

From environmental concerns towards sustainable food provisioning. Material flow and food consumption scenario studies on sustainability of agri-food systems

Doctoral Dissertation

Helmi Risku-Norja



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towards sustainable food
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From environmental concerns towards sustainable food provisioning.

Material flow and food consumption scenario studies on sustainability of agri-food systems

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Abstract

Agriculture is an economic activity that heavily relies on the availability of natural resources. Through its role in food production agriculture is a major factor affecting public welfare and health, and its indirect contribution to gross domestic product and employment is significant. Agriculture also contributes to numerous ecosystem services through management of rural areas. However, the environmental impact of agriculture is considerable and reaches far beyond the agroecosystems. The questions related to farming for food production are, thus, manifold and of great public concern.

Improving environmental performance of agriculture and sustainability of food production, “sustainabilizing” food production, calls for application of wide range of expertise knowledge. This study falls within the field of agro-ecology, with interphases to food systems and sustainability research and exploits the methods typical of industrial ecology. The research in these fields extends from multidisciplinary to interdisciplinary and transdisciplinary, a holistic approach being the key tenet.

The methods of industrial ecology have been applied extensively to explore the

interaction between human economic activity and resource use. Specifically, the material flow approach (MFA) has established its position through application of systematic environmental and economic accounting statistics. However, very few studies have applied MFA specifically to agriculture. The MFA approach was used in this thesis in such a context in Finland.

The focus of this study is the ecological sustainability of primary production. The aim was to explore the possibilities of assessing ecological sustainability of agriculture by using two different approaches. In the first approach the MFA-methods from industrial ecology were applied to agriculture, whereas the other is based on the food consumption scenarios. The two approaches were used in order to capture some of the impacts of dietary changes and of changes in production mode on the environment. The methods were applied at levels ranging from national to sector and local levels. Through the supply-demand approach, the viewpoint changed between that of food production to that of food consumption. The main data sources were official statistics complemented with published research results and expertise appraisals.

MFA approach was used to define the system boundaries, to quantify the material flows and to construct eco-efficiency indicators for agriculture. The results were further elaborated for an input-output model that was used to analyse the food flux in Finland and to determine its relationship to the economy-wide physical and monetary flows. The methods based on food consumption scenarios were applied at regional and local level for assessing feasibility and environmental impacts of re-localising food production. The approach was also used for quantification and source allocation of greenhouse gas (GHG) emissions of primary production. GHG assessment provided, thus, a means of cross-checking the results obtained by using the two different approaches.

MFA data as such or expressed as eco-efficiency indicators, are useful in describing the overall development. However, the data are not sufficiently detailed for identifying the hot spots of environmental sustainability. Eco-efficiency indicators should not be bluntly used in environmental assessment: the carrying capacity of the nature, the potential exhaustion of non-renewable natural resources and the possible rebound effect need also to be accounted for when striving towards improved eco-efficiency.

The input-output model is suitable for nationwide economy analyses and it shows the distribution of monetary and material flows among the various sectors. Environmental impact can be captured only at a very general level in terms of total material requirement, gaseous emissions, energy consumption and agricultural land use. Improving environmental performance of food production requires more detailed and more local information.

The approach based on food consumption scenarios can be applied at regional or local scales. Based on various diet options the method accounts for the

feasibility of re-localising food production and environmental impacts of such re-localisation in terms of nutrient balances, gaseous emissions, agricultural energy consumption, agricultural land use and diversity of crop cultivation.

The approach is applicable anywhere, but the calculation parameters need to be adjusted so as to comply with the specific circumstances. The food consumption scenario approach, thus, pays attention to the variability of production circumstances, and may provide some environmental information that is locally relevant.

The approaches based on the input-output model and on food consumption scenarios represent small steps towards more holistic systemic thinking. However, neither one alone nor the two together provide sufficient information for “sustainabilizing” food production. Environmental performance of food production should be assessed together with the other criteria of sustainable food provisioning. This requires evaluation and integration of research results from many different disciplines in the context of a specified geographic area. Foodshed area that comprises both the rural hinterlands of food production and the population centres of food consumption is suggested to represent a suitable areal extent for such research. Finding a balance between the various aspects of sustainability is a matter of optimal trade-off. The balance cannot be universally determined, but the assessment methods and the actual measures depend on what the bottlenecks of sustainability are in the area concerned. These have to be agreed upon among the actors of the area.

Key words:

MFA, eco-efficiency, input-output modelling, food consumption scenarios, application and evaluation of the methods, environmental sustainability, agriculture, food production and consumption

Kohti kestäväää ruokahuoltoaa.

Materiaalivirta- ja ruoankulutus- skenaariomenetelmät ruoantuotannon kestävyyden arvioinnissa

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Tiivistelmä

Maatalous on taloudellista toimintaa, joka on ratkaisevasti riippuvainen luonnonoloista ja luonnonvaraperustasta. Ruoantuotannon kautta maatalous on aivan oleellinen hyvinvointiin ja kansanterveyteen vaikuttava tekijä, mutta sen epäsuora vaikutus kansantalouteen ja työllisyyteen on myös merkittävä. Maaseutualueiden maankäytön kautta maatalous tuottaa myös monia ekosysteemipalveluja. Toisaalta maatalous myös kuormittaa ympäristöä, eikä ympäristökuormitus rajoitu maatalousekosysteemeihin, vaan vaikutukset ulottuvat laajalle niiden ulkopuolelle.

Maataloudesta aiheutuvan ympäristökuormituksen vähentäminen sekä ruoantuotannon kestävyiden kaikinpuolinen kohentaminen vaativat hyvin monen eri alan asiantuntijuutta. Tämä väitöskirjatyö kuuluu agroekologisen tutkimuksen piiriin, sillä on yhtymäkohtia sekä ruokajärjestelmä- että kestävyystutkimukseen, ja työssä on sovellettu teollisen ekologian menetelmiä. Näiden tutkimusalojen keskeinen periaate on kokonaisvaltaisuus, ja ne edustavat monitieteistä, tieteidenvälistä ja lisääntyvässä määrin myös poikkitieteistä tutkimusotetta.

Teollisen ekologian tutkimusmenetelmiä on käytetty paljon selvitellessä ihmisen taloudellisen toiminnan ja luonnonvarojen käytön suhteita. Materiaalivirtatarkastelu (MFA) on vakiinnuttanut paikkansa ympäristöä ja taloutta kuvaavissa tilastointijärjestelmissä, mutta sitä ei ole paljoakaan käytetty maatalouden yhteydessä. Tässä tutkimuksessa MFA-menetelmiä sovitetaan nimenomaan maatalouden tarpeisiin, ja tarkastellaan niiden soveltuvuutta maatalouden ekologisen kestävyiden arvioimisessa. Tutkimuksessa esitetään myös toinen lähestymistapa, joka perustuu erilaisiin ruokavaihtoehtoihin, ruoankulutus-skenaarioihin. Molempia tapoja käytetään arvioitaessa, miten muutokset ruoankulutuksessa tai tuotantotavassa heijastuvat ympäristöön. Menetelmiä sovelletaan kansantalouden, toimialakohtaisen ja alueellisen tason tarkasteluun ottamalla huomioon sekä ruoantarjonta että sen kysyntä. Empiirisenä aineistona on käytetty virallisia maataloustilastoja, ja niitä on täydennetty julkaistuilla tutkimustuloksilla sekä asiantuntija-arvioinneilla.

Tutkimuksen systemirajaus, materiaalivirtojen määrittäminen ja maatalouden ekotehokkuusmittareiden muodostaminen perustuivat MFA-laskentaan. Tulokset sovitettiin integroituun panos-tuotosmal-

liin, jonka avulla tarkasteltiin ruoantuotantoon liittyvien materiaali- ja rahavirtojen liikkeitä kansantalouden eri toimialojen välillä. Ruoankulutusskenaariomenetelmää puolestaan käytettiin alueellisen tason tarkastelussa, kun arvioitiin ruoantuotannon paikallistamisen toteutettavuutta sekä paikallistamisen ympäristövaikutuksia. Ruoankulutusskenaariomenetelmää käytettiin myös kansantalouden tason aineistoon tarkasteltaessa maatalouden kasvihuonekaasupäästöjen eri lähteitä ja niiden osuutta kokonaispäästöistä. Tämä mahdollisti kahdella eri menetelmällä saatujen tulosten rsiintarkistamisen.

MFA-tulokset sellaisenaan tai ekotehokkuusmittareina ilmaistuna ovat käyttökelpoisia kuvattaessa toimialan kehitystä yleisellä tasolla. Niiden avulla ei kuitenkaan pystytä tunnistamaan ekologisen kestävyyskannalta kriittisiä seikkoja tai kriittisiä alueita. Pyrittäessä ekotehokkuuden kohentamiseen ekotehokkuusmittareita ei myöskään pitäisi käyttää yksioikoisesti, vaan ympäristön kantokyky, luonnonvarojen riittävyys sekä mahdolliset rebound-vaikutukset pitää myös ottaa huomioon.

Panos-tuotosmalli kuvaa ruoantuotantoon liittyvien raha- ja ainevirtojen jakautumista eri toimialojen välillä, ja se soveltuu siten kansantalouden tason tarkasteluihin. Malli laskee ruoantuotanto- tai kulutusrakenteen muutosten vaikutukset ympäristöön ottamalla huomioon luonnonvarojen kokonaiskäytön, kasvihuonekaasu- ja happamoittavat päästöt, maatalouden energiankulutuksen sekä maatalouden maankäytön. Maatalouden ekologisen kestävyyskriteerien kohteiden tunnistaminen vaatii kuitenkin yksityiskohtaisempaa paikallistason tietoa.

Ruoankulutusskenaariomenetelmä soveltuu alueellisen ja paikallisen tason tarkasteluihin. Sen avulla voidaan arvioida ruoantuotannon paikallistamisen toteutettavuutta sekä paikallistamisen vaikutuksia ympäristöön. Menetelmä ottaa huomioon

monimuotoisuuden, vesistöjen rehevöitymisen sekä happamoitumisen ja ilmastomuutoksen; mittareina ovat maatalouden maankäyttö ja viljelykasvimonimuotoisuus, peltojen ravinnetaset, kasvihuonekaasupäästöt sekä happamoittavat päästöt. Ympäristövaikutusten arviointi perustuu niihin muutoksiin, joita erilaiset ruokavaliövaihtoehdot toteutuessaan näissä mittareissa aiheuttaisivat. Menetelmää voidaan käyttää missä tahansa, mutta laskennassa käytettävät muuttujat täytyy sovittaa olosuhteiden mukaan. Menetelmän avulla voidaan siten saada paikallisesti merkityksellistä tietoa ympäristövaikutuksista.

Panos-tuotosmalli ja ruoankulutusskenaariotarkastelu ovat pieniä askeleita kohti kokonaisvaltaista systeemistä tarkastelutapaa. Kumpikaan menetelmä ei kuitenkaan yksin – eivätkä menetelmät yhdessäkään – tuota riittävästi tietoa ruoantuotannon kestävyyskohentamiseksi. Ruoantuotannon ympäristövaikutuksia tulee arvioida osana kestävästä ruokahuollosta yhdessä muiden kestävyyskriteerien kanssa. Tämä edellyttää, että monen eri tieteenalan tutkimustulokset sovitetaan yhteen ja niitä arvioidaan tietyn maantieteellisen alueen puitteissa. Ruoka-alue, joka käsittää sekä ruoantuotantoalueet maaseudulla että ruoankulutuksen keskittymät kaupungeissa voisi edustaa tutkimuksen kannalta sopivaa alueellista ulottuvuutta. Jotta kestävyyskriteerien eri osa-alueet tulevat tasapuolisesti huomioonotetuiksi, tarvitaan kompromisseja. Tähän ei ole yleispätevää ohjetta, sillä olosuhteet vaihtelevat eri alueilla. Näin ollen arviointimenetelmät ja toimenpiteet riippuvat paikallisista olosuhteista, ja ne täytyy sopia yhdessä paikallisten toimijoiden kanssa.

Avainsanat:

MFA, ekotehokkuus, panos-tuotosmalli, ruoankulutusskenaario, menetelmien soveltuvuus, ekologinen kestävyys, maatalous, ruoantuotanto ja -kulutus

List of original publications

This thesis is based on four peer-reviewed articles, published in international scientific journals. The articles are referred in the text by their Roman numerals, and they are reprinted with the kind permission of their respective copyright holders.

I Risku-Norja, H. 1999. The total material requirement -concept applied to agriculture: a case study from Finland. *Agricultural and Food Science in Finland* 8, 4-5: 393-410.

II Risku-Norja, H. & Mäenpää, I. 2007. MFA model to assess economic and environmental consequences of food production and consumption. *Ecological Economics* 60, 4: 700-711.

III Risku-Norja, H., Hietala, R., Virtanen, H., Ketomäki, H. & Helenius, J. 2008. Localisation of primary food production in Finland: production potential and environmental impacts of food consumption patterns. *Agriculture and Food Science Finland* 17, 2: 127-145.

IV Risku-Norja, H., Kurppa, S. & Helenius, J. 2009. Diet choices and greenhouse gas emissions – assessment of impact of vegetarian and organic options at national scale. *Progress in Industrial Ecology* 6(4): 340-354.

As the first author of the articles I-IV included in the thesis Risku-Norja was responsible for planning, outlining and writing the articles and for interpretation of the results in the context of each article.

The articles II and III are outcomes of multidisciplinary to interdisciplinary research based on large amount of data representing various research fields. Retrieval and analysis of data has, therefore, required expertise knowledge from the respective research fields. Article II is based on analysis of ecological-economic input-output data and on a model constructed from these data; the architect of the model is Mäenpää, who is also responsible for the economic data in the article. In Article III Hietala is responsible for the Shannon diversity index data and calculations, Virtanen for those of the nutrient balances and Ketomäki produced the data dealing with the use of natural products. Risku-Norja estimated the production capacity and feasibility of localised food production and quantified the gaseous emissions. Helenius contributed to the overall design of the data presentation through application of his expertise in agro-ecological and food system research.

Article IV is based on the experiences of the previous research and is an attempt to interpret and reconcile multidisciplinary data within an interdisciplinary framework. Risku-Norja provided and analysed the data; the agro-ecological expertise of Helenius and the familiarity with the food system approach of both Kurppa and Helenius contributed significantly to overall focus and structural design of the article.

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1 Introduction

1.1 Background

Finland has adopted the common agricultural policy of the EU and agriculture is administered by the Ministry of Agriculture and Forestry. The goals for future development have been defined in the Ministry's strategy for the use of the natural resources, the core issue being sustainable production. The progress towards the defined goals is described using a number of indicators addressing topics such as production structure, use of resources, environmental consequences of production, biodiversity, animal welfare and continuity and profitability of production (MMM 2002).

Because of the northern location and of the geology, farming in Finland is challenging. The growing season is short, the soil is naturally acid and the cold winter increases energy costs. The climate also effectively reduces both yields and the variety of crops that can be cultivated. On the other hand, agriculture also benefits from the cold climate and remote location as these effectively restrict plant and animal diseases, and the prerequisites for organic production are, therefore, good in Finland. There is also abundant available farmland that would allow for considerable expansion of organic production (III).

Agriculture is an economic activity that heavily relies on the availability of natural resources. Agriculture appears to play a very small role in the Finnish national economy: in 2006 the share of agriculture, including fisheries and game and reindeer husbandry, represented about 4% of the total employed labour force; in 1970 its share was nearly 16%. The share of agriculture in the Finnish gross domestic product (GDP) has oscillated around 1% since the mid-1990s. The role of agriculture has diminished not only in

terms of employment, but also as a source of income for farm households (Statistics Finland 2008).

In a society where the status is based mainly on the economic performance, agriculture is not particularly highly regarded. However, despite the apparently small contribution to national economy, the importance of agriculture extends well beyond this. The basic task of agriculture is production of adequate quantities of healthy and safe food. Agriculture is a major factor affecting public welfare and health through food production, and its indirect contribution to GDP and employment is notable. In this role, agriculture maintains and takes care of the open cultural landscape and of the biodiversity of agro-environments.

On the other hand, the environmental impact of agriculture is considerable. Arable land comprises only about 8% of the total surface area of Finland. However, the impacts of agriculture are not restricted to agro-ecosystems, but there are far-reaching consequences, because the gaseous emissions from agriculture directly enter the atmosphere and the nutrient surpluses and biocides enter the soil, where they remain or are subsequently leached into watersheds or enter the groundwater and the food chains.

In recent years, the contribution of agriculture to overall sustainability has been stressed and understood more comprehensively rather than being solely a matter of the farming environment. In addition to supplying food, through management of rural areas agriculture also contributes to other provisioning, supporting, regulating and cultural ecosystem services (e.g. Atkinson et al. 2005b, Lal 2008, MEA 2005, Lal 2009, Lichtfouse et al. 2009).

This holistic agroecological approach emerged already in the late 1920s; the roots are in the German and American research tradition (Wezel et al. 2009). Among the pioneers of the early 20th century is the Russian agronomist Bensin, who was the first to introduce the agro-ecology concept (Bensin 1928, via reference in Wezel et al. 2009). The first agroecological publications dealt with application of ecological principles to crop production (e.g. Friederichs 1930). Regional-based human ecology perspective (without using this term) was brought about into the research already in the 1940s through analysis of the ecological, technological, socio-economic and historical factors influencing crop production (Klages 1942), whereas Aldo Leopold in his essays and reflections took up the questions of land sickness and land ethics (Leopold 1949). The nowadays widely used ecosystem health concept is largely based Leopold's environmental philosophy. In the early 1990s the theoretical and practical aspects of ecosystem health were thoroughly examined, and its philosophical and ethical underpinnings and implications for environmental policy and ecosystems management were discussed by Costanza et al. (1992) and further elaborated by e.g. Rapport et al. (2000) and Rapport (2007). Lang and Heasman (2004) raised the issues of environmental quality and human health that are inextricably connected and cannot be addressed within the present mainstream food supply system. They called for a new holistic food policy based on empowering the civil society in "sustainabilizing" food production through radical restructuring of the food supply.

The questions related to agriculture and to food production are, thus, manifold and of considerable public concern. The prevailing trend supported by current economic conditions is globalisation and scaling-up of industrial production and establishment of fewer, larger trans-national food corporations (e.g. Whatmore 2002).

Its justification is, however, increasingly questioned, and there is growing interest in alternative supplies of food (e.g. Nabhan 2002, Whatmore 2002, Halweil 2004, Lang and Heasman 2004, Patel 2008). Agricultural production and food distribution have experienced successive developmental phases during history, characterised by profound paradigmatic changes (Lang and Heasman 2004). Among the voluminous agricultural research, different foci can be identified which have addressed questions posed at different times. They are, thus, firmly anchored to the socio-material reality and reflect the state of the art and the conceptions of their era.

1.2 Agriculture, food production, environment and sustainable development – an overview

1.2.1 Productionistic approach, agrochemicals and efficiency

The focus of the mainstream food supply system consolidated in the mid 20th century is economic profit and on increasing the volumes of the saleable products. Prevailing economic conditions that favour scaling-up of industrial production and establishment of fewer but larger trans-national food corporations have driven the food trade towards a globalised system of centralisation and increasingly intensive production and distribution through long distance transports (e.g. Whatmore 2002).

The productivity is highly reliant on the input of agrochemicals, i.e. fertilisers and various biocides, antibiotics against animal diseases and chemical supplementation for improved nutritional status of the livestock. The focus on increasing the production volumes resulted in an era of agrochemicals. Synthetic fertilisers became the dominant source of plant nutrition, and the control of weeds, pests and fungal diseases became

heavily dependent on application of the chemical biocides. Production became restricted to only a few cultivated species, and the animals gave way to new races that have been bred to maximize production in large-scale industrialised agricultural enterprises (Lang and Heasman 2004, WRI 2006).

The externalities of the current global food markets imply high costs to the environment and to animal and human health. The current agricultural practices contribute to environmental detriments such as erosion and severe deterioration of the arable soils, pesticide pollution, pest adaptation and resistance, desertification, water eutrophication, decrease of biodiversity and climate change. The critical natural resources, water, plant nutrients and arable land are becoming increasingly scarce, and with the food production distanced from food consumption the environmental impacts accumulate alarmingly in the source areas of food production resulting ultimately in significant losses of yields worldwide (e.g. Atkinson et al. 2005b, Gliessman 2007). The present high costs of energy and agrochemicals also decrease economic profitability for farmers. Large fluctuations in the producer prices (FAOSTAT 2010) add insecurity to making a living out of farming.

1.2.2 Life-sciences integrated approach

Today the emphasis in mainstream food production is shifting from the simple productionistic approach based on agrochemicals towards application of biotechnology, such as nutrigenomics and genetically modified organisms and, in food processing also synthetic enzymes. The research aims at solving environmental problems through techno-scientific development. Advancements in scientific research and the technological innovations open new possibilities for environmental adaptation of the growing demand of food

production. The life-sciences integrated approach (Lang and Heasman 2004: 21–25) has been adopted particularly by those scholars who emphasize win-win solutions in regard to the environment and the economy. The focus is on developing clean technologies, re-designing products and processes, improving resource efficiency and looking for renewable substitutes for non-renewable raw materials. This perspective represents technological approach to ecological modernisation research, and it is also the key tenet of the Knowledge-Based BioEconomy strategy of the EU Seventh Framework Program (EU 2009). Ecological modernisation is a school of environmental social science, which depending on the context, can be seen as an analytical approach, a policy strategy or as an environmental discourse. In addition to technology, ecological modernisation has been used in social, economic and environmental policy contexts (Milanez and Bührs 2007).

The life-sciences integrated approach has also been criticised: Lang and Heasman (2004) claim that the rapid expansion of biotechnology in farming and in food manufacture is a modernised continuation of the productionistic efficiency era characterised by corporate power and pursuit of supremacy in global markets. Through the Knowledge-Based BioEconomy strategy it has implications also for the development of rural areas. With the strong emphasis on science and technology research, there is a risk that practical and tacit knowledge based on familiarity with local circumstances is left aside (Allaire and Wolf 2004, Lang and Heasman 2004, Marsden 2004).

From the global perspective, agriculture for food production has come to crossroads. Mainstream agri-food production features unsustainable use of natural resources such as farm land, phosphorus, and non-renewable energy sources (Lang and Heasman 2004). The strivings to slow down

the climate change is not compatible with the continuous increase of fossil energy consumption in food production and in food transports. Substitution of the fossil energy with cultivated energy crops is not a solution as it competes for the shrinking land resources for food crop production (MEA 2005). In addition, there are significant socio-economic consequences of distortions in the global food markets such as starvation and malnutrition, obesity and other food related health problems. Through nutrition transition overweight and other diet-related health problems are increasingly manifest not only in the affluent West, but also in developing countries (Popkin and Ng 2007, Popkin 2009). Despite the promising potentials biotechnological applications have not relieved global nutrition problems, but have rather increased polarisation into rich and poor both within nations and world-wide. This together with the rising prices of food, fuel and agrochemicals makes the present situation particularly unsustainable (Lang and Heasman 2004).

Introduction of new technologies need to be accompanied by fundamental changes in social structures (Geels 2004, Milanez and Bührs 2007, York and Rose 2003). This has led to serious consideration of organic and re-localised food production as alternatives, that better comply with the sustainability goals of both the agri-food sector (Puolanne et al. 2002, Allaire and Wolf 2004, Seppänen 2004) and of overall rural development (Goodman 2004, Marsden 2004, Gliessman 2007, Patel 2008).

1.2.3 Organic farming

Environmental awakening in the late 20th century was largely a consequence of the era of agrochemical intensity and the concomitant changes in the terrestrial and aquatic ecosystems (Carson 1964). The adverse impacts such as deteriorating quality of cultivated soils, erosion and

pollution of groundwater, watercourses and coastal seas became evident both within and outside the agroecosystems. This created social pressure to reduce environmental impact by promoting organic production relying on nature benign agricultural practices. The aim is to secure ecosystem health by preserving soil fertility through conservative soil management practices, intercropping, using cover crops, mulching, flaming, crop rotation and reduced tilling. These measures are also essential for the control of weed as the use of chemical herbicides is banned. Biological control, rather than insecticide, is used against insect pests (Altieri and Nicholls 2004, IFOAM 2008, Watson et al. 2008).

Organic production is strictly regulated by national and international laws. Requirements vary from country to country, but generally involve a set of production standards for farming and processing that include avoidance of synthetic chemical fertilisers, pesticides, antibiotics, food additives etc., genetically modified organisms, irradiation and the use of sewage sludge. Other requirements include use of farmland that has been free from chemicals for a number of years, keeping detailed written audit trails, and maintenance of the organic products strictly separated from other, non-certified products (EC 2007, IFOAM 2008). Organic certification, thus, defines the conditions for production, but there are no commitments as to geographic location of the production. Therefore, organic food may be of local produce or as well part of international food chains.

Organic production was an early solution to the environmental disbenefits of food production. With the focus on the environment, it has not met with the demands for productivity globally and by all production organisms. However, organic products have established their share in the food markets and, e.g. in Finland there is an imbalance between

their demand and their supply (Kottila 2010). Conventionalisation of organic production is an emerging problem. It stems from the consumers' keen interest in organic products which has created business opportunities to provide niche products with high premium and profits for the agrifood corporations. Consequently, organic products have become increasingly part of the mainstream global food trade where production is controlled by the large agrifood corporations (Pollan 2006, Holt and Amilien 2007). International trade means long transports and placeless food with the producers and consumers distanced from each other (Follett 2009).

1.2.4 Local food movement

Local food movement focuses on food sovereignty or on restoring the decision-making regarding food to local actors (Patel 2008). Contemporary consumer campaigns aim at promoting re-localisation of food production by directing the consumers toward more local food purchasing as part of sustainable eating habits (Norberg-Hodge et al. 2002, Jaffee et al. 2004, Nestle 2006, Sonnino 2007). The core of the food localisation movement is in the joint activity of producers and eaters. The consumers especially appreciate proximity, diversity, ecological sustainability, local economy and culture, ethics, seasonality, health aspects and possibilities for participation and communication (Kloppenburger et al. 2000).

The proponents claim that re-localising food production assures the environmental protection by truly challenging the foundations of the conventional global food production and of the large scale organic production – “the big organic” – with standardized products, price-based competition and consolidated power (Patel 2008, Follett 2009).

Re-localising food production is, thus, emerging as an option for improving

sustainability in the agri-food sector (e.g. Kloppenburger et al. 1996, Bellows and Hamm 2001, Pretty et al. 2005, Levidow and Darrot 2010). However, “local food” is a broad term of different dimensions ranging from physical space to historical, cultural and social features and covering also high-quality specialist food products with a guarantee of origin or traditional speciality (e.g. DuPuis and Goodman 2005, Holloway et al. 2006). It is used in various contexts ranging from food strategies (DuPuis and Goodman 2005, e.g. Delind 2006) to environmental applications (e.g. Carlsson-Kanyama et al. 2003, Pretty et al. 2005, Schlich and Fleissner 2005) and from corporate responsibility (Pollan 2006, Follett 2009) to viability of rural areas (e.g. van der Ploeg et al. 2000). A more geographically tuned definition implies, that food production and consumption are spatially close (e.g. Kloppenburger et al. 1996, Tansey and Worsley 2000, Renting et al. 2003, Watts et al. 2005). In Finland, local food has been loosely defined as production and consumption of food that promotes the economy and employment in a region by utilizing its resources (Lähiuokatyöryhmä 2000, Mononen 2006). Local farming comprises concepts such as farmers' markets, community supported agriculture (CSA) and food co-operatives. “Local food” is often equated with organic production. It may well be organic, although not necessarily certified as such, but it may also rely on the farming practices of conventional production. The signification of local food is, thus the proximity of food producers and consumers. It is not to be confused with the concept “locality food” which is identified and marketed by the specific place of origin – Protected Geographical Indication (PGI) – to the consumers, who may be very far from the site of production (Marsden et al. 2000).

For the stakeholders local food systems represent sustainability (Kloppenburger et al. 2000). However, as with organic

production there is a danger that through niche products customized for specific consumer groups, large corporations usurp local production (Pollan 2006, Hinrichs and Allen 2008). Some critics suspect also that revival of local farming in western countries may turn out to limit exportation from developing countries and reduce, the income for poor farmers (Nestle 2006).

1.3 Development in Finland

The areas suitable for agriculture in Finland were taken into cultivation already by the 1970s, and the share of agricultural land as a proportion of total land area has slightly declined since the beginning of the 1970s to 2007, from 9.4% to 8.2%. This corresponds to a reduction of about 23% in the area of cultivation or a drop from 2.6 million hectares to the stabilised level of about 2 million hectares (MMM, Annual issues). During the same time period, the number of people working in agriculture has decreased by 37%, and the number of farms fell by over 75%, the farmland having, thus, been redistributed; simultaneously with the decrease in the number of farms, the number of large farms with an area over 100 hectares arable land has increased. In 1990 their number was 486, and in 2008 it was already over 3000 (MMM 2009). Consequently, the average size of the farms has almost doubled from 18 hectares to 34 hectares (MMM 2009). The change is evident in specialisation and concentration of the main production lines both at the farm and at the regional level (Niemi and Ahlstedt 2007). Nevertheless, the majority of the farms are still family farms, and these are struggling for survival. The consequences are particularly severe in the sparsely populated rural areas, where the natural resource sectors represent 15.7% of the working places; in urban-adjacent rural areas the share is only 5.6% (Statistics Finland 2008).

The area of Finland extends 1157 km in north-south direction. Differences in natural circumstances, together with political and economic factors as well as the decisions made in the past (path dependence) have led to regional specialisation in practising agriculture. Due to the geomorphology and climatic conditions, a major part of crop cultivation is concentrated in south and southwest Finland, whereas cattle farms are mainly located further north. Most pig and poultry farms are located in southwest and western Finland. Other factors such as the size of the farms, location in relation to the markets and opportunities for additional income contribute to regional differences both regarding production structure and the overall importance of agriculture for the regional economies. Recent investments have shifted the main emphasis of agricultural production gradually to the western and southern parts of the country (Niemi and Ahlstedt 2007). The regional differences are expressed also in the rural landscape; while cultivated areas are concentrated in the western and southern parts of the country, in other areas marginalisation of agriculture has meant loss of fields with open sceneries taken over by regenerating forest, and rural areas have lost their visual diversity and traditional charm (Risku-Norja et al. 2011). Inevitably agricultural monocultures and closing-in of the landscape, with accompanying loss of field margins, have also had a negative impact on biodiversity (Hietala-Koivu et al. 2004, Stenseke 2006). The environmental impact of agriculture is considerable also in terms of greenhouse gas emissions and nutrient leaching and consequent eutrophication of the inland waterways and the Baltic archipelago (Syväsalto et al. 2004, Yli-Viikari et al. 2007).

On the other hand, agriculture has decisively contributed to the creation of open cultural landscapes and associated biodiversity, the maintenance and management of which is crucially dependent on food production. This is because grasslands, green fallows,

cultivated and natural pastures are important in securing habitat heterogeneity and providing abundant ecological niches for farmland wildlife and for game species (Benton et al. 2003, Hietala-Koivu 2003, Luoto et al. 2003a, Weibull et al. 2003, Hietala-Koivu et al. 2004), some of which have recently become rare or extinct. These areas have been created by and are maintained to a large extent by dairy cattle and other grazing animals (Luoto et al. 2003a, Luoto et al. 2003b, Pykälä et al. 2005, Stenseke 2006). It also contributes to other ecosystem services such as biofuel production, waste management, carbon sequestration, genetic resource conservation, scenery and amenity values for recreation and the viability of rural areas.

Since the mid 1990s organic production has emerged as a serious alternative to conventional farming. Following the European recommendations for sustainable public procurement, the public sector has been obliged to use organic and local food through political decisions having been made, for example in Sweden, Norway, Austria and Italy. Similar recommendations have been expressed also in Finland aiming at expanding the share of organic (local) food in public procurements by 10–15% annually, and at accounting for the environmental aspects in all public procurements by 2010 (KULTU 2005).

In 2000, organic production represented 6.7% of the cultivated area (MMM 2009). The aim was to expand the share to 15% of cultivated land by the year 2010 through promoting organic animal husbandry in particular (MMM 2001). The organically cultivated area reached 7.2% in 2004, but has since slightly decreased being 6.6% in 2008 (MMM 2009).

Basic foodstuffs, meat, milk, eggs, fish, grains, potatoes, sugar, oilseeds, vegetables, fruits and berries represent about 90% of present day average Finnish food

consumption. With the exception of sugar, Finland is practically self-sufficient in the production of the basic food items (MMM 2009). Self-sufficiency contributes significantly to food safety and food security. However, because national food production is dependent on imported energy and feed proteins, in terms of food security in times of crisis, the degree of self-sufficiency is actually lower than suggested by the domestic supply–demand relationship.

The Finnish consumers also value highly the quality of domestic foodstuffs (Isoniemi et al. 2006). Various labelling schemes have been introduced to provide information about the origin and mode of production to the customers, but regarding public catering information is usually not provided to the customers (Risku-Norja et al. 2010), and realisation of the recommendations has not been consequently followed-up. There is keen interest both among the citizens (Hyvönen and Perrels 2008, Kottila 2010) and among public caterers to improve sustainability of food supply by increasing the share of both local and organic food (Paananen and Forsman-Hugg 2005, Isoniemi et al. 2006, Muukka et al. 2008, Kottila 2010, Risku-Norja et al. 2010). In the absence of shared understanding and a holistic approach the responsibility for sustainable food choices is left on the individual actors' judgement.

1.4 Assessing environmental impacts

There is a worldwide consensus that the negative human impact on ecosystems must be radically reduced. In order to define unambiguous quantitative goals the current state of affairs and the development trends need to be known. Indicators are designed to express development trends and the extent of realisation of defined goals in a way that is simple, concise and easy-to-interpret. They are, therefore, important tools for decision-makers in planning and

monitoring (Hardi and DeSouza-Huletey 2000, Sandersson 2000, Shields et al. 2002). During recent years there has been a proliferation of measures that provide accountable quantitative measures on environmental impacts (MMM 2004a, EC 2005, Halberg et al. 2005, Yli-Viikari et al. 2007, Giljum et al. 2008, OECD 2008). Both the administrative and research communities have been active in this “indicator industry” (e.g. Herzi and Dovers 2006, Rydin 2007, Bockstaller et al. 2008, Mickwitz and Melanen 2009).

Industrial ecology is a fairly new field of science that studies the processes of industrial metabolism i.e. the natural resource use of human activities and the interactions of the resource use with nature. Various methods have been developed within this research field in order to provide accountable quantitative measures on environmental impacts based on the premise that “what can be measured can be improved” (Bringezu 2003, Hinterberger et al. 2003).

The commonly used methods are material flow accounting and analysis (MFA), substance flow analysis (SFA), input-output modelling, footprinting methods and life cycle assessment (LCA) as well as various combinations of these. In addition to the numerical quantification, the methods are also used for analysing the complex interactions within the defined systems, and they have significantly contributed to improving understanding of the processes induced through human activity and their impact on the ecosystems.

The quantitative measures provided by the MFA- and SFA- methods are expressed as a single figure in units of weight, and those of footprinting methods as area units. Whereas the MFA deals with flows of all kinds of materials, the SFA is more detailed and deals with flows of chemical compounds or even those of the elements comprising the materials. It has been used

for tracing the paths of e.g. plant nutrients within the economy in order to decrease their flows by improving the efficiency of nutrient use and by closing their cycles within the system (Antikainen 2007).

The quantification is used for descriptive purposes, often presented as time-series data in following-up the development over time. The data are also commonly used in combination with other data to construct more specific indicators. The approaches can be applied at very different scales ranging from global to individual, e.g. global ecological footprint, ecological footprint of the nations/regions or personal ecological footprint. The indicators can be calculated also for single products. LCA methods are used to provide product and process-specific data on environmental impacts; the system definition is, therefore, much more specific. Similarly to footprinting and MFA/SFA methods, the LCA results are also commensurate and expressed e.g. as CO₂ equivalents that are allocated to the different impact categories.

Input-output modelling requires statistical data in the form of economic and/or physical input-output tables, and it is used to study the interactions among the various sectors of the national economy, i.e. how the changes in one sector are propagated in other sectors.

1.5 Aims of the study

In this study the possibilities to assess environmental impacts of Finnish agriculture are explored by using quantification of the material flows and eco-efficiency indicators as well as two different analytical methods. The first method deals with the input-output modelling of the material flows of the food flux, and the other is based on the food consumption scenario approach. The methods are applied at levels ranging from national to

sector and local levels in order to capture some of the impacts of dietary changes and of changes in production mode on the environment. Through application of the supply-demand approach, the viewpoint changes between that of food production to that of food consumption.

The aim of the thesis is to develop the approaches and methods so as to design them specifically for applications in agriculture, and to critically evaluate their applicability on the basis of empirical data from Finland. The relevance of the approaches in assessing ecological sustainability and their contribution to

overall sustainability assessment is discussed in the concluding chapter.

The research tasks of the thesis are:

- Developing material flow accounting for agriculture
- Developing eco-efficiency indicators for agriculture
- Presenting the input-output model for food flux
- Developing the approach based on food consumption scenarios
- Critical evaluation of the methods
- Deriving a framework for sustainability assessment of food provisioning.

2 Conceptual framework

This study falls within the fields of agro-ecology, food systems and sustainability research and uses the methods typical of industrial ecology. The research in these sciences ranges from multidisciplinary to interdisciplinary and transdisciplinary, the differences being the depth of integration of knowledge from various research fields. While in the multidisciplinary approach each disciplinary field remains separate and uses its own methods to add breadth to the research through specific viewpoint, interdisciplinarity involves crossing the borders between various disciplines. It requires formulation of a common frame of reference among different disciplines, and integration of data and methods within this framework. Transdisciplinarity takes the research beyond the academic world by engaging the various actor groups, organizations and stakeholders through participatory processes of knowledge production and interpretation (Bruun et al. 2005, Baumgartner et al. 2008). In this

thesis, retrieval and analysis of the data has required expertise knowledge from various research fields, and an attempt is made to interpret the results from the food supply-demand perspective. The research approach is, thus, multidisciplinary to interdisciplinary.

This study deals with ecological sustainability of primary production and food consumption. The approaches have been developed on the basis of the MFA and footprinting methods, and here they are modified so as to address agriculture specifically. LCA methods are widely applied for assessing environmental loading in production and consumption systems. However, unlike in MFA, SFA, and in input-output modelling, LCA is process-specific and the system boundary is drawn around a system of a specified product. Development and assessment of LCA methods is beyond the scope of this study.

2.1 MFA approach

MFA stands both for material flow analysis and material flow accounting. All economic activity is based on use of materials, all of which are ultimately derived from nature to where they are finally returned. This creates a continuous throughput of various materials from the nature into the anthroposphere, the physical space used for human inhabitation and economic activity, and back to the nature, often in an altered form and in the wrong places. The quantity and quality of the various material flows determine the impact of economic activities on the environment. The MFA approach focuses on quantifying the material throughput and thereby reducing its volume within the economy.

The measures to relieve environmental impact have been traditionally symptomatic and focused on pollutants, repairing subsequent damage, and treating the consequences. Concerning the supply of the raw materials, the main issue has been the exhaustion of non-renewable natural resources. However, irrigation, earth translocations associated with extraction of raw materials and soil erosion alter natural ecosystems thoroughly, continuously and on a global scale. Recognising the serious threat caused by these large flows of non-poisonous materials has gradually shifted the focus upstream to preventing environmental deterioration in advance. The volumes of all these material flows are accounted for in MFA.

The methodology has been systematically developed since the late 1980s in the Wuppertal Institute of Climate and Environment in Germany and by the European network for Coordination of Regional and National Material Flow Accounting for Environmental Sustainability (Bringezu 1993, Hinterberger et al. 2003 and references therein, ConAccount 2006). A meaningful interface between the economy and the environment

has been created through MFA (WCED 1987, Ayres 1989, Adriaanse et al. 1997, Matthews et al. 2000, Bartelmus 2007), and its role in monitoring the state of the environment is now established (Bringezu et al. 2004, CEC 2005, Weisz et al. 2005, Giljum et al. 2008, SERI 2010).

The central concepts in MFA are total material requirement (TMR), direct material inputs and hidden flows. TMR comprises all the material flows caused by productive human activity. It consists of the materials the various products are made of or the direct material inputs, and of those natural resources, which are handled during the production of the commodities, but which are not included within the final product. These are the hidden flows; TMR, thus, is the sum of direct material inputs and the hidden flows. Natural resources are understood broadly to comprise both the exploitable raw materials and the nature as the object of economic activity. TMR sums up diverse material flows, and it is a general, but very unspecific indicator of environmental impact. Its use as an environmental indicator is based on the law of conservation of mass; diminishing the volume of material throughput relieves environmental impact in advance in the source areas of exploitable natural resources, and also results in reduced amounts of wastes and emissions and their undesirable effects at the front end of the nature-anthroposphere interface.

When assessing the volumes of the material flows, those natural resources that are used abroad but the exploitation of which is attributable to domestic consumption must also be accounted for. This is because with globalisation of the trade, the raw materials used in products often originate and they are refined elsewhere than where the final products are consumed. Considering only the domestic production would lower the national TMR, since the hidden flows associated with the imported goods,

including those for transportation, would be ignored (Mäenpää et al. 2000).

MFA is nowadays incorporated into statistical accounting, and the volumes of material flows are used for continuous monitoring of the state of the environment and for eco-efficiency assessments (Adriaanse et al. 1997, Giljum 2006, Giljum et al. 2008, OECD 2008, SERI 2009). In the system of environmental and economic accounting (SEEA), material flow accounting has been streamlined so as to comply with the structures of the national accounts (EUROSTAT 2001, UN et al. 2003, Wernick and Irwin 2005, OECD 2007a, Schoer et al. 2007, OECD 2008). The need to unify the concepts and calculation methods has resulted in the handbook for material flow accounting (OECD 2007b), providing the basis for compilation of national physical input-output tables. In Finland, material flow accounting has been developed in co-operation with Eurostat as a part of NAMEA, the national green account for a tool to follow up the use of natural resources (Mäenpää 2005).

2.2 Eco-efficiency and material intensity

Various phases of a product's life cycle cause unwanted environmental externalities. The impacts are usually most profound during the primary phases of production and can be related to the volume of extracted raw materials used as direct material inputs and as hidden flows that are displaced and alter thus the environment. Eco-efficiency aims at reducing the hidden flows without compromising the volume of exploitable production, the direct material inputs.

Eco-efficiency is, thus, closely connected to the material flow approach. The eco-efficiency concept was introduced in the early 1990s (BCSD 1993, OECD 1997). It is a broad term that is used to describe generally the social strategies

aimed at lowering the environmental burden without decreasing the volume of production or its profitability and human welfare. In practice, this means reducing the material flows or the throughput of materials within the economy. This means dematerialization of the economy by producing more from less. The ultimate aim of eco-efficiency is to increase resource efficiency by reducing the use of energy and materials per production unit and at the same time, to create cost savings and competitive advantage (Adriaanse et al. 1997, Ekotehokkuustyöryhmä 1998, Lovins 2008). The aims are often expressed as factor goals (e.g. Factor10 Club 1997, Reijnders 2008).

Eco-efficiency can be also expressed as a precise index as the output-input ratio, which is used as an indicator (e.g. Marcotte and Arcand 2006). Lately eco-efficiency has been increasingly used in even more precise application to describe the relationship between the economic gains and the environmental impact of productive activity; unit gross national product per total material requirement, GNP/TMR is often used as such an index, (Adriaanse et al. 1997, EUROSTAT 2001, CEC 2005, Giljum 2006, Giljum 2008, Dietz and Neumayer 2007). The inverse of eco-efficiency, material intensity, is also often used; e.g. in MIPS and SIPS measures designating material respective surface intensity per service unit, which have been introduced in order to provide information about the sustainability of performance of the products for consumers (Schmidt-Bleek and Lettenmeier 2000, Burger et al. 2009).

Focusing on eco-efficiency and resource intensity has drawn attention to the trade-off between the output of production and environmental impact. At first, eco-efficiency was used more loosely when referring to getting more out of less: more output with less environmental impact. Later the use of the concept has become

more or less fixed. It is nowadays mostly understood in economic terms to mean more economic output with fewer material or environmental inputs. Improving the labour productivity by intensifying the use of energy and materials has been the basic concept behind all economic activity already before the growth of the environmental awareness. The essence of the eco-efficiency is to widen the focus from labour productivity to resource productivity, which is the precondition for sustainable production and economies (Höhn 1997, Lovins 2008).

Increasing eco-efficiency is a means to provide new possibilities for integrated environmental protection, and it is, therefore, one of the central concepts in strivings towards improved sustainability (WBCSD 2000, CEC 2005, Voet et al. 2005, Giljum 2006, Dietz and Neumayer 2007, OECD 2008, Reijnders 2008). Sustainable development is also stated as a goal in the Finnish Matti Vanhanen's II government platform, and the various ministries of the government stress eco-efficiency as a means of promoting sustainable development (VN 2007). Eco-efficiency approach is one of the basic premises of the interdisciplinary research field of ecological economics. The concept has been keenly incorporated into the business strategies (Verfaillie and Bidwell 2000, WBCSD 2000), and it is especially advocated by the proponents of technological strand of ecological modernization aiming at favourable combination of the economy and environment (Young 2001).

2.3 Ecological footprint, foodprint, foodshed

Human existence is ultimately dependent on the availability of biologically productive land. With increasing population it is becoming an exhaustible resource and its allocation among nations is of outmost importance. Ecological footprint is a concept that relates to the area of bio-

productive land and sea needed to maintain the prevailing consumption patterns at national, regional, local, corporate/organizational or individual level (Wackernagel and Rees 1996, Wackernagel et al. 2004). Footprint accounting is similar to the MFA and LCA approaches, whereby the consumption of energy, biomass (food and fiber), building materials, water and other resources are commensurate and converted into a single measure, which in the case of footprint is normalized land area or so called global hectares.

When applied to food production only, the ecological footprint is reduced to a *foodprint*, which refers to the area needed to produce the food to satisfy the national, regional or individual food demand. Originally the term was introduced by Susanne Johansson (2005), and foodprint area was calculated in compliance with the LCA approach, by defining the system so that in addition to agricultural land (including the ca 7% fallow), also the indirect land use for ecosystem support, indirect resource use and degraded land are accounted for.

Inspired by the local food movement and food system research, David Kloppenburg et al. (1996) introduced in the mid 1990s the "foodshed" concept, as an analogy to "watershed". Foodshed designates the extent of the source areas of food production that surround the population centres. These rural hinterlands are needed to provide the population with the basic food items. The foodshed is part of a given bio- or ecoregion, which is characterised by a geographically distinct combination of climate, hydrology, soil, landforms, and species (Omernik 2004). This ecoregion dictates the natural border conditions of food production and it, thus, includes the local agricultural production systems, where food is grown. Ecoregions cover relatively large areas, and the concept is reserved for describing natural circumstances.

The “foodshed” emphasises the connectedness of place and people and of nature and society by linking food intimately to its source area and its natural circumstances. The size of the foodshed depends on the population basis of the area in question, and on the availability of year round foods and the variety of foods

grown and processed. Foodshed concept is founded on the bioregionalistic school of environmental sociology stressing the ethics, economically self-reliant communities and the cultural context of the bioregion and emphasizing the significance of local populations, knowledge, and solutions (Curtis 2003, Evanoff 2010).

3 Data requirements, data sources and methodological background

The focus here is on primary production and on food consumption; the intermediate phases of processing and distribution are beyond the scope of this thesis. A justification can be sought from the fact that by far the largest proportion of environmental impacts is attributable to agriculture (e.g. Foster et al. 2006, Virtanen et al. 2009). Since the study does not deal with the environmental impacts of the whole food chain, the process-oriented LCA approach was not considered. The methods used here have been developed on the basis of the MFA approach, and they have been greatly inspired by the footprint/foodprint and the foodshed concepts.

The starting point is the definition of the system and assessment of the material flows of agriculture (I). The articles II, III and IV deal with assessing the consequences of food production, of increasing the share of organic production or of changing food consumption habits. The assessment methods are based on food demand, and the methods are applied at national and at local/regional levels. The products accounted for comprise the basic domestic foodstuffs, meat, milk, eggs, fish, grains, potatoes, sugar, oilseeds, vegetables, fruits and berries, and animal feed.

The MFA approach is methodologically developed in Article I. In Article II the data on the physical material flows are fitted within the national physical input-output table in order to analyse the impacts of changing food demand and supply at the scale of nation-wide economy. In Article III the impacts are considered at regional and local scales. Because input-output data are not available at the local scale, the impacts were assessed using the food consumption scenario approach developed on the basis of the footprinting methods. In Article IV, the scenario approach was applied to study the GHG emissions at the national scale. The application of the methods, thus, is based on the balance between food supply and food demand, and this is considered at various levels ranging from that of the agricultural and food sector to national level in the articles II and IV, to the regional level in article III and even per capita level again in article IV. An overview of the type of data used in the four publications and the data sources is compiled in Table 1.

3.1 Quantification of the material flows of agriculture

The total volume of plant production comprises the direct material inputs of agriculture into the economy. Animal

Table 1. Overview of the type of data and their sources used in articles and in this thesis.

ARTICLE I and up-dates for this thesis	
Type of data	Data source(s)
Production statistics	
Statistics on plant production	MMM annual issues (a)
Agricultural land use	MMM annual issues (a)
Horticultural statistics	MMM annual issues (b)
Statistics on fisheries, reindeer, game	Statistics of Game and Fisheries Research
Gathering the wild	Statistics of the Forestry Research Institute
Input use	
Energy consumption in agriculture	Statistics Finland 2009; until 1996 supplied by Juutinen 1999
Agrochemical sale statistics	Statistics of the Kemira Agro Ltd/Yara, the Lime Association and the Plant Production Inspection Centre, ref. MMM annual issues
Factors for estimation ancillary biomass and erosion	Expert appraisals
Production for own use	Surveys of the Statistic Finland, Expert appraisals
ARTICLE II	
Type of data	Data source(s)
Farm models	Alamantila & Riepponen 1998, Koikkalainen & Rikkinen 2002
Material flow balances of the modelled farms	Mäenpää and Vanhala 2002
Data on food consumption	Tennilä 2000
National input-output data	Statistics Finland 1999
Import of food items	Official statistics of the Finnish customs
ARTICLE III	
Type of data	Data source(s)
Production statistics	MMM annual issues (a)
Food consumption data	MMM 2004b
Feeding requirements of production animals	Tuori et al. 2002, expert appraisals
Data on use of wild products in South Savo	Muilu 2004
Numbers of production animals	MMM annual issues (a)
Nutrient balances	OECD 2001
N and P content of the food plants	KTL 2004
N and P content of the fodder plants	Tuori et al 2002
N and P of manure	Ministry of the Environment 1998
N and P sales and other data specific for South Savo	Expertise appraisals
N losses	Grönroos et al. 1998, Pipatti 2001
Use of seeds	ProAgria 2003
Application of fertilizers	Environmental subsidy scheme, Puurunen et al. 2004
Crop diversity	McGarigal & Marks 1995, MMM 2003
Data on GHG and acid emissions	
Emissions from soil	Statistics Finland 2007
Emissions from animal husbandry	Grönroos et al. 1998, Pipatti 2001, Statistics Finland 2005
Conversion factors	IPPC 2005, Ministry of the Environment 1998

Table 1. Continue

ARTICLE IV	
Type of data	Data source(s)
Production statistics	MMM annual issues (a)
Food consumption data	MMM 2007
Feeding requirements of production animals	Tuori et al. 2002; expert appraisals
Data on GHG and acid emissions	
Emissions from soil	Statistics Finland 2007
Emissions from animal husbandry	Grönroos et al. 1998, Pipatti 2001, Statistics Finland 2005
Conversion factors	IPPC 2005, Ministry of the Environment 1998, Statistics Finland 2009
Energy consumption of different production lines	Foster et al. 2006; input-output model for agriculture
Energy consumption associated with fertilizer use	Grönroos et al. 2006

production is based on these direct inputs and, therefore, represents the next step in the material flow. In order to avoid double counting, the animal production is not accounted for in quantification of the TMR. The hidden flows consist of the ancillary biomass i.e. those parts of the plants that are necessary for plant growth but are not used further. Other constituents of the hidden flows are eroded soil, soil enrichments, fertilisers, biocides and growth regulators as well as of the energy consumption. A considerable part of the hidden flows consist of material translocations which in case of agriculture comprise the ploughed soil material and the cleared land areas, in case new land is taken for cultivation.

The data are based on the official statistics obtained and validated by standardized statistical procedures of the respective authorities. The main data sources for the plant production in Finland are the Yearbook of Farm Statistics and Register of the Garden Enterprises published annually by the Information Centre of the Ministry of Agriculture and Forestry. Because the yield volumes are crucially dependent on the weather conditions of the growing season, quantification on the yearly basis produces a highly variable zigzag

pattern that can obscure the long-term development trends. To avoid this problem, the annual variations were smoothed out by using running averages¹ of five years until 2005. From thence they were based on annual figures.

The TMR of the agricultural sector also comprises the reindeer husbandry, the catches of hunting and fishing and harvesting of the wild berries and mushrooms (METLA 2010, RKTL 2010). Because their production does not require manufactured inputs, these products are considered to be primary inputs from nature; the same applies to reindeer husbandry which is largely based on natural grazing. On the other hand, the animal production for animals' farming and the aquaculture are based on the feed feeding, whereby the primary inputs are refined into a different form. Therefore, the products from these sectors are not included; the fodder production is naturally accounted for.

¹ In time series data each value is substituted with the arithmetic average of this value and two adjacent values on both sides; the aim is to reduce seasonal or incidental variation.

The actual use of agrochemicals is not registered, but the volumes sold each year are known precisely. The data are provided by Kemira Agro Ltd/Yara, the Lime Association and the Plant Production Inspection Centre, and they have been retrieved from the Yearbook of Farm Statistics (MMMa).

Energy consumption in agriculture was quantified on the basis of the energy statistics compiled by Statistics Finland; the data until 1996 in Article I were supplied by Juutinen (pers. comm). Although in the MFA approach, all material flows should be expressed in tons, the energy consumption was expressed in terajoules; at that time the contribution from different sources of primary energy to agriculture could not be allocated, and there was considerable uncertainty also regarding the conversion factors for the different forms of energy (Juutinen 2000).

The data used in this study are based on the up-dated times series 1970–2006 of Statistics Finland in which the different forms of energy have been specified. Compared to the earlier data series, the up-dated statistics throughout the time series point to several percent lower energy consumption. Electricity consumption expressed as MWh was converted to megajoules using a conversion factor of 3.6, and the megajoules were converted to ton equivalents of primary energy source using the factor 0.02388 (Statistics Finland 2009). In the official statistics energy consumption of the machinery used in agriculture and in forestry has not been separated, but is given as a single value. In 2004, the share of forestry machinery was approximated to be 15% of the light fuel oil use (Lampinen and Jokinen 2006); this percentage has been subtracted from the volume of the light fuel oil use throughout the time series data.

Ancillary biomass was estimated on the basis of the volume of plant production

using plant-specific factors. The volume of eroded soil was estimated on the basis of the area of cultivated land using a value of 1700 kg/ha, which is an approximate average erosion loss in Finland. These factors as well as the volume of the various products for own consumption are based on expert appraisals. The details of the calculations and the conversion factors have been published separately (Risku-Norja 2000).

3.2 Farm model database

Farm models are hypothetical average-sized single-product farm enterprises that represent different agricultural production lines. The production circumstances of southern Finland are assumed in this work. With the models, the products and the production inputs of each farm type are quantified and priced. The basic principles of farm model construction were described by Ala-Mantila and Riepponen (1998) and by Koikkalainen and Rikkonen (2002); the database is maintained and up-dated by the MTT Agrifood Research Finland, Economic Research.

All the production costs are accounted for in the farm models, the production inputs are specified as material inputs, work, general costs and capital costs; the latter three categories are necessary only for the economic impact assessment, whereas data on the volumes of the material inputs are needed for assessing environmental impacts. The basic data for the models comprise agricultural statistics, published research data as well as expert appraisals.

The production lines covered by the farm models were: conventional and organic wheat, rye, barley, oat, milk, beef, pork, egg and piglet production, and in addition conventional sugar beet, rape seed, potato, open air vegetable, green house vegetable, fruit and berry as well as cut flower and

nursery garden production (Koikkalainen and Rikkonen 2002).

3.3 Material flow balances of the farms

The basic principle of the MFA approach is the principle of conservation of mass; therefore, in quantifying the material flows the inputs should balance the sum of the outputs plus the growth of the reserves. Photosynthesis is the fundamental process for both plant growth – formation of the reserves – and for creating the yield, which represents the direct material inputs of agriculture to the economy. In the internationally standardized material flow accounting procedures, photosynthesis is regarded as a phenomenon of nature and, consequently, water and air are regarded as so called free goods, and are not accounted for when quantifying the material flows (Adriaanse et al. 1997, CEC 2001). In order to account for the water, carbon dioxide and air or those free goods, that are necessary for the photosynthesis, the system boundaries were redefined so as to include also these free goods into the system (II, Figure 1). Therefore, the material flow data of the farm models were complemented by quantifying the volumes of these substances so as to balance the inputs and outputs of each farm model.

The inputs from nature are water, carbon dioxide (CO_2) and oxygen (O_2) plus solar energy, the inputs from the other sectors of the economy include fertilisers, biocides and energy in the form of fuels and electricity. The yield from plant cultivation enters the food flux as the direct material input of agriculture. The outputs to nature from plant cultivation are the gaseous O_2 , CO_2 and ammonia (NH_3) from the manure that is applied to the soil. The outputs from animal husbandry are CO_2 , water vapour, and methane (CH_4), and the output from consumption is CO_2 . Other outputs are sewage as well as the wastes from the products proper,

i.e. plant, slaughter and food wastes. The gaseous emissions end up directly into the atmosphere. The sewage is partly recycled back into the food flux and partly expelled from the system. The other outputs enter the soil, remain there or are subsequently moved into the watersheds or into the air (II, Figure 1). The details of compiling the farm balances were described by Mäenpää and Vanhala (2002).

3.4 Input-output approach

Input-output tables are a statistically organised presentation of both monetary and physical material flows, and they are often used in the context of the nationwide economies. In the cross-tabulated input-output table the columns of the table comprise the various production sectors of the economy, and the four categories of the end use of the products (private and public consumption, capital formation and export). The production sectors are shown also in the rows of the table; the labour and capital inputs are shown beneath the table as the basic inputs. The rows show how much of that sector's produce (output) has been used both as an intermediate product (input) in other sectors and as end products. The columns show the inputs or how much the sector has used intermediate products from the other sectors, and how much it has used the basic inputs of labour and capital. Therefore, in each sector the values in rows and columns add up to the same amount. The input-output table is compiled in physical and monetary terms. The flows from the producer sectors to the various user sectors are concretely illustrated with an input-output table allowing, thus, its detailed examination and analysis. The input-output model is constructed on the basis of factors derived from the matrix of the input-output table, and it shows the links between various sectors at the national scale both in terms of the products' volumes and their monetary values.

3.5 Food consumption scenario approach

Food consumption scenario approach was developed in article III and further elaborated in article IV. In this approach, food demand is coupled with the physical basis of food supply by considering the production capacity in relation to food consumption. Scenarios are various fixed dietary options, which are used to assess feasibility of re-localising food production and the impact of dietary changes on the environment. The current average food consumption is used as the benchmark, and the impact of the different food consumption scenarios is compared with that of the benchmark

scenario. Construction of the method was influenced by the area-based footprinting approach and by the modelling approach of the input-output methods.

Environmental impacts are assessed in terms of nutrient balances, greenhouse gas and acidifying emissions, agricultural energy consumption, agricultural land use and the diversity of crop cultivation. These indicate eutrophication of watersheds, climate change, acidification and landscape changes, respectively. The details of the calculations and the exact figures for the calculation parameters were published in a technical report (Risku-Norja et al. 2007). The extensive data requirements were compiled in Table 1.

4 Extending the methods to agriculture and the findings

This section summarises on the one hand the actual research results regarding the volumes of material flows, eco-efficiency development (I) and environmental impacts of changes in food consumption and food production (II, III, IV). On the other hand, the findings regarding suitability of the used approaches to agriculture are also captured. Therefore, for each of the approaches – MFA, eco-efficiency, input-out modelling and food consumption scenario – the methodological design is first described. The results from applying the method to empirical data are subsequently presented and finally, the applicability of the approach is critically evaluated.

4.1 Material flows

4.1.1 Streamlining material flow accounting for agriculture

The total material requirement of agriculture comprises both the exploitable yield representing the direct material inputs from agriculture into the economy, and the hidden flows associated with the production of the yield.

Quantification of the TMR according to the MFA guidelines (OECD 2007b), necessitates inclusion of the material flows of agriculture proper as well as the data both from the related production sectors and the data regarding products for own use. The volumes of hunting and professional fishing are well documented

by the Game and Fisheries Research Institute, and those of the retailed wild mushrooms and berries by the Finnish Forest Research Institute. However, a variable amount of the cultivated and wild products and of reindeer meat goes for own use. Estimations of their volumes are based on extrapolations from various surveys. There are, therefore, several uncertainties in the data sources. In order to improve the relevance and reliability of the MFA approach, the quantification of material flows has been simplified so as to comprise only the agricultural production as presented in the official statistics.

The MFA principles would require that even the volume of ploughed soil is part of the hidden material flows, and should be quantified. The estimated volume of ploughed soil is 3000 tons per hectare (Mäenpää et al. 2000); using that figure the share of hidden flows would be 99.9% of the TMR of agriculture, and it would essentially consist only of ploughed soil. Although estimated, ploughed soil was, therefore, not accounted for in Article I nor in the updated data of this thesis.

4.1.2 Application to empirical data

The results of the simplified quantification are shown in Figure 1, in which the data of Article I have been updated until 2007 and complemented with the volumetric data on the energy consumption, including consumption of primary energy sources of electricity. The resulting time series data do not change the picture for the overall development. Until 1998, the differences are not detectable on the graphs and there have been hardly any changes in the relative shares of the hidden flows from the TMR or of the fodder from the total yield since 1998.

TMR of agriculture in Finland is currently about 35 millions tons or about 6 tons *per capita per annum*. The exploitable yield, direct material inputs into the economy, is about 13–14 millions tons, and of this about 60% is roughage for animals, mainly hay and silage. As about half of the cereal production is also used as animal fodder, the animal feed stuffs amount thus to 67–75% of the direct material inputs. The share of the hidden flows from the TMR is

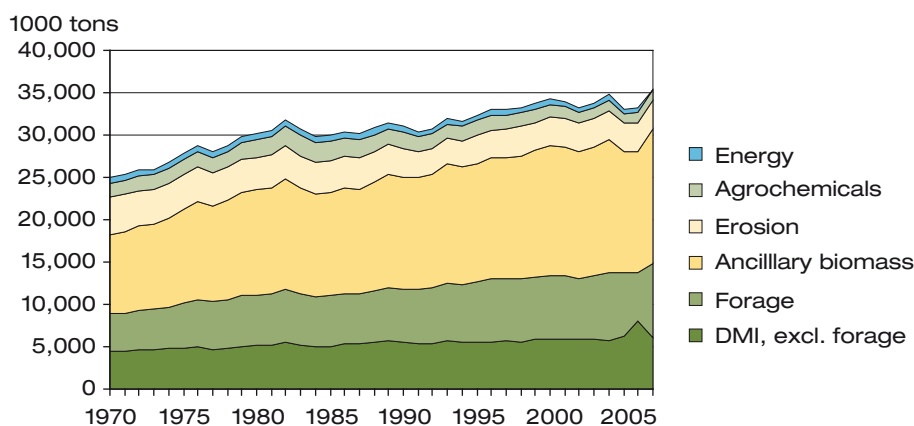


Figure 1. Development of the total material requirement (TMR) of agriculture during 1970–2006, 1000 tons. 5-years running averages until 2004, thence annual figures. Data source: Information Centre of the Ministry of Agriculture and Forestry.

considerable, about 60%, and they consist mainly of ancillary biomass and eroded soil. Agrochemicals currently comprise less than 5–6% of the hidden flows; from 1970 to the end of the 1990's their share was about 6–8%. The share of energy from the hidden flows is about 2% (Figure 1).

The up-dated time series data from 1970 to 2007 in Figure 2 show that the total yield per hectare has roughly doubled since 1970. The peak, total yield about 7 tons per ha, appears to have been attained in the 1990s. No marked differences are evident since then, and the total yield levels appear to have stabilised. Use of lime for soil improvement and of biocides increased from 1970 to the early 1990s. A short period of marked reduction was seen in the mid 1990s. Liming is now at about same level as in 1970, but biocide use has been again increasing continuously in the new millennium. The fertiliser use was fairly stable until late 1980s, but has been markedly reduced since then (Figure 2). Energy consumption increased somewhat until the latter half of 1980s, since when it has slowly decreased and was at about the same level as in 1970 in the 2000s. Regarding electricity consumption there

was a sharp increase from 1970, and at the end of the 1980s it was threefold compared to that of 1970. In the first half of the 1980s, electricity use was reduced somewhat, and during the new millennium it has remained at a fairly stable level, which is about 2.5 times higher than in 1970.

4.1.3 Critical evaluation

The purpose for quantifying material flows of agriculture was to analyse the natural resource use of the sector and to improve understanding about the material throughput from agriculture to other sectors of the economy. Because of inclusion of data on the related production sectors and on the products for own use, quantification of the material flows of agriculture according to international standards is rather tedious. The related production sectors and their share from the direct material flows comprise fisheries (under 1%), hunting, non-food production and reindeer husbandry (under 0.1%). Also gathering of the wild berries and mushrooms (under 0.1%) as well the products for own use (about 1% based on estimations) were accounted for in the MFA assessment in Article I.

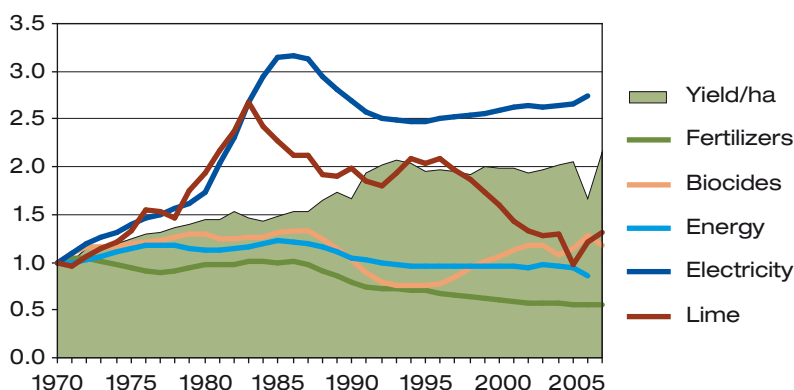


Figure 2. Development of the agricultural input use and the average total yield level in 1970–2006 compared to the base level in 1970; 1970 = 1. The figure is based on 5-years running averages of input use until 2004, after that on annual data. Data source: Information Centre of the Ministry of Agriculture and Forestry.

The total share of these from the TMR of agriculture is 1–2%. Their exclusion from the TMR of agriculture does not invalidate the conclusions based on the earlier MFA data (I; Figure 1). The simplification only makes accounting easier and increases the consistency of the data, because quantification is based on official statistics for all included data.

Without inclusion of ploughed soil over 90% of hidden flows consist of eroded soil and ancillary biomass. Ancillary biomass does not actually enter the material throughput, but is tilled back into the field already during the harvesting phase. On the other hand, erosion in Finland is of minor importance and may create occasionally problems that are restricted to confined areas (Mansikkaniemi 1982, Peltonen 1996). In those cases erosion is without doubt an important environmental factor, because a significant part of the phosphorus loading of the watersheds is brought about by the surface runoff (Uusitalo et al. 2001). However, in the national account, both erosion and ancillary biomass are calculatory estimates, and their volumes are closely linked to the

volume of the yield; erosion is estimated on the basis of cultivated area and ancillary biomass on the basis of the yield itself. Their inclusion into to the TMR does not reveal any environmentally relevant information, but hides the small flows caused by the fertiliser, biocide and energy use, the environmental impact of which is potentially much more important. In the national accounts, erosion and ancillary biomass can, therefore, be excluded from the hidden flows.

Sector-wise scrutiny of the material flows of agriculture provides an overview of the development within the sector over recent decades. Development trends may reveal details that call for further considerations. For example, the marked increase in electricity consumption and the simultaneous decrease in other energy consumption shown in Figure 2 suggests introduction of new technologies to agriculture, the environmental consequences of which are worth a close scrutiny.

When the MFA data on agriculture are disaggregated into few categories, the data

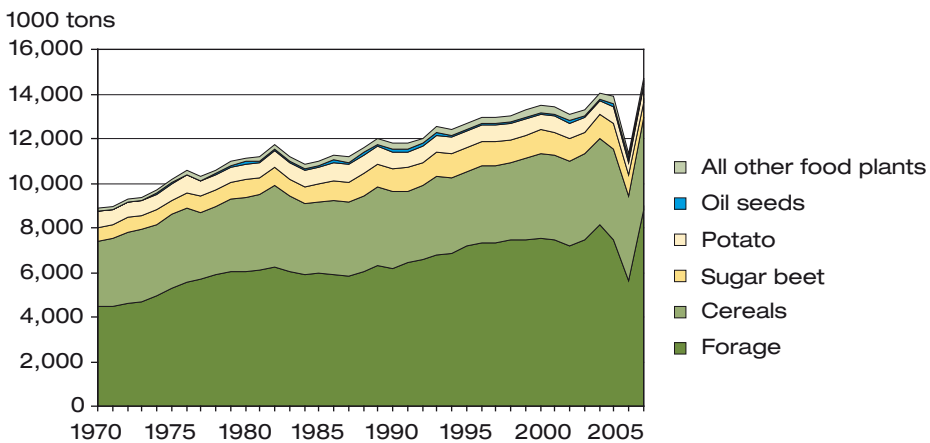


Figure 3. Development of the volumes of the direct material inputs during 1970–2008; 1000 tons. 5-years running averages until 2004, thence on annual figures; Data source: Information Centre of the Ministry of Agriculture and Forestry.

reveal a picture of relative importance of the various production sectors over time (Figure 3). The data may inspire contemplation of the underlying societal change such as food consumption patterns or export and import of agricultural products and the reasons for the change that has resulted in re-distribution of the production lines. However, before such re-distribution can be detected by analysing time series data, the changes must be very profound and would certainly not have gone unnoticed even had the time series data not been presented.

The MFA approach is suitable for analysing overall trends only at a very rudimentary level. If there are large differences in the volumes of the various contributions to the total yield-TMR -ratio, the development of the volumetrically small flows is not detectable, and it has to be considered separately. For example, there are marked changes in the mutual proportions of the products within the miscellaneous group “all other products”. Because cereal and forage production comprise about 90%, and potato and sugar beet together another 5–6% of the direct material inputs, the eventual, potentially interesting changes

within “all other products” are not evident in Figure 3. One possibility is to consider the development of the various flows in relation to a given benchmark situation. This is done in Figure 4, where the changes are made visible by considering the development of the volumes of various flows relative to that in 1970.

4.2 Eco-efficiency indicators

4.2.1 Constructing eco-efficiency indicators for agriculture

Improving eco-efficiency means getting more out of less or reducing the hidden flows in order to increase the ratio of products to environmental consequences. In agriculture, the benefit is the volume of the products from plant cultivation, which can be measured in tons or on a monetary basis. *De facto*, eco-efficiency is usually expressed in monetary terms as the ratio of e.g. gross national product or value added to TMR, which is used as an overall indicator of environmental impact. In agriculture, however, eco-efficiency indicators of this kind are not very useful. This is because the volume of production crucially depends on

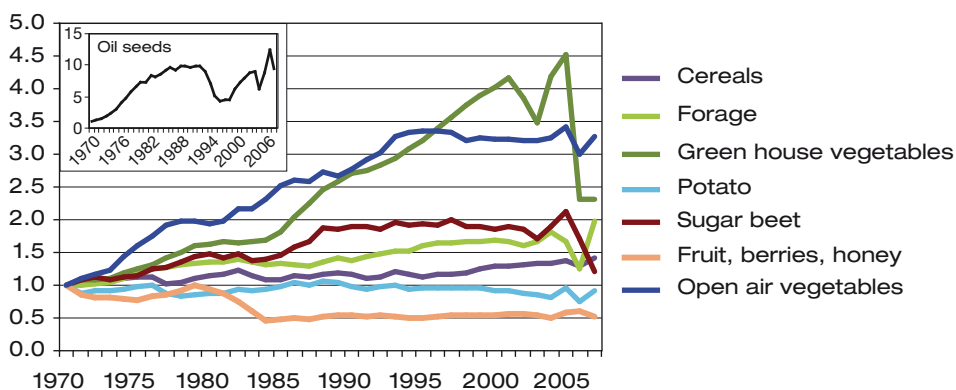


Figure 4. Development of the yields of the various products within the miscellaneous group “all other products” in 1970–2007 compared to the base level in 1970; 1970 = 1. The inserted figure shows the development for oil seed production. Data source: Information Centre of the Ministry of Agriculture and Forestry.

the weather conditions during the growing season and the added value of agriculture is largely dictated by agricultural policy.

The trade-off between the production and the environment sacrificed for the sake of the production is also one expression of eco-efficiency. In that case, the input is environmental disturbance and the benefit is expressed in terms of production, i.e. the direct material inputs into the economy. Environmental disturbance is often measurable in quantitative terms, but it is not easily translated into unambiguous universal indicators. This is because the actual impacts of the various discharges on the environment are dependent on the circumstances, which vary greatly in scales ranging from regional to field plot. This makes the interpretation far from simple. Besides, the kind of data needed for follow-up are usually not available.

Because of the intimate mutual and direct positive interdependence between ancillary biomass and erosion, which have been estimated using calculatory factors based on the average values (4.1.3) and the yield, indicators including data on erosion

or ancillary biomass or both are of no use in assessing eco-efficiency of agriculture at the national level. Locally, where erosion is a real problem, it provides important information about the phosphorus loading of the watersheds (Uusitalo et al. 2001), and should be accounted for in environmental assessments of agriculture.

Improvement in eco-efficiency means minimising the use of the inputs without compromising the volume of the production. This is shown as an increase in the ratio of the yield to the input use. Constructing indicators on the basis of the total yield, agrochemicals and energy consumption are simple indicators that provide more information than using one compound figure such as e.g. TMR. Quantitative data on use of fertilisers, biocides, and energy use are also readily available.

4.2.2 Application to empirical data

Regarding fertilisers, the indicators constructed on the basis of total yield-agricultural input -ratio show marked improvement in eco-efficiency since late

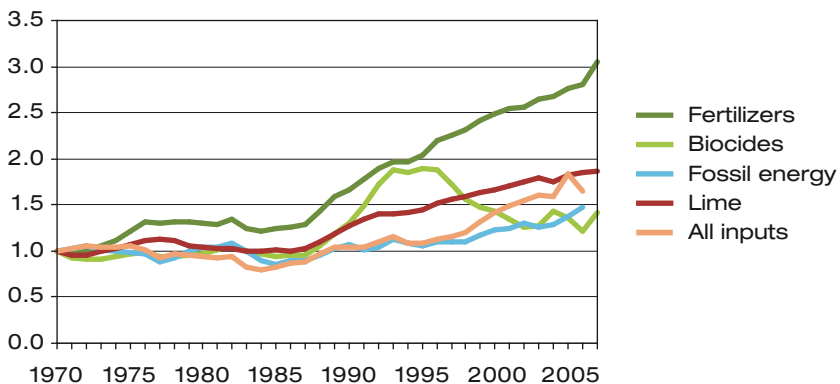


Figure 5. Development of eco-efficiency of agriculture in 1970–2007 expressed as the ratio of total yield to the use of biocides, fertilisers, lime for soil improvement and fossil energy consumption relative to the base level in 1970; 1970 = 1. Data sources: Information Centre of Agriculture and Forestry, Kemira Agro Ltd/Yara, the Lime Association and the Plant Production Inspection Centre, Statistics Finland.

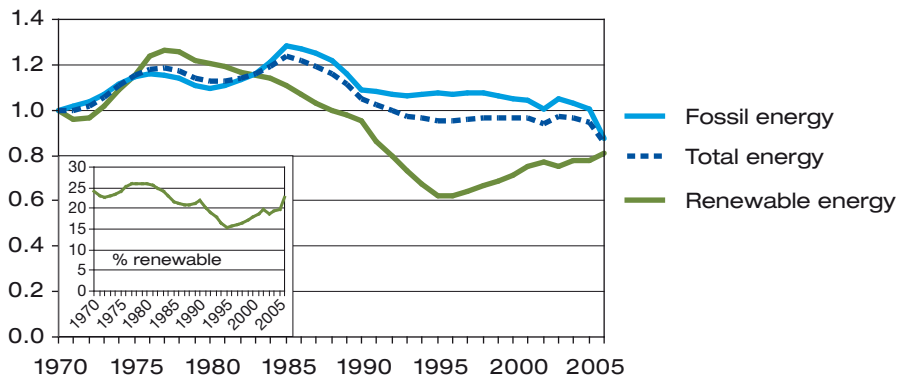


Figure 6. Development of energy consumption in agriculture in 1970–2006 expressed relative to the base level in 1970; 1970 = 1. The inserted figure shows the development of renewable energy as percentage of total energy consumption during 1970–2006. Data source: Statistics Finland.

1980s (Figure 5). As to the biocides, there was a short period of improved eco-efficiency in the mid 1990s, but around the turn of the millennium the trend changed, and the eco-efficiency is now at the same level as in 1970². Expressed as fossil energy consumption, eco-efficiency has improved by about 50% from 1970 to 2006, the improvement having taken place especially since the mid 1990s (Figure 5).

4.2.3 Critical evaluation

Eco-efficiency expresses only the ratio between output and input, not their actual volumes. This needs to be borne in mind when interpreting the figures; the cause of environmental impact is not the ratios, but the actual physical volumes of the environment-burdening materials. Improved eco-efficiency does not, thus, automatically equate with relieving environmental impact. This may be due

to systemic responses to the introduction of new measures that offset the beneficial impact of the taken measures. This rebound effect tends to be forgotten when focussing on the ratios (e.g. Hanley et al. 2009).

The rebound effect is illustrated by the development of fossil energy consumption (Figure 6), which increased from 1970 until late 1980s. Since then it has declined, and it is today at about the same level as in 1970. Thus, despite the improved eco-efficiency of about 50% shown in Figure 5, the actual use of fossil energy has varied over the considered time period, and its current use and, consequently the environmental impact associated with its use, is at about the same level as in 1970. Thus, over the considered time period, eco-efficiency improvement has taken place with concomitant increase of fossil energy use.

It is further worth noting that compared to the 1970s, the electricity consumption, which is mainly based on fossil sources of primary energy, has almost tripled (Figure 2). This substitution of energy source has also bearing on the environment and should be accounted for. However,

² Here only the volume of biocide use is accounted for; the introduction of small dose herbicides coincides with marked eco-efficiency improvement in the 1990s. Use of conventional herbicides increased again at the end of that decade.

eco-efficiency of electricity consumption cannot be expressed in terms of total yield, because electricity does not produce anything measurable, but is related to production of services such as e.g. heating or cooling of farm houses and production buildings or is needed in some phase of the production process.

Regarding renewable energy, after a short and sharp increase in the early 1970s, its use started to decline already in the 1970s, reached its bottom in the late 1990s, and has begun slowly increase again only during the 2000s. In its height in mid 1970s, the share of renewable energy from total energy consumption was about 26%, in mid 1990s it was about 15% and is now about 23% (insert graph in Figure 6).

Also the time delay between improved eco-efficiency and any detectable improvement in the state of the environment may be considerable; e.g. despite the significantly improved eco-efficiency of fertiliser use since the mid 1980s (Figure 5), the content of soluble soil phosphorus has continued to increase until the end of the 1990s. Only during the recent years has the trend been levelling out, but still it has not yet been reversed (Uusitalo and Ekholm 2003, Uusitalo, pers.com. 2010). Another delay is expected before the reduced fertiliser use improves the nutrient status of the eutrophied watersheds and of the Baltic Sea (SYKE 2005). This shows the length of time needed to evaluate efficiency of the measures introduced in environmental policy.

4.3 Input-output model for food flux

4.3.1 The model

The food flux comprises the four mutually linked loops of plant production, livestock husbandry, food processing and food consumption. The input-output model for the Finnish food flux was constructed

in order to analyse the movements of the food-related material and monetary flows within the economy and the consequent impacts on the environment. The data sources were the farm models' data basis, (3.2) material flow balances of the farms (3.3) as well as the food consumption statistics and national input-output tables.

In the national input-output table agriculture is presented as one sector (Statistics Finland 1999). In order to examine more closely the material flows of the food flux, the national data on agriculture were re-allocated to four sub-sectors: plant production, animal production, garden production and other agriculture. The number of farms in each different production line (farm model) was adjusted so as to comply with the total output of that line as expressed in the national production statistics. These data were then fitted within the national input-output table.

Biological processes – photosynthesis and animal metabolism – have a key role in the food flux. Because these processes are not accounted for in international material flow accounting standards (CEC 2001), the national input-output data of agriculture were modified so as to include the data derived from the material flow balances of each of the model farms.

Both plant and animal products contain varying amounts of water. Metabolism requires oxygen and liberates carbon dioxide and water vapour, enteric fermentation produces also methane. In order to quantify the gaseous emissions, the animal metabolism cannot be overlooked, and ignoring the water would result in a considerable material imbalance, e.g. in case of milk production the outputs would greatly exceed the inputs, which would violate the principles of MFA. On the other hand, the ancillary biomass need not to be accounted for, because it is returned

to the soil on harvesting and it does not enter the material throughput within the economy. In addition to the agricultural input use, the material flow balances of the plant production farms include data derived from the photosynthetic equation ($6\text{CO}_2 + 6\text{H}_2\text{O} \rightarrow \text{C}_6\text{H}_{12}\text{O}_6 + 6\text{O}_2$). For livestock farms the plant products are incorporated into growth and maintenance of the living animals and in animal products through transformation of the plant feed in the metabolic processes; the calculations were carried out on the dry matter basis (Mäenpää and Vanhala 2002).

The model enables assessing some environmental and economic consequences, if the production structure, share of organic production or Finnish food consumption were to be altered (II). Environmental impact is assessed on the basis of the material flow balances of the farms and it is expressed in terms of agricultural land use, total material requirement (TMR), fuel consumption, electricity consumption as well as GHG and acidifying emissions; these were given as CO_2 respective SO_2 equivalents using the conversion factors of IPCC (2005). Economic consequences are deduced from the monetary input-output data and expressed as agricultural output, agriculture's share from GDP, employment and import. The impacts can be viewed at the level of agriculture, of the food sector as a whole, of all other sectors – in combination or separately – and at the level of the national economy. The basic structure of the input-output table and the principles of constructing the model were described by Vanhala and Mäenpää (2002).

4.3.2 Application to empirical data

The integrated input-output model was used to assess the impacts of changing food production and consumption on the environment and economy (II). In this model, there are basically two approaches that can be used separately or in

combination; one is to increase the share of organic production, and this can be done with any combination of the products covered by the farm models. The other approach is based on food consumption, wherein the impact of dietary changes is assessed. Here again, any diet can be chosen as long as the total energy intake is kept constant. Thus, if meat consumption decreases, corresponding amount of the energy has to be allocated to the vegetarian products. In assessing the impacts, the environmental and economic consequences of the various options were compared against the situation in 1995. (II.)

Because of the lower yields, the more extensive organic production requires more cultivated land area to reach the same production volumes as conventional agriculture. The need for fallows, in particular, to secure biological nitrogen fixation is greater by an order of magnitude. Therefore, using the indicators provided by the model, increasing the share of organic production with greater land use requirements appears environmentally less favourable when compared with conventional agriculture. This is shown by the increase in greenhouse gas and acidifying emissions and also in the TMR. On the other hand, energy use is reduced because of the reduction in fertiliser input. The changes in consequence of increasing the share of organic production are substantial only with regard to the agricultural land use.

Organic production is economically beneficial, as it increases the value added of agriculture. Because of the small contribution of agriculture to the national economy, the environmental and economic impacts of increasing organic production are perceptible only at the level of agriculture or the food sector, at most. When viewed at the nationwide level, their contribution to the environment or economy is extremely small. (II.)

The impacts of changing food consumption patterns appeared to be more perceptible than the impact of increasing the share of the organic production. There are, however, numerous ways to compose diets with constant energy intake, and the impacts depend critically on the composition of the diet. The more vegetarian diets are environmentally less burdensome than those containing products of the more resource-intensive livestock husbandry. A major part of the GHG of agriculture originates from the cultivated soils, livestock husbandry also contributes to them, and it is the major source of acidifying emissions as ammonia (Syväsalo et al. 2004, Statistics Finland 2007, II). The negative economic impact was due to lower degree of processing of vegetarian products resulting in the lower value added. The impact was, however, restricted to the agri-food sector (II.)

4.3.3 Critical evaluation

The model captures some of the economic and environmental impacts, when either food consumption or production structure is changed. It allows increase freely the share of organic production in any single production line or in any combination of the production lines that are described with the farm models. Similarly, it allows free choice among any combination of the food items, as long as the total energy intake is kept constant. The model is very flexible, but the user has to use her own judgement in order to compose nutritionally reasonable diet options.

The results of the modelling are expressed as actual volumes or economic losses and gains, not as changes relative to a given benchmark year. When expressed this way, the significance of the change may be difficult to perceive. The model could be improved by incorporating into it a base level and expressing the results relative to that, as was done in Article II. A user-

friendly application would give the results both in figures and in graphs.

The environmental impacts are described in terms of TMR, GHG and acid emissions, energy consumption and agricultural land use. Out of these, farm land area is a more useful general indicator for agriculture than TMR, since both the environmentally significant input use and the production volume are related to it. Because of the highly aggregate nature of the data comprising the total material requirement and because a large proportion of the hidden flows is calculatory, TMR is not a good indicator for environmental impact in agriculture (see 4.1.3).

Eutrophication of the watersheds through nutrient leaching is the major environmental issue in Finnish agriculture, and it is not accounted for in the model. Evaluation of the environmental impacts is based on the material balances of the farm models, which represent national averages. Regional climate, cultivated species, cultivation methods and timing of the cultivation measures influence energy consumption and gaseous emissions as well as nutrient balances. In contrast to the energy consumption and gaseous emissions, the nutrient balances are also crucially dependent on the weather conditions of the growing season and on hydrology, topography and soil type; these vary at the scale of field plot. Still the impacts of nutrient leaching reach to regional level, and the impacts have national significance via fishery branch and recreational use of nature. Therefore, although the Finnish average nutrient balances can be calculated, such a figure would have little significance regarding the actual situations and it does not help in identifying the key areas of nutrient loading and in targeting the measures aimed at actually improving the state of the environment.

At the moment, the model is based on the input-output data from 1995, and on the

farm models constructed in the early 2000. The data requirement of the input-output model is large, and up-dating it is tedious, but not impossible. The major task, the actual construction of the model itself, is done. Also the availability and aggregation level of the data from the existing statistics compiled by various authorities for their own purposes has been clarified, and the conversion factors needed to convert all data into weight units are now available.

Input-output analysis allows sector-wise considerations, but shows also the results at the national scale, which is important in order to obtain a comprehensive view. Despite its restrictions, the model provides a general picture of what the changes in production structure and in food consumption patterns or in both can bring about and where the impacts are most evident. The significance of the input-output approach is that the model reveals the net impact at the national level. For example, when machine entrepreneurs from outside agriculture are used, in the input-output approach energy consumption would be allocated to the service sector, not to agriculture. The model cannot be cheated by redistributing the impacts among the sectors.

4.4 Food consumption scenario –approach

4.4.1 Developing the method

The starting point is the demand for food based on the number of people living within the considered area. The food demand defines the agricultural land area needed for various cultivated food plants, as well as the numbers of different production animals. The area needed for different feed crops is calculated on the basis of the numbers of production animals and their feeding requirements. Environmental impacts are estimated on the basis of changes in these key parameters.

The options used in the food consumption scenario approach can be compiled depending on the focus of the research, e.g. in Article IV one of the diets was compiled so as to exclude all the products from ruminants. In general, because in relation to the dietary recommendations, the average Finnish food consumption is still biased towards animal products (Heikkinen and Maula 1996, Helakorpi et al. 2003, Prättälä 2003), the dietary scenarios in III and IV feature an increasing use of vegetarian products ending up with a purely vegan diet. For all options, the imported fruit is substituted with domestic fruit and wild and cultivated berries. The energy intake of the diets is kept constant and the diets are also nutritionally balanced in terms of reasonable daily intakes of carbohydrates, fats and proteins.

All fodder including the protein feed for the animals – rapeseed and pulses – is assumed to be domestic in the calculations. Both in organic and conventional animal husbandry the feed intake is assumed to be the same; consequently the output per animal is also the same. However, in organic production, the yields per hectare are 20–65% from those of conventional production (Mäder et al. 2002, Lötjönen et al. 2004, Kirchmann et al. 2007, Rosen and Allan 2007, Birkhofer et al. 2008, Dresboll et al. 2008), and this accounts for differences in the areas of agricultural land needed for food and feed production.

4.4.2 Application to empirical data in local and in nation-wide context

The food consumption scenario approach was used to study the impacts of re-localising food production (III). The case study area was South Savo, and the assessment was based on different options of food demand that was to be met using locally produced basic food items. Both organic and conventional production systems were considered, and in order to find an optimal unit for re-localising, 'local

supply' was considered at three levels: municipal, joint of municipalities and province level.

Concerning the basic foodstuffs, the South Savo region could satisfy its own demand, but localising primary production for own food consumption would require some redistribution of the production lines within the farming sector. If production were based on organic farming, the current average food consumption would require all the cultivated land area to satisfy the local demand, but with the other options only part of the cultivated land area (58–79%) would be needed. (III.)

Food consumption patterns apparently do have an impact on the environment. Compared with crop cultivation, the more resource-demanding animal husbandry is in many respects more of a burden on the environment. Choosing a vegetarian diet seems to be environmentally beneficial in terms of reducing GHG and acid emissions, and nutrient loading. On the other hand, the vegetarian diet option was not optimal in terms of its effect on the diversity of wild species. For these, the areas covered with vegetation throughout the year are especially important. In agriculture, these areas include grasslands, green fallows, cultivated and natural pastures the maintenance of which is largely reliant on dairy cattle and other grazing animals. Regarding crop diversity, organic production results in higher diversity indices for all diet options; the differences, however, are very small. As to the gaseous emissions, compared with conventional production, the extensive organic production causes more GHG emissions, because the main source is the cultivated soil. On the other hand, organic production results in slightly lower acid emissions, the sources of which are animal dung and fertilisers. (III.)

Depending on the diet option, local food demand caused at most only about

half of the environmental load of food production. The remainder was due to the net production in excess of demand in the source area; this excess was exported from the area. (III.)

At the nation-wide context, the food consumption scenario approach was used to explore closer the contribution of the soil, production animals, fertilizer use and energy consumption to the agricultural GHG emissions and to assess the possibilities to reduce GHG emissions through diet changes. The impact of changing food demand on GHG emissions was calculated on the *per capita per annum* -basis, and then considered at different scales ranging from agriculture, entire food sector and nation-wide level. Both conventional and organic production was addressed (IV.)

The total volume of the GHG emissions due to consumption in Finland is about 60 000 million kg CO₂ equivalents, and the contribution of the food chain is about one quarter (Mäenpää 2004). Within the food chain, primary production produces about 70% of the GHG; this includes the fertilizer manufacture and agricultural energy consumption. The results are in compliance with LCA results recently reported elsewhere (Virtanen et al. 2009).

The major source of GHG in primary food production is the cultivated soil. For current average food consumption the emissions from the soil represent 62%, the share of the emissions due to enteric fermentation is 24% and energy consumption and fertiliser manufacture both contribute about 7%. The relative shares as well as the actual volumes naturally vary depending on the diet. Because of the extensive production mode, organic production needs more area, and regarding GHG emissions the environmental performance of organic production is consequently poor. (IV.)

A strict vegan diet would result in nearly 50% reduction in GHG emissions due to primary production, and excluding the ruminant products (milk, beef and mutton) from the present day food consumption the reduction would be 33%. Contribution of the considerable emission reductions within agriculture would result in decreasing the total GHG emissions due to consumption in Finland by about 8% for the vegan diet and about 5% for the diet with no ruminant products. (IV.)

4.4.3 Critical evaluation

The food consumption scenario approach combines food consumption, production capacity and assessment of environmental impacts caused by the changes in food consumption. The approach is based on balancing food supply and demand, and both conventional and organic production can be taken into account. In contrast to the flexibility of the input-output model which allows free choice in both food demand and percentage of organic production, the approach based on food consumption scenarios is restricted to diet options that have to be fixed in advance. The base line option is present day average food consumption, against which the impacts of dietary changes are compared. The results of changing food consumption are shown together with the present day situation; the impacts of changing food consumption habits are, thus, easily seen.

The given diet scenario represents the average food consumption of the population within the considered area. The parameters dealing with production potential, crop diversity and nutrient balances and gaseous emissions were adjusted according to the production circumstances of South Savo, which was the case study area (III). The approach can be used in other regions by changing the calculation parameters accordingly.

In the case study, the focus was on the hinterlands of the urban consumption areas (III). Because the sparsely populated rural areas also produce food for urban centres, both the rural source areas of production and urban sinks of food consumption need to be addressed in balancing food supply and demand and in assessing environmental impacts of local food production.

The geographic extent of re-localisation, the foodshed of Kloppenburg et al. (1996) within which the balance is to be reached, depends on the population basis of the surrounding consumption centres. Because of the varying production structure in the hinterland source areas, “local” is also different for different foodstuffs. “Local” is, thus, not fixed to any given distance nor is it same for all products, but remains a concept covering various spatial scales.

In Article IV dealing with GHG emissions only, national averages were used, and the data were complemented so as to include also the GHG associated fertiliser manufacture and agricultural energy consumption. Also regarding the nutrient balances and crop diversity the approach could be extended to the national level. The calculation may be an interesting exercise, but results would not be informative for identifying the problem areas. For the reasons explained in section 4.3.3, the average Finnish nutrient balances are extremely abstract figures. Calculating the average crop diversity would require aggregation of data from the field plot level and redistributing it evenly within the Finnish agricultural land; it is an enormous task, and the informative value of the result is at the very least questionable.

At this stage, the approach is a proto type application and the feasibility and various environmental impacts have been calculated separately. The approach could

be developed further so as to provide a calculation model into which the user feeds the values of the variables describing the specific production circumstances and the population size. The model would then calculate on the basis of food consumption

data the agricultural land use, numbers of various production animals, GHG and acid emissions, nutrient loading potential and crop diversity. By pricing the products, inclusion of at least some kind of economic information would also be feasible.

5 Discussion

In this section the results of the thesis are brought into a wider sustainability context. The role of the approaches presented here, their limitations and the potential usage for decision making in measuring environmental performance of food production are considered in sections 5.1 and 5.2. Subsequently the bearing of the food-related environmental information on actually improving the state of the environment is considered (5.3). In closing, a framework for sustainability assessment is outlined by pointing out on the one hand, the need to expand the scope of the issues and, on the other hand, to simultaneously bring the issues to a area-specific context so as to refrain from generic application and interpretation (5.4).

5.1 Material flow accounting and indicators

There is a global consensus that the environmental impact of food production needs to be radically reduced and more sustainable means to feed the world population need to be found. It is claimed that because the problems related to environmental deterioration as a consequence of the current way of food production are global in character, the solutions require clearly defined policy goals and combined efforts among the nations (e.g. Bringezu et al. 2004, CEC 2005, EUROSTAT 2005, Wernick and

Irwin 2005, Huppel et al. 2006, Bartelmus 2007, Schoer et al. 2007, Giljum et al. 2008, OECD 2008).

The indicators based on the MFA and footprinting approaches are used as universal ways to illustrate and monitor the progress towards the defined goals. Many of these can be used at scales ranging from national to regional, local and individual (e.g. Kitzes et al. 2009, Limnios et al. 2009, Weinzettel and Kovanda 2009). Product- and person-specific variants of the measures have been particularly designed for consumer information; these comprise, for example, ecological rucksacks and footprints, material and surface intensity per service unit, food miles (e.g. Schmidt-Bleek and Lettenmeier 2000 and references therein) as well as LCA results that are available in increasing amounts. Along with various labelling schemes (e.g. Wiedmann et al. 2006, Hyvönen and Perrels 2008, Baldo et al. 2009, Burger et al. 2009) these have been introduced in order to encourage adoption of more sustainable consumption habits both among nations and individual citizens.

Single figure compound expressions based on commensurate data such as the footprint or TMR have their place and function as a general frame of reference for descriptive purposes. When used critically and wisely, they can be used for setting

up overall goals and for monitoring the realisation of the defined goals as well as for international comparisons. They are signals, but not very specific signals, and they are of little use in locating the hot spots or the environmentally most critical target areas or issues, to which the (policy) measures should be directed in order to actually achieve an improvement in the state of the environment (e.g. Fiala 2008). Instead of compressing environmental impacts into a single figure like TMR and ecological footprint, the eco-efficiency indicators based on the category-specific measures as done in section 4.2.1 are easier to comprehend and interpret for practical purposes. Also disaggregating the compound indicators into their constituent parts is more informative than a single figure (e.g. Voet et al. 2005, Weisz et al. 2005, I; Figures 1, 3); the LCA-results although expressed as CO₂ equivalents are also always presented category-wise and allocated to the specific phases of the production chain.

Another problem associated with the indicators expressed as a single commensurate figure is their opaqueness. The basic requirement is that design of indicators is based on transparent data. In practice, the calculation procedures are extremely tedious, and the raw data are, therefore, beyond the reach of the users. This severely restricts users' possibilities to critically evaluate the information provided by the indicator. The interpretation requires expert knowledge, and transparency turns out to be rather theoretical. Furthermore, the results such as e.g. LCA-data are often not even public, but are considered to be owned by those who have produced them (Ecoinvent 2010, SimaPro 2010).

In addition, as knowledge increases, the basic presumptions or the calculation parameters or both may change. This affects comparability over time. Excluding the GHG emissions related to burning peat when quantifying the total GHG

emissions serves as an example of the first, and changing the conversion factor for N₂O to CO₂ equivalents provides an example of the latter. Unless the results are corrected, the indicators based on time series data may give an erroneous picture of the development. This is a serious problem because indicators are mostly used explicitly for follow-up and monitoring. In the worst case, the better figures are a consequence of the tricks of calculation, and have nothing to do with the impacts on the environment. In the case that a real improvement has taken place, the new way of calculating may hide what has actually happened, and what the cause of the positive contribution actually is.

Finally, measuring may become an end in itself. Research that focuses on developing measurement methods, producing internationally comparable data and universal indicators may divert the focus from the actual environmental problems, and the actors from seeking solutions to these. In striving to fulfil international policy commitments, the slogan "what can be measured can be improved", has turned in some cases into improving the measurements, a kind of a "paralysis by analysis" because of devoting disproportionate effort to agreeing about the methodology and interpretations, actual measures are not taken.

Political decision-makers and authorities at various levels have been assigned the responsibility for environmental monitoring, and in that role they need indicators when outlining the policy aims and setting quantitative goals for reducing environmental stress and following the realisation of the defined goals. Although there has been an explosive proliferation of sustainability indicators and indicator systems, the effectiveness of this "indicator industry" in promoting sustainability has been seriously questioned (e.g. Rydin 2007, Wilson et al. 2007). Also the user interviews in Finland showed that the indicators in

general, have not been particularly effective in informing the actors or in affecting their behaviour (Rosenström 2009, Yli-Viikari 2009). The use of indicators is largely influenced by how they were originally developed. If they are merely transferred from academia to policymakers, their practical relevance tends to remain modest. Producing the knowledge jointly with the researchers and policymakers and appreciating the local actors' experiences and providing them with a possibility to further develop the indicators, considerably enhances their relevance (Rydin 2007, Mickwitz and Melanen 2009).

5.2 Towards systemic thinking: modelling and scenarios

Input-output modelling has been widely used especially within the research field of ecological economics, which represents one strand of the ecological modernization -school. The aim of the method is to capture the linkages and the mutual interplay between economy and natural resource use (Sinclair et al. 2005, Huppel et al. 2006, Kerkhof et al. 2009, Weinzettel and Kovanda 2009). Specifically regarding the food sector, this approach has been applied e.g. in Switzerland (Faist et al. 2001, Kytzia et al. 2004). Even more sophisticated approaches combining LCA data into the input-output model are used to provide more information about environmental impacts of the use of materials (e.g. Sinclair et al. 2005, Seppälä et al. 2009, Weinzettel and Kovanda 2009).

The input-output approach allows analysis at national level and reveals, how the money and material flows are distributed among the various sectors of the economy, and how pulling the lever in any one of the sectors is reflected in the other sectors. The approach is unbribable in the sense that it does not allow re-allocating environmental impacts among different sectors. This kind of "emission trade" is a school example

of shifting the environmental burden, i.e. instead of improving the state of the environment, corrective measures at some part of the system create problems elsewhere within the same system (Ehrenfeld 2008).

Even though input-output models are deterministic, linear and time invariant, the approach is, nevertheless, a step towards more holistic systemic thinking. Input-output model of the food flux provides an idea about the complex interrelationships between nature, agriculture and the various sectors of the economy because the intermediate phases are also incorporated into the model. Environmental impact assessment, however, remains at a very general level. Identifying the hot spots for targeting the measures requires a lot more environmental information, and at a much more local scale. Detailed input-output data are, however, not available at local scale, and this restricts the use of the input-output methods in the Finnish case.

The food consumption scenario approach, on the other hand, is place-based; food consumption, production capacity and environmental impacts are linked together in the context of the specific area under consideration. The approach can be applied at scales ranging from personal to nationwide, and it can be slotted into the local circumstances, which are decisive as to the critical environmental issues that most urgently need to be addressed. Because of the key role of local circumstances, nationwide application of the food consumption scenario approach presented here is restricted to assessing feasibility of self-sufficient food production and quantifying the gaseous emissions (4.3.3, 4.4.3). The approach itself is applicable anywhere, but the calculation parameters need to be adjusted so as to comply with the specific circumstances. The information provided on environmental impacts is not generic, but it has to be interpreted in relation to the actual circumstances, and it is not comparable across different regions.

Even in Finland, the production conditions differ greatly in different parts of the country, not to speak of global regional differences. There are therefore, no universal solutions. The sustainability space of the area in question – the playroom within which the measures have to be fitted (Binder and Wiek 2001) is specific for the different areas, and the sustainability space needs to be defined together with the relevant actors of the area. The methods to assess environmental impacts, the measures to relieve the impacts and the changes in *modus operandi* must be tailored according to the specific situation in order to address the issues that are most pressing in view of the functioning of the system as a whole. Therefore, in evaluating the progress towards sustainability, the goals for improvement and the criteria for evaluation are to be specified for the area or region in question.

This systemic approach of the input-output modelling and food consumption scenario approach signals a paradigm change from the technical environmental management, where the main focus is on isolated phenomena towards more holistic approaches (Holling 2001, Folke et al. 2005, Ehrenfeld 2008). The two methods were used to quantify the GHG emissions of the Finnish agriculture and to assess the impact of the dietary changes or changes in the production mode on GHG emission reduction. This enabled cross-checking, and the close similarity of the results obtained with the two methods reinforces faith on the reliability and the validity of the approaches.

5.3 The impact of consumers' food choices

The results from both the input-output model (4.3, II) and from scenario approach (4.4, III, IV) suggest that negative environmental impacts can be reduced through changes in food consumption habits. In both approaches, the calculations

are based on the average food consumption patterns. The results, therefore, assume that the specified dietary changes are adopted among the whole population.

As regards the environment, it is the actual volumes that are crucial, not the reduction potential expressed as percentages, especially if expressed as the reduction potential of a single sector. For example, compared to current average food consumption, a vegan diet would nearly halve the GHG emissions of primary production, and the non-ruminant diet would reduce the emissions by about 30%. However, the net effect from the total GHG emissions of the Finnish citizens' consumption would be 8% and 5% less GHG emissions (III). The reduction in the actual volume of emissions is directly proportional to the number of people adopting the vegan or the non-ruminant diet. If an individual were to change diet to that of a vegan, it would result in a reduction of 810 kg CO₂ equivalents (representing 8% of an individual's total emissions). The corresponding figure for adoption of a non-ruminant diet would be 560 kg CO₂ equivalents (5% of an individual's total emissions). If the entire Finnish population were to adopt the diets there would be respectively 4200 million kg and 2900 million kg less GHG entering the atmosphere.

Such profound changes among the whole population are hardly realistic. Currently fewer than half a percent of the Finns are strict vegans (Vinnari et al. 2009). In addition, consumer food choice and behaviour are not consistent, but the citizens express various demands and wishes that change over time and depend on general overall trends and personal circumstances, including purchasing power. The obtainable impact through the changes of the food consumption habits on the environment is, therefore in practice, very small and can only be gauged over a very long time span, if at all. Besides,

focusing on one aspect is an example of technical environmental management, the “quick fixes” of Ehrenfeld (2008) which, by looking for isolated solutions for wicked problems such as climate change, is likely to create unexpected problems elsewhere (Haug et al. 2010). For example, extensive adoption of veganism in order to reduce the GHG emissions is likely to reduce biodiversity of the agro-environments, not to speak of the socio-economic consequences among the entrepreneurs and employees in the agri-food sectors.

Responsibility for improving the state of the environment cannot be pushed solely onto the consumers and their food choices, nor are recommendations alone sufficient. Although food itself cannot be substituted, a lot can be done by developing services and effective policy measures to gear consumer behaviour so as to promote environmental and human health (Lang and Heasman 2004, Halme et al. 2006, Collins and Fairchild 2007). Compared with individual citizens, institutional consumers as a fairly homogeneous consumer group provide a more effective channel for introducing new food consumption habits. This is done already to some extent through the sheer volume of public food purchases, but most importantly through civic education provided by the practical example of public catering services. Consumer information regarding the impacts of food choices is an important part of civic food education. Personal food choices show to what extent the message of this education has been adopted, and they also play an important role in personal health. However, acting in the private sphere does not directly improve the state of the environment. The significance of the consumer information is that increased awareness among citizens is likely to increase pressure on the decision-makers to take a proactive role and to make use of the robust tools of policy-making.

Public catering already plays an important role in guiding nutritional behaviour

among the Finns. It has contributed to increased use of vegetarian products and to improved public health, but emphasis on nutritional aspects has partly led to proliferation of imported fruits and exotic vegetables (Helakorpi et al. 2003, Prättälä 2003), and may thereby contribute to neglecting the seasonality of vegetarian products. As for nutritional education, public catering could profile as path-breaker in food education and contribute to diffusion of ideas through social learning (Brekke et al. 2003, Starr 2009, Young 2009) by providing a clear signal regarding the kind of food that meets the sustainability criteria. Integrating public catering into civic sustainability education would require new mindset and innovative actions. Regarding school food, examples already exist (City of Helsinki 2010). In transition towards sustainability the most demanding phase is the acceptance of new ideas (Ehrenfeld 2008); this was the case also in the Helsinki example, but the first steps now taken show that change is possible.

5.4 Expanding the research from disciplinary towards transdisciplinary approaches: foodshed as a frame for sustainable food provisioning

Interpreting indicators and results of quantitative measurements is a delicate task; they cannot be used to predict future development and there is no direct cause and consequence relationship. Neither do indicators account for the possible intervening factors that may be introduced because of the time delay between the measures aimed at improving the state of the environment, and the actual impact on the environment.

Rather than applying the precautionary principle, straightforward cost-benefit evaluation is often stressed and the environmentally negative consequences

are captured afterwards; the problems are addressed as they appear. It is a kind of end-of pipe thinking looking for symptomatic solutions, “quick fixes” aimed at decreasing unsustainability. Restoring the situation after the damage has occurred is more resource-demanding than preventing the damage in advance, and in some cases the environment may even have been irreversibly changed. Advancing sustainability calls for preventive measures. This requires fundamental solutions, or changes in the current *modus operandi*. Such solutions can be found only by looking for the roots of the problems.

Although the problems associated with the present day food production are global in character, and environmental deterioration has spread across the globe, the origin of environmental impacts is closely tied to site. The symptoms have to be addressed where they appear, but in order to prevent them from appearing again, fundamental solutions need to be looked for at the place of emergence. In introducing measures attention needs to be paid to the functioning of the whole system. This necessitates a system innovation approach which implies both technical innovations and re-adjustments in the structures of the society, i.e. changes in the whole socio-technical regime (Geels 2004, Geels and Schot 2007, Ehrenfeld 2008).

The overriding challenge is to address current social, cultural, economic and environmental problems that are evident at scales ranging from local to global. With regard to environmental impacts, the dispute has been whether the impacts should be measured per ton product or per hectare cultivated area. Those favouring the per ton approach argue for the increased efficiency, which would leave more room for other uses for the land. Those focussing on the environment prefer the per hectare approach. However, because global food security requires improving both the yield and the environment, regardless of the

production system the basic challenge is to advance food security so as to meet the needs of 10 billions people by the end of the present century and to keep the environmental impacts of production within the carrying capacity of the ecosystems. This has to be accomplished in compliance with the other goals of sustainability. The basic requirement is for adequate production of food, and every nation should have the right and obligation to basic food security (Helenius et al. 2007, Patel 2008).

The sustainability concept incorporates various diverse dimensions and requires that balance is achieved among them. Sustainability has, however remained, a rather abstract concept that was introduced into discussion by WCED (1987) referring generally to the documents of the Summits held by the UN in Johannesburg and Rio de Janeiro, and of the MEA (2005) and IAASTD (2009). In these, sustainability was defined broadly comprising elements of nature, people and socio-cultural interaction to secure the prerequisites of a good life for the present and future generations all over the world. When expressed in such grandiloquent but general terms, the concept is not easily be translated into action. The need to operationalise sustainability in the context of some societally significant question has been specifically emphasised (Ehrenfeld 2008, DeVries and Petersen 2009, Kauffman 2009, Scoullos 2009, van Ginkel 2009).

In the context of food and eating, the various dimensions of sustainability permeate the everyday experiences and natural bio-physical principles (Figure 7). Environmental impacts of food production deal with impacts on soil, water, air, biodiversity and landscape, while the economic dimension is approached through questions dealing with subsistence and profitability of food production. The social dimension concerns welfare of the people involved in food production, and their working conditions as well as food

security and equity, health and nutrition and the viability of rural areas. In addition, food has deep roots in the culture, and eating is an aesthetic and socially unifying experience. There are also ethical questions concerning food production (Helenius 2003, Helenius et al. 2007, Patel 2008, Risku-Norja and Mikkola 2010). These criteria for sustainable food supply include, therefore, socio-cultural and ethical aspects as well as economic feasibility; it is not merely a matter of ecological sustainability and ecological sustainability is not merely a matter of GHG emissions.

Re-localised food production has been suggested as a strategy for sustainabilizing food provisioning (e.g. Levidow and Darrot 2010). Instead of focusing on a single environmental issue, only at the plot and plant level or on farming systems, an area-based approach with the focus on the food systems is stressed (Kloppenburg et al. 1996, Gomiero et al. 2008, Lichtfouse et al. 2009). A useful unit in this research

could be an entire foodshed area including both the rural source areas of food production and the population centres of food consumption (Kloppenburg et al. 1996). In such a context the many linkages of food to sustainability shown in Figure 7 become obvious and the criteria for sustainable food provisioning can be translated into a real life situation that is concrete and approachable also in practice. This directs the focus of the research from contentious and ambiguous general environmental costs and benefits to actually promoting sustainability within a particular foodshed area. With the focus on regional based human ecology perspective and on ethical aspects, the foodshed approach actually brings the research back to the roots of agroecology as found in the pioneering works of Klages (1942) and Leopold (1949). A big step forward is taken by accounting for the new research methods and for the present day level of knowledge that has been enriched with the developments in various research fields.

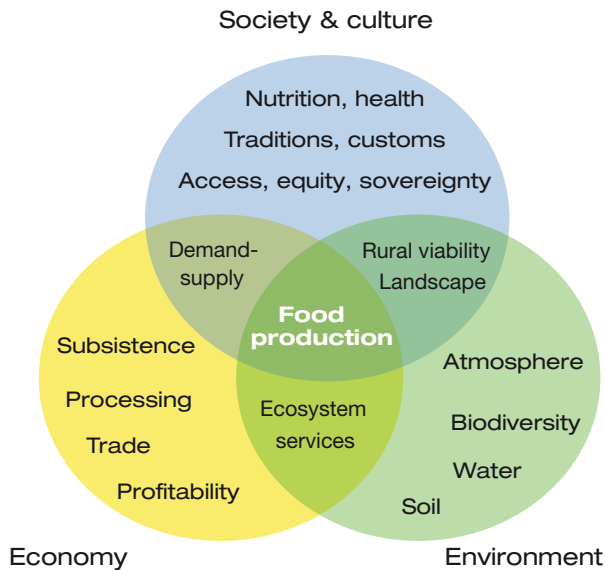


Figure 7. The many linkages in food production. The figure is a modified version of that published by IAASTD (2009).

The starting point is to define the foodshed area for a given regional population centre. This is done on the basis of food demand. Environmental performance of food production is then assessed together with the other criteria of sustainable food supply including issues concerning labour standards, animal welfare, rural communities, equity, quality and cultural aspects of food as part of the overall sustainability assessment specifically designed according to the conditions of the area concerned. The assessment methods depend on what the bottlenecks of sustainability are in the area, and also on access to data. Formulation of the management strategies and practical implementation of the measures requires transdisciplinarity, i.e. participatory research involving both the disciplinary experts and the local actors and decision makers (e.g. Atkinson et al. 2005a, Lal 2008, Lal 2009, Lichtfouse et al. 2009).

Improving sustainability of food production – “sustainabilizing food production” – requires evaluation and integration of research results from many different disciplines including agronomy, ecology, sociology, economics and politics. Finding a balance is a matter of optimal trade-off and this trade-off cannot be universally determined, but has to be agreed upon among the actors of the area. Sustainability is not a static state, but a process. The vision of an alternative post-global green future features a global network of local food systems that acknowledges the significance and sovereignty of local populations, their knowledge, and their solutions (Curtis 2003, Lang and Heasman 2004, Patel 2008, Evanoff 2010). In those conditions sustainability can become a self-orientating principle in all decision-making so that the measures are continuously revised and modified in light of new knowledge and in response to changing circumstances.

6 Conclusions

The key findings of this study and the implications based on these findings are summarised as follows:

Time series data on material flows of agriculture give an overall picture of the development, but the total material requirement (TMR) is not a good indicator of environmental impacts in agriculture. This is because the hidden flows comprise over half of TMR of agriculture, and about 95% of the hidden flows is calculatory based on approximated averages. Agricultural land use provides a better general indicator because the input use and energy consumption as well as the production volume are intimately

dependent on it, and it is not affected by the extremely changeable weather conditions of the growing seasons.

Improving eco-efficiency does not equate with improvement in the state of the environment. The carrying capacity of nature, the potential exhaustion of non-renewable natural resources and the possible rebound effect need also be accounted for. Therefore, eco-efficiency considerations require appropriate designation of system boundaries.

The case of fertilizer use (4.2.3) shows that the time perspective between introduction of the measures aimed at

relieving environmental impacts and actual improvement in the state of the environment is several decennia.

The generic indicators based on commensurate data are unspecific signals that show overall development trends. In order to translate the information provided by the generic indicators into practical measures so as to actually improve the state of the environment, the environmentally critical issues and areas need to be identified. This requires more detailed data at local scale.

The integrated economic environmental input-output model shows the distribution of money and material flows among the various sectors. In lack of sufficiently detailed data the use of the model is restricted to nation-wide economy analyses, and environmental impacts can be captured at a very general level in terms of, GHG and acidifying emissions, TMR, energy consumption and agricultural land use.

The approach based on food consumption scenarios can be applied at regional or local scales, and the environmental impacts are considered from the viewpoint of primary production. Based on various diet options the method accounts for the feasibility of re-localising food production and the environmental impacts of such re-localisation in terms of nutrient balances, gaseous emissions, agricultural energy consumption, agricultural land use and diversity of crop cultivation. The approach is applicable anywhere, but the calculation parameters need to be adjusted so as to comply with the actual circumstances of the target area. The indicators are, therefore, not universal nor is the information provided by them comparable across different regions, but it has to be interpreted in the area-specific context.

Extrapolating the results from the South Savo case study area (III) shows that national food self-sufficiency is feasible. If the share of vegetarian products is increased, self-sufficiency could even be based on organic production. In re-localizing food production, both the source areas of production and urban centres of food consumption need to be accounted for. "Local" is not fixed in regard of geographic distance, and it varies also depending on the product.

Improving environmental performance of food production calls for socio-technical innovations and policy interventions as well as for civic food education via public catering. Progress cannot be expected if the decision is left on to the individual consumers' food choices. Effectiveness of consumer information regarding environmental impact of food production is enhanced by providing means and channels for citizen activity.

Environmental performance of food production should be assessed together with the other criteria for sustainable food provisioning. There are no universal solutions, but the sustainability issues need to be considered within a geographically defined context.

The many linkages in food production to sustainability call for inter- and transdisciplinary approach. This requires actor oriented research, where the bottlenecks of sustainability are identified, the goals are defined and the measures are tailored together with the actors and according to the specific situation, by paying serious attention to the practical and tacit knowledge based on the familiarity with local circumstances.

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