The economics of meeting future protein demand

Katarzyna Markiewicz

July 2010

Author: Katarzyna Markiewicz

Registration Number: 830413-544-090

Date: April 2010-July 2010

University: Wageningen University
Business Economics

Examinator: Prof. Dr A.G.J.M Oude Lansink
Business Economics, Wageningen University

Supervisors: Dr M.P.M Meuwissen
Business Economics, Wageningen University

Course number: BEC-80424

ECTS: 24

Summary

Background

Growing global population leads to increasing demand for meat, which results in growing environmental pressure. Although the best solution for increasing problems caused by meat production would be to replace meat-derived ingredients by non-meat derived ingredients, it is likely an illusion to assume that people all over the world will convert to (or stay in) a vegetarian diet. In addition, animal production also leads to a number of benefits, like feeding animals with waste-streams, or the impact of livestock on the biodiversity of pastures and other non-arable habitats.

However, to release the pressure on the food supply, humans, as well as (production and companion) animal diets need to be changed. There are many promising prospects for future sustainable shift in protein supply chain, such as increasing efficiency of current production systems, developing meat extensions by blending meat and plant products (soy, beans, peas), shifting products in the chain to a higher value (offal, soy, grains) and using alternative sources of proteins in human nutrition (insect cells, algae). Such solutions however need to be considered with regard to their social acceptance (consumer approval), environmental sustainability, economic profitability (costs and benefits) and technological feasibility (availability of commodities and resources).

This report builds on a draft project outline of PROTEOS multidisciplinary research programme under the working title: "Innovations for the sustainable supply of protein in the future". PROTOES aims at identifying solutions towards a sustainable and economical shift in the protein supply chain, by substituting and extending future animal-derived protein sources to supply the growing world population with an adequate amount of food in a way that will be sustainable and socially acceptable.

Objectives

The objectives of this study are: (i) to review studies on dietary changes, focussing on methodology used, addressed in those studies; (ii) to design an overview of the socio-economic framework, which eventually would be involved in the shift of protein supply chain processes; (iii) to develop a scenario for the future dietary changes in the world, based on the main PROTEOS assumptions; and (iv) to form the recommendations list for the future PROTEOS project researches.

Materials and methods

In order to review the most commonly used methodologies on dietary changes studies, as well as to design an overview of the socio-economic framework grouped according to the 3-P (people, planet, profit) concept, the analysis of different modelling frameworks in a national or global context used in the literature, and their results was carried out. The main focus was on the recently published articles (from last 10-15 years), mainly because of the accuracy of the data projections. Another step was to interpret that analysis to design a scenario based on "PROTEOS" assumptions, and to create a recommendations list for the future PROTEOS project researches.

Results

In the studies on dietary changes the most commonly used methodologies are based on the following modelling frameworks: AGE (Applied General Equilibrium) models, Life Cycle Analysis (LCA) method, International Model for Policy Analysis of Agricultural Commodities and Trade: IMPACT. The most successful in this subject are the AGE models, because of their flexible structure, that allows the different issues to be included, and also that under restrictive assumptions, the analysis of the whole economy is possible. LCAs method is a perfect tool for developing efficient and sustainable production chain, because it gives an important challenge for chain management policies, and identifies the possibilities of environmental impact reduction and optimization of the system. IMPACT model results in a long-term vision and gives a consensus among researchers and policymakers about the actions necessary to feed the world in the future, decrease poverty, and to do that in a sustainable manner. There are also studies using FAO statistics, and other methodologies, like Engel curve, or material flow approach (MFA).

Different socio-economic factors found in the literature, were grouped according to triple bottom line concept (people, planet, profit) in order to capture an expanded spectrum of values and criteria for measuring possible economic, ecological and social success of future protein shift. Factors grouped under “People” were: health, consumer, food security and ethics, under “Planet”: land use, water use and gas emissions, and under “Profit”: meat demand, prices, protein supply chain, policy, livestock production, global food markets and technology development. The results showed that the main focus in the dietary changes studies, which stayed in agreement with PROTEOS objectives, was on partial transition from meat to plant-based substitutes, and the largest knowledge gap in this area is on development of successful meat replacers based on the studies of consumer preferences.

The main assumptions in this scenario are following: consumers willingness to pay for more efficient and sustainable agricultural practices is not exceeding 10% of total expenditure in the developed countries, consumers expenditure share of NPFs and extended products will increase from 2.5% to 25%, consumption increase with respect to NPFs and blended protein products is both equal to 100%, and meat consumption decrease is equal to 30%, the substitution elasticity between NPFs and blended products and meat is equal to 1.5 in the developed countries. Another assumption is the increased awareness of the consumer of all lifestyles about more efficient agricultural services provided, the awareness about the necessity of shifting products in the protein chain, and the consciousness, about the health benefits of plant-origin products consumption.

Further in this report the main recommendations for future “PROTEOS” project researches are presented. They are grouped in following categories: consumers acceptance of NPFs – the first step to success, new controversial sources of proteins, consumer concern stimulation, technological development, and the international regulatory framework. Some of the most important recommendations are to: develop the technology in a way that will make it possible to produce NPFs products as similar to those originating from animals as possible, use ad campaigns to increase consumers knowledge about vegetarianism and animal rights, make political decisions to transfer agricultural production away from meat production and promote the broadening of the selection of alternatives to meat products in stores, and place higher taxes on meat products.

Conclusions

1. Methods used in the studies on dietary changes mostly focus on the consequences of such transitions on a different aspects of economy, agriculture and environment. Missing part of

those studies is to combine those aspects with growing consumer concerns and developing technology knowledge, in order to adjust the models used into all the important parameters.

2. From the various 3-P aspects, mostly the environmental concerns are addressed, because of the increasing need for sustainable food production. Everything begins with the natural resources capacity of our planet, and the most important issues in that area is how to feed the growing population without further decreasing the environmental potential. Missing issue for further researches is to solve the problem of meat, being perceived as a high social status item. As long as situation like that continues, with increasing incomes, all over the world meat consumption will constantly increase. It is very important to realize that “People” factors in the shift of protein supply considerations are the most important one, because everything starts and begins with ones willingness to change their dietary habits. Successful substitution of NPFs for meat will decrease meat demand, change the relative prices of meat and NPFs and thus consumer food expenditures. It is also important to remember that the opportunities to create a new products, not treated only as substitutes of meat require innovation process beforehand, that will be based on three lines: cultural, structural and technological. As an overall effect of successful transition, the meat demand might decrease significantly, which will also decrease the demand for cereals for animal feed and release the big amount of grains for human food.

3. Likely key elements of a future PROTEOS scenario should address decreased meat consumption. Important economic aspects in that subject is for governments to strongly increase their investment in meat alternatives research for raising yields while reducing emissions to the environment, accompanied by a product-specific governmental policy scheme and/or policy measures designed to diminish the negative environmental effects of meat production. The significance of researches is especially important considering new sources of proteins that could contribute significantly in the global food security growth. Some of them are quite controversial in many parts of the world (like insects consumption in the Western world), but the key to success is to get to know your customers and their needs, to adjust the products to the demand.

4. Successful protein transition can be realized only if it is based on a combination of linkages that will satisfy a whole set of constraints: crop choice, envisioned use of by-products, consequences for other natural resources, food-related issues conceived by key stakeholders in the market, issues put forward by governmental and non-governmental policymakers and contours of an evolving “global food economy”. Some studies showed that combining sustainable production of protein and energy in one crop would simultaneously mitigate agricultural resource depletion, agricultural pollution, as well as climate change, and that might be the right direction for further researches in the future.

Contents

1 Introduction

1.1 Background

More than half century ago Roberts (1951) said that “within a century or so, the world’s population will almost certainly be stabilized at something like three thousand millions, which is the utmost that the earth is likely to be able to feed”. It is happening otherwise and right now scientists are dealing with other issue: “How can we feed the world in the future?” There are two main factors which contribute to that question: the rapid growth of world population and increasing prosperity. Both of them lead to increasing global demand for protein and protein-rich agronomic raw materials. According to The World Health Organization (WHO, 2003) around 2 billion people worldwide live on a meat-based diet, compared to an estimated 4 billion who stay on a plant-based diet. In the same time, WHO reported that an estimated number of 3 billion people are undernourished, and according to the report of Pimentel and Pimentel (2003) it is the largest number ever recorded in the history.

Meat production is generally unfriendly for environment and the increasing demand for meat results in an increasing environmental pressure: declining availability of land, water and energy resources per capita, pollution caused by inappropriate pest control, reduction in biodiversity and nutrients inefficiency (Pimentel and Pimentel, 2003). Although the best solution for increasing problems caused by meat production would be to replace meat-derived ingredients by non-meat derived ingredients, it is an illusion to assume that people all over the world will convert to a vegetarian diet. We also can not forget about the benefits of animal production, like feeding the animals with waste-streams, or the impact of livestock on the biodiversity of pastures and other non-arable habitats.

To release the pressure on the food supply, humans, as well as (production and companion) animal diets need to be changed. There are many promising prospects for future sustainable supply of protein, such as improvements in agricultural practices, development and improvement of protein-rich alternatives for meat, replacing animal protein (milk, eggs) in compound products, and extending the range of protein sources (e.g. marine organisms, micro-organisms, insect cells). The overview of those meat alternatives is presented in the Figure 1 in Chapter 2. Such solutions however need to be considered with regard to their social acceptance (consumer approval), environmental sustainability, economic profitability (costs and benefits, regarding protein yield and food price) and technological feasibility (availability of commodities and resources).

In theory, for the pursuit of sustainable production and consumption of food a meat production reduction and increased consumption of plant derived proteins would be a great starting point. Aiking (2009) reported that a new equilibrium between plant products and animal products will be heavily dependent on the economic variables, such as income and relative and absolute prices of the commodities under scrutiny (meat, fish, milk, eggs, cereals and soy). Helms (2004) in her work mentioned that the socio-economic barriers of the gradual shift from animal to plant foods are the powerful vested interests in the meat production chain, and the high meat status in the food chain.

1.2 Objectives

The main idea of the sustainable development is that its structure demands that the needs of the present generation be fulfilled in such a way that future generations will also be able to meet their needs (Quist, 2008). In order to achieve this some interrelated technological, cultural, organisational and institutional changes at the socio-technical systems level (e.g. related production and consumption systems, industrial sectors, household consumption domains, geographical regions and cities) are required. Those changes are being referred to as transitions, system innovations, industrial transformations, or socio-ecological changes. Despite different names, the concept behind these phenomena is basically the same: it is the transformation from one socio-technical system towards another, more sustainable one. Transition process can take several and requires the involvement of many actors that possess relevant resources, expertise and knowledge.

This report is a draft project outline of PROTEOS multidisciplinary research programme under the working title: "Innovations for the supply of protein in the future". PROTOES aims at identifying solutions towards sustainable and economical shift in the protein supply chain, by substituting and extending future animal-derived protein sources to supply the growing world population with adequate amount of food in a way that will be sustainable and socially acceptable. The main emphasis in this subject lies on the reduction of increasing meat demand, caused by the growing human population and prosperity, which cause huge environmental pressure worldwide, by the shift in protein supply chain.

The shift in the protein supply chain assume the increasing efficiency of current production systems, developing meat extensions by blending meat and plant products (soy, beans, peas), shifting products in the chain to a higher value (offal, soy, grains) and using alternative sources of proteins in human nutrition (insect cells, in vitro, algae, microbial). Such solutions however need to be considered with regard to their social acceptance (consumer approval), environmental sustainability, economic profitability (costs and benefits, regarding protein yield and food price) and technological feasibility (availability of commodities and resources).

The objectives of this study are to:

a) Review studies on dietary changes. The focus will be on methodology used, as well as on the triple bottom line account addressed in those studies.

b) Design an overview of the socio-economic factors framework, which eventually would be involved in the shift in the protein supply chain process.

c) Develop a scenario for the future dietary changes in the world, based on the main PROTEOS assumptions.

d) Form the recommendations list for the knowledge of PROTEOS programme participants.

1.3 Outline thesis

Chapter 2 of this report gives an overview of the multidisciplinary research programmes, which were conducted in the development of sustainable protein chain in the past. It also presents the PROTEOS programme, with its objectives, mission statement and assumptions. Chapter 3 focuses on the protein supply and demand in the world description. In chapter 4 the materials and methods used to elaborate 4 objectives of this study are presented. The next chapter, chapter 5, presents the results: first the review of methodologies used in the studies on dietary changes, next the list of socio-economic factors grouped according to triple bottom line concept, overview of the scenario, designed based on the PROTEOS assumptions, and finally the recommendations list. Finally, chapter 6 presents some general conclusions.

2 The multidisciplinary PROTEOS research programme

2.1 STD and PROFETAS programmes

Developing more sustainable protein production is one of the most important aims for the future food production. One of the Millennium Objectives of the United Nations is a battle against world hunger, through ensuring affordable protein consumption per capita and increased technological development, that aim at reducing the amount of land, water and other resources used as well as preservation of biodiversity. The only way to guarantee a long-term protein supply is to reduce the use of animal-based proteins and make more sources for food and feed available in a way that will be socially responsible and acceptable for consumer.

This report is a draft project outline of PROTEOS multidisciplinary research programme under the working title: “Innovations for the supply of protein in the future”. PROTEOS is a multidisciplinary research programme which aims at identifying solutions towards sustainable and economical shift in the protein supply chain, by substituting and extending future animal-derived protein sources. In order to do that PROTEOS do not have to start from scratch, since the results of a strategic programmes on Sustainable Technology Development and PROFETAS (Protein Foods, Environment, Technology And Society) are available.

Sustainable Technology Development (STD) programme was aimed at elucidating and facilitating the technological development role towards sustainability (Weaver et al., 2000). It used the “back-casting” technique (backward reasoning) in order to recognize the sustainable alternative for societal needs (Aiking et al., 2006b). The general aim of the STD programme was a 20-fold improvement of the systems environmental performance. One of the case studies was in the domain of NPFs (Novel Protein Foods) development, which are the are modern plant-protein based food products, designed in a way that should satisfy consumers desirable flavour and texture, in order to replace meat-based ingredients in meals. Two main conclusions from that study were that by the year 2035 at least 40% of meat consumption should be replaced by NPFs in order to achieve the 20-fold reduction of environmental pressure and that instead of trying to mimic the whole meat chops with plant proteins it is important to develop NPFs, which may serve as protein-containing meal ingredients (constituent of sausages, snack, etc.).

The multidisciplinary (political, environmental, social, economic, technological, ecological, and chemical) PROFETAS (Protein Foods, Environment, Technology And Society) research programme (Profetas, 2005; Aiking, 2009), on the other hand, was launched to assist in analysing future problems related to food production and consumption (Zhu et al., 2006). Specifically, it have been analysing the protein transition from meat toward NPFs based on proteins derived from plants and how this shift could actually contribute to more sustainable system of protein supply (Aiking et al., 2006a). The overarching PROFETAS structure was based on three important hypotheses: a dietary shift from meat-derived proteins into plant-derived proteins should be more sustainable than current trends, technologically feasible, and the most important of all: socially desirable. Another important part of the PROFETAS job was to identify the forces shaping protein diets and to give some insight into the differences that exist between national diets, to what range of sustainability gains can potentially be expected and also what societal differences may have to be taken into account in the pursuit of food sustainability (de Boer, 2006).

PROFETAS identified several trends (different areas: protein, resources saving, different geographic levels: local, global, and different actors: consumer, government) that should be taken into consideration together to lead towards a successful transition of proteins. The major achievement of this programme was a conclusion that all the different actors, with their own agendas and multiform aims are in fact a part of true definition of a societal transition (Aiking et al., 2006b). One of the most interesting results of PROFETAS is that the higher level of sustainable production might be a result of combining plant production and bio-fuels, in order to mitigate agricultural resource depletion, agricultural pollution, and climate change (Aiking et al., 2006b).

2.2 PROTEOS

The main objective of PROTEOS, which is a continuation of PROFETAS programme, is to supply the growing world population with adequate amount of food in a way that will be sustainable and socially acceptable. The main emphasis in this subject lies on the increasing meat demand, caused by the growing human population and prosperity, which cause huge environmental pressure worldwide. PROTEOS will base its researches on following assumptions:

- growing meat demand worldwide creates increasing need for alternative feed protein sources as well as increasing attention to environmental sustainability (Goodland, 1997; Smil, 2002; Zhu, 2004; Duchin, 2005; Zhu and van Ierland, 2005; Aiking et al., 2006b; Risku-Norjaa and Mäenpää, 2007);

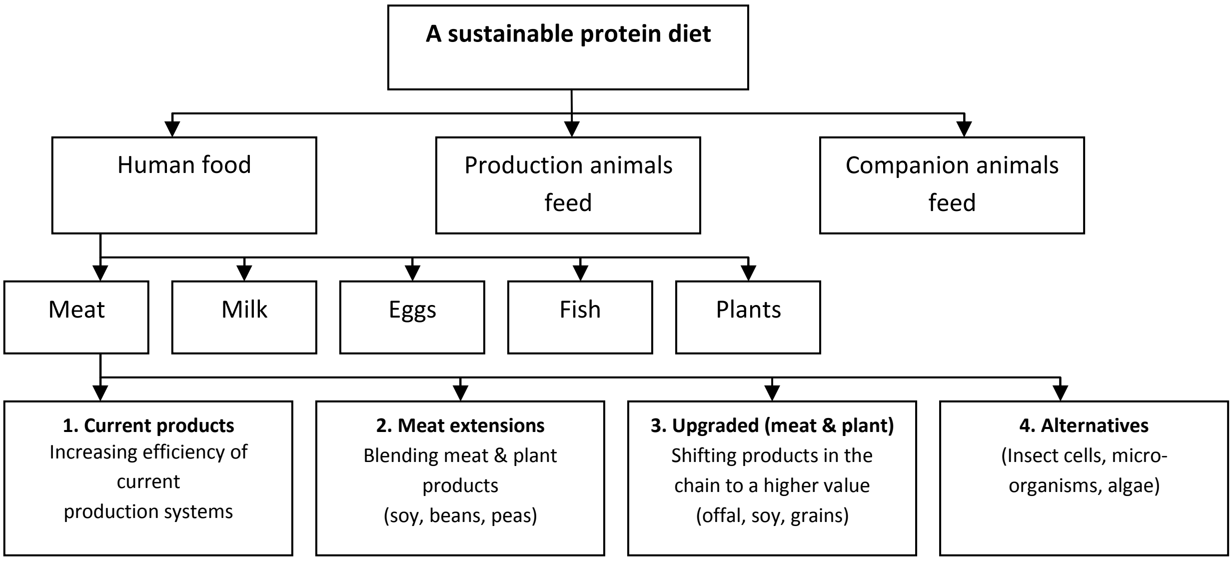
- plant-derived proteins will gain a huge importance in future human nutrition, because in order to meet future human protein demand, the shift in protein sources up the supply chain is necessary (Zhu and van Ierland, 2005; Aiking et al., 2006b; Zhu et al., 2006; Hubert et al., 2010);

- development of successful NPFs will require enhancements of sensory and textural properties, as well as high quality plant proteins that will ensure palatability of NPFs (Apaiah and Hendrix; 2005; Zhu and van Ierland, 2005; Zhu et al., 2006);

- in order to produce extended and substituted animal foods that the consumer would like to buy the socio-economic and cultural aspects must be taken into account (Aiking et al., 2006b; Zhu et al., 2006).

Figure 1 presents the prospect of sustainable protein diet regarding meat production which actually is the proposition of future solutions of PROFETAS approach in the field of human nutrition. The shift in the protein supply chain assume the increasing efficiency of current production systems, developing meat extensions by blending meat and plant products (soy, beans, peas), shifting products in the chain to a higher value (offal, soy, grains) and using alternative sources of proteins in human nutrition (insect cells, in vitro, algae, microbial). Such solutions, however, need to be considered with regard to their social acceptance (consumer approval), environmental sustainability, economic profitability (costs and benefits, regarding protein yield and food price) and technological feasibility (availability of commodities and resources).

Figure 1. A future prospect of sustainable protein diet regarding meat production.



It is PROTEOS mission statement to safeguard a sustainable protein supply by substitution and extension of animal products in efficient way, by shifting/upgrading ingredients of protein supply chain, and the most important of all: to do all that within an economically and sustainable viable boundaries, thus leading to a clear trans-disciplinary (economic, environmental, ecological, political, technological and chemical) design and evaluation of alternative protein shift options and their global impacts.

The PROFETAS aim was to make food production more sustainable through a stepwise improvement: a transition. Aiking et al. (2006b) mentioned at least four barriers to such a transition, which are also important to realise for the PROTEOS programme participants:

1) because of the high status of meat, the social forces opposing changes are strong;

2) established interests in the meat chain are powerful and that is what makes the economic forces opposing changes strong;

3) there is not enough technological knowledge about NPFs;

4) environmental gain of meat production is partially offsite by the exhaustive use of all by-products.

It is expected that during PROTEOS programme researchers will identify even more barriers to the shift in protein chain supply, and probably some of them, because of cultural, religious or ethical factors, will seem impossible to overcome. But this is the knowledge that will come with time.

The approach of PROTEOS programme will be reflected in the predominant role given to the consumer and his preferences, because that will actually be the most important during protein supply chain shift. Another important issue is to study in details the entire protein chain in order to identify which links is the weakest one, and where is the potential for successful transition located. The third approach is that PROFETAS programme will have a transdisciplinary design (political, economical, social, environmental, technological, ecological and chemical) and it will be used to evaluate the future possibilities of implementing alternative protein sources in a way that will linked all the important actors and issues.

3 Protein supply and demand in the world

3.1 Biological value of proteins and protein content of foods

Proteins play a crucial role in food supply. They are organic compounds that differ in biological value, which is calculated on the base of the presence of so called 8 essential amino acids. They are needed for human growth, and the essential amino acids can only be obtained from foods eaten (Grigg, 1995). A lack of proteins is a major cause of malnutrition in the world: currently it is over 800 million people (Alexandratos, 2009), but in the same time around 1.6 billion people are overweight (WHO, 2006).

There are significant distinctions in the protein content of foods, ranging from no proteins at all in sugar or vegetable oils, to 12% in eggs and up to 36% in dried skimmed milk. The highest content of proteins in the plants food is present in peanuts and soybeans, but they are not consumed in large quantities. The protein content of pulses (beans, peas and lentils) is higher than that of meat, fish, eggs or fresh milk, while cereals have intermediate content of proteins (Grigg, 1995). Although the differences in protein content in foods are significant, it is important to remember that malnutrition is not only caused by the lack of proteins in the diet, but also by insufficient calories intake (Aiking, 2009). Vegetarian diet can also provide the essential amino acids, but it needs to be combined in the right way: based on cereals and pulses.

One third of total protein is derived from animals, and in that group of foods meat is the most important. Animal-based food is generally richer in the protein content than plant-based food, but majority of the proteins in the world are derived from plant foods, which show that the world's diet is mostly vegetarian. So far, the most important in that group are cereals, which account for nearly half of plants food consumed globally. The second half is combined from nuts and seeds, pulses and vegetables (Grigg, 1995).

According to Gilland (2002) animal-based proteins have a closer to human physiological requirements amino-acid composition than plant-based proteins. However, it is important to remember that livestock products have a much higher fat content than plant products, and almost half of the fat content is saturated. A high intake of that fat can be detrimental to health, but the amount of harm it does has been exaggerated. Gilland (2002) reported also that animal origin foods also have higher biologically utilizable contents of minerals (Ca, P, Zi, I, Zc, and Mg), as well as vitamins (B1, B2, B6 and B12) than most plant-based products (CAST, 1999). According to him in those countries in which the average daily diet provides less than 10 g animal proteins have the highest incidence of malnourishment among children. Table 3.1 presents the global per capita supply of calories and protein from vegetable products, livestock products and marine products in 1999.

Table 3.1 Global per capita supply of calories and protein from vegetable products, livestock products and marine products in 1999.

	Protein (g/day)	**Energy (kcal/day)**
Vegetable products	47.4	2348

Livestock products	23.5	432
Marine products	4.4	28

Source: FAOSTAT, 2001.

3.2 Global protein consumption patterns

In order to analyse different ways to create more sustainable food production and consumption, it is extremely valuable to analyse how people in various countries are supplied with dietary proteins from plant- and animal-based sources (de Boer et al., 2006). According to Grigg (1995) there are four noteworthy factors, which influence the spatial variation in the quantity and source of proteins consumed in different parts of the world:

- the difference in the cost per gram of protein;
- differences in incomes;
- difference in local environmental conditions, which determine the choice of staple crops; and
- religious taboos that influence meat consumption.

In the developed world the major sources of proteins are meat and cereals, while in the developing countries, considering individual commodities, it is wheat, milk and rice, respectively. Although there are significant differences between countries with high supplies of protein provided by vegetables and cereals, both, in developed and developing countries the order of animal foods consumption is the same: meat, milk and milk products, fish and eggs.

According to WHO (2003) the protein availability increased in both developing and industrialized countries but decreased in the transition countries. The global supply of protein has been increasing, but the distribution of the increase in the protein supply is unequal. The per capita supply of vegetable protein is slightly higher in developing countries, while the supply of animal protein is three times higher in industrialized countries.

Grigg (1995) reported also great differences in global total protein consumption per capita per day, which is strictly related to income per capita, ranging from only 27 grams in Mozambique to 133 grams in Iceland. The highest protein consumption level occurs in North America, Europe, the former U.S.S.R., Australasia and Argentina, while the lowest is to be found in South Asia and tropical Africa, particularly West and Central Africa. Generally, in those parts of the world, where the incomes are high, meat and dairy products are the leading sources of proteins and this is independent of environment. It is even safe to conclude that the map of protein consumption is in fact the map of the economic development level (Grigg, 1995).

3.3 Growing meat demand and environmental pressure

In all affluent nations meat is the largest single source of animal proteins, and it holds the position of the most desirable, high-status foodstuffs in high- and low-income countries (Smil, 2002). Growing population and increasing prosperity are two main reasons for increasing meat demand in the world (CAST, 1999; Delgado, 1999). According to Evans (1998) the world population doubled during the second half of the 20^{th} century, but in the same time its appetite for meat quadrupled, and that resulted in about 40-50% of the world grain harvest is used as a livestock feed, while they could be destined for direct human consumption. According to FAO the growth in global meat consumption per capita was ranged from 27 up to 38 kg/capita/year over the 1970-2000 periods. This increase is mainly caused by growth in meat consumption in industrialised countries, like China (increase more than fivefold), Brazil and Mexico (increase by 2,5 times). It is worth to point out, that although this growth seems significant, in fact the consumption of meat in industrialised countries is still below the one in some developed countries, like The Netherlands, for example (Table 3.2). According to Smil (2002) long-term forecasts of actual meat demand are very uncertain, but even very optimistic estimates foresee during the next two generations the global consumption to increase about 50% above the current level.

Table 3.2 Meat consumption in selected countries in 2000.

Country	Consumption (kg/capita/year)
USA	122
Canada	95
Germany	90
France	100
The Netherlands	101
Brazil	68
Mexico	51
China	46
Indonesia	9

Source: FAO Food Balance Sheets (http://apps.fao.org).

Many studies (e.g. Carlsson-Kanyama, 1998; Seidl, 2000; Smil, 2000; White, 2000; Pimentel and Pimentel, 2003; Aiking, 2009) reported that an animal-based diet causes a greater environmental pressure than a crop-based diet. Environmental sustainability is calling for changes in the consumption patterns. The production of food requires large amounts of natural resources such as land, water, materials and energy and causes emissions such as greenhouse gases, pesticides, heavy metals and domestic wastes to the biosphere (Elferink et al., 2007). Nonhebel (2004) reported that currently a large part of the world's natural resources (30% of the soils, 20% of the fossil energy and a major part of the fresh water flow) is used for the food production and that amount is strictly determined by the diet of the population. More intensive animal production leads also to decrease usage of "refuse streams", from industries and households. Thus, the protein chain is a perfect starting point considering sustainable food production and consumption (Grigg, 1995; Millstone and Lang, 2003; Smil, 2000), because of the inefficient conversion: 6 kg of plant protein is required to yield 1 kg of meat protein (Brown, 1995; Gilland, 2002; Pimentel and Pimentel, 2003; Smil, 2000; Steinfeld et al., 2006).

Environmental life-cycle assessment of protein foods showed that Novel Protein Foods (NPFs) are more environmentally friendly than pork (Zhu and Van Ierland, 2004; Aiking et al, 2006a; Zhu et al., 2006), and that lead to the conclusion that through replacing animal-origin protein food with NPFs a reduction of emissions caused by animal protein production and consumption can be achieved (Zhu et al, 2006). Dornburg et al. (2008) estimated that even a partial replacement of meat in human diet could cut the world supply of meat by at least one third, and still the average protein consumption would be 20% over the RDI (recommended daily intake) and one third of our protein consumption would still come from meat. In the same time dietary changes (voluntary or through policies) could actually release cereals from livestock feed to food for poor people in developing countries and increase the world food security (Brown, 1995; Seager, 1995). It is important to realise that changes in economic variables including production, consumption, international trade and environmental variables (like emissions of CH_4, N_2O and NH_3), should accompany the introduction of NPFs and environmental policies (Zhu et al., 2006).

3.4 Alternatives for the future: Novel Protein Foods (NPFs)

NPFs are modern plant-protein based food products, which were designed in a way that should satisfy consumers' desirable flavour and texture, in order to replace meat-based ingredients in meals. They can be made of soybeans, proteins, and other protein crops – even from the grass (Linnemann and Dijkstra, 2000). The biggest advantage of plant proteins production is that it is much cheaper than animal proteins production and mostly through technology development in the production and protein extraction processes plants start to possess the properties required by the food industry.

For constantly growing number of consumers food safety and health concerns have become crucial when purchasing food products (Zhu et al., 2006), and they started to manifest themselves in the selection of diet and low-fat products. Changing attitudes towards food consumption tend to increase the demand for meat substitutes or meat alternatives (Zhu and van Ierland, 2004; Zhu et al., 2006). According to Sadler (2004) the key drivers of meat-alternative products market growth include:

- the consumer concerns over food safety, especially in relation to animal products, e.g. BSE;
- increasing number of vegetarians, meat avoiders and meat reducers;
- looking for more variety in the diet by meat eaters;
- growing interest in healthy eating which includes incorporating more plant-based foods into the diet and expectation of higher quality meat alternative products;
- the growing trend towards increased use of convenience products.

But although this looks very promising several economic arguments (Seidl, 2000; White, 2000) indicated that, due to status and cultural trends, actual practice may be not as straightforward as theory suggests. It is not possible on the global level to expect all the people to become vegetarians. In the same time, when it comes to NPFs development and acceptance one of the predominant factors that should be taken into account are consumer preferences, and right after that other relevant actors are: retailers, food processors, farmers, NGOs and policymakers from government and industry (both nationally and internationally) including GATT and its repercussions (Aiking, 2009). De Boer et al. (2006) concluded that in order to stimulate more sustainable protein diets there is an urgent need for policymakers in industry and government to address the consumer concerns properly. Apaiah and Hendrix (2005) reported that NPFs products currently available on the market are niche products that cannot be considered as the realistic alternative to meat, because they do not meet the consumers' expectations, especially when it comes to bite taste, and juiciness and comparing with meat are more expensive. More promising option seems to be a partial shift from meat-derived ingredients to NPFs, but it will only be feasible if the price of these products decreases.

3.5 Currently available meat alternatives

Although in Asian countries meat substitutes, like tofu, or tempeh, were known since many centuries, they appeared on the markets in Western countries in the beginning of 1960s (Sadler, 2004; Davies and Lightowler, 1998). In that time most of them were produced based on TVP (Texturised Vegetable Protein) or on soy protein products. At the beginning of 1990s meat substitutes started to be produced from proteins other than those from soy, like wheat gluten, for example (Vereijken et al., 2006a). Nowadays meat substitutes are also produced from extruded combinations of wheat gluten and other proteins (soy but also pea proteins), which are characterised with better fibrous texture. Other meat replacers are based on lupine proteins. Hemp seed, buckwheat, quinoa, soy, and rice are often mentioned as examples of complete vegetable proteins. In fact, only a limited number of plants are used in a process of producing meat substitutes (Aiking et al., 2006).

Different group of meat alternatives products are those which are based on fungal proteins. The era of developments with fungal proteins begin in 1960s, when scientists started to research the possibility of producing single cell protein from fungi that originally reside in the soil. The main disadvantages of producing meat replacers from micro-organisms are: resource-inefficient conversion of carbohydrates, because most of the micro-organisms cannot fix their own CO_2, and because of that they are not environmental friendly, the fact that proteins derived from plants are cheaper than those derived from micro-organisms, because of the costs of cultivation, and limited knowledge about micro-organisms primary production and protein itself (Vereijken et al., 2006a).

Another group of organisms used to produced meat replacers, that belong to the fungus kingdom are mushrooms, from which the most popular is Fusarium venenatum. One of the most popular meat substitutes made out of mycoprotein[1] is qourn. Asian food stores offer also so-called mock meats, mock seafood and mock mutton, but they are generally quite difficult to find. Some of these are based on gluten, others are soy-based. Table 3.3 presents the comparison of proteins and energy profiles of alternatives to meat with lean beef (per 100g). The total protein content of meat alternatives, except from Quorn, Tofu and Haricot beans, seems to be a good meat replacement, but the only problem is that their protein quality is not specified. Lightowler et al. (1998) reported that in

[1] Proteins derived from mushrooms.

this case it is reasonable to consume these replacers with cereals, as advocated in the "Vegan food guide", in order to enhance the protein quality.

Table 3.3 Comparison of proteins and energy profiles of alternatives to meat with beef (per 100g).

Food	Protein (g)	Energy (kcal)
Meat		
Beef – lean, raw	20.3	123
Soya beans		
Tempeh – raw	20.7	166
Textured vegetable protein – dry	51.5	257
Tofu (firm)	8.0	77
Wheat protein		
"Tivalli" – burger, raw	17.0	127
Pea protein and wheat protein		
Arrum – dry	26.0	345
Myco-protein		
Quorn – raw	11.8	86
Peanuts	25.6	557
Haricot beans (cooked)	6.6	97
Fibrous vegetable protein	28	220

Source: Adapted from Davies and Lightowler (1998) and Sadler (2004)

According to Koning et al. (2008) even better way of converting phytomass into more food offers bio-refinement. They concluded that at least one-fifth of the world's soya bean protein could be replaced by extracting proteins from residues of crops, such as cassava, N-rich fodder like alfalfa or grass from fertilized meadows.

The part of population who do not want to be reminded of meat in their everyday diet is growing on a daily basis, because of personal beliefs, but also because vegetarian diets tend to be viewed as healthy and actually the scientific studies in the vegetarian groups provide strong evidence of lower mortality and morbidity (Sadler, 2004). Therefore, the future solution for meat replacers is to develop new NPFs products and to present them as totally new and unique foods. According to Davies and Lightowler (1998) the importance of reading food labels carefully for the strict advocates of vegetarianism cannot be understated. When it comes to food manufacturers it would be well advised to veganise existing vegetarian meat alternatives.

4 Materials and methods

Chapter 4 is organized as follows: First section reviews the method of analysing different studies on dietary changes, with the focus on methodology used in the articles. The assumptions and results coming from the detailed literature overview will also constitute a base for formulating the socio-economic factors framework, which eventually would be involved in the shift of the protein supply chain process. Method for that analysis will be presented in paragraph 4.2. The third part of this chapter clarifies the way a scenario for the future dietary changes in the world, based on the main PROTEOS assumptions will be designed. Paragraph 4.4 makes clear how the recommendations list for the knowledge of PROTEOS programme participants will be formulated.

4.1 Methodology used in studies on dietary changes

In order to face the objective of presenting the most commonly used methodologies for dietary changed scenarios, based on different articles overview, the analysis of different modelling frameworks used in the national or global context will be carried out. Especially important in the light of PROTEOS assumptions are the studies focused on possibilities to shift the protein supply chain, based on NPFs development and production, and also on expected consumer behaviours (e.g. Apaiah and Hendrix, 2004; Aiking et al., 2006; Zhu and van Ierland, 2005; Zhu et al., 2006).

4.2 Formulating the list of socio-economic factors

Diets evolve over time. There are many factors which interact in a complex manner in order to shape dietary consumption patterns, like: income, prices, individual preferences and beliefs, cultural traditions, as well as geographical, environmental, social and economic factors (WHO, 2003). A key to protein shift in diets is a development of meat replacement products that will substitute meat in a sustainable matter. In order to complete that transition in a satisfactory and successful way a whole package of socio-economic options need to be taken into account. It will be possible only based on a combination of a whole set of linkages. In a free market economy any dietary choice has a consequence for food producers, but there are many more actors which have to be considered in before and after any food transition process.

In order to formulate the list of socio-economic factors, which will be directly involved in the protein supply chain shifting process, the detailed literature review will be carried out, based mainly on the studies focused on dietary changes and their implications, as well as reports on global food outlooks, trends, alternatives and choices (e.g. Rosegrant et al., 2001; Bruinsma, 2003; WHO, 2003; FAO, 2006).

4.3 Scenario design

According to Duchin (2005) a role of a scenario is to be a hypothesis that will be tested with the model. In this study the focus is on the review of the dietary scenarios in order to formulate the scenario that will be based on the PROTEOS assumptions. The hypothesis lying behind the "PROTEOS" scenario is the following: If the meat consumption, which is favoured by increasing amount of the population would be partially replaced by meat alternatives, and meat extensions, with the current production systems made more efficient and with shifting the products in the protein chain to a higher value, it would be possible to feed a growing world population in a sustainable manner. Although many studies concentrated on the dietary changes and their implications in the past, the scenario adequate to the PROTEOS assumptions has barely begun to be explored.

A detailed analysis of the studies was performed in order to provide an insight into the different methodologies used by researchers to test the dietary scenarios and formulate conclusions about the possible future implications. The analysis of those articles as well as reports on global food outlooks, trends, alternatives and choices were used in this study in order to formulate the "PROTEOS" scenario.

By contrast, a „BAU" ("business as usual") scenario will represent a situation where no lifestyle changes and no restrictions on animal diets are included. It gives an overview of current patterns of production and consumption, which means continuing Livestock Revolution, so increasing meat consumption in developing countries, as well as high satiation level of meat consumption in developed countries combined with a low preference for the meat alternatives and extended meat products, lack of consumer knowledge in the sustainability subject, as well as possibility of shifting products in the protein to a higher value.

4.4 Recommendations list for the PROTEOS programme

In order to formulate the recommendations about the future actions for the PROTEOS project participants, the detailed analysis of the literature will be carried out. The main drivers of future changes in food consumption patterns and the global trajectory of the nutrition transition over the next years will be refined, by using FAO statistics for global food and agriculture, as well as by using the reports on global food outlooks, trends, alternatives and choices (e.g. Rosegrant et al., 2001; Bruinsma, 2003; WHO, 2003; FAO, 2006).

5 Results and discussion

5.1 Studies on dietary changes

Shift in protein supply chain is a very important and complex subject for the future. It has different economic aspects, which call for the use of different model frameworks. The objective of this part of the report is to analyse the most commonly used methodologies for dietary changed scenarios, based on different articles overview that analysed alternative scenarios for the future adoption of different diets in the national or global context. Such an analysis requires an overview of articles based on constructing scenarios in terms of changes in the variables values and parameters, and using mathematical models that allow for changes in the variables subject values to the relationship constraining them (Duchin, 2005). Table 5.1 presents the overview of the main articles used in this paragraph, with their authors, scenario and commodities description, scope and triple bottom line implications and method used (model used and qualitative or quantitative evaluation distinguish).

Table 5.1 Reviewing different methodologies used in dietary changes studies.

Author(s) (dimension)	Scenario (commodities)	Scope	3 P's	Ql/Qn[1]: Model
AGE models studies:				
Aiking et al., 2006c (global)	PROTEOS (peas and pork)	different replacement levels of meat by NPFs and their implications	planet, profit	Qn:AGE model[2] (simulation)
Zhu et al., 2006 (global)	PROTEOS (meat, NPFs)	replacing meat by NPFs by "rich" consumers and introducing emission permits	planet, profit	Qn:AGE model (simulation)
van Wesenbeeck and Herok, 2006 (global)	PROTEOS (meat, NPFs)	effects of alternative model structures in the study of a transition from meat to NPFs	profit	Qn:AGE models (simulation): GEMAT[3] and GTAP[4]
Zhu and van Ierland, 2005 (EU)	PROTEOS (NPFs, pork)	an exogenous shift from pork to NPFs and a higher consumers willingness to pay for the protection of the environment	planet, profit	Qn:AGE model (simulation): GTAP
Hubert et al., 2010 (global)	Livestock Revolution (food)	increase in the livestock number by 20% and 30%, and decrease by 20%	people, planet, profit	Qn: CGE[5] model: GTEM

LCA assessment studies:				
Zhu and van Ierland (2004)	PROTEOS (peas and pork)	a shift in dietary patterns from pork to NPFs and the impact on the environment	planet	Qn:LCA[6]
Aiking et al., 2006c (global)	PROTEOS (NPFs and pork)	environmental assessment of a transition in protein foods: comparing peas and pork chains	planet	Qn: LCA
Reijnders and Soret, 2003 (W industrialized countries)	vegetarian diet (meat, cheese, fish, soybean, vegetables)	quantification of the environmental impact of different dietary protein choices	planet, profit	Qn: LCIA[7]
Jungbluth et al., 2000 (Switzerland)	vegetarian diet (meat, vegetables)	identification of constraints and options for eco-friendly food purchases by consumers	planet	Qn: LCA
IMPACT studies:				
Delgado et al., 1999 (global)	Livestock Revolution (meat, milk, cereals)	interrelationships over time between supply and demand for livestock and feed grain	profit	Qn:IMPACT[8]
Hubert et al., 2010 (global)	Livestock Revolution (food)	feeding a population of 9 billion by 2050, while preserving agro-ecosystems	people, planet, profit	Qn: partial IMPACT model
Rosegrant et al., 1999 (global)	PROTEOS (cereals, meat)	effect of reduction in meat consumption in developed countries on food consumption and food security in developing countries	people, profit	Qn: IMPACT
Studies used FAO statistics:				
Schmidhuber and Shetty, 2005 (global)	Livestock Revolution (higher food energy supplies, more fats and oils, and more animal-based foodstuffs)	future changes in food consumption patterns and global trajectory of the nutrition transition	people, profit	Ql:FAO statistics
Gilland, 2002 (global)	Livestock Revolution (cereals)	the technical feasibility of maintaining global food production per capita up to the year 2050	planet, profit	Ql:FAO statistics
Smil, 2002	PROTEOS	partial substitution of meat	people,	FAO, USDA

(global)	(meat, NPFs)	protein by plant proteins	planet	and SSB[9] statistics
Other studies:				
Risku-Norjaa and Mäenpääb, 2005 (Finland)	Vegetarian diet (food)	shift into more organic production or more vegetarian food	planet, profit	Qn: MFA[10] model
Keyzer et al., 2005 (global)	Livestock Revolution (meat, cereals)	diet shifts towards meat and the effects on cereal use	people, planet, profit	Ql:the Engel curve[11]
White, 2000 (global)	PROTEOS (calories)	how differences in diet affect the distribution of environmental impact	people, planet, profit	Qn:simple conceptual model
Rickard and Gonsalves, 2008 (USA)	USDA FGR[12] (nutrients)	USDA food guides recommendations as shifts in demand for the nutrients	people, profit	Qn: simulation model

[1] Ql – qualitative evaluation, Qn – quantitative evaluation

[2]AGE model - Global applied general equilibrium model

[3]General Equilibrium Model of Agricultural Trade

[4] Global Trade Analysis Project

[5] Computable General Equilibrium

[6]Life Cycle Analysis

[7]Life cycle impact assessment technique

[8] International Model for Policy Analysis of Agricultural Commodities and Trade

[9] US Department of Agriculture and State Statistical Bureau statistics

[10] Material flow approach

[11] Stylized, piecewise linear relation between per capita meat consumption and disposable income

[12]USDA Food Guide Recommendations. Federal dietary recommendations outlined in the 1995 Dietary Guidelines for Americans and depicted graphically in the Food Guide Pyramid are intended to help consumers improve their health and reduce their risk of diet-related disease.

5.1.1 AGE (Applied General Equilibrium) models

In many studies (e.g. Zhu and van Ierland, 2005; Aiking et al., 2006; van Wasenbeeck and Heroek, 2006; Zhu et al., 2006; Hubert et al., 2010), the agricultural and environmental AGE models were constructed, in order to analyse the consequences of a dietary transitions, and their impacts on the triple bottom line accounting. According to Zhu and van Ierland (2005) the biggest strength of AGE models is that they have a flexible structure, that allows the different issues to be included, and also that under restrictive assumptions, the analysis of the whole economy is possible. The disadvantages of using AGE models are that they rely heavily on the analysis of the secondary data, and are calibrated to a benchmark period, treated as an equilibrium, which offers no formal facility for the model structure testing. However, it is important to remember, that every technique in applied economics have their strengths as well as weaknesses.

AGE models are usually developed in order to analyse the changes in policies and shock events (Gunning and Keyzer, 1995). Aiking et al. (2006b) used AGE model to analyse the implications for international trade and resource allocation of more NPFs consumption in EU, because of their ability to deal with more extensive economic analysis, like the global dimension, for example. van Wasenbeeck and Heroek (2006) presented the effects of alternative AGE model structures: GEMAT and GTAP (General Equilibrium Model of Agricultural Trade and Global Trade Analysis Project) in the study of a transition from meat to NPFs. They showed the importance of assumptions made within the GEMAT model, considering agricultural production and consumption, technologies and patterns. In the same time they indicated equal importance of GTAP, to represent institutional arrangements, which affect agricultural production and trade. Hubert et al. (2010) in their studies used the GTEM (Global Trade and Environmental Model)—A CGE model (Computable General Equilibrium model) to analyse the key challenges of adequately and in a sustainable way feeding a population of 9 billion by 2050. Zhu and van Ierland (2005) used AGE model to assess the impacts of changes in consumers preferences, as they determine the demand and thus also supply in market economy.

5.1.2 Life Cycle Analysis (LCA) method

Life Cycle Analysis is a method based on identifying and quantitatively or qualitatively describing a product, process or activity requirements for energy and material during its entire life cycle and the emissions and waste released to the environment, in order to evaluate its environmental impact (Berlin, 2002). Zhu and van Ierland (2004) reported that LCAs method is an important tool for supporting choices at both the policy and industry levels, because of its comparative nature: the results of LCA studies have a comparative significance rather than providing absolute values on the environmental impact related to the product. LCA is usually based upon four phases: goal and scope definitions, inventory of environmental inputs and outputs, impact assessment, and interpretation (ISO, 1995). LCA also makes it possible to identify which activities in the product life cycle contribute most to their impact. Aiking et al. (2006b) pointed out that it is important to realize that next to the indication of how realistic a certain option is, also an economic value should be taken into consideration. That is why it is quite common in environmental assessments, like LCAs, to allocate environmental impacts to two or more items produced during one production process, using the economic value of each product as a environmental impact measure.

Zhu and van Ierland (2004) pointed out those LCAs method is a perfect tool for developing efficient and sustainable production chain, because it gives an important challenge for chain management policies, and identifies the possibilities of environmental impact reduction and optimization of the system. According to Aiking et al. (2006b) LCA is a good method to evaluate the environmental impact of introducing NPFs in order to replace animal products, but the limitation of it is that it will not show how the rest of the world will react if the EU consumers will follow the partly dietary transition. It is an important disadvantage of the LCA method when it comes to the shift in the protein supply chain, because as long as the meat is highly demanded in the world, and the feed is imported to the EU from many different countries, the animal-based food items remain an international issues. According to Reijnders and Soret (2003) the LCAs outcomes are not the perfect representations of the real environmental impact, because some important effects of agriculture might be neglected (quality of soil, direct effect on biodiversity). Another limitation authors see in the reliability of used data. That is why using LCAs method it is important to remember that the outcome gives only a rough indications of relative environmental impacts (Huijbregts, 2001).

The goal of the research conducted by Jungbluth et al. (2000) was to evaluate the consumers' point of view in considering sustainability of food consumption. They used simplified, modular LCA method to investigate the trade-offs among five different decision parameters: type of agricultural practice, origin, packaging material, type of preservation, and consumption. During the analysis authors used a one-score impact assessment, which is not supported by the ISO standard, to make the comparison of different product characteristics easier, although approach like that is considered also as a limitation factor.

5.1.3 International Model for Policy Analysis of Agricultural Commodities and Trade: IMPACT

The IMPACT model was developed at the beginning of the 1990s, as a result of attempt to create a long-term vision and consensus among researchers and policymakers about the actions necessary to feed the world in the future, decrease poverty, and to do that in a sustainable manner (Hubert et al., 2010). It is a model perfectly fitted for the examination of the linkage between the production of key food commodities and food demand and security at the national level. Furthermore, the model was expanded by the water parameter inclusion, because water is one of the major constraints to future food production and what comes after that: to human well-being.

The IMPACT model covers 37 countries and regions (it is virtually all world food production and consumption), and 18 commodities (all cereals, soya beans, roots and tubers, meat sand dairy products). The model specification is a set of country-level supply and demand equations, in which each country is linked by the trade to the rest of the world. In the IMPACT model demand is a function of prices, income and growth in the population. In order to determine the growth of crop production in each country the growth rates in productivity and crops prices are used. Productivity growth in the future is estimated by using its key component sources: management research, conventional plant breeding, wide-crossing and hybridization breeding, and biotechnology and transgenic breeding (Rosegrant et al., 1999).

IMPACT global projections model provides projections for a number of important outcomes (Carruthers et al., 1997): country, regional, and global production and prices of crops and livestock;

food supply/demand balances and imports or exports; per capita consumption of food and calories; and the number of malnourished children in the world.

Delgado et al. (1999) by using the IMPACT model analysed if the Livestock Revolution trends will continue in the future. The model they used details the interrelationships for livestock and feed over time, for supply as well as for demand. Rosegrant et al. (1999) examined the long-term implications of the changes in the future global food demand, supply and trade for cereal and meat, and also the assessed impact of meat consumption reduction in developed countries on the food security in the developing countries. They used the IMPACT model to analyse alternative scenarios to examine the effect of large decrease in meat consumption in developed countries on food consumption as well as food security in developing countries. Hubert et al. (2010) used the partial equilibrium agricultural sector model—IMPACT, to provide an overview of the long-term changes in food supply and demand at a regional level. During their analysis they took into consideration the trade pattern changes, by using macroeconomic assumptions as an exogenous input.

5.1.4 Studies using FAO statistics

The principal projections of food demand projections are those based on the FAO statistics, on supply (production + imports - exports) per country, per commodity. Their biggest advantage is availability, but the limiting factor is that descriptive data is crude and so are the projections based on them (Dornburg et al., 2009).

In order to analyse the main drivers of future changes in food consumption patterns and the global trajectory of the nutrition transition over the next 30 years Schmidhuber and Shetty (2005) used FAO statistics for global food and agriculture (Bruinsma, 2003). The main prospective shifts in consumption patterns changes were analysed both in terms of foodstuffs and related nutrient consumption. Another study in which the FAO statistics were used in order to analyse the technical feasibility of maintaining global food production per capita up to 2050 were conducted by Gilland (2002). Based on the global food and agriculture data he concentrated on the definition of satisfactory dietary pattern, as well as on estimation of necessary food and feed resources per capita. Smil (2002) used FAO, USDA and SSB statistics to analyse the coming quest for NPFs from a wider food supply perspective. He outlined the worldwide transformation of typical diets first, and concentrated on the environmental pressure caused by increasing meat production.

5.1.5 Other methodologies used during studies on dietary changes

Risku-Norjaa and Mäenpääb (2005) in their study assessed economic and environmental consequences of Finnish food production and consumption, by using the material flow approach (MFA). The MFA model serves as a practical planning tool within the agriculture, food sector as a whole, or at the level of the nation-wide economy.

In their study Keyzer et al. (2005) proposed a structural specification that includes a dietary shift towards meat as per capita income increases, and also accounted for a shift in animals feeding from traditional to cereal intensive. In order to do that they used a stylized, piecewise linear relation between the per capita income and meat consumption: the Engel curve, with 3 different regimes combined with a limited number of scenarios on the feeding technology intensity, and discarding price effects. The first regime considers that of the per capita income is below a given threshold, meat demand is low and hardly increasing. With the second one it rises steeply as well as the levels of per capita income are increasing. Finally, in the third regime the income comes to the point, where the Engel curve becomes flatter again, as satiation level sets in.

White (2000) using the simple conceptual model explored the distribution of the environmental impact across the world caused by different diets. Simple model in this case was based on an equation, which states that total environmental impact from the consumption of food depends on population, calories per capita, and the ratio of environmental impact per calorie consumed.

Rickard and Gonsalves (2008) explored the implications for agricultural markets of dietary transition into better compliance with nutritional Food Guide Pyramid recommendations in the study in US. They extracted the recommendations for nutrient for seven different dietary plans and later modelled them as shifts in demand for the nutrients, expressed as a percent change. In order to simulate the implications of revenue in selected agricultural markets, the shifts in nutrients demand were combined with the shares of nutrient composition. To make the simulation model as simple as possible, the changes in shifts were modelled as parallel shifts in demand.

5.2 Socio-economic factors

Tables 5.2, 5.3 and 5.4 present the overview of different socio-economic factors reported in the literature, which have been grouped according to triple bottom line account (people, planet, profit) in order to capture an expanded spectrum of values and criteria for measuring possible economic, ecological and social success of future protein shift. The tables present the assumptions or research results from different studies, which considered two different scenarios for the future food production, specifically meat production.

First scenario describes the situation in which no lifestyle changes and no restrictions on animal diets are included, and this is what is called “BAU”, or “Business as usual” scenario. It is used as some kind of benchmark against the second “Proteos” scenario, to reflect how the patterns of production and consumption can be changed through the protein shift and also what will the results be of such a transition in terms of socio-economic arguments presented in the studies.

“Proteos” scenario design, will be based on the assumption of shifting in the protein supply chain through increasing efficiency of current production systems, developing meat extensions by blending meat and plant products (soy, beans, peas), and using alternative sources of proteins in human nutrition (insect cells, in vitro, algae, microbial). This shift is a future necessity in order to provide world food security, as well as to make food production more sustainable to reduce growing environmental burden it is causing.

5.2.1 “People” factors

“In a world where the ideology of free enterprise has no real challenges, why have free markets failed so many people?”, questions Noble prize-winning economist Muhammad Yunus. As the global population is increasing rapidly towards 9 million, cities like Beijing, Los Angeles and Mumbai will soon triple in size. 3 billion people in the world have no access to clean water, 800 million are hungry, and 10 million children die before they are five. Yet, the “bottom of the pyramid” have dreams too: they seek better lives and demand more. Together, they represent an estimated €4 trillion market

(Fisk, 2010). It is very important to realize that "People" factors in the shift of protein supply considerations are the most important one, because everything starts and begins with ones willingness to change their dietary habits.

Table 5.2 presents the "People" part of the triple bottom line. It concentrates on the most important socio-economic arguments presented in the studies regarding future well-being of people around the world, considering the future food production and assumed shift in the protein supply chain: health, consumer, food security and ethics.

Table 5.2 Socio-economic factors reported in the literature, grouped according to triple bottom line (people, planet, profit): "People".

	Assumptions/results	Author(s)
	„BAU"[1]	
Health	zoonotic diseases (Salmonella, E-coli, and Avian Flu), higher pesticides and antibiotics use, increased risk of microbial contamination (higher consumption in tropical countries)	Delgado et al. (1999)
	animal disease outbreaks hit the costs of public disease control measures and cause losses to producers and consumers through destabilized markets and fluctuating prices	Aiking and de Boer (2006)
	during the last decade it was meat products from all the food items, concerning health, in which the consumer confidence decreased most	Richardson et al., 1994; Becker et al., 1998; Verbeke, 2000
	in many DPC the transition in consumption patterns and lifestyle changes already caused a rapid increase in health problems, and right now many DGC are in the similar process of dietary transition	Schmidhuber and Shetty (2005)
Consumer	consumer demand high-quality products at competitive prices, available through the entire year in various innovative forms	Apaiah and Hendrix (2005)
Food security	the food security in DGC[2] will grow slow, because of not effective changes in dietary patterns in DPC[3]	Rosegrant et al. (1999)
	progress in malnutrition in DGC will require: economic growth, investments in agricultural, rural development, in agricultural research and technologies and in health and education, the development of infrastructure and effective markets	Rosegrant et al. (1995)
	in rapidly industrialising countries (China and India) rising meat consumption will result in a global protein shortage and lead to deeper food security problems in DGC	Vereijken and Aiking (2006)

	meat-based protein diet may also be a solution to the hunger and malnutrition, not only the part of the problem	Seidl (2000)
	LR is not necessarily a threat to the poor, because increased consumption of meat and milk can actually improve the incomes of poor farmers and food processors in developing countries	Delgado (2002)
	food technology can help to alleviate some of the food security problems, through prevention of post-harvest losses, making micronutrients more bioavailable, aligning food processing to consumers wishes, and by investing in quality and safety by technological measures	Hubert et al. (2010)
	with adequate effort it should be technically feasible to satisfy future demand, and it should not cause major disruption of the agricultural markets	Delgado (1999), Bruinsma (2002)
Ethics	growing meat demand: scientists are pushing policymakers to take a closer look at the insects as a more environmentally friendlier sources of proteins. Already globally there are hundreds of different insect species that play a significant role in the diets of millions of people	Vogel (2010)
PROTEOS[4]		
Health	reduction in meat consumption in DPC may improve the health of people in these countries, but it will not have a major impact on better nutrition of the poor in DGC	Rosegrant et al. (1999)
	using plant-derived proteins should become a major part of effort as it offers substantial long-term payoffs, benefiting human health	Smil (2002)
	while choosing NPFs by consumer, in addition to sustainability, health aspects may be an issue (to enhance consumer acceptability)	Vereijken and Aiking (2006); Wandle and Bugge (1997)
	diets characterised by high intakes of plant foods are associated with lower disease risk, particularly cardiovascular disease (CVD) and cancer	Sadler (2004)
	introduction of a new food (mycoprotein) has been associated with a very low incidence of adverse reactions (allergenic)	Sadler (2004)
	substantial contraction in meat consumption in high-income countries should benefit health, by reducing the risk of ischaemic heart disease, obesity, colorectal cancer, and, perhaps, some other cancers	McMichael et al. (2007)
Consumer	dietary changes: shaped due to consumers status and cultural trends	Seidl (2000), White (2000)
	loyalty to a particular taste, brand or supplier goes next to consumers ethical nature of purchase decisions	Newholm (2000)
	consumers can pay more for ecological and ethical reasons, but they have	Vereijken and Aiking

	to know what they pay for (price not too high and background information)	(2006)
	consumers buy food produced in an ecologically way if personal health is motivating factor, next to ecological considerations and moral claims	Wandle and Bugge (1997); de Boer (2006)
	the real environmental benefits of NPFs depend on their acceptance by the consumers (health and sustainability motives)	Beardsworth and Bryman (2004)
Food security	accepting NPFs by European consumers do not mean that the meat production will be reduced, because of still growing demand in the DGC	Zhu et al. (2006)
	changes in the dietary patterns in DPC are not an effective route to improvement in food security in DGC	Rosegrant et al. (1999)
	the idea that reduced demand for feed would overcome the complex income, infrastructure, and food distribution problems that result in calorie malnutrition is an unrealistic oversimplification of the problem	Delgado et al. (1999)
	reduction in meat consumption in DPC would enable the release of cereals for human food consumption, and generate significant improvements in nutritional status in DGC	Brown (1995), Seager (1995), Rosegrant et al. (1999); White (2000)
Ethics	insects are a possible interesting source of protein: they are nutritious in terms of protein (40–75 g/100g dry weight) and minerals, and their protein is of high quality and has a high digestibility (77–98%) and concentration of essential amino acids (46–96% of the nutritional profile)	Verkerk et al. (2007)
	insects are nutritious, being a good source of protein, vitamins and energy	Ramos-Elorduy et al. (1997)

[1]"BAU" - Business as usual scenario

[2]DGC – developing countries

[3]DPC – developed countries

[4]Proteos is a multidisciplinary research initiative on sustainable food systems aiming at global shift in the protein chains.

Health

Reviewing the health aspect of shift in protein supply chain we have to consider two things: the health factors related to meat production, and the consumers health regarding meat consumption.

Meat production is increasing all over the world. Growing meat demand in the world pushed especially the developing countries to expand rapidly the livestock food production, in order to keep pace with demands on the international markets. Weak regulations governing livestock production are not dealing with increasing number of animals and growing concentration of animals and people in the urban environments (such as in Beijing, Mumbai, Lima, and Dar-es-Salaam). Delgado et al. (1999) in their studies argues that this situation can lead to dramatic consequences for human and animal health. Lack of control through enforcement of zoning and health regulations increased the incidences of zoonotic infectious diseases, such as Salmonella, E-coli, and Avian Flu. Aiking and de Boer (2006) reported that because of the growing frequency of animal disease outbreaks all over the world, not only the public disease control measures are paying the costs, but also it is negatively influencing producers and consumers through markets destabilization and fluctuation of prices. Another problem identified by Delgado et al. (1999) is referring to both the developed and developing world: it is the growing use of pesticides and antibiotics in the food chain. It is also important to remember that due to increasing consumption of animal-origin products in the countries with tropical climates, the food safety risk connected with microbial contamination become more prevalent (Delgado, 1999). Those problems can be at least partially solved through shift in the protein supply chain, so cutting on meat production.

On the consumer side, there are many researchers, who concentrate on the influence that meat (especially red meat) consumption have on humans health. During the last decade it were the meat products from all the food items, concerning health, in which the consumer confidence decreased most (Richardson et al., 1994; Becker et al., 1998; Verbeke, 2000). Increasing health consciousness, health concern and risk avoidance are held responsible for this situation. Diets based on plant-origin ingredients are associated with lower disease risk, particularly cardiovascular disease (CVD) and cancer (Sadler, 2004). McMichael et al. (2007) reported that a substantial reduction in meat consumption in high-income countries should decrease the risk of ischaemic heart disease (related to saturated fat in domesticated animal-origin products), obesity, colorectal cancer, and, perhaps, some other cancers. Smil (2002) reported in his book that in order to benefit human health in long-term, using plant-derived proteins should become a major part of global effort. Vereijken and Aiking (2006) concluded that consumer who will be aware of health benefits of eating more NPFs instead of meat products will be more willing to accept them and make them a part of everyday diet. Schmidhuber and Shetty (2005) reported that in many developed countries, the transition in consumption patterns and lifestyle changes already caused a rapid increase in the prevalence of overweight individuals, obesity and related non-communicable diseases (NCDs), and right now many developing countries are in the similar process of dietary transition. Sadler (2004) reported also that introduction of a new food, based on the mycoprotein has been associated with a very low incidence of adverse reactions, and this could be a novel ingredient development in the future meat alternatives production, but further researches in this sector are necessary. According to Rosegrant et al. (1999) it is important to realise that although the reduction in meat consumption in developed countries will improve the health of people in those countries, it will not be possible to provide by that better nutrition of the poor in developing countries.

Consumer

According to Seidl (2000) and White (2000) the dietary pattern changes are not being shaped easily, because of the consumers’ status and cultural trends. The real environmental and social benefits of shift in protein supply chain depend on the acceptance of NPFs by the consumers. Nowadays, consumers demand more food variety with higher value and quality, based on meat-origin protein diet, like meat, eggs and milk (Bruinsma, 2002). Beardsworth and Bryman (2004) argues that even in developed countries, in which the meat consumption level have reached the satiation point, only a minority of the consumers are prepared to avoid meat and if they do, health issues are a much stronger underlying motivation than environmental issues. During their studies Apaiah and Hendrix (2005) concluded that what consumer demand today is a high-quality product, sold at competitive prices and available through the entire year in various innovative forms. Another important aspect is that there is a small possibility that consumers will change their buying patterns just because of the ethical nature of purchase decisions, if the product will not be in the range of their loyalty to a particular taste, brand or supplier (Newholm, 2000). That is why the meat alternatives presently available on the market do not meet the expectations of most consumers and they cannot be really considered as realistic alternatives to meat.

Although some researchers suggest that consumers are ready to pay more for increased animal welfare and sustainability (as long as they know what they are paying for), the price difference may not be too large and clear information about the background should be available to the consumer (Vereijken and Aiking, 2006). Some researchers (Wandle and Bugge; 1997, de Boer; 2006) argues that in fact people are ready to pay more for food produced in an ecologically way, but only when their personal health is a motivating factor, next to ecological considerations and moral claims.

Food security

According to FAO definition food security exists when all people, at all times, have access to sufficient, safe and nutritious food to meet their dietary needs and food preferences for an active and healthy life. It is one of the aims of the shift in protein supply chain, to increase the global food security in sustainable and effective way. Rosegrant et al. (1999) argue in their work that it is actually not possible to assure food security in the developing countries, because the changes in dietary patterns in developed countries will not be efficient enough. According to Vereijken and Aiking (2006) in rapidly industrialising countries (like China and India) the rising meat consumption will probably result in a global protein shortage which in result will affect world-wide protein supply chains and create problems for protein supply in developing countries. In these countries the pressure to produce protein for global use at the expense of production for regional or local use may increase due to rising global protein prices and actually the food security problem might get even deeper. Delgado (2002) reported somehow contrary results in his work. He argued that the Livestock Revolution will not necessarily be a threat to the poor, because increased consumption of meat and milk can actually improve the incomes of poor farmers and food processors in developing countries. Delgado (1999) and Bruinsma (2002) also ensured that with adequate effort it should be technically feasible to satisfy future food demand, and it should not cause major disruption of the agricultural markets.

Some researchers (Brown, 1995; Seager, 1995; Rosegrant et al., 1999; White, 2000) argues that a effective way to release the amount of cereals for human food consumption and to alleviate malnutrition and hunger in the world is to reduce the meat consumption in developed countries, and by that to reduce the amount of cropland designed for animal agriculture and greater grain production. Zhu et al. (2006) actually point out that although the whole idea of cutting on meat consumption through plant-based meat alternatives will probably be accepted by European consumers, it will not guarantee higher food security in developing countries, because the meat demand in those countries is growing rapidly. It is in agreement with Delgado et al. (1999) who reported that the idea that reduced demand for feed would overcome the complex income, infrastructure, and food distribution problems that result malnutrition is an unrealistic oversimplification of the global problem. Seidl (2000) concluded that the meat-based protein diet which is commonly being perceived as a problem might also be a solution to the hunger and malnutrition in the world.

Hubert et al. (2010) in their studies described the way in which the food technology could at least partly help to solve the global food security problem. According to them the important measures should consider: the knowledge of postharvest losses prevention, making micronutrients more bio-available by adding them to food products, and preventing their losses, to align food processing to consumers wishes, in order to raise income and earn a living for the local producers, as well as processors, and finally to invest in quality and safety by technological measures, in order to gain the knowledge about the food safety and preservation technologies (like packaging).

Rosegrant et al. (1995) described the necessary requirements of a significant progress on food security in developing countries as: economic growth (to generate employment and reduces inequality and poverty), investments in agricultural and rural development, in agricultural research and technologies and in health and education, development of infrastructure to increase agricultural productivity, household incomes and food security (e.g. irrigation, domestic water supply, good roads, communications and effective markets).

Ethics

“If we are going to feed 9 billion people, we cannot ignore the efficiency of insects as protein producers,” says Paul Vantomme, senior forestry officer at the United Nations Food and Agriculture Organization (FAO) in Rome.

There is a need for novel protein sources. As the meat demand is growing in the world, some scientists are pushing policymakers to take a closer look at the insects as an more environmentally friendlier sources of proteins in order to improve global food security. According to Verkerk et al. (2007) insects are a possible interesting source of protein, because they are nutritious in terms of protein (40–75 g/100g dry weight) and minerals, their protein is of high quality and has a high digestibility (77–98%) and the concentration of essential amino acids in insect cells is very good (46–96% of the nutritional profile).

Most insect species convert plant protein to insect protein very efficiently. According to Vogel (2010) a cow needs to eat at least 8 grams of food in order to gain a 1 gram in weight, while insects need less than two grams of food. From the nutrition point of view insects provide the proteins that have the same value or even better than conventional meat, or fish. Just 100 grams of caterpillars can provide an adult’s entire recommended daily protein intake, along with iron, B vitamins, and other essential nutrients (Vogel, 2010). This statistics, as well as the growing nutrition problem all over the world, have prompted FAO to develop new policy guidelines that will encourage countries to include insects in their food-security plans, or at least will lead to more constructive global discussions about managing insects. Researchers are taking a closer look at experimental insect breeding to see whether it can be both ecologically and economically sustainable, while in the same time they are also analysing the option to use insect protein in livestock feed or even as a food additive.

The problem with these concepts lies in the ethical point of view of a consumer: insects as a food are easily accepted only where indigenous knowledge and willingness to consume them exists. Although already in the world insects are widely consumed by some societies, especially in Africa, globalization and creation of a food patterns, which are based largely on Western World values has led to their marginalization, and lack of acceptance (DeFoliart, 1999; Mbata et al., 2002). In addition to the cultural aversion to insects' consumption, it will also be necessary to find the ways to make them available throughout the year, because insects are seasonal, and there are technical difficulties in mass-rearing, processing, and storing them.

5.2.2 "Planet" factors

One of the most important challenges facing the world over the next decades is to produce sufficient amount of food to satisfy the demands of a growing human population, while at the same time to preserve the natural resources. Growing world population and incomes, with strong population move from the rural to the urban areas (primarily in the developing world) will have immense consequences on the volume and composition of global food demand, and what comes after that, on the environmental pressure caused by it. Alarming symptoms of deterioration of the resource base are being observed worldwide: land degradation, water scarcity and pollution, global warming and diminishing biodiversity. Many researchers analyzed a fast growing global demand for meat and the results it has on the natural resource base of land, water, air and biological diversity. In the same time more and more studies are concentrating on the environmental advantages of cutting on meat production and shifting in the protein supply chain. The overview of those studies is presented in Table 5.3. Three main factors on which the researchers focused the most are: land use, water use and gas emissions.

Table 5.3 Socio-economic factors reported in the literature, grouped according to triple bottom line (people, planet, profit): "Planet".

	Assumptions/results	**Author(s)**
„BAU"		
Land use	more intensive animal production in countries with cheap financial capital relative to land (e.g.Holland) and in places where land is "free" (such as African Sahel)	Delgado et al. (1999)
	at current animal food consumption levels all food residues that are generated per person are already used for feed purposes and further increase in animal food consumption requires grain-based feed, that will lead to a relatively larger increase in the land use than in the past	Efferink et al. (2008)
	doubling in the meat demand in the period 2000-2020 does not mean that the land requirement for meat will double as well	Elferink and Nonhebel (2007)
	as long as the meat is consumed, livestock should be feed with rest-streams to make the system use as little resources as it is possible	Nonhebel (2004)

Water use	water scarcity is expected to increasingly constrain production, with little additional water available for agriculture due to slow supply increases and rapid shifts of water away from agriculture	Hubert et al. (2010)
Gas emissions	agricultural activity, especially livestock production, accounts for about a fifth of total greenhouse-gas emissions, thus contributing to climate change and its adverse health consequences, including the threat to food yields in many regions	McMichael et al. (2007)
	today the billion land animals which are reared and slaughtered, either directly or indirectly contribute to total human induced greenhouse gas by 18% and total CO2 emission by 9%	Nardone et al. (2010)
PROTEOS		
Land use	partial transition from animal to plant protein might result in a 3-4 fold lower requirement of agricultural land	Dornburg et al. (2008)
	large-scale transition from meat protein to plant protein: an enormous amount of land will be provided and it can be used for any purpose, as it currently is high-quality cropland	Willemsen et al. (2006)
	even a partial transition from meat to NPFs will lead to huge changes in land-use during one generation (20 years)	Aiking et al. (2006a)
	if NPFs would supply just 25% of protein content of meat products more than 15 million hectares of land could be either taken out of production or it could be devoted to other crops	Smil (2002)
	NPFs need less land, so introducing NPFs can reduce the pressure on land for the production of food and feed, and it will give the opportunity to grow other crops on the available land	Zhu and van Ierland (2004)
	cutting on meat production and a change to a vegetarian diet does not result in the land use reduction	Nonhebel (2004)
Water use	partial transition from animal to plant protein might result in a 3-4 fold lower requirement of freshwater	Dornburg et al. (2008)
	world wide there is potential for a 30-40 fold reduction in water use	Aiking et al. (2006)
	a transition from animal to plant protein might result in a threefold lower requirement of freshwater and there is potential for an additional reduction in water use by at least another factor of 10	Aiking et al. (2006b)
Gas emissions	not always the environmental impact of vegetarian diet is lower than the one from a meat diet	Nonhebel (2004)
	if only the "rich" consumers switch to consume more NPFs meat production and emissions will hardly be reduced due to increasing demand for meat in "low	Zhu (2004) and Keyzer et al.

income" and "middle income" consumers in DGC	(2005)
long-distance transportation reduces the relative advantage of the NPFs with respect to pork (long-distance air transport of 1 kg food has roughly the same environmental impact as the primary production of 1 kg organic meat)	Jungbluth et al. (2000) and Zhu (2004)
partial transition from meat to NPFs gives a potential for a 30-40 fold reduction in acidification	Aiking et al. (2006)
using plant-derived proteins offers substantial long-term payoffs by benefiting ecosystems	Smil (2002)
enhanced demand for NPFs will help EU to decrease the gas emissions by 3%, OECD countries by 2% (because of import of pork from EU) and in the other countries emission will increase by 2% due to increased feed production	Zhu and van Ierland (2005)
global meat consumption would need to fall to an average of 90 g per person per day just to stabilise emissions from this sector	McMichael et al., (2007)

Land use

Animal agriculture is one of the most important components of global agriculture, but livestock is also one of the main users of the natural resource base. According to Sere and Steinfeld (1996) livestock use 3.4 billion hectares of grazing land and the production from about one-quarter of the world's croplands. In total, livestock make use of more than two-thirds of the world's surface under agriculture, and one-third of the total global land area. Delgado et al. (1999) in their studies reported that with continuing Livestock Revolution more intensive livestock production will take place where financial capital is cheap relative to land (such as Holland), worsening waste and air problems, and in places where land is "free" (such as African Sahel), and without additional inputs it will cause further degradation of its productivity. Efferink et al. (2008) reported that at current animal-based food consumption level all of the food residues that are generated per person are already used for as feed and further growth in animal food consumption will require more grain-based feed, that will lead to a relatively larger increase in the land use and environmental impact of animal foods than in the past. Contrary to what other researchers are saying Elferink and Nonhebel (2007) reported that doubling in the meat demand in the period 2000-2020 does not mean that the land requirement for meat will double as well.

Shift in the protein supply chain could reduce the pressure on land that livestock production is causing. Dornburg et al. (2008) argues that in fact only partial transition from animal to plant protein might result in a 3-4 fold lower requirement of agricultural land and in the same time it could be (partly) used for biomass production and for relieving the pressure on biodiversity. Aiking et al. (2006a) agrees with that and add that the effects of partial transition could be already visible after one generation (20 years), but it is also important to include the right crop choices in the land regeneration process, in order to produce food and biofuels. According to Willemsen et al. (2006) a large-scale transition from meat protein to plant protein would lead to the largest change in world agriculture through providing an enormous amount of land that could be used for any purpose, as it currently is high-quality cropland. Similar results were presented by Zhu and van Ierland (2004), who reported that NPFs need less land than meat production, so introducing it to the market, can reduce the pressure on land for the production of food as well as feed, and it will give the opportunity to grow other types of crops on the available land. Smil (2002) reported that substitution of only 25% of meat-based proteins by alternatives can take out of production or devote it to other crops 15 million hectares of land (an area roughly equal to all farmland in Poland or in South Africa). In the same time Nonhebel (2004) argues that cutting on meat production and change to a vegetarian diet does not result in the land use reduction and the solution to the land degradation problem is to feed the livestock with rest-streams to make the system use as little resources as it is possible.

Water use

According to the World Bank report (1992) at least 22 countries suffer severe water scarcity (less than 1000 cubic metres per capita per year) and a further eighteen countries have dangerously low levels (less than 2000 cubic metres per capita per year). In addition, much of the global fresh water supply is unsafe because of pathogens and industrial pollutants. According to Hubert et al. (2010) in the near future water scarcity is expected to increasingly constrain production, with little additional water available for agriculture due to slow supply increases and rapid shifts of water away from agriculture.

Dornburg et al. (2008) reported that partial transition from animal to plant protein might result in a 3-4 fold lower requirement of freshwater and it could be (partly) used for biomass production and for relieving the pressure on biodiversity. Aiking et al. (2006b) concluded that a transition from animal to plant protein might result in a threefold lower requirement of freshwater and that actually there is a potential for an additional reduction in water use by at least another factor of 10. In other study Aiking et al. (2006) reported that globally the potential of reduction in water use is even equal to 30-40 fold.

Gas emissions

Worldwide, agricultural activity, especially livestock production, accounts for about a fifth of total greenhouse-gas emissions, thus contributing to climate change and its adverse health consequences, including the threat to food yields in many regions (McMichael et al., 2007). Nardone et al. (2010) reported that today the billion land animals which are reared and slaughtered, either directly or indirectly contribute to total human induced greenhouse gas by 18% and total CO_2 emission by 9%. According to Smil (2002) using plant-derived proteins should moderate the environmental impacts of meat production, and because of that it should become a major part of global effort as it offers substantial long-term payoffs, benefiting ecosystems. Aiking et al. (2006) reported that even a partial transition from meat-based products to NPFs gives a potential for a 30-40 fold reduction in global acidification. According to Zhu and van Ierland (2005) enhanced demand for NPFs will help EU to decrease the gas emissions by 3%, OECD countries by 2% (because of import of pork from EU), but in the other countries emission will increase by 2% due to increased feed production. McMichael (2007) reported that in order to stabilise the greenhouse-gasses emission from livestock sector the global meat consumption would need to fall to an average of 90 g per person per day. In industrialized countries there actually should be a reduction in meat consumption, while in developing countries the growing demand should be constrained, especially of red meat from ruminant (methane-producing) animals.

The results of some studies (Zhu, 2004; Keyzer et al., 2005) showed clearly that the point of the whole shift in protein supply chain is not only to convince a small part of the population ("rich" consumers) to eat more NPFs, because than the gas emissions connected with meat production will hardly be reduced due to increasing meat demand in "low income" and "middle income" consumers in developing countries with concomitant effects on cereals consumption. Nonhebel (2004) reported that actually not always the environmental impact of vegetarian diet is lower than the one from a meat diet. Jungbluth et al. (2000) and Zhu (2004) showed that for example long-distance transportation reduces the relative advantage of the NPFs with respect to pork, because the emissions from NPF chain is mainly due to the energy use and pork chain is due to the manure (long-distance air transport of 1 kg food has roughly the same environmental impact as the primary production of 1 kg organic meat).

5.2.3 "Profit" factors

The factors related to the economic side of the shift in protein supply chain are all grouped in the 5.4:"Profit" table. It considers all the stakeholders of the meat and meat alternatives enterprise, and tries to find an answer to a question: how the business will be transformed by the shift, also regarding the "people" and "planet" factors in the same time. It is an attempt to define the efficiency and profitability of current meat and meat alternatives market, through overview of studies which concentrated on developing dietary changes models. The most interesting studies in this matter are those concentrated on the possible meat consumption reduction and substituting meat by NPFs. It is a good starting point to go one step further and move from transition into the shift in protein supply chain in the future studies.

Table 5.4 Socio-economic factors reported in the literature, grouped according to triple bottom line (people, planet, profit): "Profit".

	Assumptions\result	**Author(s)**
„BAU"		
Meat demand	per capita meat demand will rise faster than it is predicted on the basis of fixed income elasticities	Keyzer et al. (2005)
	the demand for meat and meat products does not increase gradually with income	Keyzer et al. (2001)
	driving force of meat demand in DGC is the shift in lifestyle that accompanies an increase in per capita income, but meat demand in the DPC decreases due to shift in preferences and high satiation level	Rosegrant et al. (1999) , van Wasenbeeck and Heroek (2006)
	per head meat consumption in east Asia, dominated by China, would reach European levels by mid-century	FAO (2006)

	people in DGC are increasing their consumption from the very low levels of the past, and they have a long way to go before coming near DPC averages	Delgado (2003)
	where incomes are high, then dairy products or meat are the leading source of protein and this is independent of environment	Grigg (1995), McMichael et al. (2007)
	the changes in animal products intake is a result of the mixture of economic, cultural, agricultural, and political factors	McMichael et al. (2007)
	after successful introduction of NPFs to the global markets, the consumption of (red) meat will have its highest growth rates in the regions of FNC and FIC[6] where the rising GDP forms the main driving force, and the RCEE[7], where the accession to the EU provides additional incentives for producers	van Wasenbeeck and Heroek (2006)
Prices	as a result of booming economies food prices soared, but they are bound to resume their upward trend simply as a result of increasing demographic pressure	Vereijken and Aiking (2006)
	controversial option: a multilateral arrangements for stabilizing international food prices through supply management, including measures to limit the production of farm-based non-foods when food prices were to exceed a maximum	Koning et al. (2008)
	increased use of feed to produce animal products for the relatively rich puts upward pressure on prices of cereals, the staple food of the world's poor	Delgado et al. (1999)
	supply side events, such as improvements in the efficiency of large-scale meat productions keep prices of animal products lower than they would be otherwise	Delgado (2002)
	the inflation-adjusted prices of livestock and feed commodities are expected to fall marginally by 2020	Delgado (2003)
Food supply chain	the growth in demand for livestock products will result in dramatic transformation of the production and marketing components of the supply chain	Pond et al. (2009)
Policy	policies affect the costs of livestock production and thus, the location and type of production at home and abroad, so there is an urgent need from government to make it possible for DGC to induce growth, poverty alleviation, and sustainability	Delgado (1999)
Livestock production	to follow up LR livestock producers will mostly give up on the traditional mixed farming practices, and livestock production itself will have to face many challenges to meet the future requirements of animal products demand	Bruinsma (2002)

	increasing livestock productivity will require developing, adapting, and disseminating new technologies and production systems - the marketing chain will be challenged to evolve rapidly by developing, adapting, and disseminating new technologies and production systems	Pond et al. (2009)
Global food markets	intensification of livestock production also results in growing demand for feed grains, and that is being met by increase in import, which in fact substitute the import of livestock products	Bruinsma (2002)
	LR will continuously increase the world markets demand for meat, milk and feed grains. For the global markets the main trade impact is that developing countries are extraordinarily increasing their already large net imports of cereals	Delgado (2003)
	with increasing frequency, animal disease outbreaks hit global meat exports and increasingly cause world trade losses through export bans or market constraints	Aiking and de Boer (2006)
	the long-term prospects for food supply, demand and trade indicate a strengthening of world cereal and livestock markets and increase in the importance of DGC in global food markets	Rosegrant et al. (1999)
Technology development	the belief that new technologies alone will suffice to maintain the world's population food supply balance indefinitely is baseless	Gilland (2002)
	without the strong technological progress achieved for the latter commodities, the world prices will surely rise further relative to beef	Delgado (2003)
	demand for food can be reduced in part through improved technology and methods that result in more efficient and environmentally sound agricultural practices: "precision agriculture"	Reijnders and Soret (2003)
	a technological way to reduce the environmental impact of meat production is by so-called "precision farming", but also by feedback coupling in chains, or by lateral integration between different production chains	Vereijken and Aiking (2006)
	increasing livestock productivity will require developing, adapting, and disseminating new technologies and production systems	Pond et al. (2009)
	food technology can help to alleviate some of the problems that we face, through prevention of post-harvest losses, making micronutrients more bioavailable, aligning food processing to consumers wishes, and by investing in quality and safety by technological measures	Hubert et al. (2010)
	land availability limits and the presence of relatively cheap labour: increase in animal production will come from intensification of production and marketing and production technologies development	Bruinsma (2002)

PROTEOS

Meat demand	reduced feed demand for cereal will in turn cause a drop in prices of cereals, inducing an increase in food demand for cereals	Rosegrant et al. (1999)
	enhanced demand for NPFs will decrease the pork consumption in the EU by 23%	Zhu and van Ierland (2005)
	substitution of NPFs for meat will decrease meat demand, changes the relative prices of meat and NPFs and thus consumer food expenditures. As an overall effect, the meat demand mostly in the EU will decrease significantly, because of the high "rich" consumers amount	Aiking et al. (2006)
Price	shift from meat-based protein sources towards NPFs will result in monopolistic behaviours on the markets and higher NPFs prices	van Wesenbeeck and Heroek (2006)
	it can be expected that the meat prices will not decrease, but rather increase as a result of changes in the world market and agro-ecological constraints on production	de Boer (2006)
	a promising solution for upward trends of food prices may be offered by partial replacement of meat proteins with plant protein products (NPFs) in the human diet	Smil (2000)
	the cost to actually produce pork is about 38-40% of retail cost of pork meat, so the NPFs manufacture is much lower	Apaiah and Hendrix (2005)
	reduced demand for meat will directly reduce the world price of meat, which will also cause a direct reduction in meat production in both DPC and DGC which will reduce the demand for cereals for animal feed	Rosegrant et al. (1999)
Food supply chain	a decrease in meat production is equal to decrease in the meat chain input and decrease in the meat chain output, as well as in increase in protein chain input and in protein chain output	Willemsen et al. (2006)
	modifying the protein production and consumption chain offers possibilities to enhance sustainability by reducing inefficiency and its environmental impacts	Zhu, X. (2004)
	design of a successful supply chain is therefore an important task: NPFs manufacturers have to be aware, that to make them successful, the important criteria are the texture and price, as well as environmental load and sustainability	Apaiah et al. (2004)
	the protein transition can be realized only if it is based on a combination of linkages that will satisfy a whole set of constraints: crop choice, envisioned use of by-products, consequences for other natural resources, food-related issues conceived by key stakeholders in the market, issues put forward by governmental and non-governmental policymakers and contours of an evolving "global food economy"	Aiking and de Boer (2006)
Policy	governments could strongly increase their investment in meat alternatives research for raising yields while reducing emissions to the environment	Koning et al. (2008)
	introduction of NPFs might be accompanied by a product-specific	van Wasenbeeck

	governmental policy scheme and/or policy measures designed to diminish the negative environmental effects of meat production	and Heroek (2006)
	considering shift in protein production, not too much should be expected of traditional government instruments such as taxes and subsidies, but it is important to assure NPFs manufacturers with "Intellectual property rights"	Kuik (2006)
	the role of governments and NGOs should not be underestimated: a company's decision on NPFs will be governed by strategic and political circumstances, such as the ripeness of certain issues, at the time the options are contemplated	de Boer (2006)
Livestock production	production of (red) meat will have their highest growth rates in the regions of FNC and FIC[6] where the rising GDP forms the main driving force, and the RCEE[7], where the accession to the EU provides additional incentives for producers	van Wasenbeeck and Heroek (2006)
	protein transition will lead to production reduction in meat sectors and production increase in the NPFs sector, which will impact other related sectors such as feed and pulses	Zhu et al. (2006)
	enhanced demand for NPFs will decrease the pork production in EU by 8% and in the other parts of the world the production of NPFs will increase by 65% in order to export to the EU.	Zhu and van Ierland (2005)
Global food markets	the international dimension of EU animal protein production means that substantial changes in the pig production sector in the EU have a direct impact on agricultural producers and traders elsewhere in the world	Aiking et al. (2006)
	the shift in protein chains will result in global changes in flows of proteins: in Europe the major importers of soy protein that is used as a animal feed is USA and Brazil, and this import might decrease with increasing prices of soy proteins and that will cause the production of protein-rich crops in Europe to increase (it is relatively low at the moment)	Vereijken and Aiking (2006)
	introducing NPFs in the EU will not change the consumption pattern in other regions but will change the production patterns through international trade	Zhu and van Ierland (2005)
	US is the world's largest beef producer, and it has recently been importing nearly as much beef as it exports - this market can be singled out as the most promising target for the introduction of plant-derived proteins	Smil (2002)
Technology development	NPFs products currently available on the market are niche products, that cannot be considered as the realistic alternative to meat, because they do not meet the consumers expectations, especially when it comes to bite, taste, and juiciness and comparing with meat are more expensive	Apaiah and Hendrix (2005)
	opportunities to create a new products, not treated only as substitutes of meat require innovation process beforehand, that will be based on three lines: cultural, structural and technological	Weaver et al. (2000)

	in Europe, potential raw materials for NPFs production might include lupin, pea, quinoa, triticale, lucerne, grasses, rapeseed/canola and potato, and that outside Europe at least soy should be added	Aiking et al. (2006b)
	combining sustainable production of protein and energy in one crop would simultaneously mitigate agricultural resource depletion, agricultural pollution, as well as climate change	Aiking et al. (2006c)
	one of the technological ways to reduce the environmental burden of meat production is the incorporation of plant proteins in meat products	Vereijken and Aiking (2006)

[5]Livestock Revolution

[6] Food Neutral and Food Insecure Countries, respectively

[7]Region of Central and Eastern European associate countries

[8]The Organization for Economic Co-operation and Development

Meat demand

During all the last decade the meat production and consumption have been under strong criticism, but the meat demand in the world is growing constantly. Consumers, industry, producers, governments, and scientists organisations are involved all the time in the debates initiated by numerous occurrences that linked meat product characteristics to human health risks. The focus is also on changing taste and preference patterns (Rickertsen, 1996; Verbeke, 2010) in the long run, as well as the meat safety incidents (Caskie et al., 1998; Latouche et al., 1999; Verbeke, 2010).

The Livestock Revolution is propelled by demand. Although the meat demand in developed countries is slowly decreasing due to shift in consumer preferences and high satiation level, the driving force of the meat demand today are the developing countries. People in developing countries are increasing their consumption from the very low level and they have a long way to go before coming near the average of developed countries (Delgado, 2003). Per capita food consumption of grains is declining, and increase in total meat consumption is combined with induced growth in cereal feed consumption (Rosegrant et al., 1999). It is a result of the lifestyle changes that accompanies an increase in per capita income (Rosegrant et al., 1999; van Wasenbeeck and Heroek, 2006). Grigg (1995) and McMichael et al. (2007) concluded that where the incomes are high, then dairy products or meat are the leading sources of proteins and this is in fact independent of environment. Although this situation seems quite easy to understand, there are some researchers (Keyzer et al., 2005) that argue that it is not valuable to predict future meat demand based on fixed income elasticities, because the demand for meat and meat products does not increase gradually with income (Keyzer et al., 2001), and actually in most developing countries a significant part of the population has just entered or is on the verge of accessing the income bracket where a significant fraction of income growth is spent on meat, and because of that the real per capita meat demand will grow even faster than it is projected. According to FAO (2006) per head meat consumption in East Asia, dominated by China, would reach European levels by mid-century. Dornburg et al. (2008) argues that the key metric with regard to any food product demand is elusive, and thus a complete study on food demand should at least consider following factors: world population, economic aspects (income and food prices), production systems and diet characterisation, and all that in sufficient geographic and temporal detail. McMichael et al. (2007) explain the entire changes in the future animal products intake all over the world by the mixture of economic, cultural, agricultural, and political factors. In their opinion it is more likely that in the near east and in North Africa, higher intake of milk, eggs, and poultry will occur, while consumption of beef and poultry is expected to dominate the increase in Latin America.

According to Aiking et al. (2006) dietary change from meat to NPFs will decrease meat demand, and as a result the changes in relative prices of meat and NPFs and thus consumer food expenditures will occur. Due to that substitution the meat demand should decrease mostly in the EU, because of high meat consumption satiation level largely due to the increased incidence of “rich” consumers. Zhu and van Ierland (2005) calculated that enhanced demand for NPFs will decrease pork consumption in the EU by 23%, and feed production by 11%, but in the other parts of the world the feed production will actually increase because EU will import it. Rosegrant et al. (1999) reported that reduced meat demand will lead to the reduction in feed demand for cereals and that will in turn cause a drop in prices of cereals, inducing an increase in food demand for cereals. Van Wasenbeeck and Heroek (2006) analyzing different scenarios for protein transition concluded that after successful introduction of NPFs to the global markets, the consumption of (red) meat will have its highest growth rates in the regions of food neutral and food insecure countries where the main driving force is formed by rising GDP, and also in the Central and Eastern European Associate countries, because in there the EU accession provides additional incentives for producers.

Prices

According to Delgado (2002) continuing Livestock Revolution have following effects on agricultural prices: it stem the fall in feed grain prices (maize and soybeans will increase in value over time compared to rice and wheat, whose real prices will fall) and also it prevents, or at least cushions, further fall in the real global livestock prices, through improvements in the efficiency of large-scale meat productions. On the other side Delgado et al. (1999) revealed different truth about the Livestock Revolution: increased animal production is connected with growing feed production, and that puts upward pressure on prices of cereals, the staple food of the world’s poor. Vereijken and Aiking (2006) reported that although the world prices of soy and feed maize, followed by meat prices, started to soar in 2006, as a result of booming economies, the increasing demographic pressure will cause the food prices to go back to their upward trend, finishing temporary price dip. Delgado (2003) reported that the inflation-adjusted prices of livestock and feed commodities are actually expected to fall slightly by 2020. Koning et al. (2008) in their work presented a controversial solution to the soaring food prices: a multilateral arrangement for stabilizing international food prices through supply management, including measures to limit the production of farm-based non-foods when food prices were to exceed a maximum.

Smil (2000) in his book argues that a promising solution for soaring food prices may be offered by partial substitution in the human diet of the meat-origin proteins with plant protein products (NPFs). Similar results have been previously reported by Rosegrant et al. (1999), who concluded that reduced demand for meat will directly decline the world price of meat, which will also cause a direct reduction in meat production in both developed and developing countries, and that will also reduce the demand for cereals for animal feed. On the contrary, de Boer (2006) shown that it can be expected that the meat prices due to changes in the world market and agro-ecological constraints on production, will not decline, but rather increase. Apaiah and Hendrix (2005) calculated that the price of the NPFs should be competitive comparing to the meat prices, because the cost to actually produce pork is about 38-40% of retail cost of pork meat, so the NPFs manufacture cost is much lower. However, van Wesenbeeck and Heroek (2006) pointed out that a protein supply chain shift will result in monopolistic behaviours on the markets, which are normal when the newly invented products are produced by just a small number of companies, and monopoly can lead to a higher NPFs prices than under perfect competition, resulting in lower demand for meat alternatives.

Protein supply chain

Today's food industry relies in a major measure upon a web of inter-company relationships. Effective and profitable food supply chain is based on successful interactions among ingredient vendors, food contact packaging providers, re-packers, co-manufacturers, brokers and other suppliers (GMA, 2008). Pond et al. (2009) reported that due to continuing Livestock Revolution the dramatic transformation of the production and marketing components of the supply chain will take place. According to them in order to meet the rapidly growing meat products demand, there must be an accompanying transformation of livestock supply, by developing, adapting, and disseminating new technologies and production systems, including growth in land area devoted to forage production, increased number of animals, as well and increased productivity of animals and land usage.

Apaiah et al. (2004) concluded that the most important part of the protein supply chain shift is a consumer acceptance of the meat alternative product that will be a result of successful supply chain design. They pointed out that the lack of popularity of currently available non-meat products is an effect of their texture, taste and also the price. That is why, in order to make meat alternatives successful on the market, their manufacturers have to remember, that from the consumers point of view the texture and price matter, but from a society's point of view, it is the environmental load and sustainability of the products that is the most important. Zhu, X. (2004) reported that the biggest challenge for the chain management policies is to modify the protein supply chain in a way that would improve its economic and environmental efficiency, to enhance sustainability by reducing inefficiency and its environmental impacts. Aiking and de Boer (2006) analyzed the protein transition process and they stated that it can be realized only if it is based on a combination of linkages that will satisfy a whole set of constraints: crop choice, envisioned use of by-products, consequences for other natural resources, food-related issues conceived by key stakeholders in the market, issues put forward by governmental and non-governmental policymakers and contours of an evolving "global food economy". However, Willemsen et al. (2006) reported that shift in a protein supply chain does not only have advantages for the future. They notified that a reduction in meat production will result in decrease in the meat chain input, which is connected with monetary costs where wastes from food industry and agriculture are fed to pigs, and decrease in the meat chain output, visible in the decrease in by-products: manure, fat, sausage casings, felting, leather, gelatine, etc., where the only solution is to look for alternatives. They also concluded that increase in protein crops grown will result in increase in protein chain input, so the use of water, land, fertilisers, energy and pesticides, and in protein chain output, like oil, starch, cellulose.

Policy

Delgado (1999) in his work claimed that because policies affect the costs of livestock production, they also affect the location and type of production at home and abroad. He also indicated that in order to help the poor in commercially viable activities the governments and development partners should follow the Livestock Revolution, and through policies towards infrastructure, pollution, access to capital, and rural organization affect the comparative advantage of smallholders versus large industrial enterprises. Delgado (1999) also pointed out that in fact lack of action from well-motivated agencies will not stop the Livestock Revolution, but it will make it less favourable for growth, poverty alleviation, and sustainability development in the developing countries.

According to van Wasenbeeck and Heroek (2006) the consumption of meat is only marginally affected by political changes. Van Wasenbeeck and Heroek (2006) concluded that especially because of the environmental background of transition from meat protein into plant alternatives, the introduction of NPFs should be accompanied by a product-specific governmental policy scheme and/or policy measures designed to minimize the negative environmental effects of meat production. Koning et al. (2008) reported similar assumptions regarding governments. They concluded that governments should strongly support research for effective meat alternatives, as well as new non-farm food production systems, to avoid serious food shortages in the future, but also to reduce environmental pressure of meat production. According to de Boer (2006) the role of governments and NGOs should not be underestimated, because a company's decision on NPFs will be governed by strategic, as well as political circumstances. Kuik (2006) reported that considering shift in protein supply chain, not too much help from government should be expected in a form of a traditional government instruments such as taxes and subsidies, but once the NPFs is introduced to the market, it is important for commercial developers to have the exclusive rights over the sale of it and to be protected against imitation by competitors, through "Intellectual property rights".

Livestock production

Global livestock production accounts for more than 40% of the gross value of agricultural production and is determined by following factors: availability, quality and cost of inputs and proximity to markets. According to Bruinsma (2002) livestock producers will mostly give up on the traditional mixed farming practices. Some of the challenges that the livestock production will have to face to meet the future requirements of animal products demand are: more livestock production will originate from more disease-prone environments (warmer and more humid), livestock production will become more intensive, raising the number of animals, improving productivity and processing, increasing marketing efficiency, integrated, large-scale industrial, with increasing environmental and public health risks, increasing competition for common property resources (grazing, water), increasing importance of pigs and poultry production, compared to ruminant species, and increasing use of cereal-based feed (Bruinsma, 2002). This is consistent with the report of Pond et al. (2009), who concluded that increasing livestock productivity will require developing, adapting, and disseminating new technologies and production systems, and the marketing chain will be challenged to evolve rapidly.

Successful protein transition will lead to the reduction in meat production sectors because less meat will be demanded and in the same time in the NPFs sector the production will increase, which will also impact other related sectors such as feed and pulses (Zhu et al., 2006). Zhu and van Ierland

(2005) reported that enhanced demand for NPFs will decrease the pork production in EU by 8%, while in the other parts of the world the production of NPFs will increase by 65% in order to export it to the EU. van Wasenbeeck and Heroek (2006) analysed different scenarios for protein transition and concluded that after successful introduction of NPFs to the global markets, the production of (red) meat will have its highest growth rates in the regions of food neutral and food insecure countries where the main driving force is formed by rising GDP, and also in the Central and Eastern European Associate countries, because in there the EU accession provides additional incentives for producers.

Global food markets

Livestock Revolution is a phenomenon that already occurred and it is important to realize how to deal with it on a global scale. Rosegrant et al. (1999) reported that the long-term prospects for food supply, demand and trade indicate a strengthening of world cereal and livestock markets, and the increasing importance of developing countries in global food markets. According to Delgado (2003) the Livestock Revolution in developing countries will last at least to the end of 2020 and it will continuously increase the world markets demand for meat, milk and feed grains. For the global markets the main trade impact is that developing countries are extraordinarily increasing their already large net imports of cereals and about half of them are maize and cereals other than rice and wheat, predestined for feed. In the same time the meat and milk production growth in developing countries match the big increase in consumption, while the meat exports from Latin America to Asia soar (Rosegrant et al., 1999; Delgado, 2003). Bruinsma (2002) reported also that because the intensification of animals' production also results in growing demand for feed grains, it is being met by increase in import, which in fact substitutes the import of livestock products. Aiking and de Boer (2006) pointed out that increased animal production cause also the growth in trade losses through export bans or market constraints, which are a result of increasing frequency of animal disease outbreaks.

Vereijken and Aiking (2006) reported that the shift in protein supply chains will result in changes in flows of proteins on the global food markets: the import of soy proteins from USA and Brazil used as animal feed in Europe will decrease with increasing prices of soy proteins and that will effect in growth of the production of protein-rich crops in Europe, which is relatively low at the moment. According to Aiking et al. (2006) because of the international dimension of animal protein production in EU, the substantial changes in this sector in the EU will result in a direct impact on agricultural producers and traders globally. Zhu and van Ierland (2005) demonstrated that introducing NPFs in the EU will not change the consumption patterns in other regions but will change the production patterns through international trade, for example the export of pork will increase due to the demand in the other OECD countries. Smil (2002) pointed out that as the largest beef producer in the world that has recently been importing nearly as much beef as it exports, US market should be singled out as the most promising target for the shift in protein supply chain starting point.

Technology development

Livestock Revolution leads to increasing livestock production. Because of the land availability limits and the presence of relatively cheap labour, the increase in animal production is expected to come from intensification of production and marketing and production technologies development (Bruinsma, 2002). In order to face the future meat demand the production of livestock will require that the technological, institutional, and regulatory structures throughout the marketing chain will be challenged to evolve rapidly by developing, adapting, and disseminating new technologies and production systems. Especially, developments in the processing and transportation will be necessary, because most livestock products are more perishable and not as easy stored as grains (Pond et al., 2009). Delgado (2003) also pointed out that new technologies development in livestock production is necessary in order to avoid the soaring process, especially in the case of beef. According to Reijnders and Soret (2003) improved technology could actually decrease the demand for food, especially through development of more efficient and environmentally friendly agricultural practices. They pointed out so called “precision agriculture” as a most desirable farming method. Similar results have been later present by Vereijken and Aiking (2006). They reported that “precision farming” is a technological way to reduce the environmental burden of meat production, and actually meat produced by this kind of farming is expected to be more sustainable than organic meat. Vereijken and Aiking (2006) also mentioned other types of technological ways to deal with increase in livestock production: feedback coupling in chains (e.g. just-in-time production) or lateral integration between different chains in production.

According to Vereijken and Aiking (2006) one of the technological ways to reduce the environmental burden of meat production is the incorporation of plant proteins in meat products. Meat alternatives products that are currently available on the market are niche products, and they cannot be considered as the realistic alternative to meat, because they do not meet the consumers’ expectations, especially when it comes to bite, taste, and juiciness and also they are more expensive comparing with meat (Apaiah and Hendrix, 2005). According to Weaver et al. (2000) there are opportunities to create a new meat replacement products, based on plant proteins, like peas, beans and Lucerne and also from micro-organisms, like Spirulina, and Fusarium species, but with required innovation process beforehand, that will be based on three lines: cultural, structural and technological. Aiking et al. (2006b) already see a potential to do that in Europe, where the raw materials for NPFs production might include lupin, pea, quinoa, triticale, lucerne, grasses, rapeseed/canola and potato, and outside Europe at least soy should be added to that ingredients list. In further studies Aiking et al. (2006c) reported also that the best way to release the environmental burden is to combine sustainable production of protein and energy in one crop. On the contrary to all the above arguments, Gilland (2002) reported that it is not possible to maintain the world’s population food supply balance indefinitely just by using new technologies, as well as it not possible to maintain it for over the next half century without growing use of mineral fertilizers.

Hubert et al. (2010) in their studies described the way in which the food technology could help to solve some of the future food demand problems that we face. According to them first of all, the knowledge of postharvest losses prevention can help increase food security as well as food safety in the world. Second, making micronutrients more bio-available by adding them to food products and preventing their losses could alleviate inadequate nutrition. Third, to connect food processing of local crops to demand of urban consumers (aligning food processing to consumers wishes), to raise income and earn a living for the local producers, as well as processors. And finally fourth, investing in quality and safety by technological measures, in order to gain the knowledge about the food safety and preservation technologies (like packaging).

5.3 Business as usual versus PROTEOS

Aiking et al. (2006b) used the modelling framework to analyse the different replacement levels of meat by NPFs in the EU and their implications on the agriculture, economy, health, food security and environment. Van Wasenbeeck and Heroek (2006) dealt with the consequences of a shift toward vegetable proteins for agricultural production and trade, and on its economic feasibility. Zhu and van Ierland (2005) investigated the influence of consumers' preference changes towards NPFs consumption and also towards favourable attitude to pay for environment protection in the EU. Zhu et al. (2006) used modelling framework in order to analyse the impacts of a changes in consumers preference for NPFs, for example the lifestyle change with respect to the consumption of meat, and also the impacts of environmental policies, on the sustainability of food production and consumption. Reijnders and Soret (2003) used in their study Life cycle impact assessment (LCIA) technique, in order to evaluate the diet choices environmentally and quantitatively. By comparing a number of input-output primary production parameters they evaluated the environmental impact of vegetarian and non-vegetarian diet. Rosegrant et al. (1999) examined with the IMPACT model the long-term implications of the changes in the future global food demand, supply and trade for cereal and meat, and also the assessed impact of meat consumption reduction in developed countries on the food security in the developing countries. More details about the overview of different articles used in this paragraph, with their authors, scenario and commodities description, scope and triple bottom line implications and method used (model used and qualitative or quantitative evaluation distinguish) are presented in Table 5.1. Table 5.5 on the other hand, presents an overview of possible factors, which will affect the meat consumption in the future. Those factors are grouped in 6 categories: social, technological, economic, environmental, political and ethical. The knowledge about those factors is also important during constructing the scenario for the future dietary changes, especially based on meat consumption reduction assumption.

Table 5.5 Possible factors, which will affect the meat consumption in the future.

	Increasing factors	**Decreasing factors**
Social	– Increase in the number of obese people –Growing meal portions size –Increase in keeping meat eating pets	–Converting people to healthy nutrition through education –Increasing number of vegetarians –Ageing of the population leading to less meat consumption –Positive image development of alternatives to meat products – Better knowledge about the preparation of vegetarian meals –Increasing knowledge about animal capabilities (such as intellect and feeling of pain) –Increasing acceptance of alternatives to

		meat products
Technological	–Development of less energy intensive meat products enabling growing consumption –Development of more easily accessible meat products (e.g. shorter cooking time) –Use of more efficient cropping and the use of supplementary amino acids to raise feed conversion efficiencies	–Development of artificial meats –More efficient use of high-quality feed to produce complete protein in milk, eggs and herbivorous fish –Development of NPFs –Development of alternative methods for field use e.g. for energy production –Development of processing and packaging (lessening the amount of unusable meat)
Economic	–More efficient (industrial) production methods affecting production costs –General increase in income levels in society	–Decreasing price of alternatives to meat products –Increasing global meat demand affecting meat prices
Environmental	–Improved management of livestock grazing, better management and use of manure, and increased care in design of intensive production operations	–Growing number of animal diseases –Increasing meat prices due to increasing energy prices influencing fertilizer prices –Increasing meat prices because of growing energy costs (e.g. transports costs) –Imminent global natural resources shortage influencing meat production and consumption
Political	–The liberalization of market policies enables cheaper meat products to be imported from other countries	–Cutting on subsidies for meat production influences production structures change towards biofuels –Interventionist policies that would influence choices in favour of healthier food consumption patterns and lifestyles
Ethical	–Increase in acceptance of wasteful usage of food –Increasing estrangement of meat production –More selective usage of animal parts in food production and consumption	–Increase in meaning of animal rights to humans –Decreasing meaning of meat as a status food –Increasing acceptance of vegetarianism

	in society –Increasing importance of health issues to humans influencing change towards more vegetarian based food consumption

Source: Adapted from Vinnari (2008)

5.3.1 A possible PROTEOS scenario

The main objective of PROTEOS project is to supply the growing world population with adequate amount of food in a way that will be sustainable and socially acceptable. The main emphasis in this subject lies on the increasing meat demand, caused by the growing human population and prosperity, which lead to growing environmental burden worldwide. The shift in the protein supply chain as a starting point of the PROTEOS project, assume the increasing efficiency of current production systems, developing meat extensions by blending meat and plant products (soy, beans, peas), shifting products in the chain to a higher value (offal, soy, grains) and using alternative sources of proteins in human nutrition (insect cells, in vitro, algae, microbial). Therefore, in order to assess the impacts of these objectives in the future they should be applied in the model to the following scenarios: “BAU” and “PROTEOS”.

”Business as usual” (“BAU”) scenario represents a situation where no lifestyle changes and no restrictions on animal diets are included. It gives an overview of current patterns of production and consumption, which means continuing Livestock Revolution, so increasing meat consumption in developing countries, as well as high satiation level of meat consumption in developed countries combined with a low preference for the meat alternatives and extended meat products, and lack of consumer knowledge on the sustainability subject, as well as possibility of shifting products in the protein to a higher value.

The development of sustainable agriculture, which goal is to maximize the net benefits that society receives from agricultural production of food and fibre and from ecosystem services, must accompany advances in the sustainability of energy use, manufacturing, transportation and other economic sectors that also have significant environmental impacts. This will require increased crop yields, increased efficiency of nitrogen, phosphorus and water use, maintaining and restoring of soil fertility (ecologically based management practices), judicious use of pesticides and antibiotics, major changes in some livestock production practices, and active exchange of information among scientists and farmers.

In the “PROTEOS” scenario the first change made with respect to the “BAU” scenario is the increase in efficiency of current production systems, which could be included in the model as consumers’ willingness to pay for more efficient and sustainable agricultural practices, because health, safety and sustainability concerns have become pivotal in purchasing food products. For a large number of consumers, these concerns become manifest in the selection of products produced in the more efficient way. The environmental AGE model could capture the economic functions of more efficient production systems in production functions and utility functions. According to Zhu and van Ierland

(2005) exogenous environmental policies, such as an emission bound, cause inefficiency. An efficient mechanism to increase the current production systems productivity but in the same time to do that in the sustainable way is proposed: users pay for the increase in the current production systems efficiency that is expressed in the environmental resource use (e.g. air quality, soil quality). The willingness to pay for the protection of the environment through purchasing articles produced in more efficient and sustainable matter is not expected to exceed 10% of consumers' total expenditure. In fact, the consumer is willing to pay some extra money for a food produce in more efficient and sustainable way, which already have a place when it comes to organic food, for example, but this assumption present this possibility in a larger scale. In reality, achieving this part of a "PROTEOS" scenario assumptions represents one of the greatest scientific challenges facing human population because of the trade-offs among competing economic and environmental goals, and inadequate knowledge on the key biological, biogeochemical and ecological processes. Willingness to pay for the investments necessary to make the production systems more sustainable, like investments in public sector research and extension education, or investments by farmers in soil testing and improved timing of fertilizer application, could make the agricultural production more efficient and environmental friendly.

Another assumption made in the scenario with regard to PROTEOS programme objectives, is the consumers lifestyle change expressed as a change in the preferences for meat and NPFs. The consumers' expenditure share of NPFs and extended products will increase from 2.5% to 25%. It is also assumed that decrease with respect to meat products consumption will not exceed 30% and it will reach at least 100% increase with respect to NPFs and meat extensions consumption for the consumers in developed countries of all lifestyles. The substitution elasticity[2] between pork and NPFs is assumed to increase threefold. This increased consumption of NPFs, not only derived from plants, but also from other sources of proteins (like fungi, or algae) and increased consumption of extended meat products will be connected with technology development in the matter of better taste and texture of replacers products, in order to make it as similar to meat products, as possible, as well as decrease of prices of the substitutes, that will enhance the purchasers even more.

For the developed countries a very important assumptions in to consider for the future transition process is the increase in the awareness of the consumer of all lifestyles about more efficient agricultural services provided, the health benefits of eating more plant-derived food, and the possibility and necessity of shifting products in the protein chain to a higher value. This implies that consumer will be enhanced to buy more often meat replacement products, and also it will be a preparation for further process of shifting in the protein supply chain. This increase in knowledge level is expected to be a result of some active ad campaigns provided by the governments, WHO as well as by NGOs, in order to educate people. Table 5.6 presents the detailed description of the two scenarios: "BAU" and "PROTEOS". Table 5.7 presents the possible 2020 world situation following the assumptions presented in the "PROTEOS scenario".

[2] Elasticity of substitution - measures the degree of substitutability between any pair of factors (in this example: pork and NPFs).

Table 5.6 Summary of scenarios and sensitivity analysis.

	Contents	Source (s)
"BAU" scenario	Consumers' willingness to pay for more efficient and sustainable agricultural practices is equal to 3% of total food expenditure in the developed countries. Substitution elasticity between NPFs and pork is equal to 0.56 in the EU, 0.58 in the OECD and 0.5 in the ROW[1]. Consumption share of NPFs and blended products in total protein is equal to 2.5% in the developed countries.	Own assumptions based on Zhu and van Ierland (2005) and van Wesenbeeck and Heroek (2006)
"PROTEOS" scenario	Consumers' willingness to pay for more efficient and sustainable agricultural practices is not exceeding 10% of total expenditure in the developed countries. Consumers' expenditure share of NPFs and extended products will increase from 2.5% to 25%. Consumption increase with respect to NPFs and blended protein products is both equal to 100%, and meat consumption decrease is equal to 30%. The substitution elasticity between NPFs and blended products and meat is equal to 1.5 in the developed countries. Another assumption is the increased awareness of the consumer of all lifestyles about more efficient agricultural services provided, the awareness about the necessity of shifting products in the protein chain, and the consciousness, about the health benefits of plant-origin products consumption.	Own assumptions based on Zhu and van Ierland (2005) and van Wesenbeeck and Heroek (2006)

[1]ROW=Rest of the World

Table 5.7 Following the assumptions presented in the "PROTEOS scenario", the 2020 world situation could look like:

Factor (s)	Result (s)	Source (s)
Health	substantial reduction in meat consumption in high-income countries should decrease the risk of ischaemic heart disease (related to saturated fat in domesticated animal-origin products), obesity, colorectal cancer, and, perhaps, some other cancers	Sadler (2004); McMichael et al. (2007)
Consumer	people will be ready to pay more for food produced in an ecologically way, but also with their personal health as a	Wandle and Bugge (1997); Newholm (2000); de Boer (2006); Vereijken and Aiking

	motivating factor, next to ecological considerations and moral claims	(2006)
food security	the reduction in the amount of cropland designed for animal agriculture and greater grain production will provide an effective way to release the amount of cereals for human food consumption and to alleviate malnutrition and hunger in the world	Brown (1995), Seager (1995), Rosegrant et al. (1999); White (2000)
land use/ water use/ gas emissions	3-4 fold lower requirement of high quality agricultural land in 20 years and it would be (partly) used for biomass production and for relieving the pressure on biodiversity threefold lower requirement of freshwater and still there will be a potential for an additional reduction in water use by at least another factor of 10 30-40 fold reduction in global acidification: for example the gas emissions in the EU will decrease by 3%, in OECD countries by 2% (because of import of pork from EU), and in the other countries emission will increase by 2% due to increased feed production.	Zhu and van Ierland (2005); Aiking et al. (2006); Aiking et al. (2006b); Dornburg et al. (2008);
meat demand and feed production	meat consumption decreases by 30% in the developed countries and feed production by 15%, but in the other parts of the world the feed production will actually increase because EU will import it. There are hardly impacts on the consumption of other goods and hardly impacts on the consumption side in other regions	own assumption based on Zhu and van Ierland (2005)
food prices	directly decline the world prices of meat, which will also cause a direct reduction in meat production in both developed and developing countries, and that will also reduce the demand for cereals for animal feed	Rosegrant et al. (1999)
protein supply chain	protein supply chain will be modified in a way that would improve its economic and environmental efficiency, to enhance sustainability by reducing inefficiency and its environmental impacts	Zhu, X. (2004)
livestock production	meat production in the developed countries will decrease by 11%, while in the other parts of the world the production of NPFs	own assumption based on Zhu and van Ierland

	and meat extensions will increase by 65% in order to export it to the EU	(2005)
global food markets	changes in flows of proteins on the global food markets: the import of soy proteins from USA and Brazil used as animal feed in Europe will decrease with increasing prices of soy proteins and that will effect in growth of the production of protein-rich crops in Europe, which is relatively low at the moment	Vereijken and Aiking (2006)

5.4 Recommendations for PROTEOS – what needs to be done?

5.4.1 Consumers acceptance of NPFs – the first step to success

The prospects for replacing meat-based proteins by NPFs are promising, but the real environmental advantages of NPFs depend on their acceptance by the consumers. In a consumer-driven economy, stimulating the purchasers' environmental concern and changing consumers' behaviour are essential factors to achieve a protein transition from animal-origin foods to plant-derived foods. This part should constitute the basic research part of the PROTEOS programme with especially strong experimental focus.

- Understanding more about the diversity of consumer views in relation to the NPFs consumption can help to make the targeting of the methods more efficient and thus any transformation process more likely to succeed (Newholm, 2000; Seidl, 2000; White, 2000);
- NPFs have to stop being a niche products and find its place on the market as a high quality, improved or totally unique products, in various innovative forms, available through the entire year, that in some way will satisfy consumers loyalty to a particular taste, brand or supplier (Newholm, 2000);
- New NPFs development must fit into ethical nature of consumers purchase decisions, especially regarding using alternative sources of proteins in human nutrition (e.g. insect cells, microbial): consumers studies are urged due to their predominant role when designing future shift in protein supply chain (Vereijken and Aiking, 2006, Verkerk et al., 2007);
- NPFs need to have competitive price regarding meat, to become a realistic meat replacers: manufacture of NPFs is much cheaper than that of meat, but monopoly on the market lead to high prices (Apaiah and Hendrix, 2005; van Wesenbeeck and Heroek, 2006);
- NPFs consumption target group should not only be the richest ones, but also low and middle incomes consumers, because more poor consumers become richer, and it is the meat demand from these consumers that continues to increase in rapid pace (Zhu, 2004; Keyzer et al. , 2005);

- There is an urgent need to increase population knowledge of the environmental consequences of food production in order to be able to make improvements that promote sustainability, but in the same time consumer must be aware about the health advantages of food products that he is purchasing (Vereijken and Aiking, 2006);

- The importance of reading food labels carefully cannot be understated: the background information about the product of interest can enhance consumer to pay more for ecological and ethical reasons, but in the same time health should also be a motivating factor, next to ecological considerations and moral claims (Tilman et al., 2002);

- Future developments, in the supply chain and technology optimisation, in the new food (e.g. mycoprotein, insects cells) sector will lead to improved eating quality and further increases in variety and choice (Vogel, 2010);

- Consumer research on different crops is required first to assess the preferred characteristics of products that replace meat in the diet. Once it is determined, it becomes possible to rank the suitability of the crops in the study and to determine research priorities in the areas of plant breeding and the technology of production (Beardsworth and Bryman, 2004);

- NPFs development ask for an integrated approach of technological research and consumer behaviour studies and proper marketing strategy (Aiking et al., 2006);

- Need for greater public-private partnership in research and development and government incentives development in order to stimulate the production of NPFs (Aiking et al., 2006; Koning et al., 2008);

5.4.2 New controversial sources of proteins

As the meat demand is growing in the world, some scientists are pushing policymakers to take a closer look at other sources of proteins, which by many consumers are perceived as controversial, as the insects for example. Those new protein sources are more environmentally friendlier and could improve global food security. The problem with these concepts lies in the ethical point of view of a consumer: insects as a food are easily accepted only where indigenous knowledge and willingness to consume them exists. Although if the insect based food is supposed to be considered as a realistic option, there are few recommendations in that subject:

- Bringing insects based food products to the market ask for an integrated approach of technological research and consumer behaviour studies to prevent preliminary rejection (Verkerk et al., 2007);

- Can the insects based food acceptance be influenced by using a proper marketing strategy, like in the case of Quorn, which is referred to as “a nutritious member of the fungi family, as are mushrooms and truffles”(Verkerk et al., 2007);

- Need for greater public-private partnership in research and development: for the technological limits as well as consumer acceptance of insect cell based food (Verkerk et al., 2007);

- Choice of cell line, growth conditions and use of the baculovirus expression system opens up possibilities to engineer the nutritional value of the biomass (Verkerk et al., 2007);
- Governments could provide incentives to investors that come up with green business ideas on mass-production of edible insects (Koning et al., 2008);
- Currently, insects such as the mopane worm are treated as open-access resources, and their increasing commercialization is raising fears of extinction. Unsustainable wild harvesting could be reduced and conservation goals achieved with arrangements that encourage on-farm production of such insects (Sileshi and Kenis, 2010);
- In addition to the cultural aversion to insects consumption, it will also be necessary to find the ways to make them available throughout the year, because insects are seasonal, and there are technical difficulties in mass-rearing, processing, and storing them (Sileshi and Kenis, 2010);
- Not all insects species are suitable to culture at a large scale (e.g. increasing vulnerability to diseases and animal welfare), and insects can produce defensive secretions and/or can be a source of inhalant allergens (e.g. cast skins, excreta), which might be irritating for people working with them – further research in this subject is necessary (DeFoliart, 1992);
- More attention should be directed toward assessing the risk factors in the edible insect groups, because some insects secrete toxins, produce toxic metabolites or sequester toxic chemicals from food plants (Verkerk et al., 2007);
- Insect cells might be a good alternative for insects. Whether this actually can be done technologically and whether the nutritional value of insect cells is the same as the one of insects still needs to be studied (Verkerk et al., 2007).

5.4.3 Consumer concern stimulation

According to Collins (1999) from an economic policy perspective, the strategies to influence the behaviour of the consumer are more successful than policies designed to affect supplies of foods. Consumers have the chance to reduce the environmental impacts significantly due to their food purchases.

- The knowledge about the environmental pressure could be used in policy design. From a policy-making perspective it would be important to advocate environmental concerns of the consumers or introduce a payment system of environmental premiums for good environmental quality (Collins, 1999);
- Stimulating the environmental concerns of consumers and providing them with information about the environmental performance of products is important for a sustainable consumption pattern (van Wasenbeeck and Heroek, 2006);
- Increasing consumer knowledge about the issue can help in attaining a positive feedback effect whereby consumers receive more knowledge about vegetarianism, then try out new products, which, in turn, results in companies receiving more finances for funding and

developing new products. Ad campaigns can be used to further increase consumer awareness (Aiking et al., 2006);

- Well-researched consumer understandings may both underpin government and expert deliberations and pressure group and producer research. Consumers may, for example, supplement the scope of ethical enquiry by experts (Aiking et al., 2006).

5.4.4 Technological development

- Technological development as a solution for coping with the growing meat consumption demand: based on laboratory grown meat (Vinnari, 2008);

- Technological development of artificial meats and alternatives to meat products is especially required when considering the importance of taste as a reason for meat consumption (Vinnari, 2008);

- Technological development can also help to bring information, about product ingredients and production methods to consumers, e.g. with the help of information chips attached to the packaging (Vinnari, 2008);

- Technological development that will focus on improving current agricultural production systems in order to make them more efficient and sustainable. Table 5.8 presents the most common agricultural problems nowadays and in the future and the possible solutions to those problems in the form of recommendations.

Table 5.8 Most common agricultural problems and their solutions.

Problems	**Recommendations**
- most of the best quality farmland is already used for agriculture, which means that further area expansion would occur on marginal land that is unlikely to sustain high yields and is vulnerable to degradation (Cassman, 1999; Aiking et al., 2006) - continuous cereal production systems, including systems with two or three crops per year, may become progressively susceptible to diseases and insect pests because of insufficient diversity in the crop rotation (Tilman et al., 2002)	- to define the real potential of crop yield increase - there is a large yield gap for rice in many parts of south and southeast Asia, and for maize in developed and developing countries, and that yield could increase with use of appropriate technologies (Tilman et al., 2002)
- only 30–50% of applied nitrogen fertilizer and around 45% of phosphorus fertilizer is taken up by crops (Smil, 1999; Smil, 2000; Tilman et al., 2002)	- large investments in public sector research and extension education, as well as investments by farmers in soil testing and improved timing of fertilizer application (Tilman et al., 2002) - development and preferential planting of crops and crop strains that have higher nutrient-use efficiency and better matching

	temporal and spatial nutrient supply with plant demand (Tilman et al., 2002) - cover crops or reduced tillage can reduce leaching, volatilization and erosional losses of nutrients and increase nutrient use efficiency (Tilman et al., 2002) - closing the nitrogen and phosphorus cycles, such as by appropriately applying livestock and human wastes, increases cereal production per unit of synthetic fertilizer applied (Tilman et al., 2002) - multiple cropping systems using crop rotations or intercropping, agroforestry and landscape-scale management (Tilman et al., 2002)
- 40% of crop production comes from the 16% of agricultural land that is irrigated - unless water-use efficiency is increased, greater agricultural production will require increased irrigation and the global rate of increase in irrigated area is declining and water is regionally scarce (Gleick, 1993) - urban water use, restoration of streams for recreational, freshwater fisheries, and protection of natural ecosystems are all providing competition for water resources previously dedicated to agriculture (Tilman et al., 2002)	- technologies such as drip and pivot irrigation can improve water-use efficiency and decrease salinization (Naylor, 1996) - water-holding capacity of soil can be increased by adding manure or reducing tillage and by other approaches that maintain or increase soil organic matter (Tilman et al., 2002) - cultivation of crops with high water-use efficiency, and the development of crops with greater drought tolerance (Charles, 2001)
- since 1945, approximately 17% of vegetated land has undergone human-induced soil degradation and loss of productivity, often from poor fertilizer and water management, soil erosion and shortened fallow periods (Tilman et al., 2002)	- increased fertilization, irrigation, and disease control (but increased production costs; Naylor, 1996) - crop rotation, tillage, cover crops, fallow periods, manuring and balanced fertilizer application (Tilman et al., 2002)
- it is unclear if conventional breeding approaches to increase the durable resistance of crops to pathogens can work indefinitely (Tilman et al., 2002)	- integrated pest management and biotechnology that identifies durable resistance through multiple gene sources (Tilman et al., 2002) - crop rotation and the use of spatial or temporal crop diversity - intermingled planting of crop genotypes that have different disease resistance profiles (a multiline) can also decrease or even effectively eliminate a pathogen (Tilman et al., 2002)

- continuing Livestock Revolution with all the disadvantages of increased meat production (Tilman et al., 2002)	-expanding base of biological and agronomic knowledge that is often specific to certain agroecosystems, regions, soil types and slopes (Tilman et al., 2002) - making the right decisions at the farm level in terms of input-use efficiency, human health and resource protection (Tilman et al., 2002) - reorienting funds to support sustainable practices: “green payments” (Tilman et al., 2002) - substantial payments for “landscape maintenance” and “environmental cross-compliance” conditions as a prerequisite for farmers to receive agricultural support payments (Tilman et al., 2002) - taxes, removal of subsidies, and implementation of new regulations (e.g. for fertilizers use) - pricing and labelling each type of livestock product to reflect the true total costs of its production could provide consumers with important information and with incentives for choosing alternative food products (Tilman et al., 2002) - ecosystem services, such as pollination or control of agricultural pests (direct benefit to a farmer) - appropriately stocked and managed, grassland–ruminant ecosystems are an efficient, sustainable method of producing high-quality protein with minimal environmental impacts (Tilman et al., 2002) - closing of the nutrient cycle by use of manure decreases dependence on synthetic fertilizer production, and is more efficient when animal and crop production are combined locally
- lack of knowledge-intensive technologies that enhance scientifically sound decision making at the field level (Tilman et al., 2002)	- active exchange of information among scientists and farmers - scientists in developing countries who understand the ecosystems, human culture and demands on local agricultural systems must be actively trained, promoted and brought into the international scientific community (Tilman et al., 2002)

5.4.5 The international regulatory framework

The international rules and regulations affecting and supporting the marketing of new products is quite complex. They can create opportunities or challenges to the shift in protein supply chain. The international regulatory framework also examines the rules for market entry, promotion and support. The most important international institutions that set the rules in this respect are the

European Union (EU), the Food and Agriculture Organization (FAO), the World Health Organization (WHO), and the World Trade Organization (WTO). However, although there are some actions that the government could take to stimulate the NPFs invention and development, it is important to realize that their success primarily depends on private, commercial means and actions.

- Before NPFs can be placed on the EU market, it has to receive governments' authorisation, and this process is long and demanding (in time and resources). For a NPFs it would be very positive as it was found to be substantially equivalent to a conventional food, because than its authorisation procedure would be relatively easy (concept of "substantial equivalence") (Kuik, 2004);

- The importance of "intellectual property rights" in stimulating the invention and development of NPFs (Kuik, 2006);

- The government could stimulate the consumption of NPFs in a more indirect way, for example by sponsoring research or by advocating them in diet-related health promotion campaigns, like WHO's Global Strategy on Diet, Physical Activity and Health (Kuik, 2004);

- Sellers of NPFs may also wish to signal to the consumer certain beneficial properties of these foods by means of (eco-) labelling schemes established by themselves or by independent third parties. Rules for such schemes are under discussion at the WTO (Kuik, 2004);

- A consumer charge on meat and meat products might also be considered as a way to stimulate the consumption of NPFs, either directly, by using the revenues of the charge to subsidise the production or consumption of NPFs, or indirectly, by its impact on the relative prices of meat and protein foods (de Boer, 2006, Kuik, 2004);

- Political actions are needed in order to make the general population understand that meat consumption is a waste of energy resources, as well as an inefficient use of farm land (de Boer, 2006);

- Changes in the way economic subsidies are given to agriculture and especially to meat production are essential (Kuik, 2006);

- Environmental taxes as a tool to alter the structure of food consumption (Kuik, 2004).

6 Conclusions

Food is a basic human need, but so is the sustainable society. Sustainable development calls for a long-term vision on the possibilities to combine environmental, social and economic needs. That is why developing more sustainable protein production is one of the most important aims for the future food production. In order to feed the future population we must economize the use of natural resources, including land and biodiversity, and conserve water and energy in every possible way. Also the society demand from food producers to restrict environmental damages, more animal friendly and safe production practices, healthier and more tasty products, and all that in competitive price. These demands, together with the technological developments, open markets and growing number of consumers who do not want to be reminded of meat in their everyday diet have changed the food production, trade and distribution beyond recognition.

This report was based on a draft project outline of PROTEOS multidisciplinary research programme under the working title: "Innovations for the sustainable supply of protein in the future". PROTOES aims at identifying solutions towards a sustainable and economical shift in the protein supply chain, by substituting and extending future animal-derived protein sources to supply the growing world population with an adequate amount of food in a way that will be sustainable and socially acceptable. The Western dietary pattern is a suitable candidate for such a shift, but even there only a minority of the consumers is prepared to reduce meat consumption and if they do, health issues are a much stronger underlying motivation than environmental issues.

The prospects for replacing meat-based proteins by NPFs are promising, but the real environmental advantages of NPFs depend on their acceptance by the consumers. In a consumer-driven economy, stimulating the purchasers' environmental concern and changing consumers' behaviour are essential factors to achieve a shift in the protein supply chain. NPFs have to stop being a niche products and find its place on the market as a high quality, improved or totally unique products, in various innovative forms, available through the entire year, that in some way will satisfy consumers loyalty to a particular taste, brand or supplier, and in the same time it must fit into ethical nature of consumers purchase decisions, especially regarding using alternative sources of proteins in human nutrition (e.g. micro-organisms). Another thing is that to become realistic meat replacers NPFs need to have competitive price regarding meat, so it will not only be purchased by the high incomes consumers. Also the population knowledge about the environmental consequences of food production needs to be increased in order to be able to make improvements that promote sustainability. In the same time consumer must be aware about the health advantages of food products that he is purchasing, by providing the food labels. NPFs development ask also for an integrated approach of technological research and consumer behaviour studies, proper marketing strategy and for greater public-private partnership in research and development and government incentives development in order to stimulate the production of NPFs.

As the meat demand is growing in the world, some scientists are pushing policymakers to take a closer look at other sources of proteins, which by many consumers are perceived as controversial, as the insects for example. But, if the insect based food is suppose to be considered as a realistic option an integrated approach of technological research and consumer behaviour studies to prevent preliminary rejection is needed, as well as proper marketing strategy, greater public-private partnership in research and development: for the technological limits as well as consumer acceptance of insect cell based food. Governments could provide incentives to investors that come up with green business ideas on mass-production of edible insects.

The strategies to influence the behaviour of the consumer are more successful than policies designed to affect supplies of foods. Consumers have the chance to reduce the environmental impacts significantly due to their food purchases. That is why the knowledge about the environmental pressure could be used in policy design to advocate environmental concerns of the consumers or introduce a payment system of environmental premiums for good environmental quality. Ad campaigns can be used to further increase consumer awareness.

Technological development can be a good solution for coping with the growing meat consumption demand through producing laboratory grown meat. It is also required when considering the importance of taste as a reason for meat consumption. Technological development can also help to bring information, about product ingredients and production methods to consumers, e.g. with the help of information chips attached to the packaging, as well as it could help to improve current agricultural production systems in order to make them more efficient and sustainable.

The international rules and regulations affecting and supporting the marketing of new products is quite complex. They can create opportunities or challenges to the shift in protein supply chain. However, although there are some actions that the government could take to stimulate the NPFs invention and development, it is important to realize that their success primarily depends on private, commercial means and actions. For NPFs it would be very positive as it was found to be substantially equivalent to a conventional food, because than its authorisation procedure would be relatively easy and short. Another important issue is the NPFs invention stimulation and development through "intellectual property rights". The government could also stimulate the consumption of NPFs in a more indirect way, for example by sponsoring research or by advocating them in diet-related health promotion campaigns, like WHO's Global Strategy on Diet, Physical Activity and Health. A consumer charge on meat and meat products might also be considered as a way to stimulate the consumption of NPFs, either directly, by using the revenues of the charge to subsidise the production or consumption of NPFs, or indirectly, by its impact on the relative prices of meat and protein foods. Political actions are needed in order to make the general population understand that meat consumption is a waste of energy resources, as well as an inefficient use of farm land. Changes in the way economic subsidies are given to agriculture and especially to meat production are essential, as well as environmental taxes, which could serve as a tool to alter the structure of food consumption.

The consumer preferences issue in fact is the one where the largest knowledge gaps in the studies on diet changes are. Successful dietary transition is based on understanding that from the triple bottom line concept the "People" factors are the most important ones, because everything starts and begins with ones willingness to change their dietary habits. Nowadays, next to product availability and price, status aspects, as well as cultural trends and religious taboos play an important role in consumer purchasing decisions. Important economic aspects in that subject is for governments to strongly increase their investment in meat alternatives research for raising yields while reducing emissions to the environment, accompanied by a product-specific governmental policy scheme and/or policy measures designed to diminish the negative environmental effects of meat production.

Successful protein supply chain shift can be realized only if it is based on a combination of linkages that will satisfy a whole set of constraints: crop choice, envisioned use of by-products, consequences for other natural resources, food-related issues conceived by key stakeholders in the market, issues put forward by governmental and non-governmental policymakers and contours of an evolving “global food economy”. Some studies showed that combining sustainable production of protein and energy in one crop would simultaneously mitigate agricultural resource depletion, agricultural pollution, as well as climate change, and that might be the right direction for further researches in the future.

References

Aiking, H., and de Boer, J. 2004. Food sustainability: diverging interpretations. British Food Journal, 106: 359-365.

Aiking, H., de Boer, J. and Vereijken, J.M. 2006a. (Eds). Sustainable protein production and consumption: Pigs or peas? Environment & Policy Vol. 45, ISBN 1-4020-4062-8, Springer, Dordrecht, The Netherlands.

Aiking, H., Zhu, X., van Ierland, E., Willemsen, F., Yin, X., and Vos, J. 2006b. Chapter 10: Changes in Consumption Patterns: Options and Impacts of a Transition in Protein Foods. In: Brouwer, F. and McCarl, B.A. (Eds.), Agriculture and Climate Beyond 2015. Springer, pp.171-189.

Aiking, H. 2009. Food or fuel? Diet transition inevitable? IVM, VU University, Amsterdam Proceedings 7th IHDP Science Conference, Bonn, Germany, 26-30 April 2009

Aiking, H. 2010. Future protein supply. Trends in Food Science & Technology. 1-9.

Alexandratos, N. 2006. The Mediterranean diet in a world context. Public Health Nutrition: 9 (1): 111–117.

Alexandratos, N. 2009. World food and agriculture to 2030/50: Highlights and views from mid-2009. Rome, Italy: FAO. Expert Meeting on How to feed the World in 2050 (12e13 October 2009). Available at: http://www.fao.org/wsfs/forum2050/wsfs-backgrounddocuments/wsfs-expert-papers/en/.

Apaiah, R.K., Hendrix, E.M.T., Meerdink, G., and Linnemann, A.R. 2004. Qualitative methodology for efficient food chain design. Trends in Food Science & Technology, 16: 204–214.

Apaiah, R.K. and Hendrix, E.M.T. 2005. Design of a supply chain network for pea-based novel protein foods. Journal of Food Engineering, 70: 383–391.

Atkinson, D. and Watson, C.A. 1996. The environmental impact of intensive systems of animal production in the lowlands. Animal Science, 63: 353-361.

Beardsworth, A., and Bryman A. 2004. Meat consumption and meat avoidance among young people: An 11-year longitudinal study. British Food Journal, 106 (4): 313-327.

Becker, T., Benner, E. and Glitsch, K. 1998. Quality policy and consumer behaviour. Summary Report on Consumer Behaviour towards Meat in Germany, Ireland, Italy, Spain, Sweden and the United Kingdom: Results of a Consumer Survey, Working paper FAIR-CT95-0046, Department of Agricultural Markets and Agricultural Policy, The University of Hohenheim, GoÈttingen.

Berlin, J. 2002. Environmental life cycle assessment (LCA) of Swedish semi-hard cheese. International Dairy Journal, 12: 939–953.

Brown, L.R. 1995. Who Will Feed China? Wake-up Call for a Small Planet. The Worldwatch Environmental Alert Series, pp.139–140. New York: WW Norton and Company.

Bruinsma, J. 2003. World agriculture: towards 2015/2030. An FAO perspective.

Carlsson-Kanyama, A., 1998. Climate change and dietary choices, how can emission of greenhouse gases from food consumption be reduced? Food Policy, 23: 277– 293.

Carruthers, I., Rosegrant, M.W., and Seckler, D. 1997. Irrigation and Food Security in the 21st Century. Irrigation and Drainage Systems, 11(2): 83-101.

Cassman, K. G. 1999. Ecological intensification of cereal production systems: yield potential, soil quality, and precision agriculture. Proceedings of the National Academy of Sciences. 5952–5959.

Charles, D. 2001. Seeds of discontent. Science, 294: 772–775.

Collins, K. 1999. Public policy and the supply of food. Food Policy, 24: 311–324.

Council for Agricultural Science and Technology (CAST). 1999. Animal Agriculture and Global Food Supply. CAST. Ames, Iowa.

Davies, J., and Lightowler, H. 1998. Plant-based alternatives to meat. Nutrition and Food Science, 2/3: 90-94.

de Boer, J., Helms, M., and Aiking, H. 2006. Protein consumption and sustainability: Diet diversity in EU-15. Ecological economics, 59: 267 – 274.

Delgado, C., Rosegrant, M., Steinfeld, H., Ehui, S., and Courbois, C. 1999. Livestock to 2020: The next food revolution. Food, Agriculture and the Environment Discussion Paper 28.

DeFoliart. G.R. 1999. Insects as food. Why the Western Attitude Is Important. Annual Review of Entomology, 44: 21-50.

DeFoliart, G.R. 1992. Insects as human food. Crop Protection, 11: 395-399.

Delgado, C. 2002. Impact of Changing Market Forces and Policies on Structural Change in the Livestock Industries of Selected Fast-Growing Developing Countries. Final Research Report of Phase I - Project on Livestock Industrialization, Trade and Social-Health-Environment Impacts in Developing Countries.

Delgado, C. 2003. Rising Consumption of Meat and Milk in Developing Countries Has Created a New Food Revolution. American Society for Nutritional Sciences: 3907S-3910S.

Dornburg, V., Faaij, A., Verweij, P., Langeveld, H., van de Ven, G., Wester, F., van Keulen, H., van Diepen, K., Meeusen, M., Banse, M., Ros, J., van Vuuren, D., van den Born, G.J., van Oorschot, M., Smout, F., van Vliet, J., Aiking, H., Londo, M., Mozaffarian, H., and Smekens, K. 2008. Biomass Assessment. Assessment of global biomass potentials and their links to food, water, biodiversity, energy demand and economy. Netherlands Research Programme on Scientific Assessment and Policy Analysis for Climate Change (WAB).

Elferink, E.V., and Nonhebel, S. 2007. Variations in land requirements for meat production. Journal of Cleaner Production, 15: 1778-1786.

Elferink, E.V., Nonhebel, S. and Moll, H.C. 2008. Feeding livestock food residue and the consequences for the environmental impact of meat. Journal of Cleaner Production, 16: 1227-1233.

Evans, L.T. 1998. Feeding the Ten Billion: Plants and population growth. Cambridge University Press, Cambridge.

Fisk, P. 2010. People, Planet, Profit. How to embrace sustainability for innovation and business growth. Published by Kogan Page.

Food and Agricultural Organization statistics database (FAOSTAT). 2001. Available from: www.fao.org

FAO. 2006. Livestock's long shadow. Environmental issues and options. Rome: Food and Agriculture Organisation: 414.

GMA. 2008. Food supply chain handbook. The association of food, beverage and consumer products companies.

Gilland, B. 2002. World population and food supply. Can food production keep pace with population growth in the next half-century? Food Policy, 27: 47–63.

Gleick, P. 1993. Water and conflict: fresh water resources and international security. International Security, 18: 79–112.

Goodland, R. 1997. Environmental sustainability in agriculture: diet matters. Ecological Economics, 23 (3): 189–200.

Grigg, D. 1995. The Pattern of World Protein Consumption. Geoforum, 26 (1): 1-17.

Gunning, J.W., Keyzer, M.A. 1995. Applied general equilibrium models for policy analysis. In: Behrman, J., Srinivasan, T.N. (Eds.). Handbook of Development Economics. Elsevier Science B.V., pp. 2025–2107.

Helms, M. 2004. Food sustainability, food security and the environment. British Food Journal, 106 (5): 380-387

Huijbregts M. Uncertainty and variability in environmental life cycle assessment. PhD dissertation. Amsterdam: University of Amsterdam, 2001.

Jungbluth, N., Tietje, O., Scholz, R.W. 2000. Food purchases: impacts from the consumers' point of view investigated with a modular LCA. The International Journal of Life Cycle Assessment, 5:134–42.

Keyzer, M.A., Merbis, M.D. and Pavel, I.F.P.W. 2001. Can we feed the animals? Origins and implications of rising meat demand. Staff Working Paper WP-01-05, Amsterdam: SOW-VU.

Keyzer, M.A., Merbis, M.D., Pavel, I.F.P.W. and van Wesenbeeck C.F.A. 2005. Diet shifts towards meat and the effects on cereal use: can we feed the animals in 2030? Ecological Economics, 55: 187–202.

Koning, N.B.J., Van Ittersum, M.K., Becx, G.A., Van Boekel, M.A.J.S., Brandenburg, W.A., Van Den Broek, J.A., Goudriaan, J., Van Hofwegen, G., Jongeneell, R.A., Schiere J.B., and Smies, M. 2008. Long-term global availability of food: continued abundance or new scarcity? NJAS Wageningen journal of life sciences, 55-3.

Kuik, O. 2004. The international regulatory framework for novel protein foods: challenges and opportunities. PROFETAS report.

Kuik, O. 2006. Chapter 5.4: International institutions. In: Aiking, H., de Boer, J., and Vereijken, J. (Eds), Sustainable Protein Production and Consumption: Pigs or Peas. Springer, Dordrecht, pp. 144-150.

Lightowler. H., Davies, J. and Long, A. 1998. A vegan food guide for vegans: a possible approach. Nutrition & Food Science, No. 1.

Linnemann, A.R., Dijkstra, D.S., 2000. Towards sustainable production of protein-rich foods: appraisal of eight crops for Western Europe: Part I. Analysis of the primary links of the production chain. Publication in the framework of a collaborative research project of the Graduate School VLAG and the Graduate School EPW. Wageningen University, Wageningen.

Mbata, K.J., Chidumayo, E.N., and Lwatula, C.M. 2002. Traditional Regulation of Edible Caterpillar Exploitation in the Kopa Area of Mpika District in Northern Zambia. Journal of Insect Conservation, 6: 115-130.

McMichael, A.J., Powles, J.W., Butler, C.D., and Uauy, R. 2007. Food, livestock production, energy, climate change, and health. Energy and Health. Lancet, 370: 1253–1263.

Millstone, E. and Lang, T. 2003. The atlas of food: Who eats what, where and why. ISBN 1-85383-965-5. Earthscan Publications Ltd, London, UK.

Nardone, A., Ronchi, B., Lacetera, N., Ranieri, M.S., and Bernabucci, U. 2010. Effects of climate changes on animal production and sustainability of livestock systems. Livestock Science, 130: 57–69.

Naylor, R. 1996. Energy and resource constraints on intensive agricultural production. Annual Review of Energy and the Environment, 21: 99–123.

Nestle, M. 2000. Ethical dilemmas in choosing a healthy diet: vote with your fork! Proceedings of the Nutrition Society, 59: 619-629.

Newholm, T. 2000. Consumer exit, voice and loyalty: Indicative, legitimation, and regulatory role in agricultural and food ethics. Journal of Agriculture and Environmental Ethics, 12: 153-166.

Nonhebel, S. 2004. On resource use in food production systems: the value of livestock as 'rest-stream upgrading system'. Ecological Economics, 48: 221–230.

Ortiz, R. 1998. Critical role of plant biotechnology for the genetic improvement of food crops: perspectives for the next millennium. Journal of Biotechnology, 1: 1–8.

Pimentel, D., and Pimentel, M. 2003. Sustainability of meat-based and plant-based diets and the environment. The American Journal of Clinical Nutrition, 78:660-663.

Pimentel, D., and Pimentel, M. 2003. World population, food, natural resources, and survival. World Futures, 59:145–67.

PROFETAS. 2005. Protein Foods, Environment, Technology And Society. Up-to-date information available from <www.profetas.nl> Amsterdam.

Quist, J. 2008. Does backcasting lead to system innovations to sustainability? The case of meat alternatives and novel protein foods. Paper for the 2008 Berlin Conference "Long term policies: governing socio-ecological change". Berlin 22-23 February 2008.

Ramos-Elorduy, J., Manuel Pino Moreno, J., Escamilla Prado, E., Perez, M.A., Otero, J.L., Ladron de Guevara, O. 1997. Nutritional value of edible insects from the State of Oaxaca, Mexico. Journal of Food Composition and Analysis, 10:142–57.

Reijnders, L., and Soret, S. 2003. Quantification of the environmental impact of different dietary protein choices. The American Journal of Clinical Nutrition,78:664S–8S.

Richardson, N., MacFie, H., and Shepherd, R. 1994. Consumer attitudes to meat eating. Meat Science: An International Journal, 36: 57-65.

Risku-Norja, H. and Mäenpää, I. 2007. MFA model to assess economic and environmental consequences of food production and consumption. Ecological Economics, 6 0: 700–711.

Roberts, M. 1951. The Estate of Man. Faber and Faber, London, UK.

Rosegrant, M.W., Agcaoili-Sombilla, M., and Perez, N.D. 1995. Global Food Projections to 2020: Implications for Investment. Food, Agriculture and the Environment Discussion Paper no. 5. Washington, DC: International Food Policy Research Institute.

Rosegrant, M.W., Leach, N., and Gerpacio, R.V. 1999. Alternative futures for world cereal and meat consumption. Proceedings of the Nutrition Society, 58: 219–234.

Rosegrant, M.W., Paisner, M.S., Meijer, S., and Witcover, J. 2001. 2020 Global Food Outlook Trends, Alternatives, and Choices. A 2020 Vision for Food, Agriculture, and the Environment Initiative. International Food Policy Research Institute. Washington, D.C.

Sadler, M.J. 2004. Meat alternatives – market developments and health benefits. Trends in Food Science and Technology, 15: 250-260.

Schmidhuber, J. and Shetty, P. 2005. The nutrition transition to 2030. Why developing countries are likely to bear the major burden. Acta Agriculturae Scand Section C, 2: 150-166.

Seager, J. 1995. The State of the Environment Atlas. Harmondsworth, UK: Penguin Books Ltd.

Seidl, A. 2000. Economic issues and the diet and the distribution of environmental impact. Ecological Economics, 34:5–8.

Sere, C. and Steinfeld, H. 1996. World Livestock Production Systems: Current status, issues and trends. Animal Production and Health Paper No. 127. FAO. Rome.

Sileshi, G.W. and Kenis, M. 2010. Food security. Farming insects. www.sciencemag.org

Smil, V. 1999. Nitrogen in crop production: an account of global flows. Global Biogeochemical Cycles, 13: 647–662.

Smil, V. 2000. Phosphorus in the environment: natural flows and human interferences. Annual Review of Environment and Resources, 25: 53–88.

Smil, V. 2000. Feeding the world: A challenge for the twenty-first century. MIT Press. Cambridge (Mass.).

Smil, V. 2002. Worldwide transformation of diets, burdens of meat production and opportunities for novel food proteins. Enzyme and Microbial Technology, 30: 305–311.

Steinfeld, H., Gerber, P., Wassenaar, T., Castel, V., Rosales, M., and de Haan, C. 2006. Livestock's long shadow: Environmental issues and options. ISBN 978-92-5-105571-7. FAO, Rome, Italy.

Tilman, D., Cassman, K.G., Matson, P.A., Naylor, R., and Polasky, S. 2002. Agricultural sustainability and intensive production practices. Nature, 418: 671-677.

van Wasenbeeck, L, and Heroek, C. 2006. Chapter 5.3: European and Global Economic Shifts. In: Aiking, H., de Boer, J., and Vereijken, J. (Eds), Sustainable Protein Production and Consumption: Pigs or Peas. Springer, Dordrecht, pp. 138-144.

Verbeke, W. 2000. Influences on the consumer decision-making process towards fresh meat. Insights from Belgium and implications. British Food Journal, 102 (7): 522-538.

Vereijken, J.M., Heng, L., O’Kane, F., Yin, X. Vos, J. Lantinga, E.A., Tzitzikas, E.N., Vincken, J.-P., Raemakers, K., Visser, R.G.F., Apaiah, R.K., Willemsen, F., and van Boekel, M.A.J.S. 2006a. Chapter 3: Technological feasibility. In: Aiking, H., de Boer, J., and Vereijken, J. (Eds), Sustainable Protein Production and Consumption: Pigs or Peas. Springer, Dordrecht, pp. 51-98.

Vereijken, J.M., and Aiking, H. 2006. Chapter 6.5: Actor feedback. In: Aiking, H., de Boer, J., and Vereijken, J. (Eds), Sustainable Protein Production and Consumption: Pigs or Peas. Springer, Dordrecht, pp. 181-187.

Vereijken, J.M., and Linnemann, A. 2006. Chapter 6.2: Crop options. In: Aiking, H., de Boer, J., and Vereijken, J. (Eds), Sustainable Protein Production and Consumption: Pigs or Peas. Springer, Dordrecht, pp. 157-165.

Verkerk, M.C., Tramper, J., van Trijp, J.C.M., and Martens, D.E. 2007. Insect cells for human food. Biotechnology Advances, 25: 198–202.

Vinnari, M. 2008. The future of meat consumption — Expert views from Finland. Technological Forecasting & Social Change, 75: 893–904.

Vogel, G. 2010. For More Protein, Filet of Cricket. Science, 327: 811.

Wandle, M., and Bugge, A. 1997. Environmental concern in consumer evaluation of food quality. Food quality and Preference, 8: 19-26.

Weaver, P., Jansen, L., van Grootveld, G., van Spiegel, E., Vergragt, P. 2000. Sustainable technology development. Sheffield, UK: Greenleaf Publishing.

White, T. 2000. Diet and the Distribution of Environmental Impact. Ecological Economics, 34 (1):145–153.

Willemsen, F., Apaiah, R., Stegeman, D., and Aiking, H. 2006. Chapter 6.3: Combined chains. In: Aiking, H., de Boer, J., and Vereijken, J. (Eds), Sustainable Protein Production and Consumption: Pigs or Peas. Springer, Dordrecht, pp. 166-175.

World Bank. 1992. World Development Report. Development and the environment. Oxford University Press, New York.

World Health Organization. WHO. 1996. Micronutrient malnutrition—half of the world's population affected. World Health Organization, 78:1–4.

World Health Organization. WHO. 2003. Diet, nutrition and the prevention of chronic diseases. Report of a Joint WHO/FAO Expert Consultation. WHO Technical Report Series 916.

World Health Organization. WHO. 2006. Obesity and overweight. Fact sheet No. 311. Geneva: World Health Organization.

Zhu, X. 2004. Protein Chains and Environmental Pressures: A Comparison of Pork and Novel Protein Foods. Environmental Sciences (Vol.1), 3: 254–276.

Zhu, X. and van Ierland, E.C. 2005. A model for consumers' preferences for Novel Protein Foods and environmental quality. Economic Modelling, 22: 720–744.

Zhu, X., van Wesenbeeck, L., and van Ierland, E.C. 2006. Impacts of Novel Protein Foods on Sustainable Food Production and Consumption: Lifestyle Change and Environmental Policy. Environmental & Resource Economics, 35:59–87.