Articles for

ORAL PRESENTATIONS

Wednesday Special Session

Towards A sustainable Food Chain

Future Protein Supply and the EU

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Abstract. *Rapid increases in 1) world population and 2) affluence have had huge environmental impacts. Sustainability requires a radical systems change, rather than gradual improvement. Priority areas for such a societal - and industrial - transition include food, water, and energy. All three areas converge in the food system, which appropriates over 30% of all ice-free land, 70% of available freshwater and 20% of energy. Therefore sustainable food production requires far-reaching changes.*

Within the food area, protein is crucial, for anthropogenic contributions to the carbon cycle are 1-2%, but to the nitrogen cycle 100-200%. Before large-scale application of fertilisers, the global population was capped at 3 billion people by nitrogen limitation. Animal protein production has disproportionate environmental impacts, since 1 kg animal protein requires circa 6 kg plant protein, wasting 85% of valuable crop proteins and turning them into polluting emissions, targeting terrestrial and aquatic biodiversity. Intensive livestock farming increasingly results in biodiversity loss, freshwater depletion, climate change, eutrophication, and incidence of emerging diseases, such as avian influenza.

To counter the impacts, we must economize our use of natural resources, including land, water and energy. Crops should be used exclusively for cascaded production of food - feed - feedstock - fuel. Applying this biorefinery principle will favour different crops, which should also be robust with respect to changing climate zones. Developing novel plant protein foods (NPFs) will simultaneously fight malnutrition, food prices, emerging diseases and environmental impacts.

In summary, sustainability driven innovation should focus on protein, combining insights from the agriculture, processing, biodiversity, water, bioenergy and health research communities. Such will provide win-win opportunities to address several important issues at once, including resource depletion, as well as pollution, poverty, and public health. In addition, it will provide a boost towards European self-sufficiency with respect to proteins, as well as biofuels.

Keywords. protein, transition, sustainability, biodiversity, health

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Introduction

Mankind's increasing impacts on global systems have resulted in feedback mechanisms slowing down further increases of population and affluence. Everybody without exception needs food, water, shelter, and energy. Unsurprisingly, food production as a human activity is one of the main drivers responsible for environmental degradation and resource depletion, if only because food production appropriates major shares of freshwater (70%), land (35%) and energy (20%) production (Aiking, De Boer, & Vereijken, 2006). As an added complexity, biofuels may compete with food for the same scarce land and freshwater resources (Fischer, 2009).

In the next four decades we will face an unprecedented dual challenge of global food security and global food sustainability. By 2050, a world with 2.3 billion more people will need 70% more food (Bruinsma, 2009). Simultaneously, the environmental impacts of food production must be reduced. Taken together, the impacts per tonne of food need to be quartered. This paper argues 1) that three main environmental impacts: biodiversity loss, nitrogen cycle disruption and climate change (Rockström, Steffen, Noone, Persson, Chapin, Lambin et al., 2009) are strongly interlinked - rather than independent of one another, 2) that protein is the linking pin - rather than carbohydrates and calories, and 3) that these insights carry potential for multiple combined gains - provided we are prepared to adjust our lifestyles considerably.

World population and food production impacts

Food provides nutrients and also generates income. The evolution of agriculture, industry and technology has shaped world population growth and *vice versa* (Evans, 1998). Figure 1 illustrates the world population and its unprecedented rate of growth during the last two centuries, in particular.

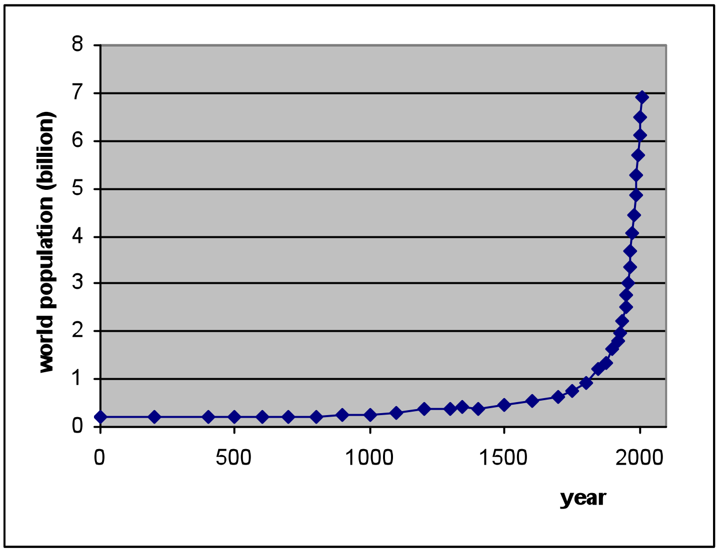

Figure 1. World population until 2010.

Due to continued growth of both world population and per capita income a major proportion of global environmental pressure is generated by food-related activities. Crops are produced, processed and turned into food products in ever larger volumes, with ever increasing impacts on the environment (Tilman, Cassman, Matson, Naylor, & Polasky, 2002). Currently, about one-third of all transport is food-related and, moreover, one-third of the ice-free land area is used for food production, plus almost three quarters of the available freshwater (Smil, 2002b). The environmental impacts of food production include resource depletion and pollution on all scale levels from local to global. Prominent examples include impacts on biodiversity (Nierenberg, 2006), climate change, as well as human health (McMichael, Powles, Butler, & Uauy, 2007). This clearly illustrates the anthropogenic environmental impacts of food production.

Food production has been able to keep up with population growth mainly by increasing the yield per hectare (mainly by increasing irrigation and fertiliser application), and protein production by intensifying animal production. The latter resulted in problems with human and animal health, as well as a decrease in animal welfare, as is evident from a string of food scares (BSE, foot-and-mouth disease, swine fever, avian influenza, dioxins, hormones, etc.) and an obesity epidemic. Resistant bacteria (e.g. MRSA, ESBL) result from antibiotics routinely added to livestock feed (Johnson, McCabe, White, Johnston, Kuskowski, & McDermott, 2009). Emerging diseases such as avian influenza are strongly coupled to intensive livestock production (Pilcher, 2004).

Protein as a linking pin

Producing enough food for 10 billion people seems technologically feasible (Evans, 1998), but doing so without compromising sustainability - both by pollution and by resource depletion - is a formidable challenge (Tilman et al., 2002). Dietary protein is nutritionally crucial (Smil, 2002a), since nitrogen is an indispensable constituent of DNA, RNA and protein. Smil (2001) calculated that before large-scale application of fertilisers, world population was capped at ca. 3 billion people by nitrogen limitation, less than half the current number. The tremendous energy input involved in nitrogen fertiliser production (by itself responsible for 37% of all energy expenditure in US agriculture: Lang, Barling, & Caraher, 2009: p. 193) causes significant climate change (Smil, 2001; Erisman, Sutton, Galloway, Klimont, & Winiwarter, 2008).

Invariably, a large proportion of fertiliser nitrogen is lost to the environment. In 2005, just 17% was consumed by humans in crop, dairy and meat products, and the global nitrogen use efficiency of crops is decreasing consistently. In parallel, ammonia emissions from manure are rising. Much of this “reactive nitrogen” is transported by air to be deposited in nitrogen-limited ecosystems. There it leads to unintentional fertilisation of ecosystems (such as several types of forest) unable to cope with this nutrient inflow, which is one of the leading causes of terrestrial biodiversity loss (Townsend & Howarth, 2010). In addition, fertiliser run-off in coastal ecosystems may lead to algal blooms and dead zones, with inevitable repercussions on aquatic biodiversity (Erisman et al., 2008). Pollution from livestock enterprises impacts both aquatic and terrestrial ecosystems (Raney, Gerosa, Khwaja, Skoet, Steinfeld, McLeod et al., 2009: p. 59).

Table 1. Ranking environmental impacts (boundary value for sustainability = 1).

Rank	Environmental impact	Current status
1	Rate of biodiversity loss	>10
2	Nitrogen cycle disruption	3.45
3	Climate change (Carbon cycle disruption)	1.1-1.5
4	Phosphate cycle disruption	0.77-0.86
5	Ocean acidification	0.81
6	Land-use change	0.78
7	Freshwater use	0.65
8	Stratospheric ozone depletion	0.50

Source: Rockström et al. (2009).

Thus, nitrogen is crucial to aquatic and terrestrial biodiversity loss, climate change, human health and many other issues (McMichael et al., 2007; Erisman et al., 2008; Townsend & Howarth, 2010). Anthropogenic contributions to the natural carbon cycle are 1-2% (by mineral fuel combustion), but to the natural nitrogen cycle 100-200% (by production of artificial fertiliser). Consequently, Rockström et al. (2009) rank the impacts of disrupting the nitrogen cycle in between those of biodiversity loss and carbon cycle disruption, because the current status of biodiversity loss exceeds their proposed sustainability boundary by a factor of more than 10, that of nitrogen cycle disruption by a factor of 3.45, and that of carbon cycle disruption (climate change) by a factor of 1.1-1.5 (Table 1). Since nitrogen cycle disruption has strong impacts on both biodiversity and the carbon cycle, protein production is the pivotal link between the three main issues in Rockström et al.'s ranking.

Disproportionate environmental impacts of animal products

Within the realm of food, meat takes a unique place for its high social status (Beardsworth & Keil, 1997). While the world population doubled during the second half of the 20th century, its appetite for meat increased fivefold, resulting in 40% of the world grain harvest to be fed to livestock (Evans, 1998). Table 2 illustrates this effect of increasing average income. While another 50% will be added to the world population during the period 2000-2050, it is estimated that another 100% will be added to meat production. This projected doubling holds for animal food products in general, since dairy production is projected to increase from 580 to 1043 million tonnes (Steinfeld, Gerber, Wassenaar, Castel, Rosales, & De Haan, 2006: p. 275). Important increases in meat consumption are projected in China, and in dairy consumption in India.

Table 2. World population and meat production 1950-2050.

Year	World population (billion)	Meat production (billion kg)
1950	2.7	45
2000	6.0	229
2050	9.1	465

Source: Steinfeld et al. (2006).

Conversion of plant protein into animal protein is a metabolic process optimised for animal survival. Turning protein from feed crops into animal protein for human consumption is inherently inefficient, however. This makes intensive meat and dairy production responsible for a disproportionate share of environmental pressure (Gilland, 2002; Steinfeld et al., 2006). Thus, 6 kg of plant protein is required to yield 1 kg of meat protein, on average (Smil, 2000; Pimentel & Pimentel, 2003). Consequently, a mere 15% of protein and energy in these crops will ever reach a human mouth (indirectly), and 85% are wasted. In 2000, for example, 942 and 617 million tonnes of grains were required for food and feed, respectively (Msangi & Rosegrant, 2009: p. 27). Of the latter, therefore, over 500 million tonnes are essentially wasted for human consumption and, moreover, turned into polluting emissions, such as from manure. In addition to 40% of the grain harvest, some 75% of soy is fed to livestock, with similar resource losses of some 85%. Evidently, the actual protein conversion efficiency depends on the type of animal under consideration, as well as on the conditions (such as the prevailing diet and climate). Poultry and pigs are more efficient protein converters than beef cattle, but when grass-fed, the latter do not appropriate feed crops. In addition, their multiple stomachs are unsuited to digest maize, which turns them ill. In a watershed report on the environmental impacts of livestock production, the FAO are explicitly addressing both resource depletion and pollution (Steinfeld et al., 2006). Overall, meat and dairy production are playing a crucial role in *all three* of the "planetary boundaries" that have already been overstepped by humanity (i.e. biodiversity loss, nitrogen cycle disruption and carbon cycle disruption), and livestock production is deeply involved in *at least three more* (i.e. land-use change, freshwater use and the phosphorus cycle) of the “planetary boundaries” under threat of transgression (Rockström et al., 2009).

Novel protein foods

A promising solution to reduce protein production impacts may be offered by partial replacement of meat with novel plant protein products (Novel Protein Foods, NPFs) (Smil, 2002c). The multidisciplinary (technological, environmental, social, economic, political, ecological, chemical) PROFETAS programme (Protein Foods, Environment, Technology And Society) showed unequivocally that even partly replacing animal proteins with NPFs might result in a 3-4 fold lower requirement of agricultural land and freshwater and, moreover, that world wide there is a clear potential for a 30-40 fold reduction in acidification and in water use (Aiking et al., 2006).

In PROFETAS (2011), at least four barriers to such a stepwise transition towards decoupling protein production from concomitant environmental impacts have been identified: 1) social forces opposing change are strong, because meat has a high status, 2) economic forces opposing change are strong, because established interests in the meat chain are powerful, 3) technological know-how on novel (plant) protein foods is lacking, and 4) for centuries the meat chain has been optimised for exhaustive use of all by-products, potentially offsetting a large part of the theoretical environmental gain. Relevant actors include consumers, retailers, food processors, farmers, NGOs and policymakers from government and industry, both nationally and internationally, including WTO and OECD, but the environmental benefits of NPFs really depend on their acceptance by consumers (Aiking et al., 2006).

It should be noted that modern “meat substitutes” generally contain 20-30% egg protein. This is added to keep the plant proteins - which are globular - together when fried by consumers. Resulting from the inherent conversion loss from plant protein to egg protein, their environmental performance can be improved substantially. Like in-vitro meat, they may provide stepping stones on the road to fully plant-derived NPFs, with inherently lower environmental impacts. So with R&D directed towards developing NPFs devoid of animal proteins, the food industry can provide a concrete contribution towards a sustainable future (Aiking, 2011).

Innovative ideas may also include the application of insects such as grasshoppers (Vogel, 2010) to upgrade agricultural and urban waste streams to high-quality protein food. Once more, the challenge will be to bring down the cultural barriers of - and to educate - Western consumers. So, with respect to both approaches to make future protein more sustainable - NPFs and insects - the food industry should be receptive to sustainability-driven innovation, on the one hand, and they should take part in consumer education, on the other hand.

Changing food habits

Food has become more affordable, as it is now less than half as expensive in real terms as it was in 1960. To a large extent this is a result of increases in yield per hectare. Even per capita, the world now produces 40% more food than forty years ago. However, in the next forty years another 70% more is required. In addition, climate change and accompanying degradation of land and water resources are to intensify in future. Consequently, world market price projections of the International Food Policy Research Institute (IFPRI) show that world grain prices will increase 30-50% before 2050, and that meat prices will increase an additional 20-30% beyond current high levels (Msangi & Rosegrant, 2009). In their most recent Food Outlook (FAO, 2010) the FAO warned that food prices were likely to rise beyond the 2008 peak values. In January 2011, a few months after publication they did, in fact, and the end does not seem in sight yet.

So we may seem on the brink of a transition, but even in Europe food habits change slowly (De Boer, Helms, & Aiking, 2006; Elzerman, Hoek, Van Boekel, & Luning, 2011). Therefore, Western politicians, industry and consumers should be much more proactive, because if they don't, a transition towards less animal protein is likely to be brought about by rising prices (which will hurt the poor and increase world hunger), rather than by a voluntary and timely drive towards more sustainability and equity.

The biorefinery principle

Biofuels are controversial (Wiebe, Croppenstedt, Raney, Skoet, Zurek, Tschirley et al., 2008; Fischer, 2009), because they were held responsible for the 2008 food price spike. Later analysis clearly showed other causes to have been much more important (Baffes & Haniotis, 2010). Moreover, biofuels may be extremely useful by-products of NPF production. In fact, the first generation of biofuels (sugarcane, maize, palm oil) competes with food, and the second generation (Jatropha etc.) is likely to waste environmentally precious nitrogen. In order to prevent atmospheric, aquatic and terrestrial pollution with active nitrogen compounds, nitrogen should be removed before combustion without exception. Furthermore, the energy input into nitrogen fertiliser production should be recovered. So a sustainable next generation of biofuels can be derived exclusively by fractionating a crop in a food - feed - fibre - feedstock - fuel cascade, retaining the nitrogen in the edible front part of the chain.

Such integrated use will make crop selection a compromise between different goals. In Europe, potential protein crops may include lupin, pea, quinoa, triticale, lucerne, rapeseed/canola, potato, grass, and maybe even soy. Since just 20-40% of the seeds is protein, useful application of the non-protein fraction is indispensable to sustainability. At present, therefore, oilseed crops (such as rapeseed or soy) seem preferable over starchy crops (such as pea) with regard to biofuel production. Nevertheless, it is evident that combining sustainable production of protein and energy in one crop will simultaneously mitigate resource depletion, pollution, as well as climate change: a clear case of win-win-win (Aiking et al., 2006). In contrast, dedicated energy crops (such as oil palm, maize and sugarcane) may be considered a waste of valuable protein and of energy-intensive nitrogen fertiliser, as well as a waste of precious land and water resources (Tilman, Socolow, Foley, Hill, Larson, Lynd et al., 2009).

Conclusions

Global food demand is rapidly increasing and so are the environmental impacts of production. Inevitably, the prices of food and feed crops will rise also, primarily hurting the poor. To weather the storm, the goal can no longer be simply to maximize productivity, but to optimize across a far more complex landscape of production, environmental, and social justice outcomes (Godfray, Beddington, Crute, Haddad, Lawrence, Muir et al., 2010). Whether for environmental reasons, exploding prices, or - more likely - a combination, a trend reversal towards diets containing less animal protein in Western countries seems not just strongly recommendable, but inevitable. At least some consumers seem ready to play their parts (De Boer, Boersema, & Aiking, 2009). The positive impacts on sustainability will largely depend on the extent of a diet shift. In actual reality, a new equilibrium between plant products and animal products is likely to be critically dependent on economic variables such as income and prices.

Food prices are determined primarily by food demand, which is determined in turn by world population, income and consumer preferences. With respect to the latter, it was shown earlier (Aiking et al., 2006) that if consumers in developed countries were to reduce their overall protein intake by about one third, and replace their intensively produced meat by either plant-derived protein products or extensively produced meat, the majority (87-94%) of prime agricultural land currently used for feed crops (400 million hectares world wide, approximately equal to the surface area of EU-27) might be set free. Such a diet transition would result in a tremendous reduction of the pressure on land, freshwater and biodiversity resources, with additional benefits for animal welfare and human health, including reduced incidence of both obesity and emerging diseases, such as MRSA, ESBL, BSE and avian influenza.

Before 1950, animal protein was a luxury that globally few people could afford to eat on a daily basis. Large-scale nitrogen fertiliser application subsequently removed the nitrogen-limited capping of the world population at 3 billion people, which is projected to increase from under 7 to over 9 billion in the next 40 years. The price we may have to pay is that animal protein will become a luxury once more. We must economize our use of natural resources, including land and biodiversity, and conserve water and energy in every possible way. Sustainability-driven innovation should focus on protein, rather than calories, deriving and combining insights from the agriculture, processing, biodiversity, water, bioenergy and health research communities. Reducing consumption of animal products, developing novel plant protein products (NPFs) and reducing food waste will be crucial. Such will provide win-win opportunities to address several important issues at once, including resource depletion, as well as pollution, poverty, and public health. In addition, it will provide a boost towards European self-sufficiency with respect to proteins, as well as biofuels. But there is no time to waste.

References

Aiking, H. 2011. Future protein supply. *Trends in Food Science & Technology* **22**(2-3): 112-120.

Aiking, H., J. De Boer, and J. M. Vereijken. 2006. *Sustainable protein production and consumption: Pigs or peas?* Environment & Policy, Vol. 45. Dordrecht, The Netherlands: Springer, 232 pp.

Baffes, J., and T. Haniotis. 2010. *Placing the 2006/08 Commodity Price Boom into Perspective*. Policy Research Working Paper 5371. Available at http://econ.worldbank.org/. Accessed 23.02.2011. Washington DC, USA: World Bank, 40 pp.

Beardsworth, A., and T. Keil. 1997. *Sociology on the menu: An invitation to the study of food and society*. London, UK: Routledge, 272 pp.

Bruinsma, J. 2009. *The resource outlook to 2050: By how much do land, water and crop yields need to increase by 2050?* Expert Meeting on How to feed the World in 2050 (12-13 October 2009). Available at http://www.fao.org/wsfs/forum2050/wsfs-background-documents/wsfs-expert-papers/en/. Accessed 23.09.2009. Rome, Italy: FAO.

De Boer, J., Boersema, J. J., & Aiking, H. 2009. Consumers' motivational associations favoring free-range meat or less meat. *Ecological Economics* **68**: 850-860.

De Boer, J., Helms, M., & Aiking, H. 2006. Protein consumption and sustainability: Diet diversity in EU-15. *Ecological Economics* **59**: 267-274.

Elzerman, J. E., Hoek, A. C., Van Boekel, M. A. J. S., & Luning, P. A. 2011. Consumer acceptance and appropriateness of meat substitutes in a meal context. *Food Quality and Preference* **22**(3): 233-240.

Erisman, J. W., Sutton, M. A., Galloway, J. N., Klimont, Z., & Winiwarter, W. 2008. How a century of ammonia synthesis changed the world. *Nature Geoscience* **1**(10): 636-639.

Evans, L. T. 1998. *Feeding the ten billion: Plants and population growth*. Cambridge, UK: Cambridge University Press, 248 pp.

FAO 2010. *Food Outlook November 2010*. Rome, Italy: FAO. Biannual report, available at http://www.fao.org/worldfoodsituation/wfs-home/en/. Accessed 23.02.2011.

Fischer, G. 2009. *World food and agriculture to 2030/50: How do climate change and bioenergy alter the long-term outlook for food, agriculture and resource availability?* Expert Meeting on How to feed the World in 2050 (12-13 October 2009). Available at http://www.fao.org/wsfs/forum2050/wsfs-background-documents/wsfs-expert-papers/en/. Accessed 23.09.2009. Rome, Italy: FAO.

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.

Godfray, H. C., Beddington, J. R., Crute, I. R., Haddad, L., Lawrence, D., Muir, J. F., et al. 2010. Food Security: The Challenge of Feeding 9 Billion People. *Science* **327**(5967): 812-818.

Johnson, J., McCabe, J., White, D., Johnston, B., Kuskowski, M., & McDermott, P. 2009. Molecular Analysis of Escherichia coli from Retail Meats (2002–2004) from the United States National Antimicrobial Resistance Monitoring System. *Clinical Infectious Diseases* **49**(2): 195-201.

Lang, T., D. Barling, and M. Caraher. 2009. *Food Policy: Integrating health, environment & society*. Oxford, UK: Oxford University Press.

McMichael, A. J., Powles, J. P., Butler, C. D., & Uauy, R. 2007. Food, livestock production, energy, climate change, and health. *Lancet* **370**(9594): 1253-1263.

Msangi, S., and M. Rosegrant. 2009. *World agriculture in a dynamically-changing environment: IFPRI's long-term outlook for food and agriculture under additional demand and constraints*. Expert Meeting on How to feed the World in 2050 (12-13 October 2009). Available at http://www.fao.org/wsfs/forum2050/wsfs-background-documents/wsfs-expert-papers/en/. Accessed 23.09.2009. Rome, Italy: FAO.

Nierenberg, D. 2006. Rethinking the global meat industry. In *State of the world 2006 - A Worldwatch Institute report on progress towards a sustainable society*, pp. 24-40, D. Nierenberg, ed. London, UK: Earthscan.

Pilcher, H. 2004. Increasing virulence of bird flu threatens mammals. *Nature* **430**: 4.

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

PROFETAS 2011. *Protein Foods, Environment, Technology And Society*. Up-to-date information available via: http://www.profetas.nl/. Amsterdam, The Netherlands: VU University.

Raney, T., S. Gerosa, Y. Khwaja, J. Skoet, H. Steinfeld, A. McLeod, et al. 2009. *The state of food and agriculture 2009: Livestock in the balance*. Rome, Italy: FAO.

Rockström, J., Steffen, W., Noone, K., Persson, A., Chapin, F. S., Lambin, E. F., et al. 2009. A safe operating space for humanity. *Nature* **461**(7263): 472-475.

Smil, V. 2000. *Feeding the world: A challenge for the twenty-first century*. Cambridge (Mass.), USA: MIT Press, 360 pp.

Smil, V. 2001. *Enriching the earth: Fritz Haber, Carl Bosch, and the transformation of world food production*. Cambridge (Mass.), USA: MIT Press, 338 pp.

Smil, V. 2002a. Nitrogen and food production: Proteins for human diets. *Ambio* **31**(2): 126-131.

Smil, V. 2002b. *The Earth's biosphere: Evolution, dynamics, and change*. Cambridge (Mass.), USA: MIT Press, 346 pp.

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

Steinfeld, H., P. Gerber, T. Wassenaar, V. Castel, M. Rosales, and C. De Haan. 2006. *Livestock's long shadow: Environmental issues and options*. Rome, Italy: FAO.

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

Tilman, D., Socolow, R., Foley, J. A., Hill, J., Larson, E., Lynd, L., et al. 2009. Beneficial Biofuels - The Food, Energy, and Environment Trilemma. *Science* **325**(5938): 270-271.

Townsend, A. R. & Howarth, R. W. 2010. Fixing The Global Nitrogen Problem. *Scientific American* **302**(2): 64-71.

Vogel, G. 2010. For More Protein, Filet of Cricket. *Science* **327**(5967): 811.

Wiebe, K., A. Croppenstedt, T. Raney, J. Skoet, M. B. Zurek, J. Tschirley, et al. 2008. *The State of Food and Agriculture 2008 - Biofuels: Prospects, Risks and Opportunities*. Rome, Italy: FAO.

The Canadian Food Market and the concept of sustainability; interest of the consumer, impact for the industry

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Abstract. *In recent decades agriculture has undergone significant changes in response to evolving marker demands and new production technologies. In Canada, there was a shift towards larger and more intensive operations that has increased awareness by farmers, government and the public of the fundamental links that exists between agriculture and the environment. Canadians are placing increasing demands on farmers and processors to find the proper balance between meeting production objectives and the environment soundness of production methods. In response to that, Agriculture and Agri-Food Canada has developed a set of science-based agri-environmental indicators that measure the agriculture and agri-food sector's environmental performance for soil, water and air quality, farm land management, and resource use efficiency in the food and beverage industries. A brief overview of significant results will be presented. Broad national-level observations and regional variations will be outlined on the status and trends of agri-environmental sustainability of the Canadian Agriculture and agri-food sector. Moreover, this information can be used as a report card to highlight where further efforts are required and provides information that decision makers can draw from to develop and evaluate agricultural policy. While reporting and monitoring will remain an important science focus, agri-environmental research in Canada is re-focussing on the impact of climate change, climate change adaptation and water quality. In an effort to move towards sustainability, research activities are currently being developed through the implementation of clusters at sector level.*

Keywords. Food chain, Environment, Consumers, Industry, Energy

The Sustainable Food Production in Brazil: How Far Can We Go to Feed the World?

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Abstract. *Fostered by a dynamic and stable domestic economy, and by the growing international demand for grains, fiber and renewable bioenergy, Brazil harvested last season a record of 147 million tons of grains, an increase of 9.4% as compared to 2009. However, the planted area did not change significantly, staying in a little over 47 million of hectares, less than 6% of its large territory. The expansion of the agricultural frontier for the establishment of plantations has been strongly discouraged at present, since it is estimated that there are at least another 50 million hectares suitable for intensive use only in the Cerrado, the Brazilian savannah. At the same time, the recovery of degraded pastures and the intensive use of conservation practices such as crop-livestock integration to mitigate emissions of greenhouse gases are stimulated in the fields. Even though a large quantity of agricultural inputs is still imported, the widespread adoption of practices of inoculation to promote biological nitrogen fixation provides annual savings of about 3.2 billion of Euros per year, only for soybean. This fact minimizes the emission of N2O and increases the whole sustainability in terms of energy balance. For sugarcane, the gradual elimination of cane burnings prior to harvesting until its abolition by 2022, with legal basis, will tend to reduce the levels of air pollution and increase carbon stocks in soil. To meet the quality criteria of the international consumer markets of the Brazilian agricultural commodities, a number of initiatives are being taken aiming to give greater transparency in the food production chains regarding the use of natural resources, energy efficiency, environmental and social impact, and the conduction of further life-cycle studies.*

Keywords. Leave the word "Keywords." then type keywords or key phrases, separated by commas. List both specific and general terms that will aid in searches.

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Refrigerated Warehousing as a Smart Tool to Store Renewable Energy for Improving the Food Chain and Power Supply Sustainability

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Abstract. Distributed renewable energy resources (such as wind and solar energy) have a substantial potential for energy supplies and reducing CO_2 emissions but have been difficult to integrate so far because of their intermittent contribution. The integration of wind power into the national or EU energy supply systems becomes more complicated with increasing the production capacity of installed wind turbines, because of the mismatch of supply and demand of energy. Wind energy is generated at random times, whereas the energy use pattern shows distinct demand peaks during day time and office hours, and low consumption during the night. The use of a refrigerated warehouse for storing renewable wind energy affords economic benefits from the cost difference between low and peak-hour electricity tariffs and permits to offset undesired peaks in the electrical grid. Energy is stored by producing more cold than necessary (thereby refrigerating the products below the prescribed temperatures), while turning off the refrigeration plant releases virtual energy matching the difference between the average and the zero cold store demands (and letting foods warm up back to the recommended temperatures of storage). For example, if the temperature of stored frozen products throughout EU is permitted to vary by 1 °C only, all refrigerated warehouses can act as a giant battery on the grid – they could store twice the planned EU's wind power production for 2010. While balancing the wind power production by fossil fuel power generation is inefficient, such balancing by refrigerated warehouse load management is a sustainable (environmentally friendly and cost effective) alternative with reduced running costs for the cold chain operators.

Such a concept needs optimal strategies for fine control of the cold store operation, based on economic criteria (e.g. balance between the instantaneous wind energy production and actual electricity demand, predicted dynamic/stochastic variations of electricity tariffs on the stock market, etc.), along with engineering and food quality requirements. Hence, this contribution pays special attention to the resulting food quality by investigating quality attributes of selected frozen foods undergoing temperature fluctuations (daily freeze-thaw cycles) during storage. The study revealed that the quality of frozen products subject to fluctuations of storage temperature is generally acceptable but, as expected, inferior in comparison with food maintained at a constant temperature (in compliance with the established food refrigeration standards and good practices). However, for many products this quality decay is rather negligible and can be offset by the obvious economic and sustainability-related advantages of the smart technology employed.

Keywords: food chain, food refrigeration, cold storage, refrigerated warehousing, frozen foods, load management, energy efficiency, environmental friendliness, food quality, sustainability

Sustainability of the Food Cold Chain

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Abstract. *The food cold chain is an essential component of the urbanised and industrialised world. This paper examines the sustainability of cold chains by analysing product carbon footprints for some refrigerated foods produced in NZ and consumed in the UK. The impact of the refrigeration component is only about 20% of the total impact of the food supply chain. The main environmental impacts of the cold chain are due to refrigerant leakage and energy use, although water use and construction materials can also be important factors. The impact increases with length of storage and/or transport, so eating local seasonal production after minimal storage is often the most sustainable option. Imported counter-seasonal food can be more sustainable than storage of local production especially when primary production in the exporting country is significantly more efficient. On-going efforts to reduce refrigerant leaks, transition to non-ODP and low GWP refrigerants such as natural refrigerants, and improve energy efficiency are all high priority ways to improve sustainability of the cold chain. If year-round supply of perishable products is demanded, then refrigerated storage offers a relatively low cost and low impact solution that is better than most other preservation methods or high rates of food wastage. Changes to eating habits are probably necessary if very large improvements in sustainability of the food chain are to be achieved.*

Keywords. *sustainability, food cold chain, refrigerated food, international trade, carbon footprint.*

Introduction

Food preservation technology has had a key role in allowing the industrialisation and urbanisation of many developed countries and overcoming malnutrition in many developing countries (IIR, 2009). In particular, extension of shelf life allows food supplies to be transported from production areas to population centres with reduced wastage and loss of quality.

Refrigeration is the preservation technique that most closely maintains the original food quality attributes. Therefore its use has grown faster than other preservation techniques such as salting, canning and drying particularly in the developed world, which demands high quality, and not just safe and nutritious foods.

This paper examines the sustainability of the refrigerated food supply chain (the cold chain), identifies the key components of the chain and the key issues requiring attention and suggests ways to improve the cold chain sustainability. Many of the components of the cold chain are common with other food supply systems (e.g. primary production) so the focus will be on aspects of the cold chain that are different or additive to other food supply chains.

SUSTAINABILITY

Many businesses are now concerned about the environmental credibility of their products and the potential impact on their business if they are perceived to have poor environmental performance. It is generally accepted that sustainability has at least three dimensions: environmental, economic and social. Ideally, all three dimensions are considered but in many cases there is a trade-off between criteria requiring subjective rather than objective comparisons of quite different aspects.

There are well established metrics for the economic dimension (e.g. GDP). Considerable effort has been made to devise good environmental and social metrics. Some social metrics are obvious (e.g. life expectancy) but aspects such as happiness are more difficult to quantify. Rates of use of abiotic resources are often obvious environmental metrics but environmental impacts can be highly varied and can be regional in importance. Methodologies such as Life Cycle Assessment (ISO 14040 Series) and the PAS 2050 (BSI, 2008) have been developed to systematize the process of quantifying environmental impacts. Williams et al. (2009) and Heller and Leoleian (2000) give some quantitative metrics developed and used in the UK and the US respectively. Indices that attempt to combine the multiple dimensions and attributes such as the "Genuine Progress Indicator" have been proposed but agreement on what is the best integrated approach is difficult because of different perspectives and values between individuals, groups and countries (Costanza et al., 2004).

Figure 1 shows maps of the world transformed to show country size in proportion to land area, population, ecological footprint and agricultural a agricultural water use (Dorling, 2006). The ecological footprint is the combined land and water area required to both produce the resources consumed and to assimilate the wastes created by the population using prevailing technology and resource management schemes (Rees, 1992). The demands and impacts of human activities exceeded the planet's natural ability to support them by about 20% in 2001 and continue to grow as population and economic growth outpace technological improvement (WWF, 2005).

COLD CHAINS

Characteristics of Cold Chains

Figure 2 shows the supply chains used in LCA studies for both fruit and meat products that are refrigerated and exported from NZ. For a locally consumed product, the usual difference is that there is one less storage and transport (often shipping) stage. In some supply chains, rail transport may be used instead of road transport. For highly perishable and/or valuable products, air freight may be used rather than shipping but this is quite rare due to the high costs let alone the environmental impact (less than 1% of foods are transported by air freight; Garnett, 2008). In some cases, use of more sophisticated refrigeration technology has lengthened shelf life sufficiently to allow a move from air freight to shipping in a manner that the saving in transport costs and impacts are far greater than the extra refrigeration costs and impacts (e.g. vacuum packed chilled beef and lamb). The consumer component of the supply chain includes processes such as cooking but some products such as fruit might be consumed raw.

The stages of production, transport, retail and consumption are very similar for refrigerated food and food preserved in other ways. The key marginal aspects for refrigerated food is the need to cool the food and keep it refrigerated during storage by each of the manufacturer, retailer and consumer and during any long duration transport stages. Therefore the key margin impacts for refrigerated foods relate to use of refrigerants (e.g. toxicity, **O**zone **D**epleting **P**otential and **G**lobal **W**arming **P**otential), provision of refrigerated equipment and facilities, energy use by refrigeration systems (and consequential GWP, eutrophication etc) and in some cases different packaging requirements. Aspects such as direct water use and eutrophication due to refrigeration are generally very small relative to that due to primary production (e.g. irrigation and use of fertilisers) and processing (e.g. water use and discharges to water).

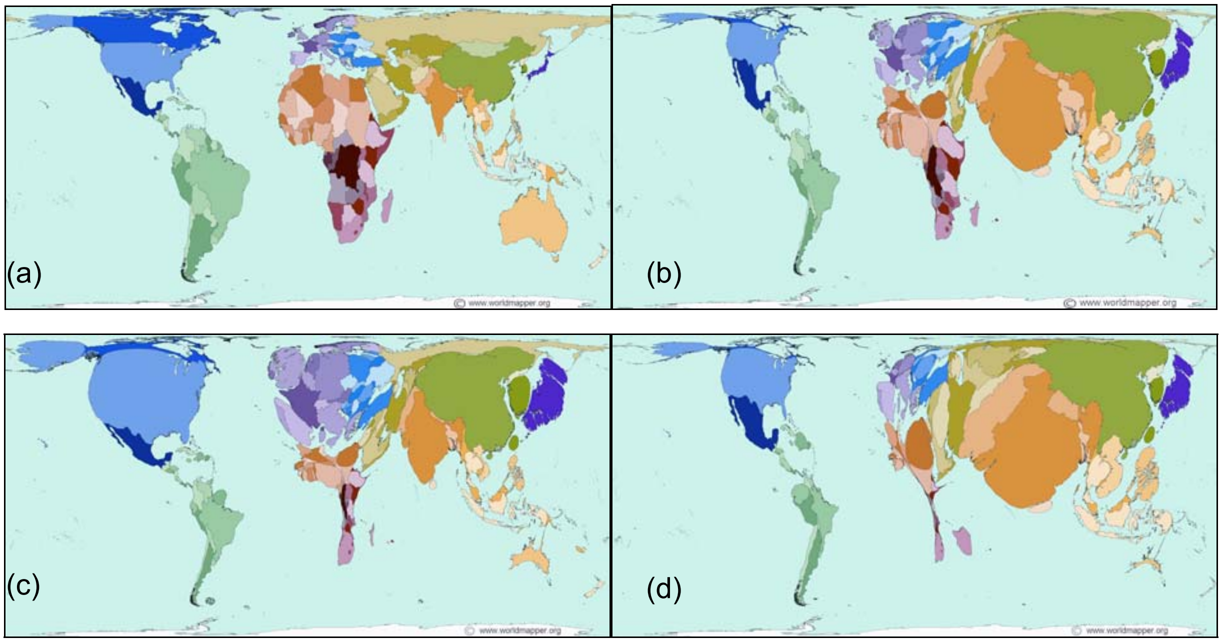

Figure 1. World maps with country sizes shown in proportion to various attributes (a) land area, (b) population (c) ecological footprint (d) agricultural water use. (Source: www.worldmapper.org)

Comparison With Other Preservation Methods

Table 1 provides a high level comparison of three common food preservation technologies. In summary, relative to other preservation methods, refrigerated foods offer better quality and cheaper processing but more expensive storage and transport and higher on-going losses. Currently, cost and quality considerations seem to dominate consumer choice between such options rather than any strong environmental driver.

Another useful comparison is between refrigerated and non-refrigerated (no other means of preservation) supply chains. The key question is whether reduction in waste, increase in production yield and efficiency in other geographical regions and/or increase in quality, justify the extra costs and environmental burden. The existence of refrigerated supply chains show that they clearly do, from an economic and social sense. This is particularly because the availability of seasonal products is extended and consumers have access to a greater variety of higher quality products, including those not produced in the local climate.

Sustainability of Cold Chains

A few years ago, food miles were used as a de facto measure of sustainability, particularly in Europe. The limitations of this approach have now largely been recognised scientifically (e.g. Smith et al., 2005; Coley et al., 2009) but it continues to be used to provide market advantage by some commercial interests. The key limitations are that transport is only one component of the impact, different transport options have quite different impacts, local production may be less efficient than in more distant locations and, for an out-of-season product, then importing may be a better option than long term storage of local production.

It is now accepted that a full life-cycle assessment approach is needed, but currently many analyses are limited to carbon footprints (essentially GWP). Reasons include climate change concerns, interest in the Kyoto Protocol, the fact that GWP data is generally more readily available or easier to estimate yet covers a wide range of emissions, and that many of the other impacts are highly correlated to GWP. Analyses are likely to extend to other metrics once information sources improve and agreement on the best composite measures is reached.

Cold Chain LCAs

Figure 2 summarizes recent carbon footprint LCA studies for kiwifruit and apples produced in NZ but consumed in the UK. While international shipping is an important component of the total (30 or 45%), the consumer, retailer and local distribution chain are also significant. Transport at various stages in the chain accounted for 50 to 70% of the total footprint, while refrigeration in transport and storage (energy for cooling, refrigerant emissions and capital) accounted for only about 10% of the footprint. The total footprint for kiwifruit was about 30% higher than for apples reflecting quite different orchard practices and yields, greater use of fluorocarbon refrigerants (rather than ammonia) in storage facilities and a 50% longer average storage period. These factors were countered by greater use of reefer ships for kiwifruit relative to greater use of refrigerated containers for apples. Interestingly, organically grown kiwifruit had a slightly higher footprint than non-organic, mainly due to lower yields and greater use of farm machinery rather than relatively low carbon footprint agri-chemicals.

Garnett (2008) estimated that the total carbon footprint for the food supply chain (both refrigerated and non-refrigerated) is about 19% of the complete UK carbon footprint, and that of this about 45%, 19%, 12%, 13% and 11% were due to primary production, manufacturing and storage including packaging, retail and food service, transport in all sectors and the domestic (consumer) sectors respectively. Further, it was estimated that food refrigeration throughout the supply chain contributes about 3 to 3.5% of the UK carbon footprint (i.e. about 15% of the footprint due to all food). Garnett (2007) estimated that the total carbon footprint for the refrigerated component of the food supply chain (omitting transport refrigeration) was about 2.4% of the complete UK carbon footprint and that about 8%, 41% and 51% of this was due to manufacturing/storage, retail and domestic (consumer) sectors respectively. These estimates are consistent if transport refrigeration is about 0.5 to 1% of the UK footprint. If so, the breakdown of the refrigeration component by sector becomes about 6%, 31%, 24% and 40% for manufacturing/storage, retail, transport and domestic (consumer) sectors respectively.

Table 2 summarises a study that compared the carbon footprint of apples and meat products consumed in the UK but originating either in NZ or the UK (Williams et al., 2009). The study excluded the supply chain after the UK regional distribution centre because this would be identical for both supply chains. The Garnett (2007, 2008) data suggests that between 20 and 40% of the complete footprint is omitted. While the broad trends and overall footprint are similar to other studies for meat (e.g. Schlich & Fleissner, 2003) and the Figure 3 study for apples from NZ to the UK, there are significant differences due to differing assumptions and data sources.

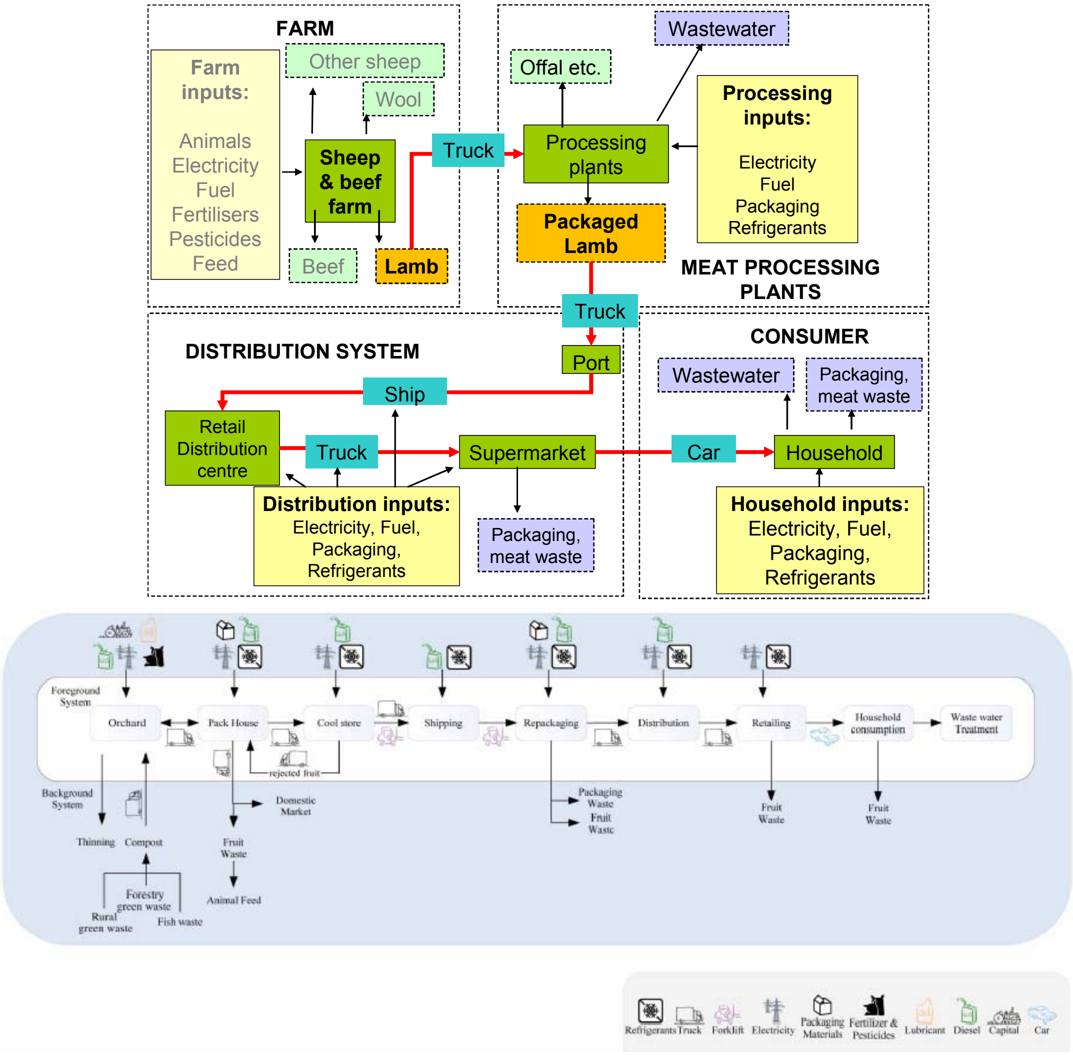

Figure 2. Typical supply chains used for LCA studies for a meat and fruit export products.

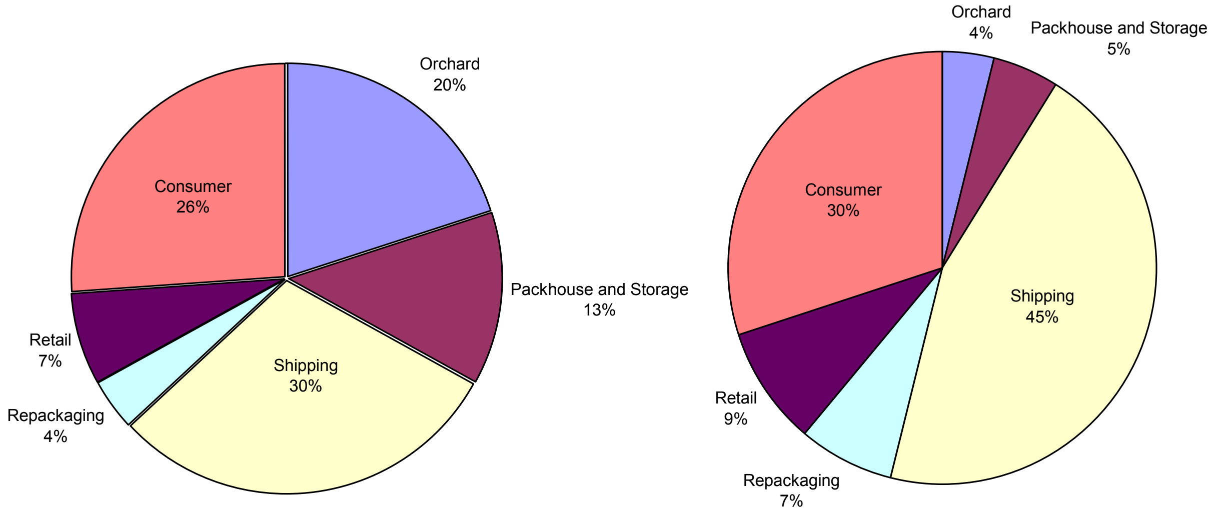

Figure 3. Contributions to the carbon footprint from different parts of the supply chain for kiwifruit (left) and apples (right) being supplied from NZ to the UK.

Table 1. Comparison of different food preservation methods.

Preservation Method	Refrigeration	Drying	Canning
Perceived Quality	fresh	processed	processed
Eating Quality	"fresh" (chilled) near fresh (frozen)	inferior as reconstituted	precooked
Transport	extra cost of insulation, refrigeration system & energy	lower weight; dry freight	extra weight of "sauce" and can; dry freight
Storage	below ambient; special facilities; high energy	ambient	ambient
Packaging	cardboard and plastic (heavy)	cardboard and plastic (light)	metal
Shelf Life	short to medium	long	long
Processing Equipment	simple, moderate cost	high cost	high cost
Processing Energy	low to medium (cool by about 30°C or freeze water)	high (evaporate water)	medium (heat by 100°C and cool)
Approx. Enthalpy Change	150 kJ/kg (chilled) 350 kJ/kg (frozen)	2500 kJ/kg	400 kJ/kg
Typical Energy Efficiency	200% (COP = 2)	50% drying 300% evaporation	70% (boiler)
Losses/Wastage	moderate	low	low

Table 2. LCA comparison of the carbon footprint for different food cold chains excluding retail distribution, retailing and the consumer components (Williams et al., 2009).

Supply Chain	Pre-Farm Gate (kg CO_2 eq./kg)	Post-Farm Gate (excluding retail & consumer) (kg CO_2 eq./kg)	Total (kg CO_2 eq./kg)
NZ Apples – 0 months storage	0.08	0.78	0.87
NZ Apples – 3 months storage	0.09	0.83	0.92
UK Apples – 0 months storage	0.16	0.14	0.30
UK Apples – 5 months storage	0.16	0.19	0.35
NZ Lamb	9.71	1.85	11.56
UK Lamb	13.45	0.69	14.14

Some lessons from such analyses are:

1. ODP, GWP and energy are dominant for the refrigeration specific part of the supply chain.
2. Across the full supply chain, the GWP impact of refrigeration is less than 20% of the total.
3. For lightly processed foods grown outside, such as many fruit and vegetables, differences in primary production impact are small relative to storage and transport impacts. For seasonal supply products, longer supply chains may be compensated by shorter storage periods but the relativity particularly depends on refrigerants used and leakage rates, electricity emission factors, and transport type and distance. For example, refrigerated storage in NZ has a relatively low impact because about 70% of electricity generation is renewable.
4. The footprints for meat and dairy products are much higher than for fruits and vegetables due to the high farm emissions (e.g. ruminant methane), greater processing, the need for refrigeration in the retail and consumer sectors and more cooking by the consumer.

5. For meat and dairy products, the primary production impact dominates, so differences in transport and storage are less influential on the difference between supply chains.
6. Embodied impacts in refrigeration equipment and facilities are small relative to refrigerant emissions and energy used if 15-20 year life cycles are assumed (for materials used in refrigeration systems a typical embodied energy content is 65 MJ/kg). Therefore, while economically desirable, extreme longevity of equipment is unlikely to significantly reduce impact. Conversely if refrigeration equipment needs replacement on less than a 5 year cycle, then the embodied footprint could be significant. Overall, it is more important that equipment is energy-efficient so increased initial investment to ensure good efficiency is likely to lead to lower life cycle environmental impact.
7. Over the whole food cold chain, the impacts of refrigerant emissions are less than 15% of those due to energy use (Heap, 2001). However, for retail, transport and fluorocarbon industrial systems the refrigerant leakage impact can be significantly worse than for domestic (hermetic) and natural refrigerant systems.
8. There is considerable uncertainty in such analyses. In particular, despite websites such as www.shippingefficiency.org, definitive footprint data for international shipping of refrigerated goods is still required. For example, the difference in emission factors for refrigerated containers and reefer ships (refrigerated holds) is difficult to find, yet intuitively should be significant. This is surprising given the well defined nature of this activity but may reflect commercial sensitivity!
9. Irrespective of the supply chain and food, the impacts of the retail and consumer sectors are significant. Transport by the consumer from retailer to home is particularly significant!

For a comparison of local versus imported seasonal product, the issues are higher local cost of production and/or storage versus transport cost and impact. In many cases these are offset. In theory, economics should drive supply to the most environmentally benign. In practice, many environmental costs are externalities borne by society as a whole (or future generations) and can lead to claims of exploitation of developing countries by developed countries. There are many attempts to address this internationally in an equitable manner. Some, such as the Montreal Protocol for ozone-depleting substances, have been generally regarded as successful, whereas the success of the Kyoto Protocol for global warming is still uncertain.

IMPROVED SUSTAINABILITY

Given the above analysis, improved sustainability of refrigerated foods is best addressed in 3 main areas – refrigerants, energy efficiency and eating habits.

Refrigerants

Less than 15% of the direct refrigeration impact is due to refrigerant emissions but this is higher for some sectors of the cold chain e.g. retail, some industrial and transport.

In terms of the cold chain, given that CFCs have largely been phased out of use under the Montreal Protocol, the main refrigerants that are relevant are HCFCs such as R22, HFCs such as R134a, R404A, R407C, R507 and blends for replacement of R22, and natural refrigerants such as ammonia (R717), CO_2 (R744), air (R729) and hydrocarbons including propane (R290), isobutane (R600a) and ethane (R170).

Table 3 provides a high level comparison of the various refrigerant groups. Clearly, refrigerant choice is often a trade-off between competing issues and there is no perfect refrigerant. Improving sustainability means choosing zero ODP and low or zero GWP refrigerants without impacting energy efficiency, reducing refrigerant charges so the quantum of leaks is restricted, and improving system design, maintenance practices and disposal systems so leakage rates are reduced. Currently leakage is minimal from small scale hermetic systems. Although, the number of such systems is huge so retirement and disposal are important, while transport and field-erected commercial systems have the worst leakage rates (Heap, 2001). It is ironic that leakage rates are often largest for systems using so-called safe refrigerants that have high GWPs and low for refrigerants with safety concerns.

Table 3. Comparison of refrigerants assuming application in appropriate temperature ranges.

Criteria	HCFCs	HFCs	Natural Refrigerants
Cost	medium	high	low
System Cost	medium	medium	high
Capacity	good	good	very good
Energy	good	good	very good
ODP	yes	no	no
GWP	very high	high	very low
Safety (flammability, toxicity, high pressure)	good	generally good	significant risks

Energy Efficiency

Refrigeration system energy use is significant at all stages in the cold chain but transport, retail and domestic sectors are the most important. Energy use has low environmental impact if it is from a renewable source. Most non-transport refrigeration systems operate on electricity so the emission factor for the local electricity supply system is important. Given that refrigeration is less than 20% of the total food supply chain impact, improved energy efficiency of the non-refrigerated components of the chain is at least as important.

Most commentators feel that reductions in energy use by 20 to 50% are readily achievable in an economic manner in most sectors. However, there is a need to shift from first cost to life cycle cost mentality when equipment is purchased, as well as a need for greater system knowledge by designers, operators and maintenance engineers to ensure lower energy use is achieved.

Improvements in refrigeration are most likely to arise from incremental technology enhancements such as improved insulation, higher efficiency compressors and fans, more compact higher performance heat exchangers, expansion engines and improved controls but improved design, commissioning and servicing must also occur.

In some sectors, fundamental changes to the supply chain may occur (e.g. road to rail transport if inter-modal constraints can be addressed; air to surface transport if packaging and adjunct preservation techniques can lengthen shelf-life; bulk transport then pack, rather than pack then transport)

Economics is likely to remain a strong driver, especially if environmental externalities can be internalised, but policy instruments such as Minimum Energy Performance Standards (MEPS) might be appropriate for some sectors.

Eating Habits

Garnett (2007, 2008, 2011) suggests reducing the refrigeration dependence by change in diet and habits. If the population was willing to change their habits to eat local seasonal products, then the need for long term storage and long distance transport of food could be reduced. Table 2 data suggests a diet change away from meat and dairy products would have the biggest benefits. The environmental impact benefits arise more from avoiding the intensive primary production and processing for such products than the refrigeration component. However, the effect on health and well-being including mood may well offset the direct environmental benefits. This is a delicate trade-off between environmental impacts and “quality of life” factors.

Another aspect of this idea is for consumers to only purchase non-refrigerated perishable food. To stop food waste becoming excessive this would probably require both a greater tolerance of product not being blemish free and/or more frequent shopping for such products, which could increase the consumer transport component to more than compensate for the saved refrigeration impact. It might also require change in food preparation habits to ensure food wastage was minimised. The offset of more transport might be reduced if the food retail were sufficiently local that car transport was unnecessary but this would require a significant change in infrastructure and habits. Internet buying and workplace or home delivery mechanisms might reduce such impacts but the changes in habits required are not trivial and have an element of being “back to the future”.

Developing Countries

The above analysis applies mostly to developed countries. Developing countries are facing the issues of under-nourishment and economic development. It would be preferable if the best features of a local food supply system could be supplemented with targeted refrigeration technology to reduce waste, and improve food safety and nutrition/diet in particular. A challenge is to avoid the mistakes of the developed world in terms of supply chain design and food choice expectations (refrigeration dependence). Also refrigerant choice and system designs for the cold chain must be affordable. Systems need to be simple (appropriate) and, if possible, use renewable energy. Some possible approaches are to focus on bulk preservation and transport to local markets and to use passive rather than active cooling e.g. evaporative cooling. Avoiding the start of refrigeration dependence for such countries is difficult because often an obvious choice for economic development is to export food to the developed world, thereby starting a need for sophisticated cold chains!

CONCLUSION

Sustainability involves a complex trade-off between environmental, social and economic factors. Carbon footprints (GWP) capture most of the environmental impact of the cold chain that differs from other food supply chains. LCA approaches are needed to compare alternative supply chains because the system with least impact is not always obvious. Direct refrigeration-related impacts are only about 20% of the total GWP impact for refrigerated foods, so often it is primary production or transport impact differences that determine the supply system with least overall impact. Change in eating habits away from dairy and meat products and towards local seasonal products would have the biggest impact on the footprint but is probably socially unacceptable. If full diet choice is retained, improved sustainability of the cold chain is most likely to be achieved by improved energy efficiency, different refrigerant choices, charge minimisation and leakage prevention but requires environmental impacts to be internalised and life cycle costing approaches to be widely adopted. In many cases, the best opportunities for significant improvement in energy efficiency in existing cold chains are incremental technology, design and operational enhancements.

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References

BSI. 2008. PAS 2050 – Specification for the Assessment of the Life Cycle Greenhouse Gas Emissions of Goods and Services (draft), Publicly Available Specification, British Standards Institution.

Coley, D., Howard, M., Winter,M. 2009. Local food, food miles and carbon emissions: A comparison of farm shop and mass distribution approaches. *Food Policy* **34** (2011): 150-155.

Costanza, R., Erickson, J., Fligger, K., Adams, A., Adams, C., Altschuler, B., Balter, S., Fisher, B., Hike, J., Kelly, J., Kerr, T., McCauley, M., Montone, K., Rauch, M., Schmiedeskamp, K., Saxton, D., Sparacino, L., Tusinski, W., Williams, L. 2004. Estimates of the Genuine Progress Indicator (GPI) for Vermont, Chittenden County and Burlington from 1950 to 2000. *Ecological Economics* **51**: 139-155.

Dorling, D. 2006. Worldmapper Project, http://www.worldmapper.org, SASI, University of Sheffield. Accessed 28 September 2009.

Garnett, T. 2007. Food Refrigeration: What is the Contribution to Greenhouse Gas Emissions and How Might Emissions be Reduced?, Food Climate Research Network working paper, April 2007, Centre for Environmental Strategy, University of Surrey, UK.

Garnett, T. 2008. Cooking Up a Storm: Food Greenhouse Gas Emissions and Our Changing Climate, Food Climate Research Network, Centre for Environmental Strategy, University of Surrey, UK, September 2008.

Garnett, T. 2011. Where are the best opportunities for reducing greenhouse gas emissions in the food system (including the food chain)? *Food Policy* **36** (2011): S23-S32.

Heap, R.D. 2001. Refrigeration and air-conditioning – the response to climate change, *Bulletin IIR*, **2001-5**: 2-16.

Heller, M.C., Keoleian, G.A. 2000. Life Cycle-Based Sustainability Indicators for Assessment of the US Food System, Report No, CSS00-04, December 2000, Center for Sustainable Systems, University of Michigan, Ann Arbor, MI

IIR. 2009. The Role of Refrigeration in Worldwide Nutrition, 5th Informatory Note on Refrigeration and Food, International Institute of Refrigeration, Paris, June 2009.

Rees, W. 1992. Ecological footprints and appropriated carrying capacity: what urban economics leaves out. *Environment and Urbanization*, **4** (2):121–130.

Schlick, E.H., Fleissner, U. 2003. Compaisons of regional energy turnover with global food. *International Journal of LCA* **8** (4): 252.

Smith, A., Watkiss, P., Tweddle, G., McKinnon, A., Browne, M., Hunt, A., Treleven, C., Nash, C., Cross, S. 2005. The Validity of Food Miles as an Indicator of Sustainable Development, Final report to Defra (ED50254), July 2005, AEA Technology plc, UK.

Williams, A.G., Pell, E., Webb, J., Evans, D., Moorhouse, E., Watkiss, P. 2009. Comparative Life Cycle Assessment of Food Commodities Procured for UK Consumption Through a Diversity of Supply Chains, Final Report for Defra Project FO0103, Defra, www.defra.gov.uk. Accessed 30 September 2009.

WWF. 2005. Europe 2005 – The Ecological Footprint, WWF European Policy Office, Brussels, Belgium, June 2005.

Sustainable Agro-Food Production Concept: Food Clusters

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Abstract. *In the past decades adaptation of agro-food chains' spatial organization has lingered behind technological, social and (international) market developments. Currently, over 50% of the world population lives in cities, whereas most agricultural production still is organised in a typical rural setting. Scaling-up and industrialisation of food production and distribution chains has widened the gap between food producers and consumers. Furthermore, utilisation and valorisation of by-products has suffered from increased specialisation and focus on the chains' primary product. These developments have led to vast logistic transport, with poor conditions for sustainable innovations.*

Modern interpretations of sustainable traditional principles (short chains and mixed farming with various methods of recycling nutrients) can largely reduce such drawbacks of the current agro-food chains. Through spatially combining various farming activities and agro-food processes (still with modern specialised companies and chains) a suitable context can be created for (re-)introduction of biomass valorisation and recycling pathways, and hence contribute to sustainable food production and biobased economy development. This principle is used to support development of food clusters in NW-Europe and upcoming economies.

Results demonstrate the added value of spatial clustering of different production chains: reduced logistics and improved conditions to valorise residuals and by-products.

Keywords. Greenports, industrial ecology, food chains, utilization of residues, market responsiveness.

Introduction

The food production system is rapidly changing. Currently, over half of the worlds population is living in cities; in the forthcoming decades this will increase to two thirds. With the advancing industrialisation welfare increases and the food demands of the new citizens are changing from a high energy rich carbohydrate menu towards a protein rich menu. Agro-food production responding to that demand, is nowadays organised in world-wide chains and networks, involving industrial supply of raw materials, primary production and industrial processing (Smeets, 2009).

With an eye on efficiency and market position, most dominant development strategies applied are aiming on intensification, specialisation, increasing spatial concentration and scaling-up of primary production and processing. Main focus of agro logistics research has upon now been the optimisation of logistics within the boundaries of a logistic chain, principally focussing on the chains' primary product. This development strategy results in spatial separation of different production chains.

The current system depends on vast logistics. Not only the chains' primary product, but especially valorisation by-products and residuals requires intensive transport. The volume and logistic movements related to by-products and residuals often are comparable or larger than those due to the primary product. This is caused by the ongoing process of at the level of individual companies.

In order to make further progress with respect to bio-mass resource efficiency and CO_2 foot-printing, returning to traditional principles applied on e.g. mixed farms is very promising. Purposive spatial clustering of different production chains forms the basis:

- reduced logistic costs for mutual exchange of by-products between chains,
- improved economics (and feasibility) of utilisation of by-products and residuals, forming a basis for symbiosis (according to principles of industrial ecology),
- reduced quality losses of by-products and residuals.

Utilisation of the by-products and residues not only contributes to bio-mass resource efficiency, but also lowers emissions and waste and the increases energy efficiency. In particular the efficiency of exchanging low-valued voluminous streams like waste heat and biomass waste will be better in a spatial cluster. Furthermore, reduction of transport in animal production chains result in improved animal comfort and reduced veterinary risks.

Utility sharing of energy systems, waste water treatment and other supporting facilities) will be another important argument for clustering.

On the negative side, it is recognized that locally negative effects may occur, such as concentration of emissions, the increase of heavy transport, the industrial image, etc.

Inefficiencies due to spatial organisation of production chains − some examples

Suboptimal interactions between different production chains leads to considerable inefficiencies. Some illustrative figures:

- Greenhouse gas emissions per kg fat and protein corrected milk of grassland based (mono-functional) dairy systems are about 50% higher than for mixed systems (FAO, 2010).

- Volumes and logistic movements related to by-products and residuals often are comparable or larger than those connected to the primary product. This is caused by the ongoing process of at the level of individual companies. Some illustrative examples:
  - In regular pig farming, feed consumption is about 3kg per kg pig production, whereas the manure production is much larger: over 5.5kg per kg pig (Blonk and Hellinga, 2005). In the past, the manure was most commonly used on the land owned by the pig farmer. Because of specialisation, intensification and environmental regulations, an increasing fraction is carried away over considerable distances.
  - In cereals production, the amount of straw largely exceeds the amount of grains.
  - In the fruit and vegetable processing industry the amount of water used and the amount of waste water produced is considerably larger than the amount of primary products produced: 2.5 to 9 ton/ton (World Bank Group, 1998).
- Relatively small scale size of primary producers hinder sustainable solutions. For example, for biogas plants the economy of scale shows large gains for larger plants (Nielsen, Hjort-Gregersen, Thygesen & Christensen, 2002). In practice, however, large plants require supply of materials from different parties. This transport largely influences optimum scale. Up-scaling at primary (agricultural) level would improve the feasibility. And, in line with this: further processing of digestate to valuable fractions is most feasible in large-scale systems.

Spatial clustering of different activities in fresh production chains as well as clustering of different production chains set conditions for increasing production efficiency and sustainability. Potential merits are reduction of transport, increasing product quality and improving feasibility of processes for utilization of residuals (co- and by-products).

The gap between producers and consumers

Scaling-up and industrialisation of food production and distribution chains has widened the gap between food producers and consumers. Because the typical scale size of food production (farming) is very small compared to food processing and trading parties, the primary producers have become anonymous suppliers. As a result, implementing social/environmental/consumer-oriented innovations (including sustainability measures) at the level of the primary producer is very difficult and depends on government societal organisations support (Duffy, Fearne & Healing, 2005).

Towards more eco-efficient and market-oriented agro-food chains

Alternative spatial organisation and innovative utilisation of by-products will result in more sustainable agro-food production systems, not only fulfilling the increasing food needs, but also contributing to needs of the foreseen biobased economy.

Visibility for consumers as well as market responsiveness can be largely improved through spatially clustering of processing/trading with primary production – potentially combined with scaling-up primary production. This is exemplified by so-called *Greenports* in the Netherlands. The name *Greenport* stands for a spatial cluster comparable to a *mainport*, with a concentration of companies involved in the area of vegetables/food production. The companies business activities varies from breeding, growing, trading, suppliers and other support activities. Such *greenports* fit in the concept of clusters as formulated by Porter (1990). According to Porter synergy between the stakeholders in a cluster improves the competitiveness of the business and facilitates innovations. Further development of the clusters is supported by the existing parties as well as governments and other stakeholders. And indeed *greenports* have developed to highly respected suppliers of vegetable products (with broad ranges of products) for the large retail chains in the Netherlands and surrounding regions. Specific strengths are:

- broad product spectrum,
- market-orientation and responsiveness,
- efficient food logistics,
- education and innovations (including innovations of greenhouse systems)

This concept is considered as a good example for other agro-food sectors as well.

Development of chain-crossing innovations with an eye on valorisation of residuals is less far well developed, but is expected to surge the coming years. Traditionally entrepreneurs focus on their primary product, with lower priorities for valorisation of residuals. However, due to increasing awareness of sustainability challenges, the interest is increasing. Distinguished development lines are:

- Development of new food/feed/materials/etc. based on bio-materials and bio-residues. To prevent competition between food, fuel and other applications, primary focus is on utilisation of residues. Typical examples are the second generation of bio-fuels from straw and wood-like biomass. Also development of food products based on residues is gaining more attention, for example in:
    - Recently started initiatives by Dutch industries to develop solutions for food waste (including alternative use within the food area) on request by the Dutch government.
    - EU FP7 projects in the area of food applications based on by-products, such as the EU-India initiative Namaste (Fava, Waldron, Bald, Sebők, Broeze, Garijo & Brendle, 2010).

  Experiences so far in such initiatives learn that

    - Fresh trading/marketing of by-products require drastic measures in existing processing plants (hygienic measures for the by-products) and potentially redesign of the processes, with direct processing/marketing of the by-product. Preferably, by-product processing/marketing is co-siting with the existing plant.
    - Technical and economical feasibility is far from obvious, with tension between required investments, yields and quality of the products.
- Spatial cluster developments, using existing and new processes for valorisation of what used to be residuals. Some examples developed in previous decades are Kalundborg in Denmark (Kaiser, 1999) and the agro-industrial park Zuid-Groningen (People Planet Profit, 2003). More recent developments include:
    - *New Mixed Farm* in Horst (The Netherlands): an initiative by a variety of farmers (pigs, poultry, greenhouses, mushrooms). The animal farmers develop a collective bio-energy and manure processing system taking account of the typical properties of the various types of manure. Heat, compost and possibly organic fertilisers can be sold to greenhouses and mushroom growers. Residues of the biomass and manure processing are upgraded to highly valuable (and concentrated) fractions.
    - In India and China various initiatives are in development (in the vicinity of large markets (cities) and highly promising agricultural production regions). Since agro-food chains are still poorly developed in the regions considered, the primary focus is on clustered agro-food collection and processing facilities, combined with development of a spectrum of processing outlets and processes for valorisation of residues. These initiatives are in

different stages of development, varying from preliminary exploration phase to first steps of development and construction.

Research supporting this development is characterised by two themes:

1. Winning, extracting, separating, etc. valuable components from residues (including quality & safety management). This research theme is closely connected to biorefinery research.
2. Integrated design analysis of processing chain for by-products. For decision taking when developing such new chains, estimates of costs and benefits on processing details are needed. Through applying modelling approaches material and energy flows can be connected to process layouts, predicting costs (fixed costs as well as operational costs) and yields (per process as well at the over-all effects). Such modelling approaches facilitate entrepreneurs' decision taking at the stage of process development. As shown with the development of *New Mixed* Farm, it may also take away uncertainties about mutual behaviour when different entrepreneurs are involved.

Conclusions

Spatial clustering of different agro-food productions provide a basis for increasing eco-efficiency of food production and utilisation of biomass (in line with biorefinery). Research lines associated with this development are (1) producing valuable products from by- and rest-streams and (2) integral design of new chains for their valorisation. Through connecting these lines with practical initiatives a good basis for sustainable innovations of agro-food production is created.

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References

Blonk T.J. & Hellinga, C.H. 2005. Monitoring van de duurzaamheidsprestaties van de Nederlandse Varkenshouder. Blonk Milieu Advies, Gouda, The Netherlands (in Dutch).

Broeze, J & Smeets, P. 2010. Agribusiness parks. In: *Towards effective food chains*, pp. 137-148, J. Trienekens, J. Top, J. van der Vorst and A. Beulens, eds. Wageningen, The Netherlands: Wageningen Academic Publishers.

Duffy, R., Fearne, A. & Healing, V. 2005. Reconnection in the UK food chain: Bridging the communication gap between food producers and consumers. *British Food Journal* **107**(1): 17-33.

FAO. 2010. Greenhouse gas emissions from the dairy sector: A life cycle assessment.

Fava, F., Waldron, K., Bald, C., Sebők, A., Broeze, J., Garijo, V.M. & Brendle, H.-G. 2010. New advances in the integrated management of food processing by-products in India and Europe: use of sustainable technologies for the exploitation of by-products into new foods and feeds (NAMASTE EU). EurasiaBIO-2010, Moscow, Russia, April 12-16, 2010 (poster).

Kaiser, J. 1999. Industrial ecology: turning engineers into resource accountants, *Science*, **285**(5428): 685-686.

Nielsen L.H., Hjort-Gregersen K., Thygesen P. & Christensen J. 2002. Socio-economic Analysis of Cetralised Biogas Plants. Danish Ministry of Food Agriculture and Fisheries, Report no. 136.

People Planet Profit 2003. Industriële ecologie. Een immitatie van de natuur. People *Planet Profit*, summer 2003 (in Dutch).

Porter, M., 1990: *Competitive advantage of nations*. New York, USA, The Free Press.

Smeets, P.J.A.M. 2009. Expedition Agroparks. PhD thesis Wageningen University, Netherlands.

World Bank Group. 1998. Pollution prevention and abatement handbook: Fruit and vegetable processing.