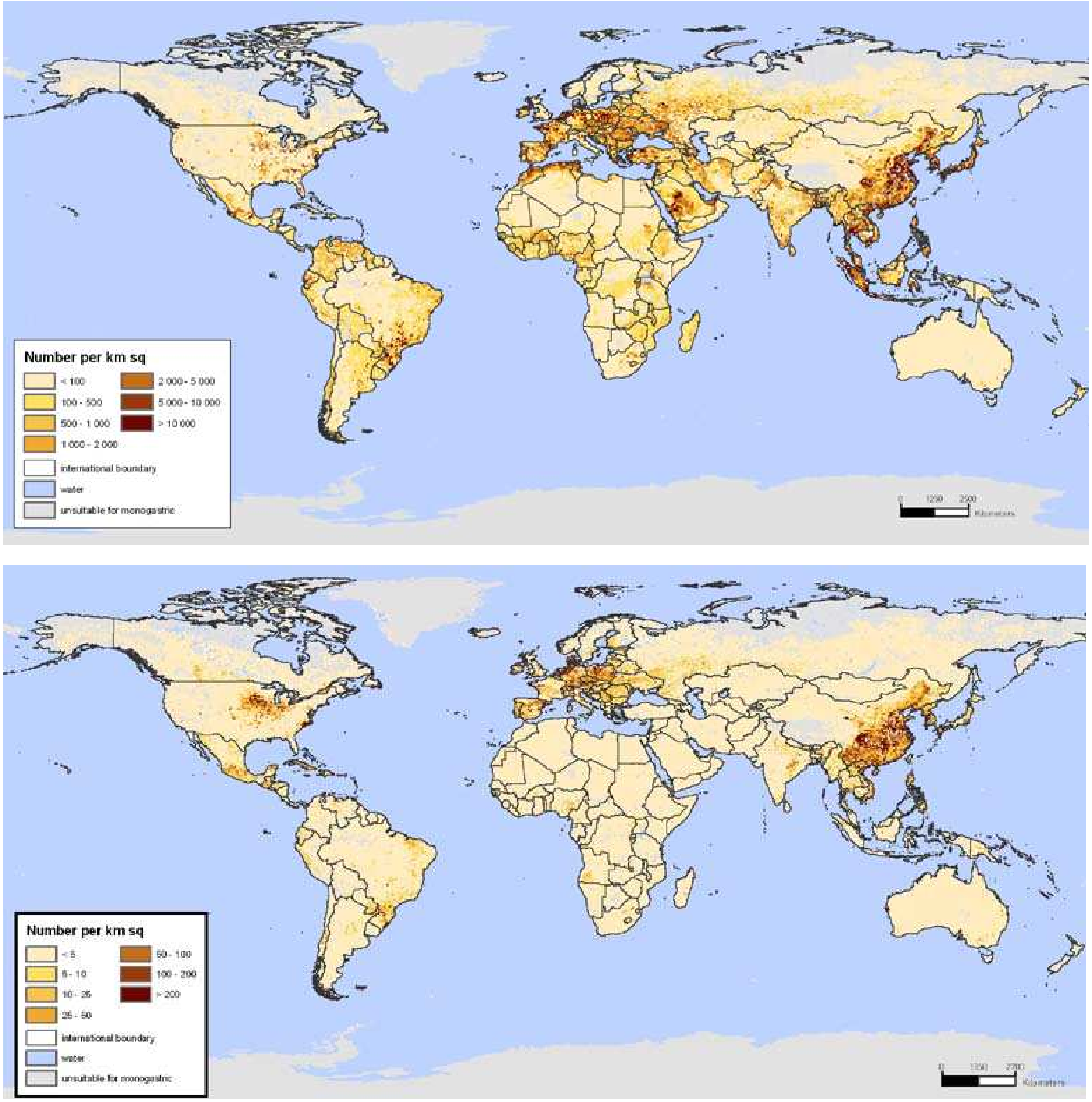

Fig. 4.1: Global overview of poultry stocking densities (upper picture) and hog stocking densities (lower picture). Source: FAO (2007).

Industrial farms have introduced measures to prevent the spread of pathogens. These are termed biosecurity. Biosecurity combines the two strategies bioexclusion and biocontainment. Bioexclusion describes measures to prevent pathogens entering a livestock facility, whereas biocontainment describes actions that are implemented after introduction of such pathogens to a certain livestock unit. Biocontainment measures are used to prevent pathogens spreading within the animal units of a farm or being released from the farm (Dargatz et al., 2002). Nevertheless, livestock farms are open to incoming animals from other farms, hatcheries and livestock markets (an example of the latter can be found in Gibbens and Wilesmith (2002)), and incoming feed and water. They also produce huge amounts of excrement and deliver animals to other farms, markets or slaughterhouses. All these are potential routes for pathogens to or from farms. Insects are another option for pathogens to enter or leave livestock units, such as poultry farms (Sawabe et al., 2006).

Data reported to OIE show that large industrial livestock units appear to be overrepresented in the list of HPAI H5N1 outbreaks with 40 percent of such outbreaks in domestic poultry being reported between late 2005 and early 2007 from poultry units with 10000 birds or more, although even in countries like Germany, France, the UK or Belgium, less than 10 percent of flocks consist of more than 10000 birds. Even if this overrepresentation of large livestock units in reported outbreaks can partly be explained by such cases being more likely to be detected in bigger animal units, it nevertheless shows that bioexclusion measures seem to be insufficient to protect against H5N1 incursions. The lower probability of infections in small flocks suggests that commercial transactions are a major route for the spread of diseases between livestock units (Otte, Roland-Holst et al., 2007).

4.2 Environmental pollution and its effects on human health

Besides being a potential source of (new) diseases, livestock facilities can also directly harm the human population in their vicinity. A Dutch report shows the direct influence of emissions of pathogens on humans living near (industrial) livestock units. Pathogenic germs often adhere to particulate matter and thus spread around such farms. In addition, increased values of endotoxines (toxic decomposition products of certain bacteria) as well as certain livestock specific MRSA (multidrug-resistant *Staphylococcus aureus*) bacteria that can cause infections in humans that are hard to treat have been detected within a radius of up to 1000 meters around such facilities (Heederik and IJzermans, 2011).

4.3 Antibiotic resistance and foodborne diseases

A report sponsored by the Pew Charitable Trusts found that drug resistant bacteria caused by the rampant use of antibiotics on feedlots threaten human health and the economy. Probably the biggest share of US antibiotics is used for animals. The Food and Drug Administration and other agencies, even regulators, can only estimate how many drugs are being used in livestock facilities. With thousands of animals kept in confined conditions, diseases spread quickly. To prevent some of these outbreaks or only to spur faster growth of the animals, industrial livestock farms routinely treat animals with antibiotics, according to The Pew Charitable Trusts (2008). The European Food Safety Authority states that ceasing to use a special kind of effective antibiotic in livestock, i.e. cephalosporins of the 3rd and 4th generation, has been found to be a highly effective control option to avoid *E. coli* and non-typhoidal *Salmonella* germs becoming resistant against these antibiotics (EFSA, 2011).

4.4 Consumption of livestock products and health

In recent decades a few prospective cohort studies have been conducted to compare vegetarian lifestyles in western countries with common meat based diets. Mortality and health conditions have been measured. Some of these studies have tried to eliminate the effects of other health risk or health benefit factors aside from diet, such as smoking or sports habits, alcohol consumption, age, gender and social state and have tried to extract the effect of a vegetarian diet as effectively as possible. These papers, which are presented in this chapter, show benefits of an ovo-lacto vegetarian lifestyle over meat-based diets. Exclusively plant based diets, so called vegan diets, have not been the examined in most of these prospective cohort studies, either because veganism has not been the research objective of the studies, or because the lack of people following such a diet made it impossible to compile a statistically relevant cohort of vegan subjects. Therefore, based on such cohort studies, as yet, no reliable statement can be made for vegan nutrition.

Prospective mortality studies do not allow conclusions on the effect of single nutrition factors or foods, but they give an overall picture of different forms of nutrition on health (Hoffmann and Wittig, 2011). It should be noted that almost all of these studies have been carried out in industrialised countries with people much more likely to be suffering from supernutrition than from malnutrition. Animal-source foods could be appropriate for combating malnutrition and a range of nutritional deficiencies with poor, undernourished people (Randolph, Schelling et al., 2007). Research has indicated that for the diets typical of most people living in poverty in developing countries the beneficial role of meat can outweigh the associations with cancer or cardiovascular disease (Glew et al., 2001; Biesalski, 2002). On the other hand, it is likely that plant-based protein rich foods such as vegetarian meat products (see chapter 9) could have a similar beneficial effect especially on undernourished humans, and it is not meat by itself, but the nutrient density that leads to health benefits under such circumstances. This hypothesis opens up an interesting field for future studies.

In general, results from prospective cohort studies carried out in Europe and the USA cannot be transferred to malnourished people and vice versa. But for well-nourished people they reveal strong evidence that vegetarian lifestyles bring positive health effects.

4.4.1 *Overview of large prospective studies on vegetarian diets (with focus on general mortality and coronary heart disease)*

One of the largest prospective studies ever undertaken is the Seventh-Day Adventist-study in the 1970s. In this 6-year prospective study of 24044 Californian Seventh-Day Adventists coronary heart disease (CHD) mortality was investigated. The authors concluded that "*the risk of fatal CHD among non-vegetarian Seventh-Day Adventist males, aged 35 to 64, was three times greater than among vegetarian Seventh-Day Adventist males of comparable age, suggesting that diet may account for a large share of their low risk. This differential was much smaller for older males and Seventh-Day Adventist females*". The authors considered other CHD risk factors, which were more frequent among non-vegetarians, but summarized that "*a significant differential persists even after adjustment for each of six other CHD risk factors*" (Phillips et al., 1978).

Another extensive prospective study with approximately 11000 participants (6000 vegetarians and 5000 meat eaters in the UK) being surveyed over 12 years is the Oxford Vegetarian Study. The authors concluded that "*after adjusting for smoking, body mass index and social class, death rates were lower in non-meat-eaters than in meat eaters for each of the mortality endpoints studied*". The relative risks and 95 percent CIs were 0.80 (0.65 respectively 0.99) for all causes of death. They were 0.72 (0.47 respectively 1.10) for ischemic heart disease, and 0.61 (0.44 respectively 0.84) for all malignant neoplasms (cancers). The authors also found that meat eaters had a double risk compared to non-meat-eaters of requiring an emergency appendectomy (Appleby et al., 1999).

After compiling results of 3 prospective studies in the UK, namely the Health Food Shoppers Study, the Oxford Vegetarian Study and the EPIC-Oxford, the differences between vegetarians and non-vegetarians were not significant. Mortality for major causes of death was not significantly different between vegetarians and non-vegetarians after adjustment for age, sex and smoking. Nevertheless, a non significant reduction in mortality from ischemic heart disease among vegetarians remained (Key et al., 2003).

In 2004, a further investigation on a cohort of 11000 subjects in the UK showed that relative risk in vegetarians compared with non-vegetarians for colorectal cancer was 0.85, the and 95 percent CIs being 0.55 respectively 1.32 (Sanjoaquin et al., 2004).

The Greek European Prospective Investigation into Cancer and nutrition (EPIC) prospective cohort study investigated the effects of a Mediterranean diet on more than 23000 participants. Stricter adherence to a Mediterranean diet was associated with a significant reduction in total mortality.

Mediterranean diets were defined as including moderate ethanol consumption, low consumption of meat and meat products and high vegetable, fruit and nut consumption (Trichopoulou et al., 2009).

4.4.2 *Results of smaller scale studies and of summarizing studies*

Leitzmann (2005) summarises scientific results and concludes that in most cases vegetarian diets are beneficial in the prevention and treatment of certain diseases, such as cardiovascular disease, hypertension, diabetes, cancer, osteoporosis, renal disease and dementia, as well as diverticular disease, gallstones and rheumatoid arthritis.

Ströhle et al. (2006a) investigated existing results of studies and showed that high consumption of fruits, vegetables, whole grains and nuts can lower the risk for several chronic diseases.

The chief dietary advisor of former US president Bill Clinton, Dean Ornish, also conducted a prospective trial and showed that a low-fat vegetarian diet, no smoking and stress management training can lead to regressions of even severe coronary atherosclerosis within a year. Drawbacks of this trial were the small number of 48 patients participating and the multiple measures that could have led to these health benefits, somewhat concealing the dietary impact (Ornish, 1990).

4.4.3 Historical results from Denmark

A historical, involuntary large scale experiment with 3 million "participants" was carried out in Denmark during World War I. Due to food shortage in 1917 the Danish physician and nutritionist Mikkel Hindhede convinced the Danish committee in charge of proportioning the crops between people and animals, to put the major part of the population on a vegetarian diet. This diet consisted mostly of milk, vegetables and bran. Alcohol production was also massively restrained, as cereals and potatoes were required for human nutrition instead of being used by distillers.

	1900	1901	1902	1903	1904	1905	1906	1907	1908	1909
All diseases	152	151	131	142	137	148	144	145	152	142
Epidemic diseases and tuberculosis	46	41	30	34	36	41	33	31	35	31
Other diseases	106	110	109	108	101	107	111	114	117	111
Ratio, compared to avg. 1900 - 1916 (=100)	97	101	100	99	93	98	102	105	107	102
	1910	**1911**	**1912**	**1913**	**1914**	**1915**	**1916**	**1917**	**1918**	
All diseases	135	148	138	130	133	134	145	123	93	
Epidemic diseases and tuberculosis	26	32	30	28	27	26	35	33	27	
Other diseases	109	116	108	102	106	106	110	90	72	
Ratio, compared to avg. 1900 - 1916 (=100)	100	106	99	94	97	97	101	**83**	**66**	

Tab. 4.1: Results of the Danish “vegetarian experiment” starting in 1917. Results from Copenhagen for men aged between 25 and 65 years, death rates between 1900 and 1918 per 10000 persons (Hindhede, 1920). Food restriction began in 1917, and death rates from non-epidemic diseases fell to 66 % of former figures in 1918.

The results are shown in Table 4.1 (Hindhede, 1920). Comparing the death rates of men in Copenhagen, and placing the average for the period from 1900 to 1916 at 100, the variation (ratio) is small, from 93 to 107, until food regulation began. During the year of severe regulation, it fell to 66, a decrease of 34 percent. It is likely that the vegetarian diet as well as alcohol restrictions caused this effect.

4.4.4 *Animal products and cancer*

In recent decades various studies have been conducted on the relationship between consumption of animal products and various forms of cancer. In this chapter, studies that specifically focused on this relationship are presented.

In a case study with over 88000 women in the 1980s the relative risk of colon cancer in women who ate beef, pork, or lamb as a main dish every day was 2.49 (with the 95 percent confidence interval being 1.24 and 5.03), as compared with those who reported consuming these foods less than once a month (Willett et al., 1990).

A case study in the UK with nearly 62000 participants showed an overall reduction for all cancers in vegetarians and in persons who eat fish but do not eat other kinds of meat. The relative risk for all cancers – compared to meat eaters - was 0.82 (with 95 percent CI being 0.73 and 0.93) in fish eaters and 0.88 (0.81–0.96) in vegetarians after adjustment for smoking, alcohol consumption, body mass index and physical activity levels (Key, 2009), see Table 4.2.

A smaller German cohort of around 1900 subjects was surveyed in the 1980s and early 1990s by the German Cancer Research Centre and also showed that longer duration of vegetarianism (more than 20 years) - but also moderate vegetarianism - lowered cancer mortality (Chang-Claude and Frentzel-Beyme, 1993; Frentzel-Beyme and Chang-Claude, 1994).

Cho et al. (2006) observed a strongly elevated risk of ER+/PR+ (oestrogen and progesterone receptor positive) breast cancers with higher intakes of red meat in more than 90000 monitored females.

Several cohort studies have shown a significant correlation between higher dairy consumption and increased prostate cancer (Snowdon et al., 1984; LeMarchand et al., 1994; Giovannucci et al., 1998; Chan et al., 2001), others found only a small effect (Schuurman, 1999) or no such correlation (Mills et al., 1989; Severson et al., 1989; Thompson et al., 1989; Hsing et al., 1990).

Within the European Prospective Investigation into Cancer and Nutrition (EPIC) cohort 521457 men and women have been surveyed, and an association between total, red and processed meat intakes and an increased risk of gastric noncardia cancer was found (González et al., 2006).

Cancer Site (selection)	Meat Eater		Fish Eater		Vegetarian	
	Number of cases	Relative Risk	Number of cases	Relative Risk (95 % CI)	Number of cases	Relative Risk (95 %CI)
Upper GI tract	56	1.00	4	0.44 (0.16–1.25)	18	0.81 (0.45–1.46)
Stomach	38	1.00	2	0.29 (0.07-1.20)	9	0.36 (0.16-0.78)
Colorectum	243	1.00	31	0.77 (0.53-1.13)	110	1.12 (0.87-1.44)
Pancreas	46	1.00	6	0.82 (0.34-1.96)	19	0.94 (0.52-1.71)
Lung	114	1.00	8	0.59 (0.29-1.23)	43	1.11 (0.75-1.65)
Female Breast	654	1.00	133	1.05 (0.86-1.28)	237	0.91 (0.77-1.08)
Ovary	98	1.00	8	0.37 (0.18-0.77)	34	0.69 (0.45-1.07)
Prostate	207	1.00	14	0.57 (0.33-0.99)	70	0.87 (0.64-1.18)
Kidney	37	1.00	2	0.36 (0.09-1.52)	11	0.76 (0.36-1.58)
Bladder	65	1.00	7	0.81 (0.36-1.81)	13	0.47 (0.25-0.89)
Lymphatic/haematopoietic tissue	180	1.00	28	0.85 (0.56-1.29)	49	0.55 (0.39-0.78)
All sites	**2204**	**1.00**	**317**	**0.82 (0.73-0.93)**	**829**	**0.88 (0.81-0.96)**

Tab. 4.2: Numbers of incident malignant cancers (*N*) and relative risks and their 95 % confidence intervals (95 % CIs) by diet group among 33697 meat eaters, 8901 fish eaters and 21810 vegetarians·
Estimated by Cox proportional hazards regression with age as the underlying time variable, adjusted for smoking (never smoker, former smoker, light smoker (<15 cigarettes per day, or cigar or pipe smokers only), heavy smoker (≥15 cigarettes per day)), alcohol consumption (<1, 1–7, 8–15, 16+ g ethanol per day, unknown), body mass index (<20.0, 20.0–22.4, 22.5–24.9, 25.0–27.4, 27.5+ kg m^{-2}, unknown), physical activity level (low, high, unknown) and, for the women-only cancers, parity (none, 1–2, 3+, unknown) and oral contraceptive use (ever, never, unknown), and stratified by sex (where appropriate) and study/method of recruitment, using separate models for each end point Source: Key (2009).

4.4.5 Animal products and osteoporosis, MS, gall stones, rheumatoid arthritis and diabetes

Besides cancer and cardiovascular diseases, other human diseases have been found to correlate with the consumption of animal products. Some of the according results of studies are presented here in brief.

Osteoporosis shows close connections to high animal protein intakes. This might shed some light onto the apparent contradiction that milk and dairy products are supposed to obviate osteoporosis due to their high calcium content, while on the other hand, osteoporosis is mostly prevalent in countries with high dairy consumption. Of course, one reason for this situation is the longer lifespan in industrial countries with high dairy consumption, making it more likely for individuals to reach an age where osteoporosis is likely to occur. However, in countries like Japan life expectancy is comparably high, but dairy consumption and also osteoporosis prevalence is much lower than in Europe or the USA (Fujita, 1991). In a smaller research initiative vegan women showed significantly more bone formation than omnivore women. Specifically, over time, the net effect of a lower amount of bone formation is likely to be a decrease in bone density (Van Loan, 2003). Elderly women with a high dietary ratio of animal to vegetable protein intake have more rapid femoral neck bone loss and a greater risk of hip fracture than those with a low ratio. The authors conclude that "*an increase in vegetable protein intake and a decrease in animal protein intake may decrease bone loss and the risk of hip fracture*" (Sellmeyer et al., 2001). Sulphur-containing amino acids are supposed to be the reason for these findings.

The connection between multiple sclerosis (MS) prevalence and dairy consumption in an investigation in 27 countries around the world showed a highly significant correlation between liquid cow milk consumption and MS prevalence. To a lesser extent cream or butter consumption also correlated with MS occurrence (Malosse et al., 1992).

Gall stones and their relation to vegetarianism have also been the focus of research into nutrition. After adjustment for age and body mass index, the occurrence of gall stones in vegetarian women was significantly reduced by a factor of 1.9 compared to omnivore women in a study with 762 participants (Pixley et al., 1985).

A trial in Norway in the late 1990s showed that patients suffering from rheumatoid arthritis can benefit in the long term from a fasting period followed by a vegetarian diet (Kjeldsen-Kragh, 1999).

Diabetes has already been mentioned in brief in the previous subchapters. It has reached epidemic levels, affecting nearly 350 million adults worldwide (Pan et al., 2011). There are indications that the metabolic syndrome and insulin resistance, risk factors for type 2 diabetes, can be reduced by avoiding cow’s milk (Lawlor et al., 2005). Also for infants and children, high dietary intake of cow's milk protein prior to the onset of diabetic symptoms has been associated with a significantly increased risk (Verge et al., 1994).

An analysis of 3 studies about type 2 diabetes covering 4,033,322 person-years and adjusted for age, BMI, and other lifestyle and dietary risk factors, both unprocessed and processed red meat intakes, were positively associated with increased risks. The results were confirmed by a meta-analysis with 442,101 participants and 28,228 diabetes cases, making this the largest survey of its kind so far. A daily serving of 100 grams of unprocessed red meat was associated with a 19 percent increased risk of type 2 diabetes and a daily serving of 50 grams of processed red meat with a 51 percent increased risk (Pan, Sun et al., 2011).

4.4.6 General statements on vegetarian and vegan diets

One of the few statements to include vegan diets was published by the American Dietetic Association (ADA): The papers conclude that "*appropriately planned vegetarian diets, including total vegetarian or vegan diets, have been shown to be healthful, nutritionally adequate, and may be beneficial in the prevention and treatment of certain diseases*". Vegetarian diets are "*appropriate for all stages of the life cycle*" (Craig and Mangels, 2009). The ADA also examined the results of an evidence-based review and concluded that a vegetarian diet is associated with a lower risk of death from ischemic heart disease and that vegetarians also appear to have lower low-density lipoprotein cholesterol levels, lower blood pressure, and lower rates of hypertension and type 2 diabetes than non-vegetarians. "*Furthermore, vegetarians tend to have a lower body mass index and lower overall cancer rates. Features of a vegetarian diet that may reduce risk of chronic disease include lower intakes of saturated fat and cholesterol and higher intakes of fruits, vegetables, whole grains, nuts, soy products, fibre and phytochemicals*" (Craig and Mangels, 2009). The ADA also states that increased fortification of foods for vegetarians with key nutrients (at least in the USA) legitimates the assumption that present research data could bring even better results of the nutritional status of vegetarians and vegans compared to older investigations (Mangels et al., 2003; Craig and Mangels, 2009).

A similar, slightly more cautious statement comes from the Canadian Paediatric Society. This paper concludes that a well-balanced vegetarian diet (including totally vegan diets) can provide for the needs of children and adolescents. Supplementation may be required in cases of a vegan diet and "*particular attention should be paid to adequate protein intake and sources of essential fatty acids, iron, zinc, calcium, and vitamins B12 and D*" (Canadian Paediatric Society, 2010).

In spite of the evidence given in this chapter that current vegetarian nutrition seems suitable for human health, it is still useful to think about ways improving a plant based diet in terms of protein quality (essential amino acids), minerals and mineral bioavailability, fatty acid compositions (Omega-3) as well as vitamins such as B12. This point is discussed in chapter 7.5. Such a diet is likely to be an optimum diet in preventing various diseases as seen in this chapter and at the same time supplying all essential ingredients in sufficient quantities.

CHAPTER 5

Meat Production (Livestock) and Animal Welfare / Animal Rights

This doctoral thesis does not have its focus on animal welfare and veterinary science, nor on philosophy and the various animal rights schools of thought and their concepts. A discussion of whether and to what extent animals are comparable to humans in their ability to suffer physically or mentally or in terms of intelligence and consciousness as well as the definition of all these terms and the discussion of their relevance in the animal welfare or animal rights discussion is far beyond the scope of this chapter. The same applies to the legal standing of animals and a comparison of animal welfare legislation in different countries in the world.

Having said that, as livestock and meat production affect over 65 billion animals globally each year (Schlatzer, 2010), there is a strong imperative to dedicate a chapter to this huge issue. Most papers presented in the chapters 2 to 5 have their focus solely on either environmental issues of livestock production, or health issues and world nutrition issues, with an absence of holistic conclusions, even in their discussion sections. Animal welfare aspects are often completely excluded, with only a few exceptions, for example Bouwman, von de Hoek et al. (2006) and Schlatzer (2010).

5.1 Animal welfare issues in livestock production

The multitude of animal welfare issues connected to livestock production, especially in its industrial forms, spans the whole life of an animal. The following compilation is taken from various publications (Ewbank et al., 1999; Webster, 2010). The situation for livestock animals in China, meanwhile the most important market, is also documented (Li, 2009). Issues of animal welfare start before birth with breeding resulting in the development of extreme characteristics detrimental to the health and welfare of the animals, e.g. broiler chicken reaching their full weight within five weeks, or dairy cows selected only for highest lactation performance (Knaus, 2009) resulting in their producing in excess of 10000 litres of milk annually. Immediately after birth, 4.2 billion male chicks of the breed of chicken used for egg laying are annually gassed or killed otherwise worldwide, as they are neither useful for meat nor for egg production (Millar, 2009). Many other farm animals face mutilations shortly after birth, including beak trimming, dehorning, castration (EFSA, 2004) and clipping of teeth or tails, usually all performed without anaesthesia, and often to adapt them to the crowded conditions in industrial farms that await them. In many cases, young animals are separated from their mothers at much younger ages than their natural weaning age, leading to acute stress. Although stress release has been monitored in dairy cattle in the case of immediate separation of calves and cows after birth compared to the (still unnatural early) weaning after 4 days or 2 weeks (Weary and Chua, 2000; Flower and Weary, 2001), this simply seems to be the lesser evil of different scenarios of premature separation of mother and child.

Crowded conditions are typical in CAFOs, in industrial livestock farms. Globally, over 60 percent of egg laying hens are kept industrially. In most countries battery cages systems are used almost exclusively. This keeping method offers a bird an area of less than a DIN A4 sheet of paper for life (Perry, 2004; CIWF, 2010). Mother sows are often kept their entire life in sow stalls, cages the size of the sow herself, not even allowing her the space to turn around (European Commission, 1997; EFSA, 2007; CIWF, 2009). Fattening pigs, broiler chickens, turkeys, rabbits, ducks and many other animals are often also kept densely packed. Dairy cows are sometimes tethered the whole year, especially on smaller farms.

Fig. 5.1: An example of an industrial housing system detrimental to the welfare of animals: Narrow cages, so called sow stalls, for pregnant mother sows.

In some countries, especially in France, the force-feeding of ducks and geese for foie gras (fatty liver) production is common. Force feeding with pipes makes the livers of the birds swell up to ten times their natural size. The animals are fed up to and over 20 percent of their live weight each day (SCAHAW, 1998; CIWF, 2008).

When animals such as pigs are injured and therefore no longer of any economic value, they are often simply left to die of thirst, as undercover footage has revealed (PeTA TV). Abnormally small sized animals ("runts"), e.g. too slow growing broiler chickens that fail to grow fast enough, are often no longer able to reach the drinking troughs as the other animals grow larger and the water pipes are elevated. Such animals eventually face the same cause of death. Furthermore, the breaking down of ventilation systems in industrial farms can lead to animals suffocating within the facilities (Münchner-Merkur, 2007; ORF, 2010).

Within their lifespan or at the end of it, animals are transported, sometimes half way around the world, e.g. sheep or cattle from Australia to the Middle East (Norris et al., 2008). In many countries animals are killed without being stunned, this is especially the case for kosher butchering, whereas in western countries stunning is usual. There is much research (Anil and McKinstry, 1993; Grandin, 1998; Gregory, 2005) and undercover footage available (PeTA-TV) showing that stunning sometimes malfunctions and animals' throats are slit while they are still conscious, some are even still alive when they reach the tanks where they are scalded (CIWF, 2001). Undercover footage from individuals who have infiltrated industrial farms or slaughterhouses also documents various forms of abuse and sadism carried out on animals. Finally, some animals, such as lobsters are usually not stunned at all, but boiled alive.

5.2 Examples of other animal welfare issues

Apart from food production for humans there are many other forms of animal welfare relevant issues: Vivisection and testing on animals including combusting, poisoning or cauterizing them, pest control with various forms of poison, trapping of animals including spring traps that do not kill the animals but, instead often leave them to die over days or fur farms where foxes, mink and other wild animals are usually kept in tiny wire cages. In China, undercover footage documented that fur animals are even skinned alive (Rissi, 2009). Stray dogs are poisoned in many countries. Hunted animals sometimes survive for several days after being injured. Circus animals are usually kept in small cages or trained using violent methods. Live plucking of geese and ducks for down production is another animal welfare relevant topic, as well as bullfighting, the list goes on and on.

5.3 Animal welfare versus animal rights

All the severe grievances listed in the previous subchapters have led to the formation of animal welfare and animal rights organisations that try to improve the situation for animals

Animal welfare can be defined as "*the physical and psychological well-being*" of non-human animals (Hewson, 2003). Animal Welfare, as defined by the American Veterinary Medical Association, is a "*human responsibility that encompasses all aspects of animal well-being including proper housing, management, disease prevention and treatment, responsible care, humane handling, and, when necessary, humane euthanasia*" or slaughter (Edwards, 2004). In the Saunders Comprehensive Veterinary Dictionary, animal welfare is the "*avoidance of abuse and exploitation of animals by humans by maintaining appropriate standards of accommodation, feeding and general care, the prevention and treatment of disease and the assurance of freedom from harassment, and unnecessary discomfort and pain*" (Blood and Studdert, 1998)

Animal rights on the other hand, emphasize that "*many non-human animals have basic interests that deserve recognition, consideration, and protection. In the view of animal rights advocates, these basic interests give the animals that have them both moral and legal rights*" (Wise, 2006).

One widely accepted principle within animal rights philosophy is Peter Singer's "*principle of equality*". This principle "*does not require equal or identical treatment, but equal consideration of interests*", if these are comparable (Singer, 1993; Singer, 2002). Animal rights philosophy states that the neglect of a comparable interest of one individual compared to another individual simply because the individual belongs to a different species is discrimination analogous with discrimination based on gender (sexism) or race (racism). As a result, the phrase "*speciesism*" was coined for disregarding interests of "*non-human animals*" compared to interests of humans, even if the former are similar or equal or even more eminent (Ryder, 2000). Science has revealed overlaps in cognitive abilities between some humans and some (non-human) animals, but nevertheless, strict moral lines are drawn between these two groups all over the world. Attempts to uphold these moral borders with philosophical or religious constructs, such as "*human dignity*" are merely seen as nicer terms for "*speciesism*" by animal rights philosophers (Singer, 2009), as they are not measurable or verifiable.

Animal rights and animal welfare can go hand in hand, but can also lead to contradicting conclusions: While the animal rights position holds that humans do not have the right to slaughter and eat animals, the animal welfare position is that animals should be treated humanely before and during slaughter.

5.4 Conclusions and short discussion

Today's practices of producing animals for food severely impair the welfare of billions of farm animals globally. Livestock population continues to increase rapidly and animal production globally is becoming ever more industrialized.

The animal welfare movement does not challenge the use of animals for food per se, but tries to reverse the trends in modern farming towards better standards for animals or tries to demand certain standards for the development of new housing systems. There has been some progress in the last decades, for example, the ban of battery cages for laying hens in countries such as Switzerland and Austria (Ottensamer, 2006). The EU also banned the barren cages for laying hens, but only replaced them with so called "enriched cages", allowing the hens just a bit more space and offering perches and other small enrichments to them. Trends such as the shift towards freestalls in modern dairy farms instead of permanent tethering of cows, are considered as animal welfare successes (Schrade, 2010). However, these are more or less exceptions to the rule: Firstly, it seems a barely realizable task to produce 65 billion animals or more per year giving each of them enough space and care, secondly, to convince a vast majority of consumers globally to pay higher prices for animal products from better husbandry and thirdly, to introduce animal welfare standards and animal welfare consciousness into huge new markets such as China. Therefore, the animal rights movement takes a much more radical step and demands a total renunciation of the use of animals for food production and the acceptance of certain rights for animals. Again, at first sight the realization of this stipulation appears to be very unlikely, but together with the synergic demands coming from global problems caused by livestock (as seen in chapters 2 to 4) and with the help of emerging technological food innovations (as described in chapters 9 to 12) this could be a potentially more realistic scenario than a global free range breeding of 65 billion animals annually.

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CHAPTER 6

Ethical Evaluation Models for Foods

6.1 Requirements for ethical evaluation models of foods

In contrast to measuring food quality (see chapter 8), not much research has yet been done to quantify food products mathematically in terms of ethics. In this chapter a short simple model is presented to improve this process of measuring the ethics of foods quantitatively.

As shown in chapters 2 to 5, four major ethical factors can be found as being critical in food production, especially animal based food production: An ecological factor, an animal welfare factor, a health factor and a world nutrition factor. Of course, further aspects could be added that are perceived as "ethical" by many people, but many of these aspects can be assigned to the four mentioned ethical factors. Regional production can be assigned to the ecological factor, fair prices to farmers and social criteria can be assigned to world nutrition, as far as imported products from developing countries and fair trade aspects are concerned. Other aspects, as mentioned in Zander and Hamm (2010), such as the revival of traditional processing methods, remain unconsidered in the evaluation models in this chapter. The same applies to aspects such as abusive labour practices or boycotting products from countries with repressive regimes (mentioned in Starr (2009)).
In the ecological modelling technique "*NutriMod*" the four major dimensions are defined as follows: Environment, health (in accordance to the present chapter), economy and society. Animal welfare is part of the dimension society, as well as food security and other aspects such as need satisfaction. And the dimension economy covers aspects such as costs or employment issues (Metz and Hoffmann, 2010; Schneider et al., 2011)

There are two main obstacles to evaluating a food product ethically. First of all, all ingredients of a product have to be known in their accurate quantity in the end product. Secondly, and even harder to determine, the production process of each ingredient has to be known or at least estimated as accurately as possible. If this can be achieved, then the four ethical factors must be estimated for each ingredient (Figure 6.1):

- The ecological factor (called EC in the following formulas) includes all effects of the ingredient on the earth as shown in chapter 2. Demand for water resources, area demand, climate effects, waste and so on.
- The animal welfare factor (called AW in the following formulas) will evaluate plant based ingredients by giving them the highest score, whereas the score of animal based ingredients depends on their production methods, the way animals are kept. Here again, another obstacle arises when an ingredient is produced in various farms with better or poorer animal welfare standards. In this case, the AW factor must be determined by estimating an average condition for the farm animals on these farms, also taking into account the size of the farms (and the probability that a product comes from this farm). Other animal welfare issues, for example effects of the production of goods on natural habitats also have to be considered here.
- The health factor (called HE in the following formulas) will evaluate the effect of the ingredient on human health based on scientific knowledge. The health related interactions of various ingredients within a food product cannot be taken into account by applying the formulas in this chapter (in chapter 8, health issues are also part of evaluation models of

foods, and here a holistic approach is applied, and so such interactions can be addressed there).

- The world nutrition or world hunger factor (called WH in the following formulas) will evaluate the effect of an ingredient on world nutrition, world hunger and global food crises. Here, the requirements for agricultural space needed to produce a defined amount of the ingredient have to be taken into account as well as whether the ingredient is imported from countries where malnutrition is present.

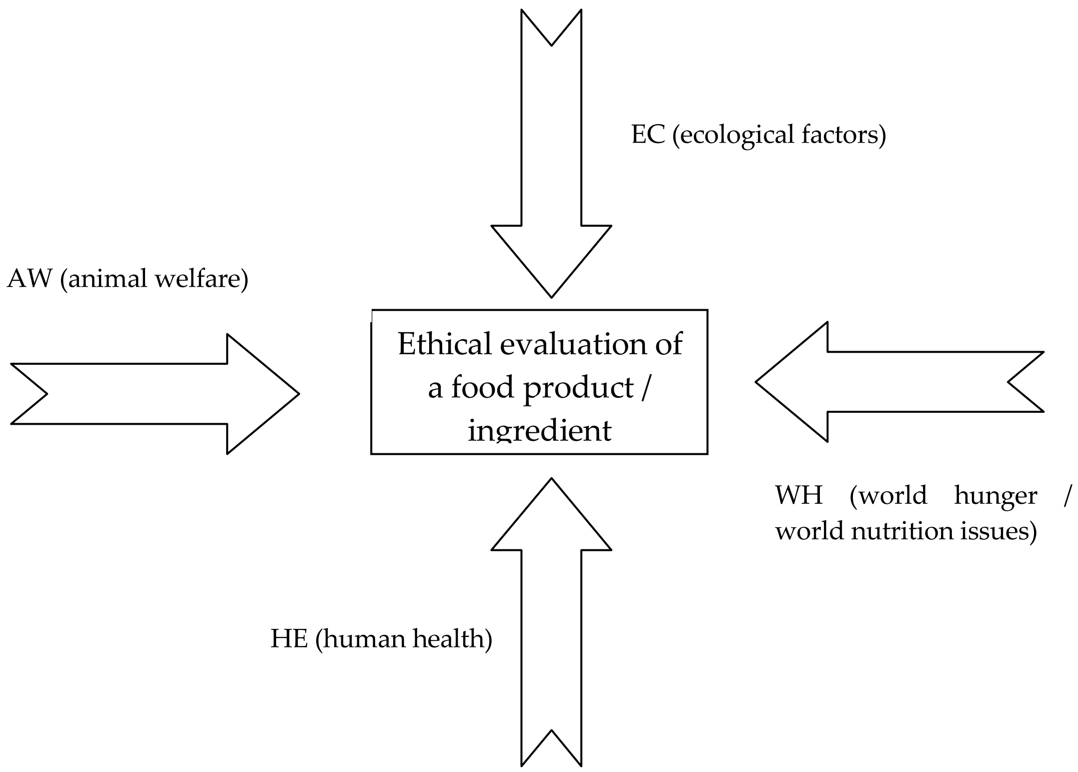

Fig.6.1: The four main ethical factors for evaluation of a food ingredient / total food product.

6.2 Simple mathematical evaluation models

Based on the assumptions above, the EC-, HW-, HE- and WH-scores of an ingredient could be summed up to evaluate one single ingredient. The drawback of such an approach is that a zero score in one of the four ethical factors could still lead to an acceptable total rating of the ingredient. But, it stands to reason that an ingredient with a zero score in animal welfare or in health will result in a total rating of zero, even if the ingredient scores well in the other areas (factors).

Therefore, multiplication instead of addition is a better choice. Each of the four ethical factors is a "knock-out criterion", which means, that totally neglecting one of the factors leads to a zero total score of the ingredient (as multiplying with zero leads to a zero result).

The overall formula for an ingredient then is as follows:

$$RatingIng = \frac{\sqrt[4]{EC.AW.HE.WH}}{\sqrt[4]{EC\max.AW\max.HE\max.WH\max}}.100$$

Each criterion can have values from 0 (lowest score) to 100 (highest score). In this way, all factors are weighted equally in this case, and with the following meaning of the 4 factors:

EC *ecology*

AW *animal welfare*

HE *human health*

WH *world hunger/world nutrition*

RatingIng is the resulting rating of the ingredient, and in this case also ranging from 0 (lowest score) to 100 (highest score). The 4th root is extracted from the numerator and the denominator to smoothen the result (make it more linear). Without the application of the 4th root, the total result of an overall average ingredient (scoring 50 in EC, AW, HE and WH) would be just 6,25, with the application of the 4th root, the result is 50, as could be expected.

The maximum values ECmax, AWmax, HEmax and WHmax are all defined as 100, so the formula can be simplified in this case to

$$RatingIng = \sqrt[4]{EC.AW.HE.WH}$$

For the overall evaluation of the food product, addition can be an appropriate method in this basic model, although it is still questionable should a zero result for one of the ingredients lead to a low overall score, even if the other ingredients score well. By simply adding up, as in the following formula, this demand is not met.

$$TotalEvaluation = \frac{RatingIng1.Percent1}{100} + \frac{RatingIng2.Percent2}{100} + ... + \frac{RatingIngN.PercentN}{100} = \sum_{I=1}^{N} \frac{RatingIngI.PercentI}{100}$$

with

RatingIng *rating result of the ingredient*

Percent *percentage of an ingredient within the food product.*

In the case described here, the *TotalEvaluation* is the total result of the food product in terms of its ethical standard and results in a value from 0 (totally unacceptable) to 100 (optimal).

As mentioned above, the formula could be altered to be more restrictive, so that in the case of one ingredient having a zero score, the overall evaluation for the food product would be zero as well.

In this case, addition would have to be replaced by multiplication and root extracting once again. As already mentioned, all the models described here can be seen as an initial attempt to evaluate a food product by ethical standards mathematically.
It should be noted that water (if separately cited in the ingredient list) should be excluded from the calculation, and the other ingredients should add up to 100 percent.

6.3 Alternative evaluation concepts

Models used for evaluating the animal welfare quality of livestock systems can be found in Botreau et al. (2007), but the principles of such models can also be applied to completely different evaluation systems, such as ethical evaluation models for food. First, several principles (in this paper 12) will be checked thanks to a combination of relevant measures. Second, the information will be compounded into four criteria and finally aggregated to form one overall assessment. Different mathematical methods can be used to process the information allowing for decreasing the level of compensation along the hierarchical structure (Botreau, Bracke et al., 2007).

Instead of calculating a total score, it is also possible to use a categorical approach for an ingredient specifying minimum scores in EC, AW, HE and WH as seen in Table 6.1. This approach is also able to handle "knock-out criteria", as the result of an ingredient scoring perfectly (100) in 3 out of 4 criteria (e.g. EC, AW and WH), but zero in HE (for example, because the ingredient is poisonous) would be accordingly "*unacceptable / deficient*".

Ethical evaluation category	Category minimum requirements for the ingredient
Excellent	Each of the 4 criteria (EC, AW, HE and WH) for the ingredient with a score of >= 60 out of 100, and 2 of these criteria with a score >= 80
Good	Each of the 4 criteria (EC, AW, HE and WH) for the ingredient with a score of >= 40 out of 100, and 2 of these criteria with a score >= 60
Acceptable	Each of the 4 criteria (EC, AW, HE and WH) for the ingredient with a score of >= 25 out of 100, and 2 of these criteria with a score >= 50
Poor	Each of the 4 criteria (EC, AW, HE and WH) for the ingredient with a score of >= 10 out of 100, and 2 of these criteria with a score >= 30
Unacceptable / deficient	None of the above requirements have been met

Tab. 6.1: Example of an evaluation approach using quality categories for the evaluation result of a single ingredient.

Total evaluation for the end product considering all the ingredients could again be done by using a categorical approach, as seen in the example in Table 6.2. The drawback to this approach is that all ingredients are treated equally, regardless of whether they are chief ingredients of the end product or only present in trace amounts. Using weighing factors representing the weight proportions of the ingredients in the end product would again introduce a mathematical approach.

Ethical evaluation category	Category minimum requirements for the end product
Excellent	60 % of the ingredients rated "*excellent*" and 80 % of the ingredients rated "*good*" or better and all ingredients rated "acceptable" or better.
Good	60 % of the ingredients rated "*good*" or better and 80 % of the ingredients rated "*acceptable*" or better and all ingredients rated "*poor*" or better.
Acceptable	20 % of the ingredients rated "*good*" or better and 60 % of the ingredients rated "*acceptable*" or better all ingredients rated "*poor*" or better.
Poor	20 % of the ingredients rated "*acceptable*" or better and all ingredients rated "*poor*" or better.
Unacceptable / deficient	None of the above requirements have been met

Tab. 6.2: Example of an evaluation approach using quality categories for the evaluation result of the final end product. The percentages presented in this table can be either seen as a percentage of ingredient categories (e.g. in the case of 5 different ingredients, each ingredient represents 20 %), or as a percent representation according to the weight proportions (e.g. 1 of 5 ingredients in the end product that makes up 50 % of the total weight represents 50 %).

6.4 Further evaluation concepts in literature

A further model presented in literature is the so called "*Ethics Matrix*", as shown in Figure 6.2, which takes into account the environment, the consumer (including health aspects) and farm livestock (including animal welfare), and is therefore in good compliance with the four ethical factors presented in chapters 2 to 5. The only difference is that the ethical value "*people in agriculture and food industry*" is added whereas the world nutrition issues are omitted. However, the "*Ethics Matrix*" does not provide for a formal output from the matrix. It provides for a detailed analysis of food policy and individual choices but does not allow for a quantitative analysis (Food-Ethics-Council, 2001; Manning et al., 2006).

	Well-being	Autonomy	Justice
People in agriculture and food industry	Satisfactory income and working conditions	Appropriate freedom of action	Fair trade laws and practices
Citizens	Food safety and acceptability Quality of life	Democratic informed choice	Availability of affordable food
Farm animals	Animal welfare	Behavioural freedom	Intrinsic value
The ecosystem	Conservation	Biodiversity	Sustainability

Fig.6.2: The "*Ethics Matrix*": A detailed analysis of food policy and individual choices but does not allow for a quantitative analysis. Source: Food-Ethics-Council (2001).

Other quantitative methods deal with food risks, which also represent an important ethical aspect. Risk is defined as the mathematical product of probability and consequence.

$$Risk = \Pr obability.Consequence$$

This risk estimation forms the basis of the so called "*Ethical Significance Screening Model*" (Donoghue, 2000; Manning, Baines et al., 2006).

CHAPTER 7

Success Criteria for Alternatives to Animal Products

7.1 Is there a need for new plant based foods?

Chapters 2 to 5 have shown that there is a massive body of scientific evidence pointing to a global change in world nutrition being necessary. In principle, this could be achieved with existing foods, but new plant based foods will assist such a transition and make it much more realistic (Aiking, de Boer et al., 2006).

The following chapters 9 to 12 of this dissertation are designated to such new plant based foods, those already in existence and those not yet in existence. In the current chapter we will focus on these plant based foods and develop marketing success criteria for them.

An important issue is market introduction and entry, especially authorisation by governments prior to entering food markets such as the EU market. A good overview and explanation of this procedure is described by Kuik (2006).

Interesting sales figures and trends in marketing of soy foods for North America are published by the Soyfoods Association of North America, showing that tofu and soy based meat alternatives together reached total sales of US$ 877 million in 2008 (Soyfoods-Association-of-North-America, 2009) compared to sales of over US$ 100 billion in the USA for meat products (Goodland and Anhang, 2009). This suggests much room for growth in the meat alternatives market.

Consumer trends in vegetarian meat alternatives have also been compiled in reports by organisations such as Cultivate Research (Cultivate Research, 2008).

7.2 The Stability-/Energy Minimum-Hypothesis

As shown in chapters 2 to 5, it is desirable to find ways to shift global food-consumption increasingly towards plant based foods.
This chapter will investigate the success criteria that alternatives to animal products must meet if a wide audience should be won.

As one basic input for the models developed in this chapter and chapter 8, we will use a model derived from a theory from Balluch (2009) and adapt it for nutritional aspects for this dissertation. The basic assumption of this model is the fact that most individuals in a society try to live in a way that costs least extra effort or a minimum of energy. In Figure 7.1 this is the trough, the red marked minimum of the displayed curve. Applied to eating habits, this means that people tend to eat what is cheap, widely available, tasty and socially accepted. For example, living as a vegetarian or even a vegan can exclude being able to eat in certain restaurants. It may well cause stressful situations, for example, when attending a business lunch or being invited to dinner or a barbecue where meat will be served. It will cost more energy to find the right foods, as these might not be available in all supermarkets. It will be harder when such individuals travel to countries where they do not speak the language and cannot identify the ingredients of a product easily. It could be harder for vegetarian parents to find all-day school places for their children offering a varied vegetarian menu. It could also cost the children more energy to avoid becoming an outsider by not joining their contemporaries in going to fast food restaurants and eating meat-based burgers. Most individuals attempting to change, tend to revert back to behaviour that makes their lives easier, which – in the case of nutrition – is the behaviour of the majority of the

society they belong to. In Figure 7.1 the green coloured right side of the curve's minimum represents a diet which is more sustainable than the average diet in a society, but the more uncommon these eating habits are the more energy is required from an individual to keep to them. The (black coloured) left side of the minimum is a less sustainable and less ethical way of eating than society’s average. It can be seen that keeping up such dietary behaviour also costs more energy for the individual. Examples for the left part of the curve could be eating animals that are commonly not eaten in a society, for example, pets, eating especially unhealthy foods, or as an extreme, human cannibalism. An individual that eats dogs in Europe or the USA might risk disdain, the cannibal has to face court trials and arrest. All these are adverse effects on the individual and so it costs perpetual energy to keep up these habits.
It can be seen, although totally opposed to the desirable, more sustainable forms of nutrition on the right side of the curve, the individuals on the left side also have to put much energy into keeping up their habits.

To sum up: Living outside the trough, the red coloured minimum of the curve in Figure 7.1, costs energy, individuals "roll back", if they do not invest energy perpetually. It needs a lot of motivation to keep individuals outside the trough and their position there is not stable in the long term.

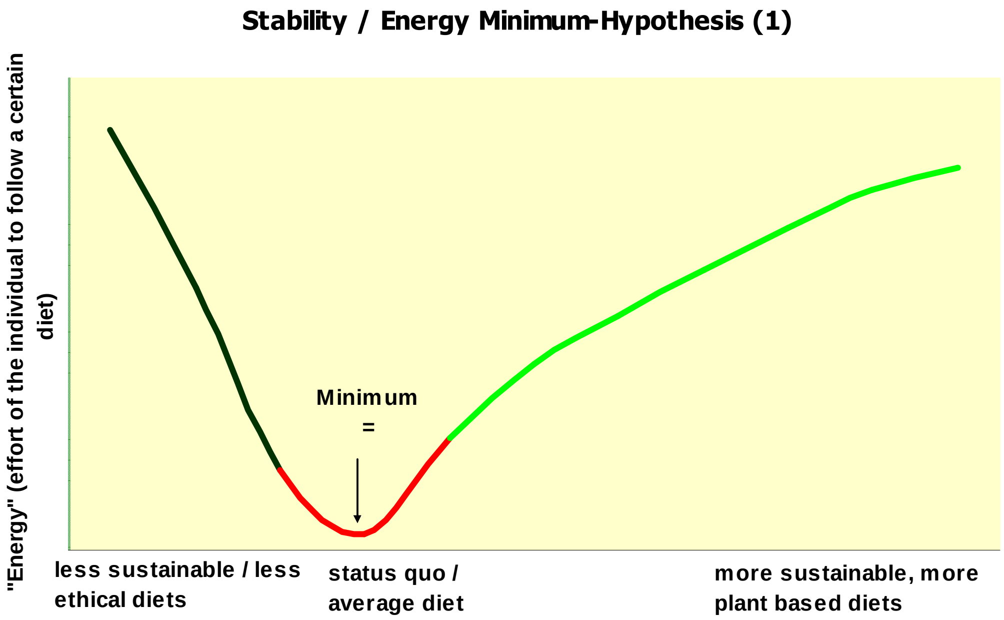

Fig.7.1: Energy effort of an individual following certain diets. The political and economical system as well as the food markets shape the curve. Living outside the trough (energy minimum, red) costs energy, individuals "roll back", if they do not invest energy perpetually. It needs a lot of motivation to keep individuals outside the trough and their position there is not stable in the long term.

This chapter shows concepts for pushing the energy minimum for eating habits of individuals in a society to the right, as shown in Figure 7.2. To increase the share of new plant based foods in the diet of most individuals in a society, obvious criteria can be established: A wider variety of plant based foods may well attract more people to eat them more frequently. This can lead to a decline in prices and can make these foods more easily available, which again, attracts new consumers. Health issues would help with health conscious consumer segments. New companies joining these emerging markets could bring higher qualities, improvements in taste or texture of the products, fully automated processing steps can again beat down prices. Gaining more and more shares of total markets, the new plant based foods would also gain more and more shares of the total marketing and advertising budgets, which would again attract more people and make the shift of the curve to the right in Figure 7.2 easier. Based on this model and on existing publications, we will extract success criteria for new plant based foods later in this chapter.

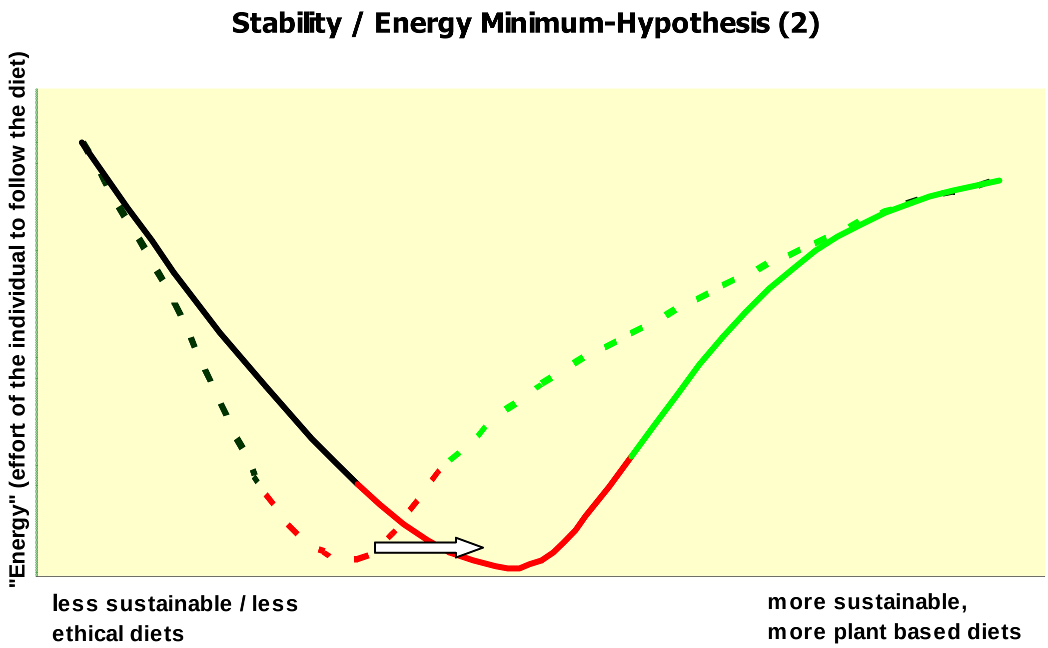

Fig.7.2: Changed conditions on food markets and/or in the political and economical system can push the energy minimum to the right, to a more sustainable diet.

A variant of Figure 7.2 is shown in Figure 7.3, which goes beyond the model from Balluch (2009). Here, social groupings within a society, for example vegetarian organisations and their members and communities, could create local minimums on the curve to the right of the absolute minimum. In these local minimums, individuals feel that their way of living is accepted, in our case, their diet that differs from the average, most common diets. They find special information and can have social interactions with like-minded people in their communities, which makes such local minimums relatively stable for the individual to remain there. Figuratively we can say, the more individuals such a social grouping consists of, the more "weight" will be exerted on the curve and the deeper such a local minimum will become. Such local minimums could finally also lead to a shift of the energy minimum to the right as shown in Figure 7.2, if they become deep enough and connect with the current actual minimum.

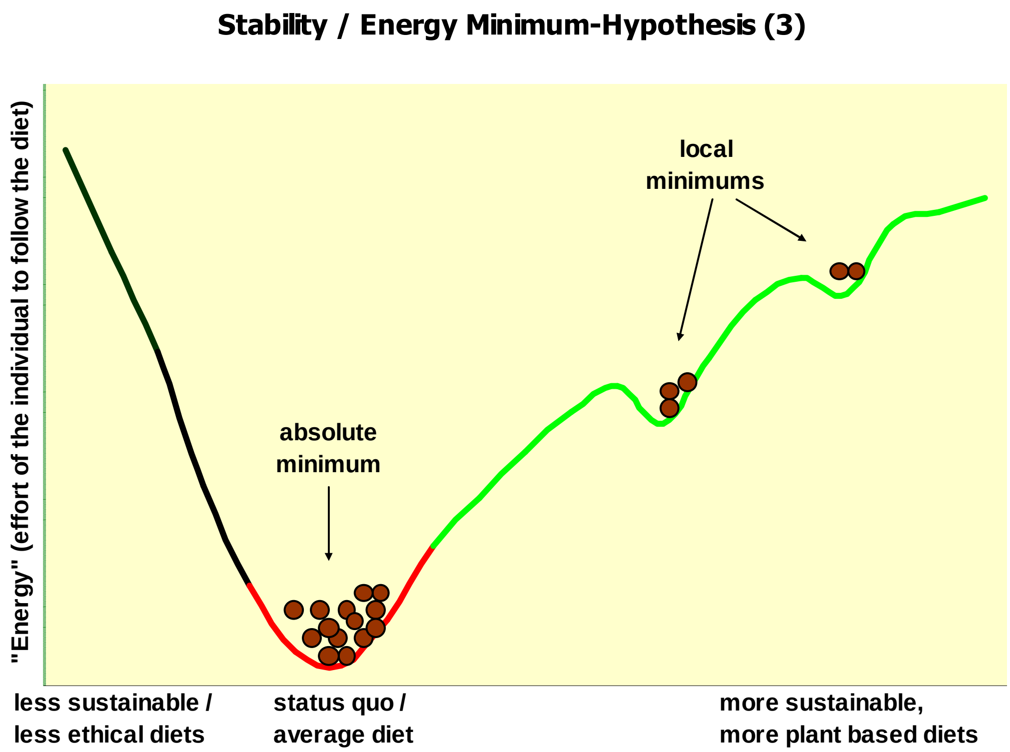

Fig.7.3: Local minimums might also attract groups of individuals to practise a more sustainable diet. The more people that follow such a diet, the deeper and relatively more stable the local troughs (minimums) become. Such local minimums might also lead to shifts of the absolute minimum as shown in Fig.7.2

7.3 Success Criteria for Foods (ethically orientated target groups)

As seen in the "*Stability-/Energy Minimum-Hypothesis*" in chapter 7.2, only a small segment of consumers can be motivated to consume in way that is further away from the norm of consumer patterns in a society. The motivations for a broader target group to consume a certain product are shown in detail in chapter 7.4. However, this subchapter gives a short side note to the motivations of ethically orientated consumer minorities and success criteria for products when targeting such consumer segments.

The net benefit of consuming ethically can be defined as the total benefits of consuming ethically minus the incremental cost of consuming ethically. The total benefits consist of an intrinsic value of consuming ethically (personal satisfactions of behaving ethically) and a social benefit of consuming ethically (if such consumption is perceived in a positive way by others within society). Therefore, the formula for this net benefit of consuming ethically is (Starr, 2009)

$$Nj = Tj(vj, Sj(a)) - Cj$$

with

j	*a given individual*
a	*the share of the population consuming ethically*
Nj	*net benefit of consuming ethically*
Tj	*total benefit of consuming ethically, depending on*
	vj : intrinsic value of consuming ethically and
	Sj(a): incremental 'social' benefit of consuming ethically, which is assumed to vary with a
Cj	*incremental (monetary) cost of consuming ethically (Starr, 2009).*

Social benefits of consuming ethically are often reversed to social disadvantages (see chapter 7.2). In this case the individual needs especially high values of *vi*, i.e. a high level of personal motivation to keep up the ethical consumption pattern. Thus, if ethically produced products are to reach a broader market, or in other words, if the energy minimum in the "*Stability-/Energy Minimum-Hypothesis*" is to be pushed to the right, to a more sustainable food consumption, the products must fulfil other success criteria, which are presented in the next subchapter.

7.4 Success Criteria for Foods (broad target groups)

Which criteria do new plant based foods, such as non-dairy milk drinks, vegetarian meat alternatives and also cultured meat, have to satisfy before they are accepted by consumers? What advantages must they offer in order for them to be a success on the market and to make them impervious to traditions and habits? Or, referring to the last chapter, what saves the individual consuming such new products energy in the "*Stability-/Energy Minimum-Hypothesis*"? What makes the shift of the absolute minimum in Figure 7.2 to the right possible? And, what attracts the food industry and the food trade?
Molnár (1989) considers the following groups of attributes in his evaluation model to describe food quality: Sensory attributes, chemical composition, physical properties, microbiological and toxicological contaminants, shelf-life, packaging and labelling.
Based on these findings and on the criteria defined in de Boer et al. (2006), the following criteria can be extracted:

7.4.1 *Taste / Texture / Satiety Feeling / Aroma*

Aim: New plant based foods – Should taste, feel and smell better, or at least as good as animal meat, dairy products and egg products according to the perceptions of the majority of consumers.

Any form of vegetarian meat alternative, cultured meat, egg replacement product or non-dairy milk product has to completely satisfy the flavour preferences of the majority of the population. It is very probable that flavour is the most important key to success, and at the same time, one of the biggest challenges.

It should be pointed out that talking about "flavour" not only covers taste by definition, but also considers the texture of the product, its aroma and how filling or satisfying it is to eat as well as trigeminal perceptions. Textures can vary, and can be fibre-like (such as in meat products), gel-like (such as in yoghurt), coagulated (such as in cheese, tofu), and so on (O'Kane, 2006). For vegetarian meat products, meat-like sensory properties and luxury aspects are also emphasized as success criteria by Hoek (2006), and in addition a higher protein content in a product improves satiety sensations.

7.4.2 *Price*

Aim: New plant based foods – Should be cheaper than conventional meat, milk or eggs derived from animals.

The wasting of resources inherent in producing animal products (see chapters 2 and 3) due to the metabolism of the animals makes them in principle costly. Generous subsidies (at least within the EU) and applying intensive farming methods simply make animal products "appear" cheaper (Hnat, 2006). Therefore, it stands to reason that it must be possible to produce animal-free products at less cost than products from farmed animals. A model calculation shows that pea based meat substitutes are cheaper than pork (Apaiah, 2006). This price gain can be optimised, if the starch fraction that is accumulated while producing pea based meat substitutes is utilised exhaustively and efficiently. Such useful options for the usage of this starch fraction are available (Willemsen, 2006). In depth analysis of byproducts of the pork chain and their replacement with alternatives if pork is replaced (partially) by vegetarian meat products show some obstacles that can be solved. Alternatives for byproducts such as fat, leather, gelatine and pet-food have yet to be found (Willemsen et al., 2006) or, where they already exist, perfected.

In the special case of cultured meat, which is far from being ready for the market as shown in chapter 12, the following strategy could be applied to fulfil the price criterion. In the initial stages producing cultured meat will be cost intensive. It would therefore make sense to start with an expensive delicatessen product such as foie gras: this would make it possible to achieve a competitive price. An in-vitro foie gras could probably be healthier and without the associated animal cruelty involved in production.

7.4.3 Marketing / Target groups / Advertising

Aim: New plant based foods – Must appeal to a wide target group, not only to vegetarians.

Until now, vegetarian foods have primarily been aimed at particular target groups. The existing products have been developed with health-conscious people or vegetarians in mind. However, it is essential that future products, if superior to animal products in terms of price, flavour and health-issues, have a wide audience as target group, not just a small segment. Advertising and marketing going into future products should not, under any circumstances, be geared to the vegetarian market alone. This is in accordance with other market segmentation theories on vegetarian meat products (Hoek, 2006). Calling vegetarian meat product "meat substitutes" is considered a bad name by consumers according to market explorations in 2001 in the Netherlands. Favoured properties for vegetarian meat products were: Brown, soft, smooth, crispy, seasoned, spicy and meat-like flavour (Elzerman, 2006). Campaigns for vegetarian meat alternatives should avoid negative themes. Messages about new foods should "*evoke feelings like comfort, familiarity, happiness, ease, low price and popularity*". Such campaigns should "*pitch the theme of eating all week long a line of food products that is tasty, easy to prepare and includes a superfood, such as soy*", that will enrich the consumers' lives (Goodland and Anhang, 2009). Vegetarian meat alternatives should be placed side by side on the same shelf with meat products to expose them to many consumers. The business risk for manufacturers of vegetarian meat alternatives should be mitigated by the fact that much of the necessary infrastructure (the growing and processing of grains or for the processing of meat, for example) already exists (Goodland and Anhang, 2009). An Austrian investigation showed that the target group for vegetarian meat alternatives could be boosted if these products were more often available in supermarkets and discount stores. Also, the advertising for vegetarian alternatives to animal products, especially at the point of sale, is still in its infancy (Ruiz, 2007). Consumer segments generally tending to show "food neophobia" are the target group which is least likely to be convinced (Hoek, 2006). And finally, information is also an important issue as proven by the following example: Given that 85 percent of the global soy production is used for animal feed and thus animal products (Pachauri, 2008; WWF, 2008), and in contrast, that soymilk-products in Austria are commonly made from non-rainforest, non-GMO and often organic soy, the fact that 35 percent of Austrian consumers associate Austrian soymilk with rainforest-destruction (see Integral Marktforschung (2011)) is a paradox based on a lack of information.

7.4.4 *Health*

Aim: New plant based foods – Should be healthier than animal products in an overall health appraisal.

The objective for vegetarian meat alternatives, non-dairy products, egg replacement products, as well as cultured meat all must be to lead to health improvements for humans. Animal epidemics such as BSE, bird flu (avian influenza) or swine flu as well as antibiotic resistance and salmonella (see chapter 4) should cease to be problems. With reference to cultured meat, it should be possible during production to make it easier to control the combination of amino acids or fatty acids or, for example, to omit unwanted cholesterol. As seen in much more detail in chapter 4, it is realistic to expect that new planet based foods can outperform animal products as far as health is concerned.

7.4.5 *Shelf-life / Hygiene*

Existing animal-free products, such as soy milk drink, tofu and vegetarian sausages usually have a longer shelf-life than their equivalent animal based products. Aseptic packaging allows some tofu to be stored for 1 year at room temperature (Golbitz, 1995). As always, dehydrated products such as dried textured soy proteins (TSP, TVP) show the longest shelf lives, according to the manufacturers in Tables 9.1 and 9.2 in chapter 9 shelf lives of dried TVP-products are typically one year or longer. Due to this fact there are many savings to be made in production, transport and sales, for example, by making cold chains unnecessary in many cases.

Usually, spoilt animal products are by far a greater health risk than spoilt animal-free products. A survey from Austria for the year 2006 shows that almost 100 percent of foodborne diseases originated from animal products (forum-ernährung-heute, 2007), although this is probably an overestimation due to possible methodical restrictions in this survey. Nevertheless, generally lower risks of foodborne diseases with plant based foods are weighty advantages for the food industry and the end-user alike, and have yet to be fully recognised and realized.

7.4.6 Conclusion

Based on the five elemental success criteria presented in 7.4.1 to 7.4.5 we will create a basic economic evaluation model for foods, especially for new plant based foods, in chapter 8.

7.5 Food fortification and new breeds of plants for improved human nutrition

As shown in chapter 4, prospective cohort studies show strong evidence that replacing animal products is possible while still fulfilling good standards of human nutritional health or even improving them. Nevertheless, it will be useful to optimize a plant based diet in those areas, where plant foods usually lack essential nutrients. Food fortification can help prevent the potential danger of malnutrition and crop fertilization is another option for increasing the nutritional value of crops. Food processing steps, such as fermentation, cooking and so on are also commonly known to either destroy antinutritive contents and toxins or to produce nutrients that are not contained in the unprocessed plant material. Another way to improve the nutritional value of foods is to develop new breeds of plants.

All these measures should focus on contents and bioavailability of the key nutrients for vegetarians, which are essential amino acids (especially methionine, but also tryptophan, threonine, and lysine), iron, zinc, calcium, iodine, the vitamins D, B2, B12 and A as well as long-chained omega-3 fatty acids, such as EPA and DHA. Alternative approaches to include these nutrients into modern diets are available, for example, vegetarian DHA or EPA derived from microalgae (Mangels, Messina et al., 2003).

7.5.1 Food fortification and crop fertilization

Fortification of foods is a straightforward method used to overcome weaknesses of a particular diet. The American Dietetic Association has listed various options for fortification of the mentioned key nutrients for vegetarians (Mangels, Messina et al., 2003). Fortification is more common than most people think, for example, the use of iodized salt is already common practice in developed nations, as well as food fortification with minerals and vitamins. Fortification of food is in fact, mostly restricted to industrialized nations.

Plant nutrient content can also be enhanced via crop fertilization. Zinc sulphate fertilizers for example, have helped overcome the zinc deficiency in Turkish soils (Cakmak et al., 1999).

7.5.2 New breeds of plants for improved nutritional value

In the past decades, the focus in crop breeding has almost exclusively concentrated on optimal yields, minimal costs and pest resistance.
These drivers sometimes go hand in hand with improved nutritional qualities of crops, for example, crop lines biofortified with mineral nutrients that correlate with higher yields (Bouis, 2000). But often, these commercial drivers conflict with improved nutritional values of crops. To overcome global food shortage, high yielding crops were globally introduced that often resulted in high-carbohydrate, low-quality protein cereals (Morris and Sands, 2006). Currently, cereal grain protein contains only about 15 percent essential amino acids (Shewry and Halford, 2002). Improved nutritional qualities of crops have also showed other surprising results: Grasshoppers, rats and aphids have shown a preference for feasting on fields with lysine enriched wheat over neighbouring fields with conventional wheat (Sands et al., 2009). Thus, it can be hypothesized as argumentum e contrario, that selection for insect resistance could have lowered the nutritional value of crops (Morris and Sands, 2006).

Improved nutritional crops should provide protein high in essential amino acids, but also balanced fatty acid contents (high in Omega-3), essential minerals and vitamins in sufficient dosages and bioavailability, to mention but a few. In addition, the plants should contain low levels of toxins and antinutrients.

One example of an improved nutritional quality crop that was developed in the past, is QPM (quality protein maize), with enhanced levels of the essential amino acids lysine and tryptophan (Vasal, 2002). Golden rice, containing provitamin A (β-carotene) is another (Beyer et al., 2002; Paine et al., 2005), as well as increased levels of the essential amino acid lysine in barley (Miflin and Shewry, 1979) and in wheat (Harris et al., 1994). Another example is the transformation of a super protein gene, expressed in *E. coli* and with strongly elevated levels of lysine, methionine, tryptopan, threonine and isoleucine, into potato (Jaynes et al., 1985). In general, high protein qualities should be aspired to in future plant breeding. Various evaluation methods for measuring protein quality are summarized by the FAO (Boutrif, 1991). A more recent method for measuring protein quality is the Protein Digestibility Corrected Amino Acid Score (PDCAAS) which is defined as follows (Schaafsma, 2000), with interpretations in Reeds et al. (2000):

$$PDCAAS(\%) = \frac{\text{mg of limiting amino acid in 1 g of test protein}}{\text{mg of same amino acid in 1 g of reference protein}}.\text{fecal true digestibility}$$

Increased levels of Omega-3 fatty acids in cereals could help to reduce chronic human inflammatory diseases (Serhan, 2005), are essential for optimal brain development (Novak et al., 2008) and also important in the prevention of depression (Hibbeln et al., 2006).

For bioavailability of zinc and iron, lower levels of phytic acids are advantageous, as phytic acid binds these minerals and prevents assimilation by humans (Oberleas and Harland, 1981). In conjunction with improved protein crops it should be kept in mind that free amino acids can also be harmful in many ways, for example, asparagine as a precursor of toxins such as acrylamide (Mottram et al., 2002). With respect to genetic engineering, the risks as well the low consumer acceptance (especially in Europe) must be considered.

7.5.3 *Use of a wider range of existing crop species*

Although there are about 7000 species of cultivated plants available, we use only 4 plants, wheat, rice, potatoes and maize, to supply over 50 percent of the globally required food calories, and about 30 plants cover more than 90 percent of calorie requirements globally (Lanzerath et al., 2008). The use of a wider range of cultivated plants for human nutrition could be an alternative, natural trend to reach the goal of providing a higher variety of critical nutrients in a plant based nutrition, besides food fortification, crop fertilization or new breeds of plants.

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CHAPTER 8

Economical Evaluation Models for Food Quality

8.1 Existing evaluation models for food quality

Molnár (1984) has introduced evaluation models for food quality using so-called "*quality indices*". He developed this model further to an overall evaluation model, and he introduced the idea of "*primarily critical*" characteristics, that eliminate the final result of an overall quality index (Molnár, 1989). For example, if a product is harmful to health, this represents such a "*primarily critical*" characteristic. According to Molnár (1989), a product is classified by the final result, the overall quality index, ranging between 0 (unsatisfactory) and 1 (excellent).

Other approaches to measuring food quality with a focus on cultivation methods have been published by Schulz (1997). Here, measurement of food quality is not based on attributes of the food product itself, but as a result of whether the food was cultivated on northern or southern situated side sites, with fresh manure or compost or if it was treated with biodynamic preparations or left untreated.

A more integrated approach to food quality instead of reductionist approaches is emphasized in more recent papers (Peri, 2005), based on previous works (Checkland, 1994). In Figure 8.1 an analytical model of food quality is shown. Two perceptions can be distinguished. The one called "*homo edens*" could be translated as the perception of consumers, whereas "*homo oeconomicus*" could be translated as the perception of customers, but the author leaves this open. Furthermore, he argues that a complete failure to meet any one of the requirements in Figure 8.1 might lead to a rejection of the product even when all other requirements are fully satisfied. It is also possible that excellence in only one of the requirements may be sufficient to guarantee the success of a product. Thus, Figure 8.1 does not exhaust the complexity of measuring food quality and success. A possible solution is the concept of minimising rejection, as this forces food researchers to a more comprehensive optimization (Peri, 2005). The author gives no hint to how such holistic approaches could be expressed mathematically.

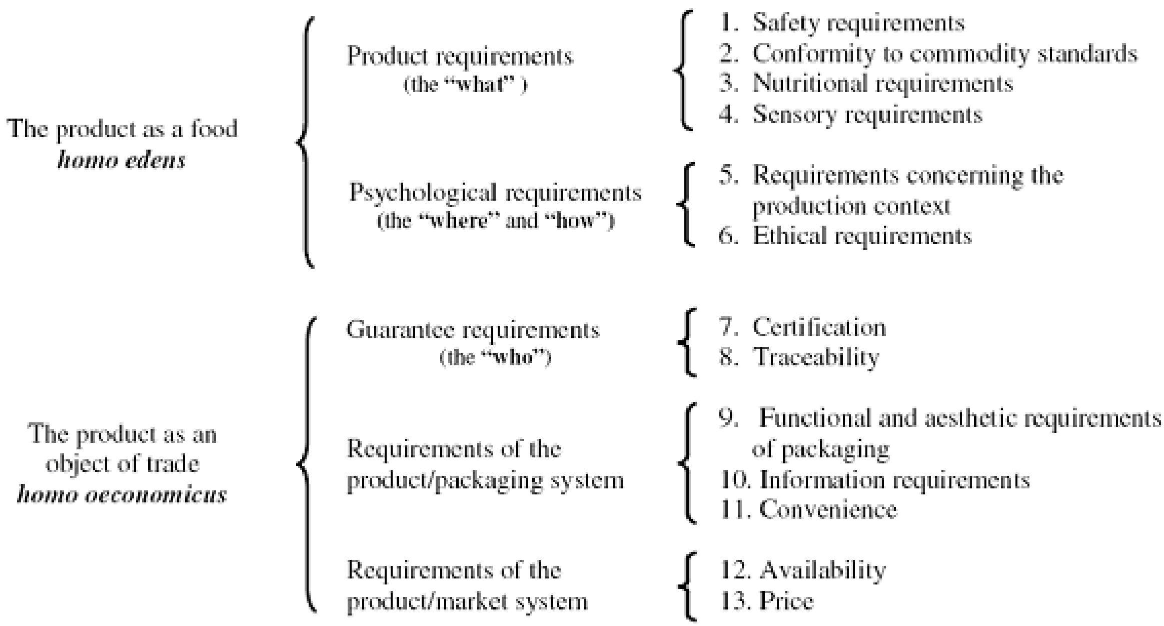

Fig. 8.1: An analytical model of food quality. Source: Peri (2005).
Two perceptions can be distinguished. The one called "*homo edens*" could be translated as the perception of consumers, whereas "*homo oeconomicus*" could be translated as the perception of customers
Safety requirements primarily mean absence of risk factors.
Conformity to commodity standards requires that the product equals its definition.
Nutritional and sensory requirements cover health and taste issues.
Production context and ethical requirements cover many fields, e.g. whether the food product has been produced by organic farming methods, or issues such as animal welfare, child labor or ecology.

A similar differentiation, this time between a consumer approach used in marketing and consumer behaviour research, and a food science approach emphasizing measurable qualities can be found in earlier publications (Bowbrick, 1992).

Another option for measuring food qualities is using ratings from 1 (best rating) to 5 (worst rating) in the following categories (Becker, 1999):

- Extrinsic and intrinsic cues of (animal) foods: Colour, marbling, leanness, brand/label, place of purchase, price, country of origin.
- Eating quality attributes: Flavour, tenderness, texture, colour, juiciness, smell, leanness.
- Safety cues of foods: Feed, brand/label, organically produced, freshness.
- (Animal) food concerns: Hormones, antibiotics, fat/cholesterol, salmonella, BSE.

In the following subchapter and in chapter 7, the extrinsic and intrinsic cues attributes are summarized as "*marketing*" and "*price*", partly they affect the "*flavour*" criterion, the eating quality attributes correspond with the "*flavour*" criterion, and the safety cues and concerns partly fulfil the "*health*" and "*hygiene*" criteria and to a small extent "*marketing*".

The International Organisation of Standardization (ISO) defines food quality as the "*totality of features and characteristics of a product or service that bear on its ability to satisfy stated or implied needs*" (ANSI/ASQC, 1987).

8.2 Possible models for food quality and success on the market

Simple mathematical approaches to food quality and economical success, similar to those presented for the ethical evaluation of foods in Chapter 6, could start as demonstrated here, with zero being the lowest rating for the factors in the formula:

$$\text{RatingProduct} = \frac{(MA + HE + SLH + PR).FS}{(MA\max + HE\max + SLH\max + PR\max).FS\max}.100 =$$

$$\frac{(MA + HE + SLH + PR).FS}{24}.100$$

with

MA *Marketing (ranging from 0-2)*

HE *Health (ranging from 0-2)*

SLH *Storage Life/Hygiene (ranging from 0-1)*

FS *Flavour, sensory attr.(Taste, texture, aroma)/Satiety properties (range 0-3)*

PR *Price (ranging from 0-3)*

and

RatingProduct *final result between 0 (total failure) and 100 (excellent)*

The selection of the 5 factors or summands, as well as their ranges, and finally the exceptional position of the "*FS*" factor are somewhat arbitrary, but are, nevertheless in accordance with the conclusions about consumer aspects in the Dutch Profetas project (de Boer, Hoek et al., 2006) and summarizing the criteria in subchapters 8.1 and 7.4. Positioning "*FS*" as a multiplier instead of a summand makes it a "knock-out criterion", with a total failure of a product in terms of the taste, aroma, texture and satiety-properties leading to an overall zero-result for the economical evaluation of the product, which is reasonable for normal foods, as consumers will reject it, even when the other criteria are met satisfactorily. This also satisfies the holistic approach of minimising rejection (Peri, 2005) to some extent.

The problem with the initial formula is that the result is non-linear (e.g. an average score in all of the criteria leads to an overall rating of 25 instead of 50 which could be expected). Thus, extracting a square root is used to smoothen out the result and make it more linear.

$$\text{RatingProduct} = \frac{\sqrt{(MA + HE + SLH + PR).FS}}{\sqrt{(MA\max + HE\max + SLH\max + PR\max).FS\max}}.100$$

Figure 8.2 shows the effect of smoothing out the result by extracting a square root.

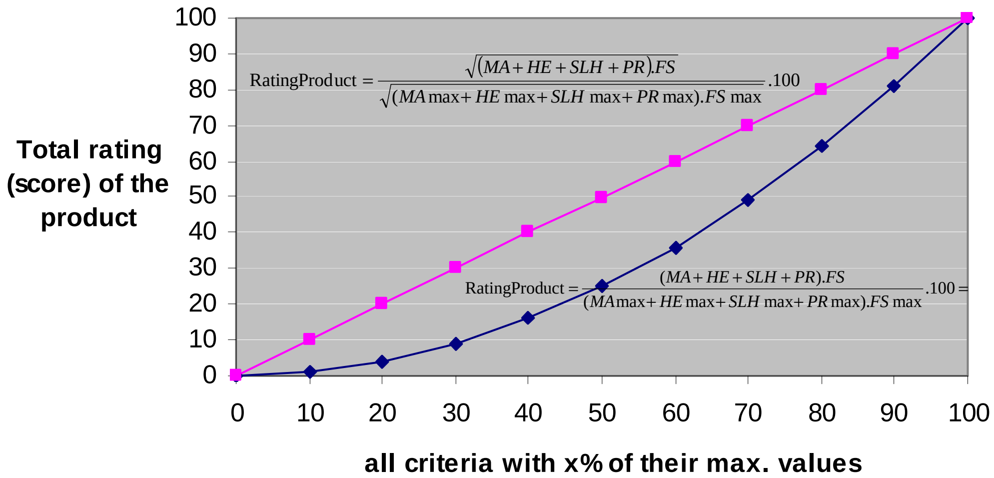

Fig.8.2: The effect of smoothing out the result by extracting a square root. On the abscissa the scores of the 5 criteria are shown in percent of their maximum values, the ordinate shows the score (rating) of the product.

To generalise this approach, it can be said that the more criteria that should be applied to the formula as multipliers, the more the formula has to be smoothed out. If N multipliers should be applied to the formula, then the Nth root should be extracted of the numerator and the denominator.

8.3 Alternative evaluation concepts

As shown in chapter 6.3, it is also possible to use a categorical approach instead of calculating a total score. Such an approach is also able to handle "knock-out criteria", as shown in Table 8.1. The categorical system can be configured in such a way that, for example, a total failure in the flavour or in health aspects of the food product would lead to the rating "*unacceptable / deficient*", regardless of the scores of the other criteria.

Economical rating of the product	Category minimum requirements for the product
Excellent	FS and HE with a score of >=80, the other criteria (MA, SLH and PR) with an average result >=60
Good	FS and HE with a score of >=60 (and one of the two >=80), the other criteria (MA, SLH and PR) with an average result >=45
Acceptable	FS and HE with a score of >=40 (and one of the two >=50), the other criteria (MA, SLH and PR) with an average result >=30
Poor	FS and HE with a score of >=30, the other criteria (MA, SLH and PR) with an average result >=20
Unacceptable / deficient	None of the above requirements have been met

Tab. 8.1: Example for an economical evaluation approach for a food product using quality categories. 5 criteria are defined:

MA Marketing
HE Health
SLH Storage Life/Hygiene
FS Flavour (Taste, texture, aroma)/Satiety properties
PR Price

Here, each of the five criteria can have values from 0 (unacceptable) to 100 (excellent).

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CHAPTER 9

Vegetarian Meat: Plant Based Alternatives to Meat Products

One strategy of catalyzing a possible turning away from animal products towards more sustainable foods is finding alternatives that simulate or copy animal derived products. This chapter presents different approaches to vegetarian meat alternatives, and goes on to introduce some highly remarkable products and producers, and evaluates some of them with the evaluation models presented in 6 and 8.

9.1 Various base foods for the production of vegetarian meat alternatives

The Dutch Profetas-project used peas as a possible precursor for producing meat alternatives because of their high protein content, their ability to grow in Western Europe, the absence of unwanted substances in the pea and the available expertise (Aiking, 2006). But, as the Profetas-project only produced theoretical models and no actual vegetarian meat, and no producer of vegetarian meat based on peas can be found globally so far, peas are not included in the following list of basic substances.

As existing source proteins for meat substitutes, Profetas mentions tofu, tempeh, texturised vegetable protein (TVP), wheat gluten, lupine proteins and Quorn, which is based on the fungus Fusarium venenatum (Vereijken, 2006).

Fig. 9.1.: Impressions of various vegetarian meat alternative products.

9.1.1 Wheat gluten / seitan

Wheat gluten is also known as seitan. It consists of the protein components gliadin and glutenin which are isolated from wheat by rinsing the wheat dough until the starch and bran have been washed out. It is one of the most cost effective and simple raw materials for producing vegetarian sausages, burgers, nuggets, schnitzel as well as minced meat. In addition, wheat is a crop that is native to the majority of countries around the world. Thus, the production of seitan is possible on a regional level. The consistency of seitan is remarkably similar to the stringy fibres that make up the consistency of meat. Seitan can be seasoned and prepared in a wide variety of ways.

9.1.2 Tofu

Tofu is a traditional Asian foodstuff and a basis for meat replacements made from soya. It is made by adding a coagulant to soymilk and by compressing the resulting protein solids until the right consistency is achieved. Tofu is easily digested and contains all essential amino acids. Unlike seitan, tofu does not have a meat-like consistency, therefore it is often not classified as a meat alternative in the narrower sense. Tofu can be seasoned in many different ways and is popular smoked.

9.1.3 Soya meat / TVP

Soya meat, or textured vegetable protein (TVP), is produced from soy beans primarily in Asian countries. The production method is somewhat laborious but, the end product has a fibrous consistency which is very similar to meat. With different seasonings a great variety of flavours can be achieved. Soya meat is extremely rich in protein with protein contents of over 50 percent, but the protein content drops when TVP is rehydrated (Riaz, 2005).

TVP has been developed in the USA and introduced to the European market in the late 1960s, with modest success (Vijver, 2006). But it should be noted that the quality of TVP has improved for the last 40 years.

TVP is produced using hot extrusion of defatted soy proteins, resulting in expanded high protein chunks, nuggets, strips, grains and other shapes, where the denaturated proteins give TVP textures similar to meat. The fibrous, insoluble, porous TVP can soak up water or other liquids a multiple of its own weight.

9.1.4 Tempeh

Tempeh is a traditional fermented food from Indonesia, it is made by the controlled fermentation of cooked soybeans with a Rhizopus mold. The soy beans are soaked, hulled, hacked, damped and fermented (Streinkraus et al., 2006). The fermentation binds the soybeans into a compact, firm white patty form. Tempeh is not fibrous like meat. It contains, amongst others, many B vitamins (Murata et al., 2006), has high protein contents and is very versatile.
The Swedish Department of Food Science has introduced tempeh based on barley and oats instead of soya but, it is not yet commercially available to any noteworthy extent (Swedish-Research-Council, 2008).

9.1.5 Meat alternatives based on sprouted soybeans

The Hungarian company Fitorex has introduced a new patented meat analogue called Yaso, based on sprouted soybeans, with a taste reminding one of peanuts (for more information, see Table 9.2). Production details have not yet been published by Fitorex.

9.1.6 Quorn

Quorn is an innovation from the English company Marlow Foods. The main ingredient is the so called Mycoprotein. This is made from a fermented fungus which is processed and textured to produce a food which can be easily mistaken for meat. Quorn products include steaks, burgers, chicken breasts as well as sliced meats and ready meals such as lasagne. Quorn is available from supermarkets in many European countries and in parts of the USA. However, Quorn is not animal-free as egg white is used as a binding ingredient.

9.1.7 Fibres from lupines

The seeds of sweet lupines can be used for vegetarian meat production, too. Meatless (a product by the Dutch company Meatless BV) is made of 100 percent vegetable fibres, made from lupine or wheat. The fibres are produced in different shapes, flavours and colours. Meatless is used for meat-substitute products as well as for developing "*hybrid products*", which are meat-products in which a large portion of the meat is replaced by Meatless. There are also other lupine based meat alternatives on the market, but these have not entered relevant market segments so far.

9.1.8 Rice based products

The US company Bahama Rice Burger produces rice burgers and sausages based on what they call "*Risofu*", a word derived from riso, the Italian word for rice, and tofu, meaning rice tofu. According to the company, it developed the product with inspiration from the Shan region of Thailand, where rice based tofu is made. Risofu mixes white, brown and wild rice to obtain as many nutrients as possible.

9.1.9 Algae

Algae could also be a potential precursor of vegetarian meat alternatives, together with cereals, rice, edible oils and thickening agents. Small manufacturers in different countries offer such products, e.g the German producer Remis Algen.

9.2 Noteworthy vegetarian meat alternative products and producers

9.2.1 *Remarkable intermediate products for the production of vegetarian meat alternatives*

Table 9.1 gives an overview of some remarkable intermediate products for the production of vegetarian meat alternatives. Customers for these products are therefore not the end consumers and the products are only precursors for the final production of edible meat alternatives.

9.2.2 *Remarkable vegetarian meat alternatives (final products for end consumers)*

Here some of the most remarkable companies and products in the field of vegetarian meat alternatives based on various techniques and food precursors are presented. Table 9.2 gives an overview of such remarkable end products, designed for direct consumption by the end consumer.

Company Name – Product Name	Country	Website	Description
Meatless BV - Meatless	NL	http://www.meatless.nl/	Vegetable hydrated fibres, made from lupine or wheat, basic material for the production of vegetable meat free products. Meatless is also used worldwide to develop hybrid products containing meat or fish and vegetable raw materials. Texture, bite and mouth-feel are similar to meat. Nutritional values of lupine based Meatless (according to Meatless BV) : • Calorific value: 70 kcal/100g • Protein: 10 % (containing all 8 resp.9 essential amino acids) • Fat: 0.3 % (75 % unsaturated) • Carbohydrates: 6,4 % • Minerals/micronutrient: Fe, Zn, …
MGP Ingredients – Wheatex	US	http://www.mgpingredients.com/01_vegetarian_applications.htm#	Textured wheat protein, for meat extension and/or vegetarian formulations, showing a low flavour profile and pronounced fibrous, structure that mimics meat. Wheatex fibres are produced using extrusion technologies. Protein contents (according to MGP): • Protein (N x 6.25): Ranging from 50 to 75 %

Company Name – Product Name	Country	Website	Description
CHS Inc.- Ultra-Soy and Imagic	US	http://www.legacyfoods.com/pdf/ultra_soy_meat_analogs.pdf	Textured vegetable proteins, various shapes and flavours of vegetarian meat analogues to extend or replace meat, and textures resembling meat. Nutritional values (according to CHS Inc.): • Protein: Ranging from 21 to 46 % • Fat: Ranging from 6 to 23 % • Dietary fibre: 9-14 %
Solae - Solae's soy protein isolates and concentrates	US	http://www.solae.com/en/Soy-Ingredients/Protein.aspx	Soy isolates and concentrates for applications with poultry, beef, pork, seafood and in meat-free systems with meat-like textures. Nutritional claims (according to Solae): • Solae claims that Solae Soy Protein Isolate reaches a PDCAAS (Protein Digestibility Corrected Amino Acid Score) of 1.00, the maximum possible value.

Company Name – Product Name	Country	Website	Description
Nexcel – NEXSOY textured soy proteins	US	http://www.nexcelfoods.com/tsp.html	Textured soy proteins in various shapes for vegetarian burgers, sausages, and hot dogs. According to Nexcel, the Nexsoy processing method is entirely mechanical and the product is free of the "*soy taste*".

Tab. 9.1: Overview of some leading products and producers of intermediate products for the production of vegetarian meat alternatives. Several products can also be used to extend meat products and reduce their meat contents.

Company Name – Product Name	Country	Website	Description
Marlow Foods Ltd – Quorn	UK	http://www.quorn.com/ http://www.mycoprotein.org/assets/ALFT_V2_2.pdf	For more information on Quorn see chapter 9.1.6. Nutritional values (according to Marlow Foods): • Calorific value: 94 kcal/100g • Protein: PDCAAS for mycoprotein is 0.91 (and due to egg albumen in Quorn pieces the PDCAAS for Quorn is 1.0). Quorn contains all essential amino acids. • Fat: 2 % (75 % of these unsaturated) • Dietary fibre: 6 %
Valsoia – Valsoia	IT	http://www.valsoia.it/moduli/catalogo/famiglia.php?codice=9	Burgers, cutlets, meatballs, and others based on soy protein and wheat protein. Nutritional values (according to Valsoia) for the various products: • Calorific value: 148-224 kcal/100g • Protein: 12-18 %, containing all essential amino acids • Carbohydrates: 3.4-16 %, • Dietary fibre: 2.5-7 % • Fat: 7-12 %, low in saturated fatty acids

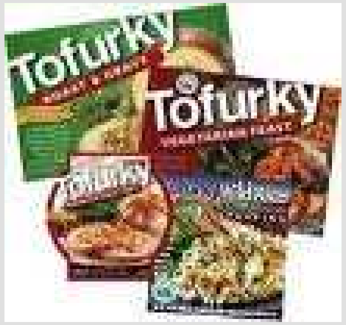
Company Name – Product Name	Country	Website	Description
Pural – Pural	FR/DE	http://www.pural.de/	Various meat alternatives, specialities are the fish sticks and bio nuggets, mainly based on wheat gluten, sunflower oil, soy flour. Nutritional values (according to Pural) for the bio nuggets: • Calorific value: 343 kcal/100g • Protein: 16.5 % • Carbohydrates: 23.5 % • Fat: 20.4 %
Fry Group Foods – Fry's	ZA	http://www.frysvegetarian.co.za/product-range/frys-special/	Wide range of vegetarian meat alternatives, based on soya protein and wheat protein. Nutritional values (according to Fry's) for the wide variety of products: • Calorific value: 123-247 kcal/100g • Protein: 11.7-20.4 %, containing all essential amino acids • Carbohydrates: 5-20 % • Dietary fibre: 1-11 % • Fat: 6-14 %, high in unsaturated fatty acids

Company Name – Product Name	Country	Website	Description
Topas – Wheaty	DE	http://www.wheaty.de/de/sortiment.html	Sausages, cold cuts, gyros, roasts, goulash and many more, based on wheat protein, sometimes in combination with tofu. Nutritional values (according to Topas) for the wide variety of products: • Calorific value: 113-316 kcal/100g • Protein: 7.8-35.2 % • Carbohydrates: 3.2-12 % • Fat: 1.2-16.8 %
Viana – Viana	DE	http://www.viana.de/en/our-products/	Bolognese, ragout, gyros, nuggets, schnitzel, cevapcici, hamburgers, steaks, sausages and many more, mainly based on tofu and wheat protein. Viana also distributes pure tofu, tempeh or seitan. Nutritional values (according to Viana) for the typical products based on wheat protein and tofu: • Calorific value: 230-290 kcal/100g • Protein: 19-27 % • Carbohydrates: 3-12 % • Fat: 14-19 % (low in saturated fatty acids)

Company Name – Product Name	Country	Website	Description
Vegi-Service AG – Vegusto	CH	http://www.vegi-service.ch/de/shop/shop.php	Burgers, sausages, cold cuts, roasts, schnitzel and many more, based on wheat protein. Nutritional values (according to Vegi-Service) for the extensive variety of products: • Calorific value: 220-309 kcal/100g • Protein: 20.3-35.2 % • Carbohydrates: 5.3-9.4 % • Fat: 8.6-20.2 %
Sojvita - sojvita	AT	http://www.sojvita.at/	Soya products such as tofu or tempeh, smoked or non smoked and also seitan (wheat gluten) and other vegetarian meat alternatives. According to Sojvita tofu products are high in protein contents while rather low in calories (106 kcal/100g), tempeh is high in proteins, minerals and vitamins (including vitamin B12).The products have low saturated fatty acid contents.

Company Name – Product Name	Country	Website	Description
Ulmafit – Ulmafit	DE	http://www.ulmafit.de/index.php	Tofu, sausages, cold cuts, gyros, schnitzel, steaks and many more, based on 3 protein sources (tofu, wheat protein and sweet lupine protein). Nutritional values (according to Ulmafit) for the various products: • Calorific value: 164-369 kcal/100g • Protein: 17.1-41.8 % • Carbohydrates: 3.6-19.6 % • Fat: 5.3-18.4 %
Fitorex - Yaso	HU	http://www.yaso.hu/what-a-yaso http://www.yaso.hu/composition	New patented meat analogue based on sprouted soybeans, practically stachyose and raffinose free (preventing distension), with taste similar to peanuts. Nutritional contents according to Fitorex: • Calorific value: 188 kcal/100g • Protein: 16 %, contains all essent. amino acids. • Fat: 11 % (66 % of that polyunsaturated omega-3 and omega-6) • Carbohydrates: 5 % • Dietary fibre: 13.2 % • Minerals: phosphorus, calcium, magnesium, potassium, iron, zinc. • rich in vitamins (like A, Bs, E, K)

Company Name – Product Name	Country	Website	Description
King International Pty Ltd – Kingland and Pureland	AU	http://www.kingintl.com.au/	Tofu, burgers based on soy. Nutritional contents according to King International: • Calorific value: 85-261 kcal/100g • Protein: 10-14 % • Fat: 8-10.5 % • Carbohydrates: 4-23 % • Dietary fibre: up to 4 %
Garden Protein International - Gardein	CA	http://www.gardein.com/index.php	"Chicken"-wings, -filets, -breasts and –strips, skewers and more, based on soy protein and wheat gluten. Nutritional values (according to Garden Protein Int.) for the various products: • Calorific value: 110-180 kcal/100g • Protein: 15-27 % • Fat: 2-3 % (low in saturated fatty acids) • Carbohydrates: 4-18 % • Dietary fibre: 1-2 %

Company Name – Product Name	Country	Website	Description
Linda McCartney Foods – Linda McCartney	UK	http://www.lindamccartneyfoods.co.uk	Sausages, burgers, roasts, soya mince in pies, meatballs and more based on (textured) soy protein and/or wheat protein, some products contain egg. Nutritional values (according to Linda McCartney Foods) for the various products: • Calorific value: 124-260 kcal/100g • Protein: 5.2-22.5 % • Fat: 1.7-15.9 % (low in saturated fatty acids) • Carbohydrates: 8.3-24.9 % • Dietary fibre: 1.5-5.8 %
Turtle Island Foods – Tofurky 	US	http://www.tofurky.com/index.html#	Deli slices, sausages, roasts and others, based on tofu and wheat gluten, but also tempeh products. Nutritional values (according to Turtle Island Foods) for the various products: • Calorific value: 180-270 kcal/100g • Protein: 16-29 % • Fat: 2-16 % (low in saturated fatty acids) • Carbohydrates: 8-25 % • Dietary fibre: 5-15 %

Company Name – Product Name	Country	Website	Description
Field Roast Grain Meat – Field Roast	US	http://www.fieldroast.com/products.htm	Roasts, cutlets, meatloaf, sausages and others, primarily based on wheat gluten. Nutritional values (according to Field Roast) for the various products: • Calorific value: 200-335 kcal/100g • Protein: 15-29 % • Fat: 2-20 % (low in saturated fatty acids) • Carbohydrates: 8-30 % • Dietary fibre:2-6 %
Morini Brands – Bahama Rice Burger	US	http://www.bahamariceburger.com/varieties.htm	Rice based burgers, meatballs or sausages (for more details see chapter 9.1.8). Nutritional values (according to the producer) for the various products: • Calorific value: 100-210 kcal/100g • Protein: 2.8-5.7 % • Fat: 3.5-7 % (low in saturated fatty acids, high in polyunsaturated fatty acids) • Carbohydrates: 13-29 % • Dietary fibre: 3.5-8 % • Free of the world's top 8 allergens; soy, wheat, egg, dairy, tree nuts, peanuts, fish and shell fish.

Company Name – Product Name	Country	Website	Description
AB Foods, LLC – **Match Premium Meat Alternatives**	US	http://www.matchmeats.com/aboutmatch.php	Sausages, "ground beef", "ground pork", "ground chicken", based on texturized soy protein and wheat protein. Nutritional values (according to the producer) for the various products: • Calorific value: 120-140 kcal/100g • Protein: 16-18 % • Fat: 4-5 % (very low in saturated fatty acids) • Carbohydrates: 7-9 % • Dietary fibre: 3-5 %
VegieVegie – VegieVegie Premium Meat Alternative 	TH	http://www.vegievegie.com	Thailand based producer of sausages, ham, burgers, hotdogs, "fish", bacon, nuggets, meat loafs and many more, primarily based on textured soy protein, but also to a smaller extent on wheat gluten.

Company Name – Product Name	Country	Website	Description
CK Foods - CK Foods	TW	http://english1.104web.com.tw/cetacean/front/bin/form.phtml?Nbr=645	Taiwan based producer of burgers, nuggets, “fish” and “seafood”, ham, stews, meatballs, chops and more. Products are mainly based on TVP, but also partly on whey protein or textured wheat protein. Also a producer of tofu products, some products are made from gums and mushrooms. Nutritional values (according to the producer) for the various TVP and texture wheat protein products: • Calorific value: 110-230 kcal/100g • Protein: 6.4-18 % • Fat: 8-16 % (very low in saturated fatty acids) • Carbohydrates: 3.2-14 % • Dietary fibre: 0-6 %
Hung-Yang Foods – Hung Yang 	TW	http://www.hungyang.com.tw/en/index.html	Taiwanese TVP products, some products are also based on wheat gluten, dried products, but also soy jerky and soy fibre shred. Ingredients according to Hung Yang: • Protein (dry basis): 50-60 % for the dried chunks and strips.

Company Name – Product Name	Country	Website	Description
Remis Algen – Remis Algen	DE	http://www.remis-algen.de/Produkte.html	Sausages, burgers and other products based on algae (of the Laminaria species), oils, cereals, rice and thickening agents (Xanthan). Some products contain eggs. Nutritional values (according to the producer) for the algae sausage: • Calorific value: 252 kcal/100g • Protein: 13.5 % • Fat: 18.2 % • Carbohydrates: 8.6 %

Tab. 9.2: Overview of some leading products and producers of vegetarian meat alternatives (end products for direct consumption). This is just a small selection of the products available.

9.3 Exemplary evaluation of vegetarian meat alternatives

It is not the objective of the following evaluations to rank various meat alternatives against each other. And in any case, companies do not generally hand out accurate recipes, making such a ranking unachievable. The real objective of this chapter is to demonstrate application of the principles and methods presented in the chapters 6 and 8 on two representative examples, and to show exemplarily the typical strengths and weaknesses of today's existing vegetarian meat alternatives.

Although detailed recipes of products are not publicly available, the German company Topas has given the permission to do ethical and economical evaluations on two typical virtual Topas products, with compositions which are representative averages for their product range: We will call the representative wheat protein product artefact "*Topas Statistical Wheaty*", and the representative tofu product artefact "*Topas Statistical Tofy*".

9.3.1 Ethical evaluation on the example of "Topas Stat. Wheaty" and "Topas Stat. Tofy"

"*Topas Stat. Wheaty*" contains the ingredients with the according percentages and origins as shown in Table 9.3. The 50 percent water in the product is excluded from the calculations, thus the other ingredients are multiplied by a factor of 2 to make up a sum of 100 percent. The analogous data for "*Topas Stat. Tofy*" is shown in Table 9.4.

Ingredients	Percentage*	Origin
Wheat protein (dry)	60	Mainly Germany, partly Italy (organic farming)
Sunflower oil	24	Italy and Hungary (organic farming)
Coconut oil (only smaller amounts in some products)	2	Organic farming
Hydrocolloids (Agar Agar, locust bean gum, guar gum)	2*	Locust bean gum and guar gum from organic farming
Onions	4*	Organic farming
Spices (Paprika, …)	4*	Organic farming
Salt	2*	
Yeast extract	2*	

Tab. 9.3: Ingredients of an average wheat based meat alternative from the German company Topas (we will call this statistical artefact "*Topas Statistical Wheaty*"), information according to CEO Klaus Gaiser (information per e-mail from 24.01.2011). The percentages of the minor ingredients with an asterisk had to be estimated.

Ingredients	Percentage*	Origin
Tofu	90	Austrian soybeans (organic farming)
Hydrocolloids (Agar Agar, locust bean gum, guar gum)	2*	Locust bean gum and guar gum from organic farming
Onions	2*	Organic farming
Spices (Paprika, …)	2*	Organic farming
Salt	2*	
Yeast extract	2*	

Tab. 9.4: Ingredients of an average tofu based meat alternative from the German company Topas (we will call this statistical artefact "*Topas Statistical Tofy*"), information according to CEO Klaus Gaiser (information per e-mail from 24.01.2011). The percentages of the minor ingredients with an asterisk had to be estimated.

Applying the ethical evaluation model as established in chapter 6.2, Table 9.5 shows the scores for EC (ecology), AW (animal welfare), HE (health-aspects) and WH (world-hunger, world nutrition aspects). The scores for HE mainly include positive nutritional aspects (protein quality, fatty acids quality, vitamin or mineral contents and so on) as well as negative nutritional aspects (cholesterol, trans-fatty acids, …), but also hygiene risks and other health risks (animal diseases, foodborne diseases).

Ingredient	EC	AW	HE	WH	Discussion
Wheat protein	90	100	50	90	Organic farming, only small production steps required to produce wheat gluten out of wheat, giving a much more efficient calorie yield compared with animal products (feeding animals with wheat or cereals), much lower GHG-emissions and lower area and water requirements per calorie compared with animal products. Wheat protein with relative low PDCAAS values, risk of celiac disease. The PDCAAS could be improved if the wheat protein is combined with a protein from legumes e.g. soy, which could contribute deficient amino acids such as lysine.
Tofu	90	100	80	90	Organic farming, efficient and resource saving production when compared with animal protein (area requirements, GHG-emissions, water footprint, and so on). Soy protein with a maximum PDCAAS value of 1.00, soy as an allergen, isoflavones and other substances in tofu claimed both as health benefit as well as potential health risk.
Sunflower oil	90	100	50	90	Ecological and world nutrition issues similar to wheat protein or tofu. High in the essential vitamin E and low in saturated fatty acids, high in Omega-6 and low in Omega-3, thus not ideal for reaching an optimum omega-3:omega-6 ratio.
Coconut oil	30	95	30	60	Ecologically contended (e.g. rainforest destruction aspects, although less severe than palm oil; note that dairy butter as another solid fat alternative has especial high LCA carbon footprints). Positive: organic origin. Animal free product (would lead to AW score of 100), but rainforest destruction affects animal welfare (endangered habitats for various species) to some extent, but only to a small extent for organic coconut oil, thus AW of 95. High in saturated fatty acids.
Hydrocolloids (Agar Agar, locust bean gum, guar gum)	80	100	50	80	No major ecological and health related concerns.
Onions	90	100	60	90	No major ecological and health related concerns. Local organic production.

Other spices (Paprika, …)	80	100	90	90	No major ecological and health related concerns. Mostly local, organic production. Various spices with positive health effects (antioxidants, …).
Salt	80	100	20	90	Health concerns in typical Western diets with overconsumption of salt, no major ecological concerns.
Yeast extract	80	100	10	90	Used for Umami taste. Contains a high concentration of glutamic acid, a known excitotoxin. No major ecological concerns.

Tab. 9.5: Scores for each ingredient of "*Topas Stat. Wheaty*" respectively. "*Topas Stat. Tofy*" for the ethical factors EC (ecology), AW (animal welfare), HE (human health) and WH (world hunger/world nutrition), each score from 0 (worst) to 100 (best).
For the minor ingredients, the influence of their scores on the total score is small, therefore the discussion about them is kept short.

Applying the formula for the rating of an ingredient,

$$RatingIng = \sqrt[4]{EC.AW.HE.WH} \text{ (for details see chapter 6.2),}$$

to each ingredient leads to the results shown in Tables 9.6 and 9.7.

Ingredients	Result for the ingredient	Result x Percentage/100 in Product
Wheat protein	79.8	47.88
Sunflower oil	79.8	19.15
Coconut oil	47.6	0.95
Hydrocolloids	75.2	1.50
Onions	83.5	3.34
Other spices	89.7	3.59
Salt	61.6	1.23
Yeast extract	51.8	1.04
OVERALL RESULT		**78.68**

Tab. 9.6: Total scores for "*Topas Stat. Wheaty*" for each ingredient using the formula in chapter 6.2 on the data from Table 9.5.
In the right column the result is multiplied with the percentage of the ingredient in "*Topas Stat. Wheaty*" (see Table 9.3). The overall result for the ethical evaluation is therefore 78.68 out of 100.

Ingredients	Result for the ingredient	Result x Percentage/100 in Product
Tofu	89.7	80.73
Hydrocolloids	75.2	1.50
Onions	83.5	1.67
Other spices	89.7	1.79
Salt	61.6	1.23
Yeast extract	51.8	1.04
OVERALL RESULT		**87.96**

Tab. 9.7: Total scores for "*Topas Stat. Tofy*" for each ingredient using the formula in chapter 6.2 on the data from Table 9.5.
In the right column the result is multiplied with the percentage of the ingredient in "*Topas Stat. Tofy*" (see Table 9.4). The overall result for the ethical evaluation is therefore 87.96 out of 100.

Ingredients	Category	Reason
Wheat protein	Good	Good = "*Each of the 4 criteria with a score >= 40, and 2 of these criteria with a score >=60*".
Tofu	Excellent	Excellent = "*Each of the 4 criteria with a score >= 60, and 2 of these criteria with a score >= 80*".
Sunflower oil	Good	See above, wheat protein.
Coconut oil	Acceptable	Acceptable = "*Each of the 4 criteria with a score >= 25, and 2 of these criteria with a score >= 50*".
Hydrocolloids	Good	See above, wheat protein.
Onions	Excellent	See above, tofu
Other spices	Excellent	See above, tofu.
Salt	Poor	Poor = "*Each of the 4 criteria with a score >= 10, and 2 of these criteria with a score >= 30*"
Yeast extract	Poor	See above, salt.

Tab. 9.8: Categorical evaluation for each ingredient of "*Topas Stat. Wheaty*" respectively "*Topas Stat. Tofy*", based on the results in Table 9.5 using the schema as presented in chapter 6.3.

Finally, the total result can be calculated using the formula

$$TotalEvaluation = \sum_{I=1}^{N} \frac{RatingIngI.PercentI}{100}$$ (for details see chapter 6.2).

This leads to an overall scoring result for "*Topas Stat. Wheaty*" of 78.7 out of 100 and for "*Topas Stat. Tofy*" of almost 88 out of 100.

Using the alternative categorical evaluation model as described in chapter 6.3, the evaluation categories for each ingredient are shown in Table 9.8.

Final ethical categorical evaluation of "*Topas Stat. Wheaty*": Using the percentage of the ingredients as presented in Table 9.3, ingredients that make up 8 percent of the total mass are rated "*excellent*", ingredients that make up 86 percent of the total mass are rated "*good*", ingredients that make up 2 percent of the total mass are rated "*acceptable*" and ingredients that make up 4 percent of the total mass are rated "*poor*". Thus the overall result for the statistical product artefact "*Topas Stat. Wheaty*" is "*good*", which is defined as "*60 percent of the ingredients rated 'good' or better and 80 percent of the ingredients rated 'acceptable' or better and all ingredients rated 'poor' or better*" (see chapter 6.3).

Final ethical categorical evaluation of "*Topas Stat. Tofy*":
Referring to the percentage of the ingredients as shown in Table 9.4, ingredients that make up 94 percent of the total mass are rated "*excellent*", ingredients that make up 2 percent of the total mass are rated "*good*" and ingredients that make up 4 percent of the total mass are rated "*poor*". Therefore, "*Topas Stat. Tofy*" scores with an overall rating of "*good*" and misses "*excellent*" only due to the minor ingredients salt and yeast extract, which are rated "*poor*"

because of health issues. This shows that the categorical approach in chapter 6.3 is rather strictly defined, and the scaling of the model is thus debatable.

9.3.2 Economical evaluation on the example of "Topas Stat. Wheaty" and "Topas Stat. Tofy"

Leading on from the ethical evaluation in the last subchapter, the following section shows an economical evaluation of "*Topas Stat. Wheaty*" and "*Topas Stat. Tofy*".

Applying the formula presented in chapter 8.2,

$$\text{RatingProduct} = \frac{\sqrt{(MA + HE + SLH + PR).FS}}{\sqrt{24}}.100$$

with MA = marketing-aspects (scores ranging from 0 to 2), HE = health aspects (scores 0 to 2), SLH = shelf-life and hygiene-aspects (scores 0 to 1), PR = price (scores 0 to 3) and FS = flavour and sensory attributes (scores 0 to 3), the evaluation of "*Topas Stat. Wheaty*" and "*Topas Stat. Tofy*" leads to results as shown in Table 9.9.

Criter.	Score	Reason
MA	0.5 (25 %)	The target group of the products is too strongly focussed on vegetarians and not open to a wider audience, Topas products are only available in organic food stores, and not in normal supermarkets or discount stores. Therefore, Topas cannot reach a wider audience. And even in the organic food markets, the products are placed side by side with other vegetarian meat alternatives, and not with meat, thus giving another reason why typical meat eaters are unlikely to “stumble upon” them easily. There is no advertising for Topas products in mass media, and thus, they are widely unknown outside the vegetarian sector. The same applies to most other vegetarian meat alternatives currently on the market in central Europe. Looking on the bright marketing side, Topas products fulfil the wishes of consumers that meat alternatives should be brown, soft, smooth, crispy, spicy and meat-like. A further positive point is that Topas products are never labelled “*meat substitute*”, which would make them appear as a plagiarism of real meat instead of being a self-contained, self confident product. But, in summing up, the products are de facto invisible for the meat eating majority of consumers and their marketing is not designed to compete with meat from animals, which gives the products in the context of this dissertation a rather bad score of 0.5 out of 2 (or 25 %).
HE	1.0 (50 %) resp.1.5 (77 %)	The discussion and evaluation has already been done for the ethical evaluation in the subchapter 9.3.1. “*Topas Stat. Wheaty*” has an average mass weighted HE score (percentage of ingredients from Table 9.3, HE scores for each ingredient from Table 9.5) of 50 %. Thus the score here is 1 out of 2. “*Topas Stat. Tofy*” has a mass weighted HE score (data from Tables 9.4 and 9.5) of 77 %. Thus the score here is 1.5 out of 2.
SLH	0.9 (90 %)	No major ingredient used in Topas products is known as having hygiene risks, and shelf-life of 10 weeks is rather long compared with meat from animals. Topas scores well here with 0.9 out of 1.
PR	0.5 (17 %)	Topas products currently reach only a small target group and do not have a competitive price compared to cheap animal meat products. Cold cuts, for example, are usually sold for 2 EUR/100g. In the context of this dissertation, Topas fails to outcompete animal meat products with regard to price, thus, achieving a rather low score of 0.5 out of 3.
FS	1.5 (50 %)	This is the most subjective and debatable criterion, as texture, and even more so, aroma, taste, eating satisfaction and trigeminal perceptions are not easily verifiable. A possible solution to evaluate this criterion would be gestation tests. The FS criterion is the comparison of the flavour properties of Topas products and those of its counterpart within the scope of this dissertation, i.e. animal meat. A score of 1.5 out of 3 is justifiable for the flavour of a product that is very popular and highly regarded, at least among vegetarians (and thus, already available in about 20 countries according to Topas CEO Klaus Gaiser, e-mail from 24.1.2011).
Ratin g Res.	**42.6** resp. **46.1**	Rating result of 42.6 out of 100 for “*Topas Stat. Wheaty*” Rating result of 46.1 out of 100 for “*Topas Stat. Tofy*”

Tab. 9.9: Scores for “*Topas Stat. Wheaty*” respectively “*Topas Stat. Tofy*” in: MA = marketing-aspects (scores ranging from 0 to 2), HE = health aspects (scores 0 to 2), SLH = shelf-life and hygiene-aspects (scores 0 to 1), PR = price (scores 0 to 3) and FS = flavour and sensory attributes (scores 0 to 3). The formula in chapter 8.2 is used to calculate the overall rating result of 42.6 out of 100 for “*Topas Stat. Wheaty*” and an overall rating result of 46.1 out of 100 for “*Topas Stat. Tofy*”.

Using the categorical evaluation model as described in chapter 8.3 alternatively, and using the scores from Table 9.9, the overall economical ratings for "*Topas Stat. Wheaty*" and "*Topas Stat. Tofy*" are "*acceptable*": This category and its minimum requirement of "*FS and HE with a score of >=40 (and one of the two >=50), the other criteria (MA, SLH and PR) with an average result of >= 30*" is met, whereas the conditions of the higher categories in Table 8.1 are missed.

CHAPTER 10

Replacing Egg Products

Analogous to the plant based meat alternatives in chapter 9, alternatives for egg products are presented in this chapter as one strategy of catalyzing a possible turning away from animal products towards more sustainable methods of food production. This chapter presents some different approaches to such alternatives to egg products and then goes on to show some highly remarkable products and producers and finally evaluates one of them with the evaluation models presented in chapters 6 and 8.

10.1 Various raw materials and base foods for the production of alternatives to egg products

There are not yet any serious alternatives to boiled eggs, as they are known as part of a traditional breakfast, on the market. However, the situation looks completely different with products such as egg white powder and egg yolk powder, which are used in making pasta, mayonnaise and in industrial baking. Depending on the function of these egg products in the end product as a binding agent, foaming agent, emulsifier or colouring, the alternatives contain algae derived products such as agar agar, alginates or carrageens, xanthan, locust bean gum, guar gum, exudate gums such as gum arabic or tragacanth, pectin or carboxymethyl cellulose. For foaming applications, dairy proteins or soy proteins can be alternatives. For emulsifying purposes, soy lecithin or mono- and diglycerides are commonly used. For yellow or orange colouring, beta-carotene, riboflavin, curcuma, capsanthin or xanthophylls are some of the natural alternatives besides artificial dyes, such as azo compounds.

Some egg replacers also contain animal derived ingredients, especially whey proteins. Generally, the formulations used by the various suppliers are very heterogeneous.

10.2 Remarkable products and producers of alternatives to egg products

Table 10.1 gives an overview of some products especially marketed as egg alternatives. Customers purchasing these products are typically food producers, although some products are also designed for use by the end consumer.

Company Name – Product Name	Country	Website	Description
Gum Technology – Coyote Brand	US	http://www.gumtech.com/datafiles/Egg%20Replacer%20Press%20Release.pdf	Custard egg replacers contain carrageenan and locust bean gum, dough egg replacers contain konjac and soy lecithin. Baker's egg replacers contain xanthan, guar and soy lecithin. Due to the low usage levels the company also promotes the products claiming cost savings for the end product.
Solanic (Avebe Group) -	NL	http://www.solanic.nl/Markets/Food.aspx	Solanic offers non-GMO potato proteins as egg replacers which are – according to Solanic – equal or superior to animal proteins in terms of gelation, foaming, emulsification and solubility. Solanic also claims top scores in food safety, high biological value and hypo-allergenicity. Applications are bakery products, beverages and others.

Company Name – Product Name	Country	Website	Description
Natural Products, Inc.- BLUE 100 BLUE 200	US	http://www.npisoy.com/index.php	This range of egg replacers is made of "*minimally-processed*" (full fat, only dehulled) whole soy ingredients. Other ingredients include wheat gluten, corn-syrup-solids or alginate. According to NPI, the egg replacers are formulated to duplicate the functional properties of whole powdered or liquid eggs in a variety of sweet baked products (batters and doughs), ranging from cookies to muffins and cakes.
Fayrefield – GelTec	UK	http://www.fayrefieldfoodtec.com/our-products/ingredients-for-the-food-industry/geltec.aspx	Non plant-based egg replacers based on functionally enhanced milk protein for cakes, cookies and biscuits, egg custard, pancakes, mayonnaise and other applications. Fayrefield advertises the egg replacers by emphasizing shelf life extension and cost savings besides the functional properties.

Company Name – Product Name	Country	Website	Description
Alleggra	UK/NL/ US	http://www.alleggra.com/products.html	Patented technology with formulations including soy protein, vegetable oil, egg white (in some applications, thus being "egg reducers" rather than "egg replacers"), whey protein and added vitamins (A, C, and E) depending on the application, thus formulations are not purely plant based. Alleggra offers solutions for bakeries, dressings, pasta and food service.
DMV (FrieslandCampina) - Textrion Progel 800	NL	http://dmv-international.com/textrion-progel-800highlight.html	Whey protein based product for dairy applications, cakes or dressings which can be used to replace eggs. According to DMV, it adds viscosity and texture to food applications and exceptional emulsifying properties.

Company Name – Product Name	Country	Website	Description
National Starch – Eleggance	US	http://eu.foodinnovation.com/docs/ELEGGANCE.pdf	Egg replacers based on whey protein concentrate (thus not purely plant based), potato starch and sodium stearoyl lactylate. The egg replacers can be used for cookies, cakes, muffins, baking-mixtures and are delivered in form of powder.
Ener-G	US	http://www.ener-g.com/gluten-free/egg-substitute/egg-replacer.html	Plant based egg replacer containing potato starch, tapioca starch flour, leavening (non dairy calcium lactate, calcium carbonate, citric acid), sodium carboxymethylcellulose and methylcellulose. Thus it contains mainly carbohydrates. The egg replacer is primarily for individual end customers for baking purposes, but Ener-G also sells bigger quantities for industrial applications.

Company Name – Product Name	Country	Website	Description
Orgran – No Egg	AU	http://www.orgran.com/products/174/	Plant based egg replacer containing potato starch, tapioca flour, calcium carbonate, citric acid and methylcellulose. Thus it contains mainly carbohydrates. The egg replacer is primarily for individual end customers for cakes, meringues or egg free mayonnaise.

Tab. 10.1: Overview of some leading products and producers of alternatives to egg products, primarily for the food industry, some are also available for use in private households.

10.3 Evaluating an alternative to egg products

As already discussed in chapter 9.3, it is not the goal here to rank the various egg alternatives against each other, but rather to showcase the evaluation of one of the egg replacers on the market. The particularity of egg replacers is that they are very heterogeneous in terms of the ingredients used. As result, the following calculations done with potato proteins used by the Dutch company Solanic for its egg replacers are not very representative for other egg replacer products, where various gums, starches and also dairy components are used, to name but a few. Nevertheless, the following calculations show an application of the methods presented in chapters 6 and 8. The results demonstrate that the use of potato proteins that have up to now been a byproduct of the potato starch production at Avebe (Solanic's mother company) is a very sustainable and reasonable way to produce egg replacers. Solanic offers various blends of egg replacers as shown in Figure 10.1.

Solanic brand	Target market	Applications	Benefits
dairinQ™	Food emulsions	- Ice cream, sorbet; toppings and desserts - Mayonnaise, dressings and salad sauces - Cream liqueurs	- Excellent emulsion and foaming capacity - Neutral taste - Replacement of emulsifiers, allergen proteins (milk, soy, egg)
Patissionate™	Bakery, confectionery	- Bread and pastry (gluten-free) - Aerated confections (chewables, meringues)	- Excellent foaming and thermal gelation capacity - High and stable volume, better texture - Replacement of allergen proteins
Promish™	Meat & meat-free	- Formed, emulsified and injected meat products - Vegetarian meat analogues	- Excellent binding, gelation and emulsion capacity - Replacement of milk and egg proteins, phosphates

Fig. 10.1: Various blends of potato protein products from Solanic which can be used as egg replacers. Taken from Solanic's 758003 v04_food and beverage_.pdf in November 2011.

10.3.1 Ethical evaluation of the example of Solanic potato protein based egg replacers

All Solanic products are made solely of potatoes, with protein contents of >= 90 percent, ashes <= 5 percent and moisture contents <= 8 percent according to the companies information sent by email on the 7.11.2011. Thus the ingredient list shown in Table 10.2 is very simple.

Ingredients	Percentage*	Origin
Potato protein isolate (protein >= 90 %, ashes <= 5 %, moisture content <= 8 %)	100	Netherlands, conventional farming, non-GM potatoes.

Tab. 10.2: Ingredient of Solanic potato protein based egg replacers (information per e-mail from 7.11.2011).

Applying the ethical evaluation model as established in chapter 6.2, Table 10.3 shows the scores for EC (ecology), AW (animal welfare), HE (health-aspects) and WH (world-hunger, world nutrition aspects).

Applying the formula for the rating of an ingredient,

$$RatingIng = \sqrt[4]{EC.AW.HE.WH} \text{ (for details see chapter 6.2),}$$

to the single ingredient leads to the result shown in Table 10.4.

Ingredient	EC	AW	HE	WH	Discussion
Potato protein isolate	90	100	90	90	Potato protein is much more sustainable than whey protein or egg white protein: Based on fossil energy usage, global warming, and land occupation the agri-footprint of potato protein is much smaller, according to a brochure on sustainability data (Solanic, 2011) that have been calculated by BMA (www.blonkmilieuadvies.nl) and mailed by Solanic in December 2011. According to Solanic, potato protein still is the by-product of the starch production at AVEBE, Solanic's mother company. AVEBE has been producing and selling millions of tons of potato starch for many decades. Protein was sold in coagulated, non-functional form to the animal feed industry until Solanic developed a process to isolate functional food-grade potato protein. To sum up, high scores in EC and WH are justified, at least currently. If potato proteins were increasingly used starch would gradually become the by-product and the scores would have to be adjusted downwards. In such a possible future scenario the protein contents below 10 % that are typical in potatoes would lead to an inefficient production of proteins if no useful application for the dominant starch fraction could be found. But currently, the use of potato proteins as a byproduct of potato starch production seems very efficient. The high scores for HE can be justified in the following way: Potato protein is known to have high PDCAAS values. It is low allergenic compared to what Solanic replaces (egg products, dairy proteins, and also soy proteins). The product is virtually free from saturated fatty acids, trans-fatty acids, cholesterol or such like. Hygiene risks and other health risks (animal diseases or foodborne diseases for example) are low or absent. Of course, the product lacks vitamins and other essential nutrients, but as it is not a final product but a food industry ingredient with high protein quality, this fact does not influence the HE score negatively. The AW score of 100 is justified as the product contains no animal products and potato production in the Netherlands does not affect current natural habitats of wild animals (e.g. in rainforests) in any noteworthy way.

Tab. 10.3: Scores for the single ingredient of Solanic egg replacers for the ethical factors EC (ecology), AW (animal welfare), HE (human health) and WH (world hunger/world nutrition), each score from 0 (worst) to 100 (best).

Ingredients	Result for the ingredient	Result x Percentage/100 in Product
Potato protein isolate	92.4	92.4
OVERALL RESULT		**92.4**

Tab. 10.4: Total score of Solanic egg replacers based on potato protein isolate for the sole ingredient using the formula in chapter 6.2 on the data from Table 10.4.
The overall result for the ethical evaluation is therefore 92.4 out of 100.

As Solanic only contains one ingredient, the overall evaluation equals the score of this ingredient and is thus 92.4 out of 100.

Using the alternative categorical evaluation model as described in chapter 6.3, the evaluation category for the ingredient is shown in Table 10.5.

Ingredients	Category	Reason
Potato protein isolate	Excellent	Excellent = "*Each of the 4 criteria with a score >= 60, and 2 of these criteria with a score >= 80*".

Tab. 10.5: Categorical evaluation for the ingredient of Solanic potato protein based egg replacers based on the results in Table 10.4 using the schema as presented in chapter 6.3.

The final ethical categorical evaluation of Solanic egg replacers is simple: As the products only contain one ingredient with the score "*excellent*", the evaluation is as follows: Ingredients that make up 100 percent of the total mass are rated "*excellent*", making the overall result for the product obviously also "*excellent*" (see chapter 6.3).

10.3.2 Economical evaluation of Solanic potato protein based egg replacers

After the ethical evaluation in the last subchapter, the following section shows an economical evaluation of Solanic egg replacers.

Applying the formula presented in chapter 8.2,

$$\text{RatingProduct} = \frac{\sqrt{(MA + HE + SLH + PR).FS}}{\sqrt{24}}.100$$

with MA = marketing-aspects (scores ranging from 0 to 2), HE = health aspects (scores 0 to 2), SLH = shelf-life and hygiene-aspects (scores 0 to 1), PR = price (scores 0 to 3) and FS = flavour and sensory attributes (scores 0 to 3), the evaluation of Solanic egg replacers leads to results as shown in Table 10.6.

Using the categorical evaluation model as described in chapter 8.3 alternatively, and using the scores from Table 10.6, the overall economical rating for Solanic potato protein based egg replacers is "*acceptable*": This category and its minimum requirement of "*FS and HE with a score of >=40 (and one of the two >=50), the other criteria (MA, SLH and PR) with an average result of >= 30*" is met. A "*good*" rating result would also be justifiable, as the only reason this rating is not met is that the FS-score is 50 instead of 60. This score is given rather arbitrarily due to the absence of gestation tests, however, "*good*" result could definitely be reached if such tests were to confirm the advantageous texture characteristics of the Solanic products.

Criterion	Score	Reason
MA	1.6 (80 %)	The product is designed for the food industry and not for the end consumer. Therefore it must attract the interest of food designers and marketing divisions rather than of the end consumers directly. Food designers will mostly be attracted if their production chains do not have to be changed much if Solanic products replace egg products, e.g. if usage levels and applications remain similar. For the marketing divisions the labelling is important, and here, Solanic offers some benefits: Unlike when using egg products, no allergen labelling is required when using Solanic potato proteins. The product is GM-free which is relevant especially for the European market. Clean label requirements can be met with Solanic, as the product does not require E-number labelling and can be declared as "*potato protein*", which supposedly sounds rather natural in the ingredient list for an end consumer. A rather negligible positive marketing issue is that the product is suitable for vegans, too. And improved sustainability compared to egg products or dairy products (see Table 10.4) is another smaller incentive for marketing divisions to phase in Solanic potato proteins as egg replacers into their final products. Solanic products are available worldwide, but only via Solanic directly and not via regional distributors. Overall, a high marketing score of 1.6 out of 2 is justifiable.
HE	1.8 (90 %)	The discussion and evaluation has already been done for the ethical evaluation in subchapter 10.3.1.
SLH	1.0 (100 %)	Potato protein is not known for any particular hygiene risks, and the minimum durability of 3 years, according to the product specifications of Solanic is extremely long, making an optimal score of 1 out of 1 justifiable.
PR	1.5 (50 %)	Solanic gives examples of applications showing approximate cost neutral replacements of eggs in meat analogues and confectionery products. However, the price comparisons have been done with free range egg white powder, which allows the assumption that the replacement is not yet cost neutral when compared with cheaper egg products produced by more intensive methods of egg production. On the other hand, according to Solanic cost savings can be achieved e.g. in mayonnaise and dressings when 2.5 % egg yolk is replaced by 0.8 % Solanic potato protein. Altogether, an average score of 1.5 out of 3 seems reasonable for the price score.
FS	1.5 (50 %)	As Solanic products are merely ingredients in an end product where they usually should not influence taste and aroma to any great extent, but rather the texture of the product, this criterion is hard to measure, and the FS score is the most subjective and debatable criterion generally. A possible solution to evaluate this criterion would be gestation tests, but Solanic could not provide such data and results in November 2011. Given that end products using Solanic potato proteins can compete with egg products in terms of foaming, emulsifying, gelling and binding and in addition, trying to rate rather neutrally in the absence of gestation tests, an average score of 1.5 out of 3 is used here.
Rating Result	**60.7**	The ratings listed above lead to an overall rating result of 60.7 out of 100 for Solanic potato protein based egg replacers.

Tab. 10.6: Scores for Solanic potato protein based egg replacers in: MA = marketing-aspects (scores ranging from 0 to 2), HE = health aspects (scores 0 to 2), SLH = shelf-life and hygiene-aspects (scores 0 to 1), PR = price (scores 0 to 3) and FS = flavour and sensory attributes (scores 0 to 3).
The formula in chapter 8.2 is used to calculate the overall rating result of 60.7 out of 100.

CHAPTER 11

Non-Dairy Milk Drinks: Plant Based Alternatives to Dairy Products

As for meat and egg alternatives in chapters 9 and 10, the strategy of catalyzing a possible turning away from animal products towards more sustainable foods by finding alternatives that simulate or copy the animal derived products is also applicable for dairy products. In this chapter, different approaches to vegetarian alternatives to milk and dairy products are presented, and again, examples of highly remarkable products and producers are introduced. Finally, evaluation of one of the examples with the evaluation models presented in chapters 6 and 8 is demonstrated.

The term "*milk*" in relation with "*soy milk*", "*oat milk*", "*rice milk*", "*almond milk*" or other plant based "milks" is legally and scientifically debated. Thus, especially in Europe, the term "*milk*" is commonly replaced by the term "*drink*". It can be argued that the term "*milk*" should only be used for soy based milk alternatives if enriched with the essential amino acid methionine as well as iron, zinc, calcium and vitamins (Van Winckel et al., 2011).

11.1 Various base foods for the production of alternatives to dairy products

Non-dairy milk drinks are mostly based on soy, but often almonds, coconut milk, oat or rice are used as base materials. Nowadays, a wide range of yoghurts, desserts, creams, sauces, cheeses, ice-cream and other products are often made from soya. Non-dairy cheese can also be based on tapioca or arrowroot flour for example.

It should be noted that the - especially in 2009 - fiercely debated "*cheese analogues*" are not part of this chapter: The term "*cheese analogue*" is used for cheap alternatives to dairy cheese that are increasingly used for pizza toppings or other industrial applications. These products are made from vegetable fats, emulsifiers, dairy- and/or soy-proteins, flavouring agents, salt and so on. There is no sharp distinction between "*cheese analogues*" on the one hand and non-dairy cheese alternatives, as presented in this chapter, on the other. However, a distinction could be defined in such a way that producers of non-dairy cheese alternatives presented in this chapter, focus on a certain nutritional value, and although cost-effectiveness is something desirable, it is not the major driver that it is with "*cheese analogues*" (see Bachmann (2001)).

11.2 Remarkable products and producers of alternatives to dairy products

11.2.1 *Remarkable intermediate products for the production of vegetarian meat alternatives*

Table 11.1 gives an overview of some remarkable intermediate products for the production of plant based dairy alternatives. The customers of these products are therefore not the end consumers and the products are only precursors for the final production of dairy alternatives. Genetically modified soy is a bigger issue with these intermediate products, although most companies have introduced non-GMO soy products for marketing reasons, especially for the European market.

11.2.2 *Remarkable plant based dairy alternatives (final products for end consumers)*

Here some of the most remarkable companies and products in the field of non-dairy milk products based on various techniques and food precursors are presented. Table 11.2 gives an overview of such remarkable end products, designed for direct consumption by the end consumer. At least in Europe, the products are GMO free, as EU labelling regulations together with market demands in Europe leave no loop hole for genetically modified ingredients.

Company Name – Product Name	Country	Website	Description
Solae - Suproplus 9000 and 9040	US	http://www.solae.com/en/Soy-Ingredients/Milk-Substitute.aspx or http://www.dairyreporter.com/Formulation/Soy-proteins-designed-to-replace-milk	Soy based proteins as an alternative to traditional dairy proteins for food manufacturers. Benefits according to Solae: • Cholesterol free, low in saturated fats • Lactose free • Lower costs • Functional properties in the end product like viscosity, emulsion capacity, improved texture and mouthfeel, solubility, thermostability and enhanced protein content Solae’s statement on GMO: http://www.solae.com/Soy-Solutions/Soy-Food-Quality/Identity-Preserved-Commitment.aspx

Company Name – Product Name	Country	Website	Description
ADM - Nutrisoy and others	US	http://www.adm.com/en-US/products/brands/nutrisoy/Pages/default.aspx or http://www.adm.com/en-US/products/Documents/ADM-Europe-Functional%20Soya%20Proteins.pdf	Various soya flours, textured soya flours, soya protein concentrates and isolated soya proteins made from de-fatted soya flakes. Protein contents between 46 and 90 %, fat contents typically 4 %. More details at http://www.adm.com/en-US/products/Documents/ADM-Food-Ingredients-Catalog.pdf (look for "*Nutrisoy*"). ADM's statement from the year 1999 on GMO including a slight policy shift: http://www.soygrowers.com/newsroom/releases/documents/adm-consolidated.htm

Tab. 11.1: Overview of some leading products and producers of intermediate products for the production of non-dairy milk (product) alternatives.

Company Name – Product Name	Country	Website	Description
Alpro - Alpro	BE	http://www.alprosoya.co.uk/soya-products.html	A market leader in Europe for soy based milk drinks, yoghurts, desserts, cream and more. Nutritional values (according to Alpro) for various soya milk drinks: • Calorific value: 20 kcal/100g (light products) - 75 kcal/100g (chocolate drinks) • Protein: 2 % (light) – 3.5 % • Carbohydrates / sugars: 0.1 % (light), 2-3 % (standard products), but up to 10.7 % (chocolate drinks) • Fat: 1.2 % (light), 1.7–2.2 % (others). Saturated fats 0.2–0.6 %) • Fibre: 0.5-1.0 % • Calcium and vitamins B2, B12 and D2 added to many products, in the junior products for children also B1, C, E and iron.

Company Name – Product Name	Country	Website	Description
Provamel - Provamel	BE	http://www.provamel.co.uk/soya%2Dproducts/plant%2Dbased%2Ddairy%2Dfree%2Dnaturally%2Dlow%2Dsaturated%2Dfat.htm	Mainly soy based (but also rice, almond or oat based) milk drinks, yoghurts, desserts, cream and more. Provamel products are made from certified organic soya beans. Nutritional values (according to Provamel) for the different flavoured soya yoghurts (different fruits or vanilla): • Calorific value: 72-83 kcal/100g • Protein: 3.6 % • Carbohydrates: 9.2-12.2 % (mostly sugars) • Fat: 1.9-2.2 % (0.3-0.4 % saturated fats) • Fibre: 0.9-1.2 %

Company Name – Product Name	Country	Website	Description
Mona Naturprodukte – Joya	AT	http://www.joya-soja.at/produkte/	Yoghurts, milk drinks, desserts, cream and tofu made from Austrian soy beans, but also oat and rice drinks. Nutritional values (according to Mona Naturprodukte) for the different soya drinks: • Calorific value: 42-64 kcal/100g • Protein: 2.9-4.1 % • Carbohydrates: 1-7.7 % (depending on flavours and whether sugar is added) • Fat: 1.7-2.5 % (0.3-0.4 % saturated fats) • Fibre: 0.5-0.7 % • Some products are fortified with calcium or vitamins A, B2, B6, folic acid, B12, D2 or E.

Company Name – Product Name	Country	Website	Description
Isola Bio	IT	http://www.isolabio.com/pages/standard.aspx?id=21	Non-dairy milk drinks and creams based on rice, soya, almonds, quinoa, oat, millet, spelt, barley or kamut. Nutritional values (according to Isola Bio) for the "*Delice*" rice drinks with almonds, nuts or coconut: • Calorific value: 62-88 kcal/100g • Protein: 0.2-1 % • Carbohydrates: 12.7-14.1 % • Fat: 1-2.9 % (0.3-0.8 % saturated fats) • Fibre: 0.8-0.9 %
Danone – Savia	ES	http://www.saviadanone.com/historiassavia/productos.html	Yoghurts and milk drinks based on soy. Nutritional values (according to Danone) for the yoghurts: • Calorific value: 74-83 kcal/100g • Protein: 2.8-2.9 % • Carbohydrates: 11-13.4 % • Fat: 1 % • Fortified with calcium

Company Name – Product Name	Country	Website	Description
Turtle Mountain – So Delicious and Purely Decadent	US	http://www.purelydecadent.com/products/index_products.php	Organic Coconut and soy based ice cream, yoghurts and drinks. Nutritional values (according to Turtle Mountain) for the different soy based ice creams: • Calorific value: 190-225 kcal/100g • Protein: 1-5 % • Carbohydrates: 26-43 % (incl. 2.5-5.55 fibre) • Fat: 5-8 % (1.2-2.2 % saturated fat)
Valsoia – Valsoia, Rys, Naturattiva, Yogurtal	IT	http://www.valsoia.it/	Milk drinks, desserts, ice cream, confectionery based on soy, but also on rice. Nutritional values (according to Valsoia) for the different soy based milk drinks: • Calorific value: 32-54 kcal/100g • Protein: 2.1-3.4 % • Carbohydrates: 3.3-3.5 % (malt flavoured brands up to 7 %) • Fat: 1.1-2 % • Fibre: 0.2-1.8 %

Company Name – Product Name	Country	Website	Description
Oatly – Oatly	SE	http://www.oatly.com/Our-products/	Oat based milk drinks and creams. Nutritional values (according to Oatly) for the oat based cream alternative: • Calorific value: 150 kcal/100g • Protein: 1 % • Carbohydrates: 6 % (sugar 4 %) • Fat: 13 % (3 % saturated fat) • Fibre: 0.8 %
Tofutti	US	http://www.tofutti.com/#	Non-dairy cheese alternatives (both cream cheese and cheese slices) and also cuties, frozen desserts, sour cream and many more. The products are based on isolated soy protein, tofu, soybean oil and various natural gums. Approximate nutritional values (according to Tofutti) for the cream cheeses: • Calorific value: 285 kcal/100g • Protein: 3.4 % • Carbohydrates: 30 % • Fat: 16.7 % (6.7 % saturated fat)

Company Name – Product Name	Country	Website	Description
Redwood Wholefood – Cheezly, Vegideli and others	UK	http://www.redwoodfoods.co.uk/	Cheese alternatives (“*Cheezly*”) and also non-dairy cheesecakes, desserts, fudge and others. Nutritional values (according to Redwood) for the “*Cheezly*“ range of cheese alternatives, that are mainly based on vegetable fats and oils, tofu, soya protein (or pea protein), potato starch (or rice starch) and thickeners: • Calorific value: 247-277 kcal/100g • Protein: 3.5-5.8 % • Carbohydrates: 5.6-18.4 % (sugars 0.3-1 %) • Fat: 17.5-25.4 % (10.3-16.1 % saturated fat) • Fibre: 1-1.7 %

Company Name – Product Name	Country	Website	Description
Vegusto – No Muh Chäs	CH	http://www.vegi-service.ch/en/kategorie-kaese.php	Cheese alternatives mainly based on vegetable fats and oils, potato starch, rice flour, nut butter (some also with whole nuts) yeast and thickeners. Nutritional values (according to Vegusto) for the “*No Muh*” range of cheese alternatives: • Calorific value: 249-330 kcal/100g • Protein: 4.2-7.1 % • Carbohydrates: 18-27 % • Fat: 17.7-25.2 %
Daiya – Daiya	CA	http://www.daiyafoods.com/products/index.asp	Soy free cheese alternatives mainly based on tapioca and arrowroot flours, canola oil, safflower oil, coconut oil and pea protein. Nutritional values (according to Daiya): • Calorific value: 320 kcal/100g • Protein: 3.6 % • Carbohydrates: 25 % (incl. 3.6 % fibre) • Fat: 21.4 % (7.1 % saturated fat)

Company Name – Product Name	Country	Website	Description
Sojade	FR	http://www.sojade.fr	Non-dairy yoghurts, desserts, cream and milk drinks based on soy milk. Nutritional values (according to Sojade) for the fruit yoghurts: • Calorific value: 78-85 kcal/100g • Protein: 3.7-3.9 % • Carbohydrates: 11-12.6 % (mostly sugars) • Fat: 2.1-2.5 % (0.3-0.4 % saturated fat) • Fibre: 0-1.6 % Nutritional values (according to Sojade) for the plain yoghurts: • Calorific value: 50-54 kcal/100g • Protein: 4.5-4.8 % • Carbohydrates: 2.1-2.4 % (mostly sugars) • Fat: 2.5-2.9 % (0.3-0.4 % saturated fat) • Fibre: 0-0.1 %

Tab. 11.2: Overview of some leading products and producers of plant based alternatives to dairy products (end products for direct consumption). This is just a small selection of the products available.

11.3 Evaluating some alternatives to dairy products

As already discussed in the introduction of chapter 9.3, this chapter also does not attempt to rank the various dairy alternatives against each other, and, as already mentioned, companies usually do not hand out accurate recipes. The objective of this chapter is to exemplarily apply the methods presented in chapters 6 and 8 to a representative soy milk drink example and to show the typical strengths and weaknesses of today's existing dairy alternatives.

11.3.1 Ethical evaluation on the example of "Joya Soya Drink + Calcium"

"*Joya Soya Drink + Calcium*" is a soy milk drink produced in Austria by Mona Naturprodukte GmbH (see Table 11.2). It contains ingredients with the according percentages and origins as shown in Table 11.3. 96.5 percent of the final product is a mixture of water and 7.2 percent soybeans. Three ways of dealing with the large share of water are now possible:

- Omitting the water from the calculations. This is not applied as the implicit comparison of the soy milk drink with dairy milk would require that dairy milk is also reduced to its water-free dry mass. But, as, for example, LCA results (e.g. the CO_2-balance per kg) of cow's milk are usually always applied to the milk as it is (with a water content of almost 90 percent), we do not choose this option of eliminating water totally from the calculations for "*Joya Soya + Calcium*".
- Dealing with water and soybeans separately. This means evaluating 6.95 percent soybeans and 89.55 percent water separately. The water would, in that case, obviously achieve perfect scores in the ethical

factors EC (ecology), AW (animal welfare), HE (human health) and WH (world hunger/world nutrition).

- Treating the "soymilk" portion (made of 7.2 percent soybeans and water) in the product as one ingredient with a share of 96.5 percent. This is a balanced solution, a compromise between the first two options.

Because we want to compare the results with dairy milk the last option is chosen.

Ingredients	Percentage*	Origin
Soymilk basis (water + 7.2 % soybeans)	96.5	Austria, non-GMO
Cane sugar	approx. 2.5 %	Not specified, we assume Brazil and India as they are the biggest producing countries
$CaCO_3$	approx. 0.3 %	Not specified
Gellan gum (stabiliser)	0.3 %*	Not specified
Sea salt	0.2 %*	Not specified
K_2HPO_4 (acidity regulator)	0.1 %*	Not specified
Flavour	< 0.1 %*	Not specified

Tab. 11.3: Ingredient of "*Joya Soya + Calcium*", information according to the declaration and information from the company. The percentages of the minor ingredients with an asterisk had to be estimated.

For UHT Joya soy drinks, an ecological assessment has been done by the Austrian Institute for Ecology (Meissner and Pladerer, 2009), comparing the production chains with those of UHT cow's milk with 1.5 percent fat produced in the same area (in this case, Oberwart in Austria). The soybeans used for Joya soy drinks all originate from Austria. The assessment showed for the compared production chains in terms of CO_2-equivalents a ratio of 1:5, for the cumulated energy demand a ratio of 1:3.2 (for non-regenerative fossil energies of 1:1.4), for acidification a ratio of 1:17, for eutrophication a ratio of 1:4 and for land use a ratio of 1:1.4, all in favour of the UHT Joya soy drink. The assessment has been reviewed and confirmed by various institutes and includes sensitivity analyses, which show that only the assumption of cows fed without any concentrated feed would reduce these gaps in any noteworthy way while still showing clear advantages for the soy drink in terms of the mentioned ecological measures.

Ingredient	EC	AW	HE	WH	Discussion
Soymilk basis (water + 7.2 % soybeans)	90	100	80	90	Local cultivation in a GMO-free area using non-GMO soybeans. Soya with efficient and resource saving production when compared to animal protein (area requirements, GHG-emissions, water footprint, and other measures, also see Meissner and Pladerer (2009) for more details). Soy protein has a maximum PDCAAS value of 1.00, on the other hand soy is a known allergen. Isoflavones and other substances in soybeans have been claimed both as health benefit as well as potential health risk.
Cane sugar	20	90	30	20	Joya does not specify fair trade or ecological farming for the cane sugar used. As the origin is not specified, we assume a mix of countries with Brazil and India as the most important countries of cultivation due to their leading roles in world production of cane sugar. Especially in Brazil sugarcane cultivation is known as a contributor to rainforest destruction. And the cultivation in countries with known malnourishment also justifies a poor score for cane sugar in the world hunger category. A small deduction in the animal welfare score is also justified by rainforest destruction and its impacts on the natural habitats of wild animals. Cane sugar contains only small amounts of vitamins and minerals and mainly consists of sucrose (saccharose), justifying a poor rating in terms of health.
$CaCO_3$	90	100	100	100	No major ecological, world nutrition concerns,

					no animal welfare concerns and in the dose rates used here it helps to balance the low calcium contents compared to cow's milk, justifying a maximum health score.
Gellan gum (stabiliser)	50	100	50	90	E 418 is regarded as a harmless gelling agent with no ADI limit specified. It is a dietary fibre and thus, almost indigestible. No major ecological and health related concerns are known, but also no major health benefits. But, as gellan is grown on substrates of sugars or molasses, it can be assumed that a certain input of energy and agricultural resources is required for the production. As gellan is just a minor ingredient here, thus having only evanescent influence on the final result of our calculations, the ecological is set to 50 without detailed search for LCAs or similar ecological assessments on the production chain.
Sea salt	80	100	30	100	No animal welfare or world nutrition concerns, minor ecological concerns due to energy use for the production of sea salt, rather poor health rating due to overconsumption of salt, although not severe as salt is only a minor ingredient in this product.
K_2HPO_4 (acidity regulator)	50	100	50	100	No animal welfare or world nutrition concerns. As for health, dipotassium phosphate is regarded as safe, but without known health benefits. As K_2HPO_4 is a very minor ingredient having very little influence on the final result of our calculations, the energy usage and environmental impacts of its production are not examined in detail here, and an average score 50 is used.
Flavour	50	100	50	50	It is not specified which flavours are used, but the FAQ-section on http://www.joya-soja.at states that only "*natural or nature-identical*" flavours are used. As a very minor ingredient, the scores are estimated and set to rather average values, except the animal welfare score, as the product is vegan (without any animal based products) according to Joya.

Tab. 11.4: Scores for each ingredient of "*Joya Soya + Calcium*" for the ethical factors EC (ecology), AW (animal welfare), HE (human health) and WH (world hunger/world nutrition), each score from 0 (worst) to 100 (best). For the minor ingredients, the influence of their scores on the total score is small, therefore, discussion about them is kept short.

Applying the formula for the rating of an ingredient,

$$RatingIng = \sqrt[4]{EC.AW.HE.WH}$$ (for details see chapter 6.2),

to each ingredient leads to the results shown in Table 11.5.

Ingredients	Result for the ingredient	Result x Percentage/100 in Product
Soymilk basis (water + 7.2 % soybeans)	89.7	86.58
Cane sugar	32.2	0.81
$CaCO_3$	97.4	0.29
Gellan gum (stabiliser)	68.9	0.21
Sea salt	70.0	0.14
K_2HPO_4 (acidity regulator)	70.7	0.07
Flavour	59.5	0.06
OVERALL RESULT		**88.16**

Tab. 11.5: Total scores for “*Joya Soya + Calcium*” for each ingredient using the formula in chapter 6.2 on the data from Table 11.4.
In the right hand column the result is multiplied with the percentage of the ingredient in “*Joya Soya + Calcium*” (see Table 11.3). The overall result for the ethical evaluation is therefore 88.16 out of 100.

Finally the total result can be calculated using the formula

$$TotalEvaluation = \sum_{I=1}^{N} \frac{RatingIngI.PercentI}{100}$$ (for details see chapter 6.2).

This leads to an overall scoring result for "*Joya Soya + Calcium*" of 88.16 out of 100.

Using the alternative categorical evaluation model as described in chapter 6.3, the evaluation categories for each ingredient are shown in Table 11.6.

Ingredients	Category	Reason
Soymilk basis (water + 7.2 % soybeans)	Excellent	Excellent = " *Each of the 4 criteria with a score of >= 60, and 2 of these criteria with a score >= 80*".
Cane sugar	Poor	Poor = "*Each of the 4 criteria with a score >= 10, and 2 of these criteria with a score >= 30*".
$CaCO_3$	Excellent	See above, soymilk basis.
Gellan gum (stabiliser)	Good	Good = "*Each of the 4 criteria with a score >= 40, and 2 of these criteria with a score >= 60*".
Sea salt	Acceptable	Acceptable = "*Each of the 4 criteria with a score >= 25, and 2 of these criteria with a score >= 50*".
K_2HPO_4 (acidity regulator)	Good	See above, gellan gum
Flavour	Acceptable	See above, sea salt

Tab. 11.6: Categorical evaluation for each ingredient of "*Joya Soya + Calcium*", based on the results in Table 11.4 using the schema as presented in chapter 6.3.

The overall ethical categorical evaluation of "*Joya Soya + Calcium*", using the percentage of the ingredients as presented in Table 11.3, ingredients that make up 96.8 percent of the total mass are rated "*excellent*", ingredients that make up 0.4 percent of the total mass are rated "*good*", ingredients that make up 0.3 percent of the total mass are rated "*acceptable*" and ingredients that make up 2.5 percent of the total mass are rated "*poor*". Thus, the overall result for "*Joya Soya + Calcium*" is "*good*", which is defined as "*60 percent of the ingredients rated 'good' or better and 80 percent of the ingredients rated 'acceptable' or better and all ingredients rated 'poor' or better*" (see chapter 6.3), and only the "*poor*" result for cane sugar prevents the rating as "*excellent*", which is defined as "*60 percent of the ingredients rated 'excellent' and 80 percent of the ingredients rated 'good' or better and all ingredients rated 'acceptable' or better*". This shows that the categorical approach in chapter 6.3 is rather strictly defined, and the scaling of the model is thus debatable. Nevertheless, the Joya products without added sugar reach the score "*excellent*".

11.3.2 Economical evaluation on the example of "Joya Soya + Calcium"

Leading on from the ethical evaluation in the last subchapter, here an economical evaluation of "*Joya Soya + Calcium*" is shown.

Applying the formula presented in chapter 8.2,

$$\text{RatingProduct} = \frac{\sqrt{(MA + HE + SLH + PR).FS}}{\sqrt{24}}.100$$

with MA = marketing-aspects (scores ranging from 0 to 2), HE = health aspects (scores 0 to 2), SLH = shelf-life and hygiene-aspects (scores 0 to 1), PR = price (scores 0 to 3) and FS = flavour and sensory attributes (scores 0 to 3), the evaluation of "*Joya Soya + Calcium*" leads to results as shown in Table 11.7 and a total score of 62.7 out of 100.

Criterion	Score	Reason
MA	1.5 (75 %)	Unlike other non-dairy milk alternatives, Joya is available in most supermarkets and discount stores in Austria, sometimes also "disguised" by the use of store brands. Joya does not emphasize marketing geared to a vegetarian or vegan audience thus making it open to a wider audience. This kind of marketing avoids consumers giving Joya the "cold-shoulder" because they are not forced into thinking "*I am not a vegan/vegetarian, so this product is not destined for me*". Joya obviously tries to avoid being stuck in a small market niche, which is rated positively here. In some consumer markets, the chilled Joya products can be found close to dairy products, making it possible that consumers not actively looking for soy milk drinks can "stumble upon" the products. On the other hand, the uncooled, UHT products, which have economical and ecological advantage of avoiding the cold chain, are usually located in the health foods areas in food markets, making them harder to find for people not actively searching for such health foods (although easier to find for people who do actively search for such products). Joya is not using mass media for large scale commercial advertising, but it can be perceived due to reasonably professional media work, together with the organisation "*Soja aus Österreich*" (Soya from Austria). Joya can also be noticed publicly due to cooperation with large environmental and vegetarian NGOs, and also marketing cooperation with supermarkets or discount stores succeed sporadically. Another bright marketing side of the Joya products, in this special case of "*Joya Soya + Calcium*" is that it fulfils the wishes of consumers that alternatives to cow's milk should resemble cow's milk in taste, viscosity, appearance and appliance. It is also positive that Joya products are never labelled "*milk substitute*", which would

		make them appear as a plagiarism of cow's milk instead of being a self-contained, self confident product. To sum up, the products are visible to a wider audience and not only to consumers actively searching for health foods, even though Joya obviously cannot afford massive advertising in mass media. Other channels of promoting the products are used quite successfully. Thus, the score of 1.5 out of 2 is justifiable.
HE	1.6 (78.6 %)	The discussion and evaluation has already been completed for the ethical evaluation in the subchapter 11.3.1. "*Joys Soya + Calcium*" has an average mass weighted HE score (percentage of ingredients from Table 11.3, HE scores for each ingredient from Table 11.4) of 78.6 %. Thus the score here is 1.6 out of 2.
SLH	0.9 (90 %)	No major ingredient used in Joya products is known for having hygiene risks. The shelf-life of UHT products of 1 year as well as the shelf-life of fresh products of approximately 25 days are both quite good compared to dairy products. Thus, Joya products scores well here with 0.9 out of 1.
PR	0.5 (17 %)	The standard price for 1 liter of UHT "*Joya Soya + Calcium*" on October 12th 2011 in supermarkets in Austria was EUR 1.79, which is not a competitive price compared to cheap cow's milk products. In the context of this dissertation, Joya fails to outcompete cow's milk products with regard to price, thus receiving a rather low score of 0.5 out of 3. It should be noted that the soymilk drinks from Mona Naturprodukte GmbH, if sold under certain store brands have been found at prices in the range from EUR 1.20 to 1.30 in time period October 2011, sometimes on special offer for less than one Euro (e.g. Penny Markt "*Happy Soya*" from 21.-27.7.2011 for EUR 0.99). These products would achieve a better score for the price.
FS	2.1 (70 %)	This is the most subjective and debatable criterion, as texture and viscosity, but even more so, aroma, taste, drinking satisfaction and trigeminal perceptions are not easily verifiable. A possible solution to evaluate this criterion would be gestation tests. The FS criterion is the comparison of the flavour properties of Joya soymilk dinks and those of its counterpart within the scope of this dissertation, i.e. cow's milk. A score of at least 2.1 out of 3 is justifiable for the flavour of a product that is very successful on the Austrian market and has reached the score "*good*" in the category tasting in the Austrian consumer's magazine "*Konsument*" 11/2008 (VKI, 2008)
Rating Result	**62.7**	Rating result of 62.7 out of 100 for "*Joya Soya + Calcium*"

Tab. 11.7: Scores for "*Joya Soya + Calcium*" in: MA = marketing-aspects (scores ranging from 0 to 2), HE = health aspects (scores 0 to 2), SLH = shelf-life and hygiene-aspects (scores 0 to 1), PR = price (scores 0 to 3) and FS = flavour and sensory attributes (scores 0 to 3). The formula in chapter 8.2 is used to calculate the overall rating result of 62.7 out of 100.

Using the categorical evaluation model as described in chapter 8.3 alternatively, and using the scores from Table 11.7, the overall economical rating for "*Joya Soya + Calcium*" is "*acceptable*" (see Table 8.1): This category and its minimum requirement of "*FS and HE with a score of >=40 (and one of the two >=50), the other criteria (MA, SLH and PR) with an average result of >= 30*" is met. However, the score "*good*" is so closely missed that it would be justifiable to classify "*Joya Soya + Calcium*" as "*good*": "*FS and HE with a score >= 60*" is met and "*the other criteria (MA, SLH and PR) with an average result >=45*" is met, too. Only the condition "*either FS or HE >= 80*" is extremely narrowly missed (HE=78.6).

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CHAPTER 12

Cultured meat - the status quo of "*lab grown meat*"

12.1 The visions and concepts of cultured meat (in vitro meat)

Artificial meat has been increasingly seen as a possible solution for future meat production (e.g. see Thornton (2010)). The most commonly discussed approach for artificial meat is that of in-vitro meat, which is the manufacturing of meat products through tissue-engineering technologies. Cultured meat (= in-vitro meat) could have financial, health, animal welfare and environmental advantages over traditional meat (Haagsman et al., 2009). The idea is to produce animal meat, but without using an animals. Starting cells could be taken from live animals or animal embryos and then put into a culture media where they start to proliferate and grow, independently from the animal. Theoretically, this process would be efficient enough to supply the global demand for meat (Langelaan et al., 2009). Most concepts do not involve genetic manipulation steps, which could be beneficial for consumer acceptance.

Producing cultured meat for processed meat products, such as sausages, burgers and nuggets will be easier to develop (Datar and Betti, 2010), whereas cultured meat, which should be more highly structured, such as for an in-vitro steak, is considerably more of a challenge. A steak is made of muscle tissue, in which extremely fine, long capillaries transport blood and nutrients directly to the cells. The production of engineered muscle tissue and even functional tissues and organs is e.g. summarized in Dennis (2003). It is much more difficult to reproduce such a complex structure than it is to put together the small balls of cells which grow to larger balls of cells, which in turn become in-vitro chicken nuggets.

The first significant investment into cultured meat research was made by NASA, aiming for the production of cultured animal muscle protein for long term space flights (Benjaminson et al., 2002). There are already patents on the production of cultured meat (Vein, 2004; Van Eelen, 2007).

12.2 The biggest technical challenges for cultured meat

The most important challenges to overcome in order to compete with animal derived meat in terms of taste, texture, health and economics are described in this chapter. The final goal of cultured meat is the production of edible muscle tissue of cells from the common farm animal species, such as pigs, cattle, sheep, chickens and turkeys.

12.2.1 Cell culture

In the late 1990s it was discovered that eukaryotic cell tissues can be kept alive outside the animal from which it was derived for several days in a warmed salt solution (Haagsman, Hellingwerf et al., 2009).
There is still discussion on which initial type of cells should be used for the cultured meat production. Stem cells, fully defined muscle cells or something in between, such as myoblast cells, which are a type of progenitor cell? Differentiated cells exhibit a limited proliferative capacity. Fully defined muscle cells hardly multiply at all, so they cannot be used for culturing meat in vitro. Stem cells can remain in a rather undifferentiated state for many doublings while retaining the ability to differentiate into at least one specific cell type, and they can proliferate rapidly. In our context, stem cells can furthermore be divided into embryonic, totipotent stem cells, or adult stem

cells. According to current scientific knowledge, the latter are necessary for regeneration and repair of tissues (Roelen and Lopes, 2008; Haagsman, Hellingwerf et al., 2009) and do not have an unlimited in vitro proliferation capacity.

In contrast to embryonic stem cells, adult progenitor cells have been derived from farm animal species such as cattle and pigs, whereas embryonic stem cells are only available for species such as humans, rhesus monkeys, mice and rats (Roelen and Lopes, 2008).
Some scientists also mention iPS cells (induced pluripotent stem cells) as possible starter cells for cultured meat. These are differentiated cells reprogrammed into an embryonic-like state. Safety hazards are a limiting factor in this approach (Haagsman, Hellingwerf et al., 2009)

Obstacles in the usage of stem cells for cultured meat production cover:

- Generation of stem cell lines from farm animal species,
- Stem cell proliferation without differentiation
- Efficient differentiation into muscle cells

12.2.2 Culture media for culturing stem cells

The aim is to find a medium in which the cells can grow and that is cost effective and free from animal ingredients. For stem cell culturing it is important that the cells remain undifferentiated and keep their proliferation ability.
Mouse and human embryonic stem cells often require culturing on layers of feeder cells, adult stem cells are less dependent on such feeder layers for their

proliferation. Media should contain salts and minerals, glucose, amino acids, fatty acids and vitamins. Specific attention should be paid to essential amino acids (Haagsman, Hellingwerf et al., 2009).

Sterility of the process is essential, as bacteria, fungi and yeast thrive well in these rich media, too.

12.2.3 *Differentiation media to produce muscle cells*

Unlike the media for stem cell cultivation, media for the production of muscle cells should enable an efficient differentiation of the cells specifically to muscle cells.

Because cultured meat does not have the digestive organs that a live creature has, which convert nutrients to feed the cells, the medium must be able to supply the cells directly with what they need. The main elemental composition of a living farm animal cell is carbon (C), hydrogen (H), oxygen (O), nitrogen (N), sulphur (S) and phosphorus (P) (in order of numerical contribution) and the minerals potassium (K) and magnesium (Mg), so these elements have to be provided in the media.

Media must be free of animal derived ingredients, serum from calves, for example, cannot be used with cultured meat. Currently, fetal bovine serum is used, as it contains the required growth factors for cell culturing, but, besides not being applicable for cultured meat and also too expensive, a further disadvantage is that the composition of media containing serum cannot be determined exactly.

Media for cultured meat also have to be cost effective. Extracts from plant cells, in combination with partly purified growth factors are the cheapest and most straightforward approach currently, although ingredients will not be fully chemically defined (Haagsman, Hellingwerf et al., 2009).

12.2.4 *Tissue engineering of muscle fibres / edible scaffolds, …*

Many mammalian cell types prefer to be attached to a solid surface. In order to produce three-dimensional in-vitro meat, it is necessary to have a scaffold. The ideal is an edible scaffold that would not need to be extracted from the end product (Edelman et al., 2004). As tissue engineered cultured meat will not have blood vessels, especially in the initial phase when the production of processed meat will be aspired to, only thin layers of cells (max. 1 mm) will be possible because of limited nutrient diffusion. Therefore, complex three dimensional scaffolds might provide sufficient surfaces (Haagsman, Hellingwerf et al., 2009). To simulate the stretching that muscle cells undergo as a living creature moves around there are attempts to develop a scaffold that can periodically shift its form thereby "exercising" the cells. This could be achieved by using a stimuli-sensitive scaffold made of alginate, chitosan or collagen, from non-animal sources. The scaffold would then stretch periodically in response to small changes in temperature or pH levels. The cells could also attach themselves to a membrane or tiny beads which could be layered on top of each other and connected together (Mironov et al., 2009).

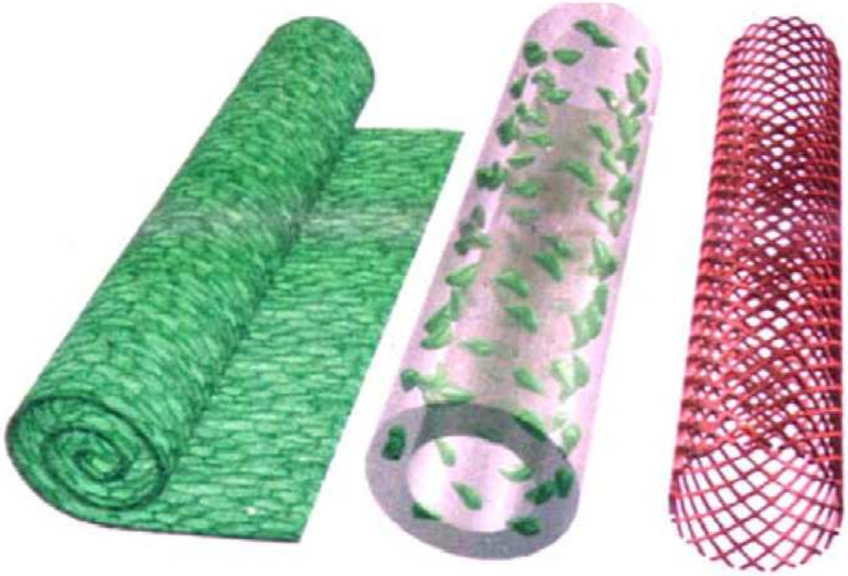

Fig. 12.1: Three of the most popular biofabrication methods in tissue engineering:
Left: Cell sheet technology—rolling a cell sheet into a tubular construct.
Middle: Embedding cells into a 3D hydrogel and molding a tubular construct.
Right: Cell seeding in a porous solid biodegradable scaffold.
Source: Mironov, Trusk et al. (2009).

12.2.5 *Large scale bioreactors*

It is in the bioreactor that everything comes together; the cells, the culture medium and the scaffold. Nutrient supply, aeration, waste removal, hygiene, cell harvest and – not to forget – process control – must be avouched by the bioreactor (Haagsman, Hellingwerf et al., 2009). Bioreactors for the production of cultured meat must be scaled up considerably from the sizes nowadays used in tissue engineering. Through fluctuations in temperature an environment is created which can be likened to a fitness centre with movement training for the muscle cells. A short overview of mechanical stimulations of different cell types grown in vitro can be found in Langelaan, Boonen et al. (2009). Besides mechanical stimulation, electromagnetic, gravitational and fluid flow fields affect the proliferation and differentiation of myoblasts (Edelman, 2005). Cultured meat must consist of small and large fibres of muscle cells in addition to connective tissue, which produces collagen and elastin as well as fat cells, which are important for the taste of the end product. Co-culturing is an issue with cultured meat: Commonly, cell cultures are grown in monoculture in vitro, but skeletal muscle of farm animals is made up from muscle cells with presence of cells forming nerves, blood vessels and others (Haagsman, Hellingwerf et al., 2009).

12.2.6 *Food processing technology*

Finally, the created myofibres and myotubes on scaffolds or microspheres will have to be processed into attractive meat products (Haagsman, Hellingwerf et al., 2009).

12.2.7 *Expert opinions: Steps and investments in cultured meat research*

Figure 12.2 shows how experts would like to conduct cultured meat research in the near and far future:

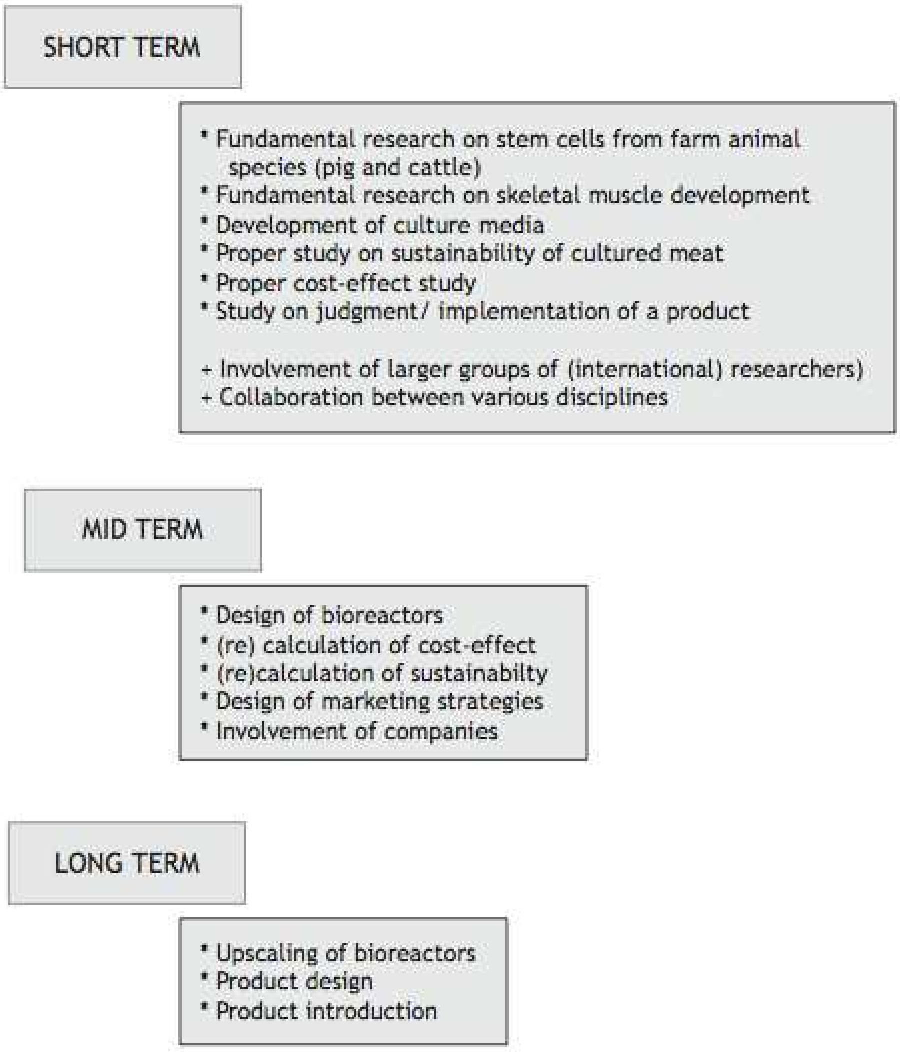

Fig. 12.2: Summary of expert opinion on how to conduct cultured meat research in the near and far future (Haagsman, Hellingwerf et al., 2009).

12.3 The Dutch research

Most of the research into cultured meat between 2000 and 2010 was done in the Netherlands and, to a smaller extent in Norway and the USA. In the Netherlands, a consortium was established in the year 2004 consisting of:

- The Faculty of Biomedical Technology at the University of Eindhoven, that is responsible for tissue engineering aspects.

- The Swammerdam Institute of Life Sciences at the University of Amsterdam, responsible for optimization for culture media for in vitro meat.
- The Faculty of Veterinary Medicine at the Utrecht University, responsible for the stem cell biology.

12.4 A few words on economics …

Economical calculations on a product that has never been produced and where most basic technical obstacles are still to be solved, is not easy, but essential when looking for funding. Thus, a preliminary economic study on cultured meat has been commissioned by the In Vitro Meat Consortium, a global board of researchers in the field of cultured meat as well as representatives of interested industrial corporations. The study concluded that in the medium term, cultured meat could be processed in large quantities for less than EUR 3300 – 3500 per tonne. This compares with the unsubsidised production of chicken meat at about EUR 1800 per tonne (eXmoor-Pharma-Concepts, 2008).

12.5 … and on naturalness

Cultured meat should replace industrialised intensive farming and poses no threat or competition to farming organic vegetables, for example. Compared to the unnaturalness of industrial animal farming, cultured meat could be seen as a progressive step in terms of health, animal welfare and ecology. A moral, ethical discussion on cultured meat can also be found in Hopkins and Dacey (2008).

Assuming cyanobacteria hydrolysate was to be used as the nutrient and energy source for muscle cell growth, an LCA has been applied to the production of cultured meat. As the process is not yet available, many uncertainties make the results worth discussing. The results showed that cultured meat production involves approximately 35-60 percent lower energy use, 80-95 percent lower GHG emissions and 98 percent less land use compared to conventionally produced meat products in Europe (Tuomisto and Teixeira de Mattos, 2010).

12.6 … and on social acceptance

The European Commission conducted a special Eurobarometer in 2005 including the question whether growing meat from cell cultures as an alternative to slaughtering farm animals would be acceptable for EU citizens. The result is shown in Figure 12.3. This survey indicates that – without huge media work or advertising efforts - cultured meat would face much scepticism and resistance, at least in Europe.

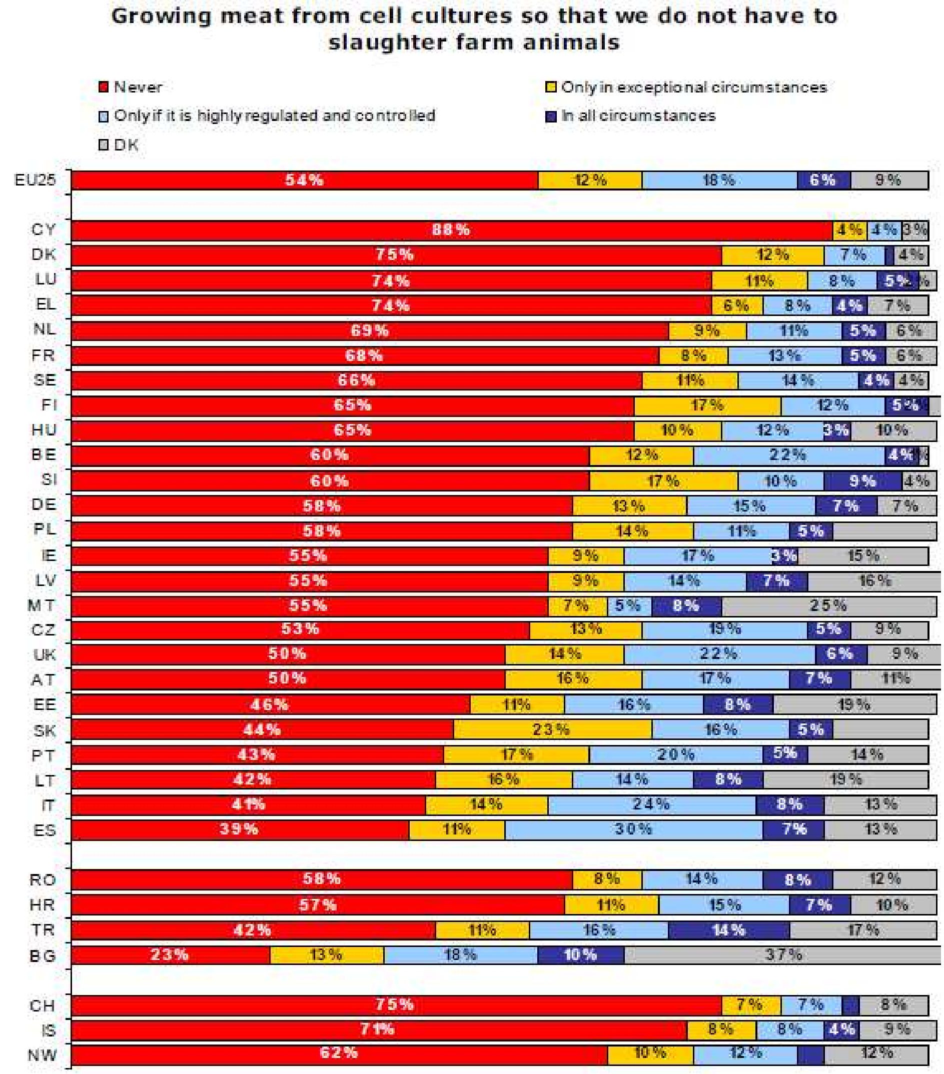

Fig. 12.3: Eurobarometer survey conducted by the European Commission in 2005. One of the questions was how receptive citizens of the EU are to the idea of cultured meat. When asked specifically to what extent they would approve of growing meat from cell cultures so that we do not have to slaughter farm animals, more than half of the respondents conveyed their opposition (European-Commission, 2005).

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CHAPTER 13

Summary/Abstract - Zusammenfassung

13.1 Summary / Abstract

This dissertation summarizes the global problems caused by livestock as well as by the production and consumption of animal products. It also presents possible global solutions and alternatives. Livestock numbers have reached dramatic dimensions with over 65 billion animals produced each year for human nutrition globally, not including sea animals – and this figure is rising. It already exceeds the number of humans on the planet almost by an order of magnitude. The implications of this mass production are manifold and serious, and can be subclassified into four main problem areas: Environment (incl. world climate), world nutrition, animal welfare (or animal rights) and human health. The loss of 80 to 90 percent of plant calories within the metabolism of livestock animals is the source of many of these problems. The majority of livestock animals have become food competitors to humans and already one third of the world's cereal harvest and 85 percent of the world's soy harvest is fed to livestock, making this form of food production the most wasteful in terms of potential human food calories. According to FAO statistics, around 754 million tons of cereals were fed to livestock in 2008, whereas the comparably "small" amount of 100 million tons of cereals were lost due to the strongly contested production of biofuels worldwide. Keeping animals on pastures without feeding them crops avoids these hitches and has advantages from a world nutrition point of view, but regarding its effect on world climate or land use, it shows very bad results. Furthermore, this pure pasture management stagnates globally, whereas the crop based livestock systems for pigs and poultry are growing rapidly and have already reached a share of 70 percent of global meat production. To sum up, livestock is the biggest land consumer on earth, contributing more to climate change than the whole traffic sector worldwide according to the UN-agriculture organisation FAO. Livestock consumes enormous amounts of water and produces large amounts of excrement and it is by far the biggest contributor to rainforest destruction in South America, to name a few examples.

The mass production of tens of billions of sentient beings and their abasement to production units leads to serious issues of animal welfare. And finally, the consumption of animal products stimulates cardiovascular diseases, some forms of cancer, diabetes and many other diseases at least in developed countries. In addition, industrial livestock units support the emergence of resistant strains of bacteria as well as new epidemics harming humans.

In this dissertation models for the ethical evaluation of foods are evolved based on the four problem areas presented above. In addition, economical success criteria for alternatives to animal products are elaborated on, such as price, taste, aroma, texture, marketing, shelf-life and health aspects. Economical evaluation models for foods are developed, based on the above criteria. The different models are presented in chapter 6 (ethical evaluations) and chapter 8 (economical evaluations).

A plant based nutrition per se offers health benefits, but can be optimized by means of breeding strategies for higher nutritional values or by means of fortification with limiting minerals, vitamins like A, D or B12, essential fatty acids (especially omega-3) or essential amino acids (for example, methionine and also threonine, tryptophan or lysine). The latter (i.e. amino acid optimization) might be regarded as an optional step, as combining various plant based proteins can compass a high PDCAAS, and there is indication

that the intakes of the different protein sources can be dispersed over a longer period of time (Young and Pellett, 1994).
A core area of this thesis is giving a global overview of vegetarian meat alternatives as well as plant based alternatives to egg products and dairy products, plus an overview of companies that already successfully produce such alternatives. The ethical and economical evaluation models in this thesis are then exemplarily applied on some of these products to detect their strengths and weaknesses und to explore the potential for improvements for future alternative products.
The outlook for and presentation of futuristic – but currently existing – approaches to solve the problems of livestock production form the remainder of this thesis. Cultured meat, cultivated in-vitro from cells in an adequate medium belongs to this category.

13.2 Zusammenfassung

Die vorliegende Dissertation beschäftigt sich mit den globalen Problemen, die durch die Tierhaltung sowie durch Produktion und Konsum von Tierprodukten entstehen und im weiteren Verlauf mit weltweit gangbaren Lösungen. Die Tierhaltung hat mittlerweile gigantische Dimensionen angenommen, und selbst ohne Berücksichtigung der Meerestiere werden jährlich weltweit für die Ernährung bereits über 65 Milliarden Tiere produziert, also fast eine Zehnerpotenz mehr als es Menschen auf der Erde gibt - Tendenz steigend. Die Auswirkungen dieser Massentierproduktion sind vielfältig und gravierend und werden im Rahmen dieser Arbeit in vier Problembereiche unterteilt: Umwelt (inkl. Weltklima), Welternährung, Tierschutz (bzw. Tierrechte) sowie menschliche Gesundheit. Der Verlust von

80 bis 90 Prozent der pflanzlichen Kalorien durch den Metabolismus der Tiere bei der Tiermast ist die Ursache vieler dieser Probleme. Der überwiegende Teil der Nutztiere wird so zum Nahrungskonkurrenten der Menschen und bereits ein Drittel der Weltgetreideernte oder 85 Prozent der Weltsojaernte werden an Masttiere verfüttert, was diese Form der Tierhaltung zum größten Verschwender an potentiellen Nahrungskalorien für den Menschen macht. Laut FAO-Statistiken wurden 2008 beispielsweise 754 Millionen Tonnen Getreide an Tiere verfüttert, während vergleichsweise "nur" rund 100 Millionen Tonnen Getreide durch den vielkritisierten Anbau von Agrartreibstoffen ("Biosprit") verloren gingen. Aber auch die reine Weidehaltung von Tieren, die aus Welternährungssicht durchaus Vorteile bietet, ist z.B. in Bezug auf die Klimabilanz oder den Flächenverbrauch sehr problematisch. Zudem stagniert genau diese Weidehaltung von Tieren weltweit, ganz im Gegensatz zur rasant steigenden Mast von Schweinen und Geflügel, die bereits 70 Prozent der Fleischproduktion weltweit ausmacht. Insgesamt ist die Tierhaltung der größte Landverbraucher der Erde, trägt laut UNO-Landwirtschaftsorganisation FAO stärker zur Klimaveränderung bei als der gesamte weltweite Verkehr, verbraucht enorme Mengen Wasser, produziert große Mengen an Gülle, oder ist der mit Abstand größte Verursacher von Regenwaldzerstörung in Südamerika, um einige Beispiele zu nennen.

Die Massenproduktion von zig Milliarden leidensfähiger Lebewesen und deren Degradierung zu Produktionseinheiten führt zudem zu gravierenden Tierschutzproblemen. Und schließlich fördert der Konsum von Tierprodukten zumindest in den entwickelten Ländern Krankheiten wie Herz-Kreislauf-Erkrankungen, manche Formen von Krebs, Diabetes und viele andere - und die Massentierhaltung selbst die Entstehung resistenter Keime sowie neuer für den Menschen gefährlicher Seuchen.

In der vorliegenden Dissertation werden Modelle entwickelt, um Lebensmittel und deren Produktion ethisch anhand der oben geschilderten vier Problembereiche evaluieren zu können. Zudem werden ökonomische Erfolgskriterien für Alternativen zu Tierprodukten ausgearbeitet, wie Preis, Geschmack, Aroma, Textur, Marketing, Gesundheitsaspekte oder Haltbarkeitsaspekte, und aus diesen Kriterien werden ökonomische Bewertungsmodelle für Lebensmittel entwickelt. Diese verschiedenen Bewertungsmodelle finden sich in Kapitel 6 (ethische Evaluierung) und Kapitel 8 (ökonomische Evaluierung).

Eine pflanzenbasierte Ernährung bietet per se viele gesundheitliche Vorteile, kann aber durch gezielte Züchtungen auf Nährstoffgehalt und durch gezielte Anreicherung mit limitierenden Mineralstoffen, Vitaminen wie A, D oder B12, sowie essentiellen Fettsäuren (speziell Omega-3-Fettsäuren) und eventuell auch Aminosäuren (beispielsweise Methionin, evtl. auch Threonin, Tryptophan und Lysin) optimiert werden.

Ein großer Schwerpunkt dieser Arbeit ist ein weltweiter Überblick über vegetarische Fleischalternativen sowie über pflanzliche Alternativen zu Milch, Milchprodukten und Eiprodukten sowie eine Übersicht über Firmen, die solche Produkte bereits erfolgreich produzieren. Die im Rahmen dieser Arbeit entwickelten ethischen und ökonomischen Bewertungsmodelle werden exemplarisch an einigen dieser Produkte angewandt, um deren Stärken und Schwächen zu erkennen und um das Verbesserungspotential für zukünftige erfolgreiche Alternativen zu Tierprodukten zu erkunden.

Schließlich kommen auch noch "futuristische" – aber real existierende - Ansätze zur Lösung der Tierhaltungsproblematik zur Sprache. Hierzu gehört z.B. die Entwicklung von in-vitro-Fleisch, das in Zukunft "im Labor" aus Zellen in Nährlösungen gezüchtet werden könnte.

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CHAPTER 14

Discussion / Future Perspectives: How Should We Eat Tomorrow? How Will We Eat Tomorrow?

14.1 Reluctance in clear scientific statements

The excessive development of livestock, i.e. the production of already more than 65 billion animals each year (excluding sea animals) has become a major threat to the environment, world nutrition, human health and animal welfare, as we have seen in chapters 2 to 5. And forecasts say that this number will exceed the 100 billion border in the next two or three decades. Still, there is no clear statement to reverse this threatening trend to be heard, regardless of the urgency of the situation. What lies behind this reluctance?

In studies, papers and reports on the huge environmental consequences of livestock production and meat consumption for instance, many authors seem to be inhibited to name a drastic reduction of the consumption of animal products as a self-evident solution. The same is true for reports on world hunger.

The fear of stating a solution which is politically or economically objectionable or simply not seen as realistic might be a key driver for this reluctance. But, also the missing interdisciplinary knowledge – climate experts for instance will usually not know which health consequences such a dietary change would have and which alternative options exist on the global market or might emerge in the near future – is arguably responsible for this reservation.

14.2 Options for future diets – Maybe purely plant based?

But what options do we have? Is a totally animal free, vegan diet as the extreme scenario in principle possible from a health point of view, at least in industrial countries?

There is an excessive supply of nutrition theories globally, which are more or less scientifically verified. Among them are those proposing a purely plant based or vegan diet. But, empirical data and scientific proof for such a diet is lacking, although, it must be said that the largest US organization of food and nutrition professionals, the American Dietetic Association (ADA) has already given the green light to a vegan diet. Compared to this, the following statement is rather moderate: A plant based vegan diet which uses well-directed fortification, specific crop fertilization, breeding enhancements for crops or fermentation processes is likely to result in the optimum nutrition from a health point of view: It would eliminate a preponderant share of pandemics, it would reduce foodborne diseases caused by bacteria and also reduce the risk of new strains of antibiotic resistant pathogens. It decreases cholesterol and saturated fat intakes, which is desirable. It also can cut down intakes of purines or arachidonic acid, which is also seen as desirable in many cases. Further common advantages of such diets include higher amounts of fibre, phytochemicals and vitamins C and E.

Empirical evidence shows that such a diet would reduce obesity, cardiovascular disease, type 2 diabetes, some forms of cancers, osteoporosis, multiple sclerosis or gallstones and that it would help to relieve symptoms of rheumatoid arthritis for example.

By means of the mentioned processing steps – i.e. well-directed fortification, breeding enhancements, fertilization or fermentation steps - the potentially lacking essential nutrients, such as vitamins as B12 or D, some minerals, possibly omega-3s such as the long-chain DHA or EPA and essential amino acids such as methionine could be added to such a diet. For all of these, animal free sources exist (i.e. extraction from plant based proteins, microbiological fermentation and chemical synthesis).

Generally, if a new form of nutrition is advocated by governments and the food industry and adopted by a large group within a society, the risk of malnutrition is likely to be much lower than if individuals follow such a special form of nutrition, as the burden of knowledge in nutritional science is taken over by experts and industries. Fortification of salt with iodine in European countries has taken the burden of worrying about eating enough of this micronutrient from individuals. Analogously, fortification of common food items with vitamin B12 would also take the burden of worrying about this vitamin from individuals, if a country's policy supported a turning away from animal products. Furthermore, an adoption of a new form of nutrition by a larger part of society would lead to a new diversity of alternatives to meat and other animal products, lower prices, improved availability and more high profile marketing. Illustratively, it would create new energy minimums for consumers with more sustainable, plant based diets in the "*Stability-/Energy-Minimum-Hypothesis*" as shown in chapter 7.2.

14.3 Grazing systems, intensive farming, plant based diets or cultured meat: What should stay, what should come, what should go?

But which kind of livestock systems could be defendable in future? From a world nutrition point of view, these are clearly those livestock systems that produce food for humans on areas where no other human food production is possible: Keeping grazing ruminants on pastures that cannot be used as croplands. The ruminants, mostly cattle or sheep are able to convert cellulose and hemi-cellulose to body mass that can be eaten as meat by humans. If no additional feed from croplands is used, this system is the only livestock system in which animals can act as "*calorie creators*" and not as a competitor with humans for food and thus, a "*calorie annihilator*" (see chapter 3). Extensive grazing systems also minimize global health risks that are associated with intensive practices, for example, antibiotic resistances. On the other hand, these extensive grazing systems require the largest total areas per unit of produced meat (although these are not croplands) and show bad results in GHG balance LCAs, and in some cases, they also drive deforestation. But, if these pastures are not located in former rainforest areas, they can on the other hand, sometimes even protect biodiversity. From an animal welfare point of view, grazing is regarded as rather animal friendly compared to the confined keeping of animals in industrial CAFOs (whereas from an animal rights point of view, any livestock system is incompatible with this concept of individual rights).

The social consequences of diet shifts on the production sector go beyond the scope of this doctoral thesis. Nevertheless, knowing that most processes in industrial intensive livestock are fully automated, the replacement of these systems with alternative methods of food production is not likely to effect employment and society more than many other changes that occur in an industrialized society. And, for the production of vegetarian meat alternatives (see chapter 9) former meat processing factories can be reused. So, only the industrial livestock facilities (which incidentally, themselves have replaced the

lion's share of farmers in industrial countries in the recent decades), animal transport and slaughterhouses would be affected.
On the other hand, the replacement of family farms with very few grazing animals in developing countries would much more likely affect the lifeblood of the population there.

In conclusion, as long as we do not have productive alternative uses for grasslands, pastures or alps to provide direct food for humans, it can be said that from all the livestock systems, extensive grazing systems are those that can most likely be justified for the future. Although, exactly the opposite kind of livestock system, the industrial CAFO system, is the one currently growing at an alarming rate on a global scale.

While drawing pictures of possible future nutrition scenarios, we should not forget possible future technologies, such as the production of in vitro cultured meat. Whether this technology will ever become relevant in food production is highly uncertain due to the huge technical and economical obstacles that are still unsolved, as well as the uncertainty regarding acceptance on the market (see chapter 12). In theory, it could be a sustainable alternative for the production of animal meat. An even more futuristic and maybe magniloquent idea, not covered in this thesis, could be finding a way to convert cellulose to edible foods for humans in huge "biofermenters" instead of using ruminants for this purpose, mimicking the potential of the digestive system of ruminants.

As we have seen, vegan diets are also possible in principle, with many benefits to be considered. Steps towards such a diet with a new variety of food alternatives and a markedly reduced consumption of animal products could accompany a total turning away from intensive and industrial livestock systems. Although this might seem unrealistic at first sight, as these systems are booming globally, such a turning away could also be driven by sudden outbreaks of pandemics, new antibiotic resistant germs, world food shortages and many other unpredictable events. The resulting freed up croplands could be used for many purposes. Possibly for growing renewable plastic alternatives to name an arbitrary example, or other materials we might need in the future, but primarily for the production of additional food for direct consumption by humans, which should always take priority.

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Employment History

2007 – current	Future Food: Setup of the new platform "*Future Food – Meat without Livestock*", www.futurefood.org
2000 – current	Scientific Games Vienna Programming, design, specifications and customer support in various projects, specialization on Oracle, PL/SQL, SQL, Java, VMS but also Pascal, J2EE, Linux, PHP, XML and others
1995 – 1999	Various NGO-projects for Vier Pfoten Hamburg, Deutsches Tierhilfswerk Munich and multiple cooperations with environmental organisations, including media-work on livestock-related issues (over 100 TV-reportages, many more printmedia-articles), setup of a monitoring system for eggs from non-caged hens in German and Austrian supermarkets, political "lobbying", …
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