Vienna Doctoral Programme on Water Resource Systems

Doctoral Thesis

Impact of diet on nutrient management and natural resources

submitted in satisfaction of the requirements for the degree of
Doctor of Science in Civil Engineering
of the Vienna University of Technology, Faculty of Civil Engineering

---

Dissertation

Einfluss der Ernährung auf Nährstoffmanagement und natürliche Ressourcen

ausgeführt zum Zwecke der Erlangung des akademischen Grades eines
Doktors der technischen Wissenschaft
eingereicht an der Technischen Universität Wien Fakultät für Bauingenieurwesen
von

Dipl.-Ing. Simon Thaler
Matrikelnummer 0040138
Schafferstraße 14, 4060 Leonding

Gutachter: Ao.Univ.Prof. Dipl.-Ing. Dr. techn. Matthias Zessner
Institut für Wassergüte, Ressourcenmanagement und
Abfallwirtschaft, Technische Universität Wien
Karlsplatz 13/2261, 1040 Wien

Gutachter: Univ.Prof.Dipl.-Ing. Dr. techn. Helmut Rechberger
Institut für Wassergüte, Ressourcenmanagement und
Abfallwirtschaft, Technische Universität Wien
Karlsplatz 13/2262, 1040 Wien

Gutachter: Dr. Ranvir Singh
Institute of Natural Resources, Massey University
Private Bag 11222, Palmerston North 4442
New Zealand

Wien, Mai 2015 ______________________

Kurzfassung

Menschliche Ernährung ist einer der Haupttreiber landwirtschaftlichen Wirtschaftens. Der Verzehr von Lebensmitteln induziert somit Ressourcenverbrauch und verschiedenste Auswirkungen auf die Umwelt. Die hier vorliegende Arbeit verbindet verschiedene Methoden, um einen neuen, möglichst ganzheitlichen, Blick auf diese Zusammenhänge zu ermöglichen. Die regionale Betrachtung, mit Österreich als Beispiel, steht dabei im Vordergrund. Aufbauend auf statistischen Daten wurde eine detaillierte Abbildung der Nähstoffströme Stickstoff (N) und Phosphor (P) sowie der Flächennutzung erstellt. Rund 1,900 m^2 Ackerland und 1700 m^2 Dauergrünland wird für die aktuelle Ernährung Österreichs genutzt. 71 % des N und 58 % des P Inputs in das landwirtschaftliche System wird für die Futterproduktion verwendet. Der Rest für den Anbau von Pflanzen für pflanzliche Nahrungsmittel und als Rohstoffe für die Industrie. Auch bei der Wassernutzung, ausgedrückt als Waterfootprint (WF), ist die Tierhaltung mit 87 % des gesamten WF der Nahrungsmittelproduktion der Hauptnutzer. Aufbauend auf einem Stoffflussmodell sowie des Nährstoffemissionsmodell MONERIS wurden Änderungen infolge der Anwendung von verschiedenen Szenarien untersucht. Die Szenarien unterscheiden sich durch verschiedene landwirtschaftliche Wirtschaftsweisen, verschiedene Marktannahmen und unterschiedlicher Nutzung verfügbarer landwirtschaftlicher Nutzfläche. Der gemeinsame Nenner ist die Annahme einer, im Durchschnitt, geänderten Ernährung der österreichischen Bevölkerung hin zu einer ernährungsphysiologisch ausgewogenen Ernährung mit stark reduziertem tierischem Anteil. Generell würde diese Ernährungsänderung rund 30 % weniger landwirtschaftliche Fläche, weniger Ressourcen (z.B. 20-25 % weniger P) benötigen und weniger Emissionen von N und P in die Umwelt verursachen. Gesamtemissionen von N und P in Gewässer würden sinken (zwischen 11 % - 15 % für N und 5-6 % für P). In Abhängigkeit der Intensität der landwirtschaftlichen Wirtschaftsweise würde es auch zu deutlich geringeren Nährstoffeinträgen ins Grundwasser kommen.

Abstract

Human nutrition is one of the main drivers of agricultural production. Therefore, it induces resource consumption and environmental impacts. In this work the focus is on combining different methods for environmental impact assessment in a novel way to improve the understanding of the impact of animal and plant based food consumption on agricultural production and the environment. Investigations consider specific regional conditions, taking Austria as an example. About 1,900 m^2 arable land and 1,700 m^2 grassland per capita are needed to supply Austria's population with the currently required amounts of food. One result of this work shows that 71 % of the nitrogen (N) input and 58 % of the phosphorus (P) input into the agricultural system is used for fodder production, the rest for production of plant based food and products for industrial use. Furthermore, animal husbandry is responsible for 46 % of the total N and 28.5 % of the total P emissions into surface water in Austria (considering all relevant pathways of emission, including waste water management), production of plant based food and of industrial products for about 3 % and 2 %, respectively. With regards to water usage, calculated as water footprint, animal husbandry is responsible for 87 % of the total food production induced water footprint. In addition to the assessment of the actual status possible impacts of dietary chances on nutrient fluxes (N and P) and land use were investigated based on scenario analyses. All scenarios assume a change from a meat based diet to a healthier balanced diet consisting of less animal based products and more plant based food in Austria as suggested by nutritional sciences. The detailed material flow analysis in combination with the nutrient emissions model MONERIS were utilized. The scenarios considerate different farming methods, varying trade options and different use of potentially available agricultural area. Our findings show that overall, a shift to a healthy balanced diet would lead to less land being used for agricultural production (-30 %), less resource consumption (e.g. 20 % to 25 % less P) and lower transfer of nitrogen and phosphorus from agriculture into the environment. Total emissions of N and P into water would decrease (between 15 % and 11 % for N and 5 % to 6 % for P) and N concentrations in groundwater would change substantially depending on the intensity of farming assumed by different scenarios.

Prof. Helmut Rechberger

Prof. Kroiss

Institut für Wassergüte

Zimmerkollegen

Unterhaltung

Hilfe

Freundschaft

Freihalten von anderen Dingen

Hinweise

herausfordern

Korrektur

Begleitung

Vertrauen

Alle Flüsse laufen ins Meer, und das Meer wird doch nicht voll; an den Ort, wohin die Flüsse einmal laufen, laufen sie immer wieder.*

Kati

Kollegen

Durchsicht

Gemma

Verzicht

Was ist gewesen? Das, was sein wird! Und was hat man gemacht? Das, was man machen wird! Und es gibt nichts Neues unter der Sonne.*

Unterstützung

Prof. Matthias Zessner

Stefanie

Alle Worte sind unzulänglich; der Mensch kann nicht genug reden, das Auge sieht sich nicht satt, und das Ohr hört nie genug.*

Dr. Ranvir Singh

Luis

Mathilda

*vermutlich Salomo (10. Jhd. v. Chr.)

Humor

Oliver

Motivation

Geduld

Kann man von irgend etwas sagen: «Siehe, das ist neu»? Längst schon war es in unbekannten Zeiten*

Danke

fachlicher Input

Table of Contents

iii Impacts of human nutrition on land use, nutrient balances and water consumption in Austria

iv Possible implications of dietary changes on environment and resources in Austria

vi Overall conclusions

vii Appendix

Index of Figures

Index of Tables

i Introduction

1 Background

The western society is rested upon a strong animal-based (e.g. meat) nutrition (de Boer et al., 2006), which is far apart from a healthily balanced diet. Recent studies show that the Austrian meat consumption (66 kg cap-1 yr-1) is about twice as high as the recommendations for a healthily balanced nutrition while vegetarian food consumption is below the recommendations (Elmadfa et al., 2009b). These “unbalanced” diet habits are a decisive factor in respect to nutrition related diseases (e.g. adiposity) (WHO, 2003). Furthermore, the production of animal based food consumes several times more resources (e.g.: area, fertilizer) compared to plant-based food and is closely connected to environmental pollution (e.g.: emission of greenhouse gases, ground water pollution, marine eutrophication) (FAO, 2009a; Isermann and Isermann, 1998; Smil, 2002; Steinfeld et al., 2006). The demand for food is also set to increase due to population growth and changing consumption patterns. Worldwide population growth of 20% is expected for the period 2010 to 2030 (UN, 2011). Average global meat consumption increased from 30 kg per capita and year to 41.2 kg per capita and year between 1980 and 2005 (FAO, 2009a). This rise in meat consumption is expected to grow further (OECD/FAO, 2010). Thus a detailed understanding of the link between food consumption patterns, agricultural production and impacts on resources and the environment is essential.

There is an increasing amount of scientific papers dealing with the relation of consumption patterns and natural resources. The scope of the literature reaches from landuse change, water demand, water quality and greenhouse gas emissions to energy consumption. A broad pool of methods and models are used to examine the relationships between different aspects of consumption patterns, resource consumption and environmental pollution. Nevertheless there are only a view publications dealing with the connectivity of human nutrition and their impacts on the environment in detail. The most of the literature observes the influence of human diet on landuse change. They often include policies and economic issues in their calculations. The purpose is in many cases the calculation of possible impacts on farmers and the agricultural markets (Arnoult et al., 2010; Rickard and Gonsalves, 2008). Some of them are concentrating on certain aspects. For example a study from the United States Department of Agriculture considers only the possible change of fruits, vegetable, grain and dairy consumption (Buzby et al., 2006). These are the food categories which are expected to rise applying healthy diet guidelines. Others are concentrating on land requirements for special fruits (e.g. cereal, energy crops) (Elferink and Nonhebel, 2007; Keyzer et al., 2005).

General water use in agriculture is another topic of many studies. Few studies are available demonstrating the relationship between human diet and water consumption for the production of food. For example (Renault and Wallender, 2000) determined the difference in water demand for different diets in California. Other literature is coping with the aspects of nutrient fluxes and consumption. Material flow analyses (MFA) have been calculated by different authors for different regions showing the relationship between food production or/and food consumption and the nutrient fluxes (Risku-Norja and Mäenpää, 2007; Zessner et al., 2010; Zessner and Lampert, 2002). Additionally there is vast literature covering environmental pollution through agriculture. Though, the link to human nutrition is mostly not drawn.

Summarizing the current state of knowledge it could be said that there are, to the knowledge of the author, no holistically observed studies investigating the relationships between human nutrition (differentiated between animal and plant based food), land and nutrient resources and impacts on the aquatic environment on a country wide scale. A gap which this work intends to close in providing a sufficient methodology and applying it for Austria as a case study.

2 Research question

The research questions defining the thesis are, on the one hand, related to the methodological challenges of this work:

- Is it possible to link human nutrition, agriculture and environmental impacts by utilizing statistical data and certain models in such a way that a balanced material flow analysis for nitrogen and phosphorus can be derived?
- Could the calculation of environmental indicators (e.g. water footprint) benefit from the balanced material flow analysis?
- Is it possible to connect the model to the natural production potential in such a way scenarios can be calculated?

On the other hand, based on the implementation of the developed methodology, research questions can be addressed to improve the understanding of the interconnection of nutrition, agricultural production, resource consumption and environmental impacts. The basic research question in this respect is, what a healthy balanced diet applied in Austria would mean regarding:

- resource consumption:
  - nitrogen and phosphorus,
  - water demand,
  - agricultural land,
- environmental impacts:
  - emissions into waters (groundwater, surface water),
  - emissions into air,
- potential usage of agricultural area, not necessary for food production anymore (e.g.):
  - for the production of renewable raw materials,

- for the extensification of agricultural production,
- for ecological buffer stripes?

3 Structure of PhD

This thesis is structured such that the main research themes that were investigated are presented in chapters as standalone documents in the manner in which they have been accepted or submitted for publication in various journals.

The first paper "Considerations on methodological challenges for water footprint calculations" (chapter 2) presents some methodological questions regarding water footprint calculations. The reason for this paper being included into this thesis is that it provides a decisive improvement of the method of water footprint accounting which later on is used as one of the analytical tools for assessment of environmental impacts of food production within this work. This work was published in Thaler et al. (2012a) in Water Science and Technology. The second paper with the title "Impacts of human nutrition on land use, nutrient balances and water consumption in Austria" (chapter 3) delivers a detailed description of the actual food-agriculture-environment system in Austria. It was published in Thaler et al. (2014) in the journal Sustainability of Water Quality and Ecology. The elaborated method is described and detailed nutrient balances presented. By assessing the actual state of the system nutrition-agricultural production-resource consumption-environment it can be seen as the basis for the forthcoming scenario investigations. The third paper named "Possible implications of dietary changes on environment and resources in Austria" (chapter 4) deals with the potential of a diet change in respect to changing impacts of agricultural production on resource consumption and environmental impacts. Different scenarios, with different objectives, are investigated. This work was published in Thaler et al.

(2015) in the journal of Agricultural Sciences. The fourth paper called “How human diet impacts on waters and resources” (chapter 5) is a summarizing chapter with focus on a straightforward presentation of the main concept and some water related results. This summarization was published in Thaler et al. (2013). The conclusions recapitulate the main objectives and summarize the main findings (chapter 6). Finally the thesis contains annexes detailed presentation of required data and additional quantitative results of the investigations.

ii Considerations on methodological challenges for water footprint calculations

1 Introduction

The concept of water footprint (WF) is based on the virtual water concept, introduced by Tony Allen in 1993. He used this term to draw attention to the fact that serious water scarcity in a region can be counterbalanced by international trade and global economy (Allan, 2003). The WF concept itself was introduced by Hoekstra and Hung (2002). Since then, it was elaborated by different authors (Chapagain and Hoekstra, 2004; Gerbens-Leenes and Hoekstra, 2009; Hoekstra et al., 2009; Hoekstra and Chapagain, 2008). Moreover, the Water footprint Network was founded in order to develop standards and tools for calculation reasons, and to promote a sustainable use of fresh water resources (WFN, 2010). Meanwhile, many projects were conducted in order to enhance the water footprint methodology. To date, the development of the methodology is not finished yet, though the second issue of the water footprint manual has been published recently (Hoekstra et al., 2011).

The methodology according to Hoekstra and Chapagain (2008) defines the WF of a good or service as the total amount of water required for production and delivery. A WF can be calculated for any well-defined group of consumers (e.g. an individual, city or nation), producers or even products. The WF of a product (a commodity, good or service) is the volume of freshwater used to produce the product, measured at the place where the product was actually produced. It refers to the sum of the water used in the various steps of the production chain. The WF of a product is sometimes also referred to as “virtual water content”. This WF consists of three components: green water, blue water and grey water. The green WF is the volume of water evapotranspirated from the global green water resources (rainwater stored in the soil). The blue WF is the volume of freshwater that is evaporated from the global blue water resources (surface and ground water). The grey WF is the volume of polluted water, which can be quantified as the volume of water that is required to dilute pollutants to such an extent that the quality of the ambient water remains above agreed water quality standards. Allocation factors are used to assign the WFs to main and by-products, if necessary.

2 Materials and Methods

For this study the WF for refined white sugar produced in Europe is examined. Certain methodological aspects are discussed. Different approaches of water footprinting were applied and compared. The WFs of beet sugar produced in 59 sugar factories distributed over Europe were calculated. Each sugar factory has an associated crop growing area, supplying the factory with sugar beet. The calculation of the final WF is divided into three parts. The first part deals with the WF of sugar beet, the second with the WF of the sugar factory and the third part combines the first two parts to the final WF using allocation factors.

2.1 WF of sugar beet

The water footprint of crops is calculated as the crop water use (m^3/ha) divided by the crop yield (t/ha). The crop water use depends on the crop water requirement and the soil water availability, which is replenished either through rainwater or irrigation water. The crop water requirement (CWR) is defined as the water demand of a crop, summed up over the whole growing period. Ideal growing conditions and therefore unlimited soil water availability is assumed. For this reason crop water use equals crop water requirement only when sufficient rainwater is available or a deficit is compensated by irrigation water (blue water). If that is not the case, crop water use is equal to effective rainfall (ER). For the calculation of the WF of sugar beet the model

CROPWAT 8.0 (FAO, 2009b) based on the works of Allen et al. (1998) and Doorenbos and Kassam (1979) was used. Global spatial maps of monthly reference evapotranspiration and monthly precipitation, each in 10 arc minutes resolution (FAO, 2004a, 2004b) were adopted for the generation of aggregated climate basis data. For each investigated region an area weighted mean value was calculated. Utilizing the thermal climate classification from Grieser, et al. (2006), crop values from the report "Water footprint of Nations" (Chapagain and Hoekstra, 2004) were chosen.

2.1.1 **Common approach (green and blue water)**

The common approach calculates the CWR, the ER and the irrigation requirements (IR) using the CWR-tab of the CROPWAT model. This calculation method calculates CWR on a 10 days basis but does not consider soil moisture storage in detail. One advantage is that no additional data about soil and irrigation management is necessary. The calculated ER was referred to as green water. Blue water was calculated by subtraction of ER from CWR. An optimal water supply of the sugar beet was assumed.

2.1.2 **Advanced approach (green and blue water)**

Another possibility to calculate ER and irrigation requirement is the use of the advanced abilities of the CROPWAT model. The irrigation-schedule-tab allows the calculation of a daily soil water balance. Additional data about average soil distribution and irrigation management for each beet growing area were used. These data were obtained utilizing statistical data on the sugar factory level. The soil moisture deficit at harvest time was calculated. This deficit was added to the effective rainfall because it is filled up during the autumn and winter rainfall. Blue water, in this case, was not calculated based on the difference between CWR and green water but was taken from specific data (surface irrigation water applied) for each crop growing area. In Mediterranean regions, irrigation areas are often close to rivers and channels. Thus shallower water tables could contribute significantly to crop water supply (Brown et al., 1987; Utset et al., 2006) as cited in Utset et al. (2007). Since no data regarding groundwater supply are available, irrigation values were adjusted to a maximum of 15 % deficit in order to obtain more realistic results (see Figure 3 “Correction of blue water”). Water deficit of up to 15 % of CWR are realistic and well in line with irrigation strategies for sugar beet cultivation. Further investigations would be necessary to improve the assumed maximum deficit allowed.

Table 1: Comparison of two different approaches used for blue and green water calculations of sugar beet

	approach	
	common	advanced
CWR and ER calculation time step	10 days	1 day
Soil moisture deficit calculated	not calculated	calculated
Green water calculation	ER	ER + Soil moisture deficit
Blue water calculation	IR = CWR - ER	specific irrigation data
Soil and irrigation data required	no	yes

2.1.3 **Grey water of sugar beet**

Grey water defines the water necessary to dilute loads of pollutants to such an extent that they would meet the water quality requirements. This study uses the common approach first introduced by Chapagain et al. (2006). It was assumed that 10 % of the applied nitrogen fertilizer is leaching to groundwater. Taking the widely used drinking water quality level for nitrogen (N) in groundwater (10 mg N/l) (EPA, 1995), the theoretically necessary dilution water can be determined. This is rather a rough assumption. Dabrowski et al. (2009) showed that grey water from crop production can have the same value as the sum of green and blue water for crop production taking phosphorus (P) and agrochemical inputs into account. Therefore, future research should enhance this approach.

2.2 WF of the sugar factory

2.2.1 Blue water

Blue water is evaporated from different sugar refining processes and from open surface water in the wastewater treatment plants and lagoons. Values for evaporated water quantities during the sugar refining processes were available. Evaporated water from the open water surface was calculated using the reference evapotranspiration (ETo) according to Allen et al. (1998). A factor (1.2) was applied to calculate evaporation based on reference evapotranspiration. The time period for the evaporation from lagoons was assumed to be 8 months (October to June, according to the sugar beet campaign). The calculation of the evaporation from the water surface area is based on Craig (2006).

2.2.2 Grey water

The grey water footprint calculation for waste water treatment plants has undergone modifications in recent years. According to the methodology promoted by the Water Footprint Network, the difference between the natural concentration of the pollutant in the receiving water body and the receiving water quality standards (ambient water quality standards) should be used for the calculation of grey water footprints (Hoekstra et al., 2011). Scholten (2009) discusses the problem of using receiving water quality standards. The main problem is that except for N no large scale applicable standards exist. Standards for other parameters (BOD, PO4-P) are not only highly dependent on local circumstances but also on national policies. For this reason the 10 mg N/l as the reference concentration is often applied, without considering other parameters. In some other studies grey water footprint calculations from factories are based on best available technology (BAT) effluent standards

(Hoekstra and Chapagain, 2008). For this study a sensitivity analysis of three different water quality standards was performed.

Emission quality standards from the EU-BAT – documents for the food industry (European Commission, 2006) were used to calculate the grey water footprint for sugar production. Hoekstra and Chapagain (2008) used an approach similar to this one.

The same calculation was made applying the drinking water standard of 10 mg N/l (EPA, 1995), as it is the only applicable large scale water quality standard.

Third, the grey water footprint of waste water from the sugar factory was calculated using specific receiving water quality standards. As large scale standards are missing for some parameters (e.g. BOD5 or P), the receiving water standards were taken from the Austrian guidelines for the type specific estimation of the general chemical/physical parameters in flowing water (Deutsch et al., 2008). This guideline was developed to fulfill the requirements for the estimation of the chemical and ecological conditions set by Directive 2000/60/EC of the European Parliament and Council (2000).

Table 2 shows a comparison between the values derived from receiving water quality standards and the water quality requirements according to the best available technique documents (BAT).

Table 2: Comparison of water quality standards in the BAT document (European Commission, 2006) and the difference between receiving water quality standards and natural conditions in Austria (Deutsch et al., 2008)

Parameter	Unit	BAT	receiving water quality standards*
BOD_5	mg/l	25	1.5
P	mg/l	1 (TP)	0.13 (PO_4-P)
* Limit concentration of the good status minus concentrations of the very good water quality status (Eastern low- and hilly-country bioregion)			

3 Allocation factors

Factors are used to distribute the derived green, blue and grey water (l/kg beet) between the main product (sugar) and by-products (feedstuff). The product fraction is defined by the quantity of an output product obtained per quantity of input product (Hoekstra et al., 2011). Individual product fractions for each sugar factory were calculated. The value fraction is defined by the fraction of revenues from one output product (e.g. sugar) to the aggregated revenues of all products (e.g. sugar plus feedstuff). The value fraction has a high impact on the resulting WF and thus different value fraction for each region (factory) would question the comparability of results. Hence a literature value (0.89) was taken from Scholten (2009) and applied for all regions. The final WF of refined sugar is derived, multiplying the green, blue and grey water (l/kg beet) with the value fraction divided by the product fraction.

4 Results

In Table 3 the distribution of the final WF for refined white sugar within Europe is shown. Green water, calculated with the advanced approach, is responsible for 71 % of the total WF. Grey water contributes with 23 % to the total WF, mostly due to fertilizer leaching. Blue water is responsible for 6 % of the WF in average.

Table 3: The average calculated WF of refined white sugar in Europe. Green water is calculated using the advanced approach. Grey water of the factory is calculated using the BAT water quality standards

	Europe mean	
	[l/kg sugar]	[%]
Crop Production		
Green	420	71
Blue	34	6
Grey	120	20
Factory		
Green		
Blue	3	1
Grey	13	2
Total		
Green	420	71

Blue	37	6
Grey	133	23
Total WF	590	100

4.1 Green and blue WF of sugar beet

Table 4 shows a comparison between the results for the common and the advanced approach. The blue WF calculated with the advanced approach is clearly lower than the results derived with the common approach.

Table 4: Distribution of green, blue and grey WF using the common and the advanced water footprint calculation approach

WF Crop Production	Europe Mean	
	Common Approach	Advanced method
	[%]	[%]
Green	50	73
Blue	33	6
Grey	17	21
Sum	100	100

In Figure 1-3, the crop water requirements of several sugar beet production areas are displayed. On the x-axis the different production areas of sugar beet and on the y-axis the distribution between green and blue WF in percent of the total CWR are shown. Figure 1 shows results applying the common approach. These results are rather unrealistic because only the Mediterranean countries in Europe irrigate sugar beet intensively. In Figure 2, the actual irrigated water, derived from available specific data, is added. Clearly, the calculation approach, where soil moisture deficit at harvest time is not considered, leads to an overestimation of blue water. Therefore, the widely used approach for calculation of blue and green water is not supported by actual irrigation data.

Figure 3 shows the results for the advanced method. Soil moisture deficit at harvest time, soil distribution data and irrigation management data were utilized. It can be observed that the total CWR for the growth of sugar beet is fulfilled, but a certain water deficit occurs. In general a water deficit up to 15 % of CWR is realistic and well in line with irrigation strategies for sugar beet cultivation which attempt to maintain a certain yield rather than to maximize it. Additionally, data uncertainties have to be considered. For some beet production areas, the calculations show water deficits higher than 20 % of the calculated total CWR. Some of these production areas are located in eastern Europeans countries with relatively low yields. Therefore, a lower effective crop water use can be assumed due to non-standard conditions (ETc adj) (Allen et al., 1998). By reason of a water supply from shallower water tables, irrigation water for some Mediterranean regions was corrected. Thus, the calculation using the advanced method leads to more reasonable results.

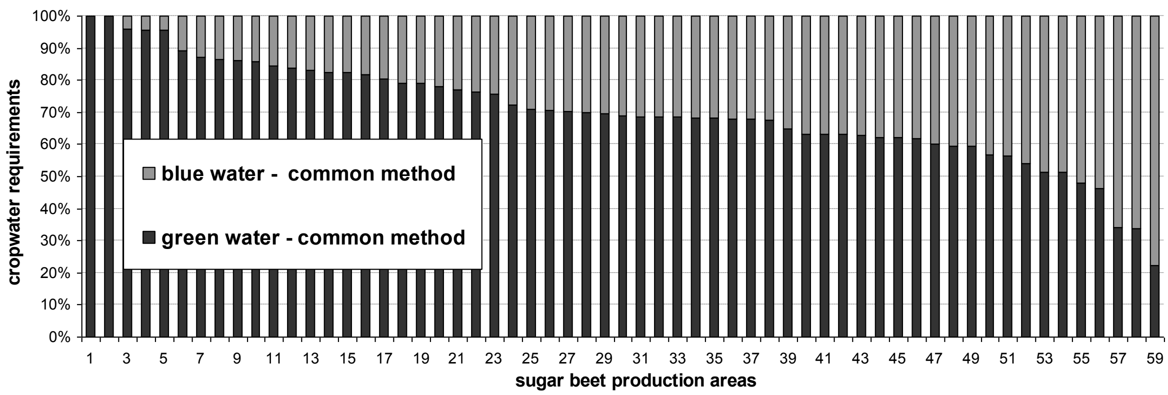

Figure 1: Distribution of green and blue water footprint calculated with the common approach expressed in % of the total CWR.

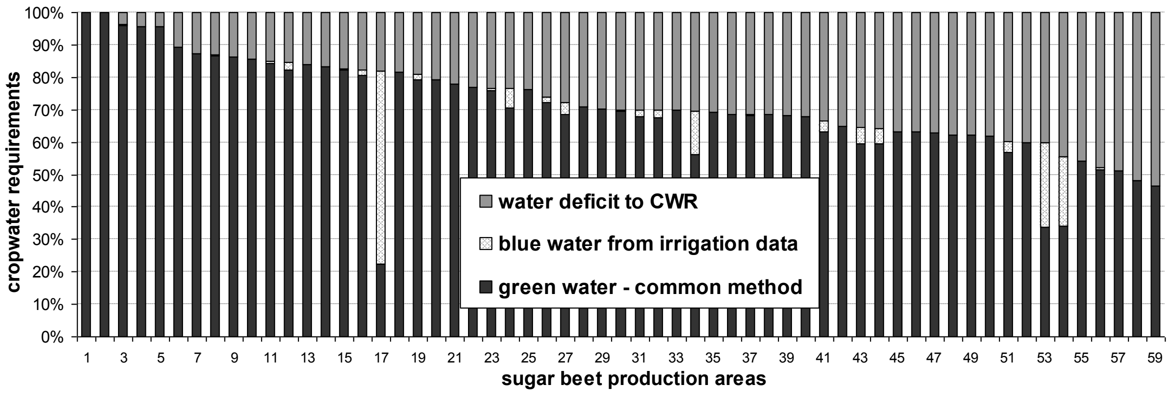

Figure 2: Distribution of green WF (calculated with the common approach), blue WF (derived from specific irrigation data) and the resulting water deficit to the total CWR.

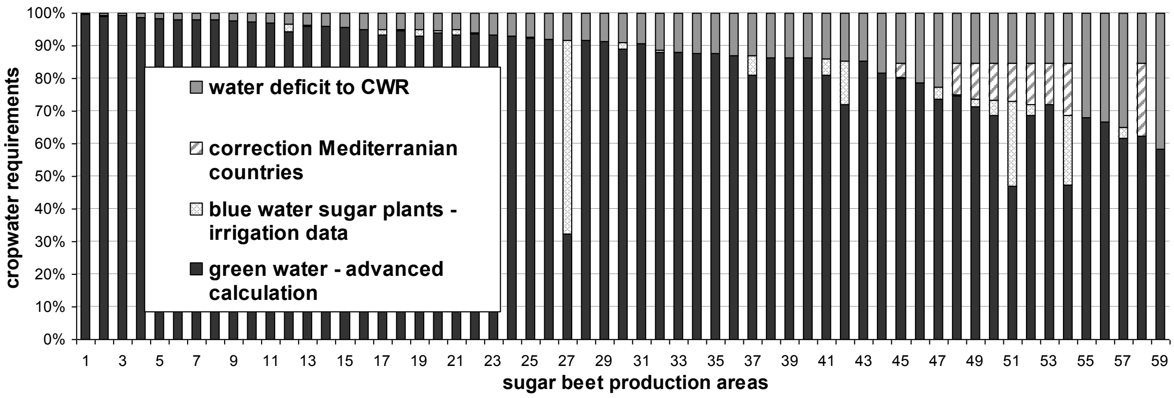

Figure 3: Distribution of green (calculated with the advanced approach), blue and corrected blue WF and the resulting water deficit to the total CWR.

4.2 Grey water of sugar factories

The sensitivity analysis of different calculations for the grey water footprint is shown for two different sugar factories, one with advanced biological treatment and the other with only mechanical treatment. The effluent concentrations of the selected factories (from two different European countries) are shown in Table 5. Table 6 shows the results of grey water footprint calculations using three different sets of standards as reference for required water quality targets. For factories with an adequate treatment (advanced biological treatment including effluent requirements for N and P) the grey water calculations have an insignificant influence on the grey water footprint. The grey water footprint for the factory increases from 2 to 14 l/kg sugar if the stringent water quality standards for BOD5 and PO4-P are used. This is less than 5 % of the total water footprint of sugar production. Nevertheless, the fraction of the water footprint caused directly by the factory increases slightly if compared to the fraction of the water footprint derived from sugar beet cultivation.

Table 5: Effluent concentrations of two different treatment plants

Effluent concentrations (yearly averages in mg/l)		
	Aerobic WWTP	Mechanical treatment
COD	44	595
BOD_5	4.7	199
total nitrogen (TN)	3.7	41
total phosphor (TP)	0.2	4

Table 6: Grey water footprint for two sugar factories calculated with three different water quality standards.

Grey water [l/kg sugar] calculations with different water quality standards		
Water quality standard	Waste water treatment	
	Aerobic WWTP (limiting pollutant)	Mechanical treatment (limiting pollutant)
1.) Quality requirements according to BAT (European Commission, 2006)	2 (N)	105 (BOD)
2.) Large scale water quality standard for nitrogen (10 mg N/l)	2 (N)	53 (N)
3.) Receiving water quality requirements (Deutsch et al., 2008)	14 (P)	1205 (BOD)

The situation is completely different for factories with a low level of treatment (e.g. mechanical treatment). In this case the choice of the reference standard for grey water footprint calculation has a decisive influence on the results. A calculation based on the large scale water quality standard for N (10 mg/l) results in the lowest grey water footprint. These results are even lower than those obtained when using the effluent BAT values as reference. This is due to the fact that the water quality target for N is the same in the BAT- documents and the drinking water standard typically used for grey water footprint calculations (10 mg/l). Thus, other parameters (COD, BOD5 or TP) become the critical pollutants when low levels of treatment exist. If the stringent water quality targets for BOD5 and PO4-P were applied, the grey WF increases by a factor of ten, up to more than 1000 l/kg of sugar, respectively. In such a case, grey water from sugar processing becomes a dominating factor in the total WF. The results of the example show a drastic increase in grey WF for sugar factories with a low level of wastewater treatment due to receiving water standard values for BOD5 and PO4-P. Considering the factories used in for this study, the grey water for sugar processing would increase by an average factor of 11. In case of low levels of treatment, the fraction of grey water from waste water is the main contributor to the total water footprint. Therefore, the largest proportion of the water footprint would not be the green water footprint (evapotranspiration of rainwater), but rather the grey water footprint caused by the discharge of waste water with different treatment levels.

5 Discussion and Conclusion

We clearly show that different approaches lead to serious differences in the resulting water footprints of a product. Meanwhile, there exist different WF calculations in literature. They have in common the basic concept of the WF but differ in applied approaches. Due to data availability issues, relative simple concepts are often used. There is no agreement on definitive guidelines for a detailed WF calculation. The WF manual (Hoekstra et al., 2011) gives a lot of freedom in choosing the appropriate calculation method. However, different methods yield different results that can hardly be compared. This fact calls for the development of a common methodology. The widely used approach for the calculation of green and blue water for crops does not suit the actual applied irrigation water. The argument that higher blue water incorporates the additional loss of irrigation water through irrigation management (supply and storage of water) does not fit to the case where crops are essentially rain-feed. In this case, the simple approach will lead to wrong and therefore misleading results, which might influence subsequent impact assessments. Blue water has higher opportunity costs compared to green water (Chapagain and Orr, 2009), thus an accurate determination should have high priority.

High priority should also have the choice of water quality targets for the grey water calculation. As shown in this study, the use of different water quality targets leads to different WFs. The most appropriate approach to calculate grey water footprint is the use of receiving water quality standards for N, P, BOD and COD at least. No large scale applicable standards exist for all of these parameters and no common approach has been developed within the water footprint community so far. Calculations with this advanced approach would lead to results that are hardly comparable to other water footprint calculations. This underlines the need for further development and standardisation of the grey water footprint calculation methodology based on receiving water quality standards. The best solution from our point of view would be the development of a local receiving water quality standard inventory for some selected parameters covering the whole world. In this way, regional circumstances and demands could be met and the influence of different environmental policies in different countries could be minimized. The improvement of the methodology has to go hand in hand with impact assessments because water footprint alone has only limited relevance. Therefore, goal-orientated development of the method as a guideline for a sustainable lifestyle regarding the irreplaceable resource water should be the research topic of further investigations.

iii Impacts of human nutrition on land use, nutrient balances and water consumption in Austria

1 Introduction

Food supplies us with essential energy, protein and other nutritional required substances. The production of food consumes resources and leads to severe impacts on the environment. Negative effects on climate and water quality are of particular concern and resource availability as well as management challenges are gaining increasing attention. Suitable agricultural area is limited. This is clearly demonstrated by the ongoing debates on land grabbing, along with discussion of the associated problems (Cotula et al., 2009).

Phosphorus, used as fertilizer, is a limited resource as well. Mineable ores are predicted to become scarcer within the next centuries (Cooper et al., 2011). Nitrogen fertilizer production has a high energy demand and as such it is subject to similar questions and issues as energy (e.g. fossil vs. renewable). The demand for food is also set to increase due to population growth and changing consumption patterns. Worldwide population growth of 20 % is expected for the period 2010 to 2030 (UN, 2011). Average global meat consumption increased from 30 kg per capita and year to 41.2 kg per capita and year between 1980 and 2005 (FAO, 2009a). This rise in meat consumption is expected to grow further (OECD/FAO, 2010). Livestock puts extensive pressure on land and forest resources and negatively affects water quality, biodiversity and ecosystems, and is boosting global warming (FAO, 2009a; Steinfeld et al., 2006). Thus a detailed understanding of the link between food consumption patterns, agricultural production and impacts on resources and the environment is essential.

There is an increasing amount of scientific work dealing with the relation of consumption patterns and natural resources. Nevertheless, there are only a view publications dealing with the connectivity of human nutrition and its impact on the environment in detail. In many cases the purpose of these publications is the calculation of possible impacts on farmers and the agricultural markets (e.g. (Arnoult et al., 2010; Rickard and Gonsalves, 2008)). Other studies only concentrate on certain aspects or products (e.g. (Buzby et al., 2006; Elferink and Nonhebel, 2007; Keyzer et al., 2005)). General water use and water pollution from agriculture is another topic (e.g. (Leinweber et al., 2002; OECD, 2012)) of concern. Few studies are available demonstrating the relationship between human diet and water consumption for the production of food (e.g. (Renault and Wallender, 2000; Vanham, 2013)). Material flow analyses have been calculated by different authors for different regions showing the relationship between food production and/or food consumption and the nutrient fluxes (e.g. (Bleken and Bakken, 1997; Risku-Norja and Mäenpää, 2007; Zessner et al., 2010; Zessner and Lampert, 2002)). However the distinction between animal based food and plant based food production is mostly not performed. Additional there is literature covering environmental pollution through agriculture. Though, the link to human diet is not drawn. There are, to the knowledge of the authors, no holistically observed studies investigating the relationships between human nutrition (differentiated between animal and plant based food), land and nutrient resources and impacts on the aquatic environment on a country wide scale. A gap which this paper intents to close in providing a sufficient methodology and applying it for Austria as a case study.

In Austria, 1.38 10^6 hectares of arable land and 1.78 10^6 hectares of grassland are farmed. The population consumes an average of 330 kg animal products (fresh matter) per capita and year and 306 kg plant products (fresh matter) per capita and year (Zessner et al., 2011a). In this article we want to show the relationship between production and consumption of food and the resulting impacts on nitrogen (N) and phosphorus (P) resources, agricultural area utilized, impacts on the aquatic environment, losses of N gases into the air, and water requirements for the agricultural crop production on a clearly defined regional scale. We distinguish between plant based and animal based food in terms of food production and the environmental impacts. Thus impacts on environment can be tracked to the source of origin. Further research towards minimization of external environmental effects of food consumption can be conducted in follow up publications.

2 Materials and Methods

The total quantitative assessment of agricultural production and consumption and its impact on resources and the environment is based on data for the period 2001 to 2006, unless otherwise specified. The agricultural data sources utilized for the calculations were the official Austrian agricultural reports (BMLFUW, 2008a). The supply balances for agricultural products were taken from the Statistics Austria (2007a). The supply balances give information about production (harvest), imports, exports, losses, seed usage, food usage, feed usage and industrial usage. The food usage is not the same as the food consumed because losses during processing and food preparation stages and wastage in the households have to be considered additionally. Therefore additional factors for calculation of food consumption from food usage were applied to account for those losses (Elmadfa et al., 1998). Zessner et al. (2011c) show the conversion factors in detail and describe the basic assumptions. The resulting food supply chain is the basis for the N and P balances and area calculations. Results are related to one Austrian inhabitant. The mean population between the years 2001 and 2006 was 8,130,515 inhabitants (Statistik

Austria, 2009a) and is the reference population for this work. Incoming foreign tourist travel almost balances Austrian outgoing travel abroad and is therefore neglected (Statistik Austria, 2010a, 2010b, 2009b).

2.1 Area calculations

The agricultural area can be divided in grassland (used for roughage consuming animals) and arable land (used for animal fodder and crop production for plant-based food and industry). Official land use statistics (BMLFUW, 2008a) were used to estimate the proportion of grassland and arable land. A portion of the farmed area is used for the production of exported goods (e.g. milk and beef). Goods such as animal feed and tropical fruits are imported into Austria. Exported and imported goods can be expressed in terms of the agricultural area required for their production. This is termed the “virtual imported/exported area” and can be allocated to specific crops and animal products. The area demand of specific animal products was calculated using feed balance statistics (BMLFUW, 2008a; Statistik Austria, 2009c). Imported rice was linked to average world yields (FAO, 2009c). Austrian yields were used for the calculation of all other virtual imported/exported areas. Details can be found in Zessner et al. (2011a) and in the supplementary material.

2.2 N and P balances

The material flow analysis (MFA) (Baccini and Brunner, 1991) was used for calculation of N and P balances of Austria. The main principle of the MFA is the conservation of mass. Complex relationships of material flows can be expressed with clearly defined “processes” and “fluxes” between them. One of the first steps of a MFA is the definition of the system boundaries. In our calculations the horizontal system boundary is the national territory of Austria. The vertical system boundary is built up by the groundwater and the troposphere. The system is shown in Figure 4 for

N and Figure 5 for P. This system is the basis for further investigations regarding resource consumption, import and export of resources and emissions (losses) of nutrients into waters and the troposphere. For the calculation of N and P fluxes first mass flows of the different goods between the processes are assessed and consequently the N and P substance fluxes are calculated with corresponding N and P concentrations within the goods (Baccini and Brunner, 1991).

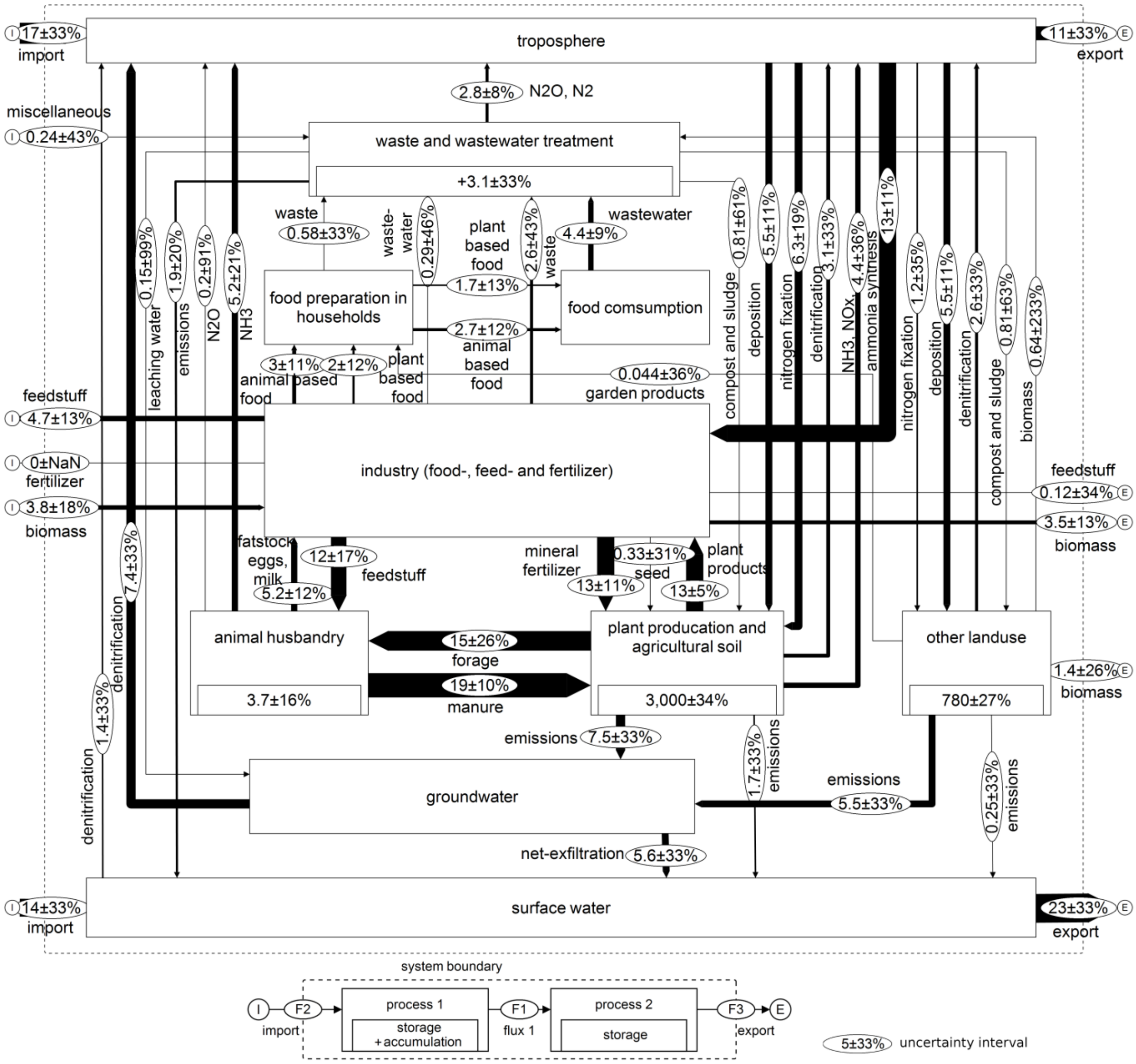

Figure 4: Nitrogen fluxes within the food production and consumption system in Austria (average over the years 2001-2006) (Fluxes and accumulation in kg N capita^{-1} year^{-1}; storage in kg N capita^{-1}).

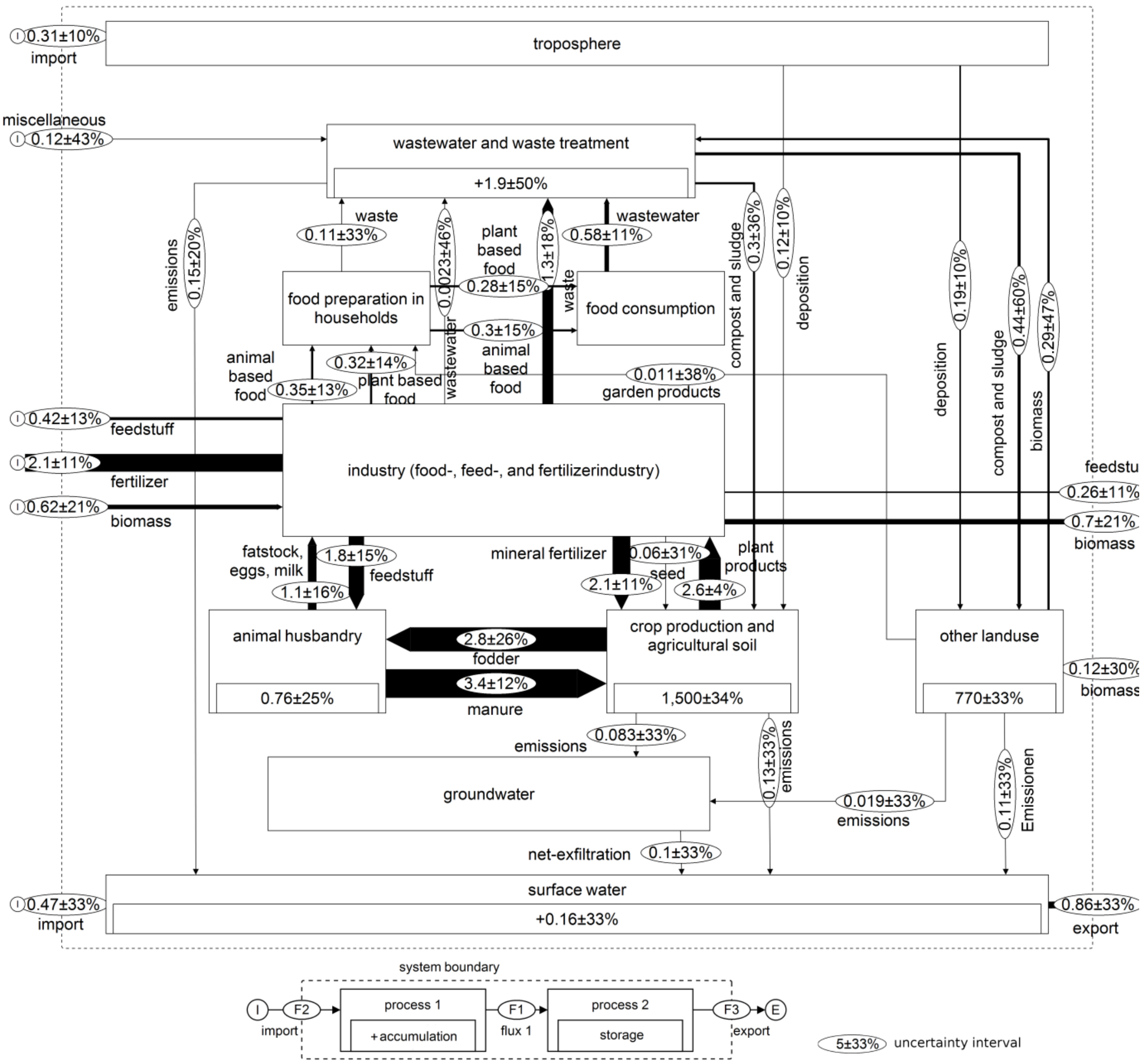

Figure 5: Phosphorus fluxes within the food production and consumption system in Austria (average over the years 2001-2006) (Fluxes and accumulation in kg P capita^{-1} year^{-1}; storage in kg P capita^{-1}).

In the following sections, the main “processes” of the system and their interrelation by fluxes (Figure 4 and Figure 5) are described. Detailed source data and calculation characteristics are published in Thaler et al. (2011) and are included into the supplementary material of this publication.

2.2.1 **Processes and fluxes**

The whole system is subdivided into ten different processes. In total 61 fluxes (goods or substances) enter the system as imports, leave it as exports or connect processes as output of one process and input into another (see figure 1 and 2 and supplementary material). The process "food consumption" can be seen as the driving force for the whole system. It includes all food eaten. Inputs come from the process "food preparation in households", which receives its input from "industry". All eaten food (animal based or plant based) is considered. The outputs are excreta to the waste water which enter the process "waste and waste water treatment".

Main basis for the food supply is the process "Plant production and agricultural soil". It receives mineral fertilizer and seed from industry as well as manure from "animal husbandry". Outputs are food and fodder which are produced on arable land and grassland. The process "animal husbandry" uses fodder, produced in the process "plant production and agricultural soil" and other fodder delivered by the process "industry" and produces food (meat, eggs, milk) going to "industry" and manure which – except from losses to the "troposphere" – is returned to "plant production and agricultural soil" .

The process "industry" plays the role of distributor and purchaser for agriculture and the role of food supplier to households. For example soy fodder imports are a flux coming from outside the system boundaries (flux: feedstuff). Soy fodder is distributed by the process "industry" to the process "animal husbandry" where it is utilized to produce fatstock, eggs and milk delivered to the process "industry" again.

The process "other land uses" is not directly necessary for research on food consumption and production in Austria. However it is important to draw a more complete picture of the nutrient balances. Including several land uses and emissions into the water system give the possibility to check the calculated nutrient emissions into the water systems against measured data (e.g. nutrient loads in rivers calculated from measured values).

"Surface water", "groundwater" and "troposphere" are the environmental compartments receiving nutrient emissions from different anthropogenic activities (processes "plant production and agricultural soils", "animal husbandry" or "waste and waste water treatment"). While nutrient fluxes between anthropogenic processes are calculated based on statistical data on usage and production of different goods and concentrations of nutrients in these goods, emissions into the environment are calculated using different model approaches. Emissions into air (NH3, N2O, N2) were calculated using methods from IPCC (Houghton et al., 1997) and EMEP/CORINAIR (EEA, 2006) with national factors derived from UBA (Anderl et al., 2010; UBA, 2008). For point source emissions via waste water treatment plants information based on measurements exists to a high extent. Diffuse emissions into waters were calculated using a version from the MONERIS (Modeling Nutrient Emissions in River Systems) model (Behrendt et al., 1999) which was adopted by Zessner et al. (2011b) for Austrian conditions specifically addressing alpine catchments. Results from the application of this adaption are presented in C. Schilling et al. (2011) and are the basis for nutrient flows presented here. MONERIS is an empirical conceptual model modeling different pathways (groundwater, erosion, surface runoff, urban runoff, point sources and deposition) for N and P emissions on the level of sub-catchments. For this purpose Austria has been subdivided into 376 sub-catchments. Validation of modelling results was possible for about 100 sub-catchments were sufficient data for calculation of river loads from water flow and nutrients concentrations were available. The capability of MONERIS to distinguish between nutrient emissions pathways was used for allocating the emissions into water to the related processes. Finally the results from the different sub-catchments have been summed up to be used for the total Austrian nutrient balance.

2.2.2 Allocation between fodder and cash crop production

Based on the systems shown in Figure 4 for N and Figure 5 for P, other aggregations of processes and fluxes were calculated in order to present results more comprehensively. To investigate the influence of animal husbandry including fodder production, the process “crop production and agricultural soil” has been redistributed to the different sources. According to the statistical data (BMLFUW, 2008a) the agricultural area was split into two groups, 1) area for fodder production and 2) area for cash crop production. Deposition as well as sludge and compost application were distributed equally according productive area. N fixation was calculated according to the growing area for legumes. Emissions into groundwater and surface water were allocated according to calculations of nutrient surpluses for “agricultural soil” and “other land uses”. The distribution of mineral fertilizer between fodder and other crop production was more complex. Bach and Frede’s (2005) approach has been adapted for Austrian conditions. Equation 1 shows the basic calculation for mineral fertilizer. The quantities of mineral fertilizers applied in Austria are known from the official agricultural statistics. Therefore the factor of effectiveness for manure can be calculated. The factor of effectiveness defines the annual fertilizer activity assumed by the farmer. In a second step the mineral fertilizer applied for fodder production and for other crops can be calculated using the average Austrian factor of effectiveness. The resulting input – output balance error indicates the appropriateness of the applied method.

Equation 1: $MF = N_R * C_{HD} - F_M * C_E - F_O - N_{FIX}$

MF … mineral fertilizer applied (kg N year^{-1} or kg P year^{-1})
N_R …total nutrient removal from field (kg N year^{-1} or kg P year^{-1})
C_{HD} … coefficient of higher demand (calculated from the fertilizer recommendations of the official fertilize guidelines (Fachbeirat für Bodenfruchtbarkeit und Bodenschutz, 2006) divided by the nutrient removal; similar to Bach and Frede (2005) the coefficient was determined with 1.2) (dimensionless)

F_M …manure fertilizer minus housing, storage and management losses (kg N year^{-1} or kg P year^{-1})
C_E … coefficient of effectiveness of nutrients in the manure as expected by farmers (dimensionless)
F_O … compost and sludge (other organic fertilizer) used as fertilizer on agricultural area already converted to mineral fertilizer equivalent with factors from Galler (2009) (kg N year^{-1} or kg P year^{-1})
N_{FIX} … N fixation by bacteria (kg N year^{-1})

2.2.3 Uncertainty considerations

Uncertainty considerations for MFA's have different aspects. Basically balancing each process is a multiple quality control of the investigated fluxes as different processes are interlinked by fluxes in several directions. However, the total balance of each process and the total system gives no information of the uncertainty of the different fluxes itself. An uncertainty calculation for each flux needs an investigation of the data sources. Various data sources are necessary for the nitrogen and phosphorus balances. Data uncertainty analysis must deal with the lack of information regarding uncertainties of measured or calculated values. Hedbrant and Sörme (2001) developed a robust uncertainty calculation method dealing with these limitations. The method classifies data sources into different uncertainty levels. The uncertainty levels are expressed as interval Y /X (i.e. from 1/Y . X to Y . X). In Table 7 the uncertainty levels we used are given. Hedbrant and Sörme assumed that the uncertainty interval has similar qualities to the standard deviation for a normal distribution. The uncertainty calculations follow the same procedures as the standard deviation calculations in traditional statistical methods, with small modifications reported in Hedbrant and Sörme (2001). The procedures for multiplication and addition of various data with different uncertainty factors were applied in order to estimate a final uncertainty interval for each flux of the MFA.

Table 7: Uncertainty levels with examples used in this study.

Level	Uncertainty factors	Source of data (information)	Example
0	interval */1	Values in general (literature)	molecular weight, e.g. N_2O, P_2O_5
1	interval */1.1	Official statistics on local, regional and national levels; values in general	stock of animals, area distribution, mineral fertilizer use, yields
2	interval */1.33	Official statistics on local, regional and national levels; values in general; expert judgement	nutrient content
3	interval */2	Own estimations; own calculations; expert judgement; modelled data	NO_x-emissions, faecal sludge of decentralized wastewater treatment plants

For calculation of nutrient fluxes into groundwater and surface water the empirical emission model MONERIS has been used in the frame of the nutrient balance calculation. The sum of all emissions minus retention and denitrification in the water system sums up to the river loads. For validation of model results observed river loads have been compared to modeled ones. For this validation monitoring points in rivers from all over Austria have been used, which are monitored by continuous flow measurements (usually based on continuous gauge reading) and water quality sampling and analyses of nutrient parameters. Monitoring points with a frequency of at least 12 samples per year over at least 3 years within the period of 2001 to 2006 were used. Finally appropriate load observations for validation of results have been available for total phosphorus for 99 and for dissolved inorganic nitrogen (DIN) for 102 measuring points out of the 376 sub-catchments into which the Austrian territory has been subdivided for emission calculation (Zessner et al., 2011b). The comparison of measured DIN (dissolved inorganic nitrogen) and TP (total phosphorus) loads and the nutrient loads calculated with MONERIS show a good congruence in most of the sub-catchments (see supplementary material). Though for some of the catchments there are still some deviations but no systematic error was detected. All catchment results were summed up for the Austrian wide MFA’s.

2.3 Calculation of the water footprint

Based on ideas of virtual water from Allan (1993) the water footprint concept was developed by Hoekstra and Hung (2002). According to the methodology published in the official manual of the water footprint network we can distinguish green, blue and grey water use (Hoekstra et al., 2011). Generally the water footprint (WF) describes the consumptive water use of a product, business or geographical area (e.g. catchment or federal territory). Blue water indicates the use of surface or groundwater (evaporated water or water incorporated into products, or water not returned locally or temporally to the catchment). Green water indicates the use of precipitated water stored in soils and available for use by plants. Grey water indicates fresh water pollution. It is defined by the volume of freshwater necessary to dilute a load of substances to such an extent that certain quality levels are reached when ambient background concentrations are considered (Hoekstra et al., 2011). For this research, the green, blue and grey water footprints of crop products for the whole of Austria were calculated. For plant based food, the WF of crop production on agricultural area is considered; further processing, distribution and preparation of agricultural products are not considered. Therefore product and value fraction for the water footprint calculations are expected to be one. The value and product fraction describes the proportion of the WF split between different items produced from one raw product (e.g. sugar and feedstuff (molasses) from sugar beet). For animal based food the production of fodder on agricultural area is considered. Drinking water of the animals as well as fodder from industrial byproducts is ignored. A detailed WF calculation for the whole food supply chain should be topic of further research. Finally the water footprints results ($m^3\ yr^{-1}$) are related to one capita and one day ($m^3\ cap^{-1}\ day^{-1}$).

2.3.1 Green and blue water

To accurately depict the Austrian conditions regarding climate and therefore crop water use, the federal territory was split in eight agricultural main production zones (Statistik Austria, 2010c). Unproductive areas (e.g. mountainous areas) and forests were excluded using the Corine Land Cover data (ETC/LUSI, 2010) and geographical information software (GIS). Mean precipitation and evapo-transpiration were calculated for every main agricultural production zone using spatial precipitation and potential evapotranspiration data published by the FAO (2004a, 2004b) based on the data and calculations from the Centre for Climate Change Research (New et al., 2002). These were then used as input data for the Cropwat model (FAO, 2009b). Cropwat was used to calculate the crop water requirement, effective rainfall and irrigation needed for each plant and for each main agricultural production zone. The most crops are solely rainfed, so no irrigation is applied. For sugar beet (cultivated in the main production zone "Nordöstliches Flach und Hügelland"), fruits and vegetables irrigation is assumed if necessary (crop water requirement minus effective rainfall minus soil moisture deficit at harvest > 0). Crop data from Chapagain and Hoekstra (2004) were adapted with phenological data from ZAMG (2011). The irrigation schedule modus was used to calculate irrigation water, assuming medium soil (moderate clay fractions) conditions. Soil moisture deficit at harvest time was included as part of the green water because the deficit is refilled during winter precipitation (Thaler et al., 2012a). The resulting green and blue water footprints were calculated by multiplying rainwater and irrigation water use per hectare by the related crop area for each main agricultural production area (Figure 6). Individual crop production areas were extracted from the InVeKoS (IACS) dataset (Integrated Administration and Control System) (BMLFUW, 2007) Combining all water footprints over entire Austria leads to the final green and blue water footprint for Austrian crop production. A distinction between fodder production and other crop production was made with the approach mentioned above.

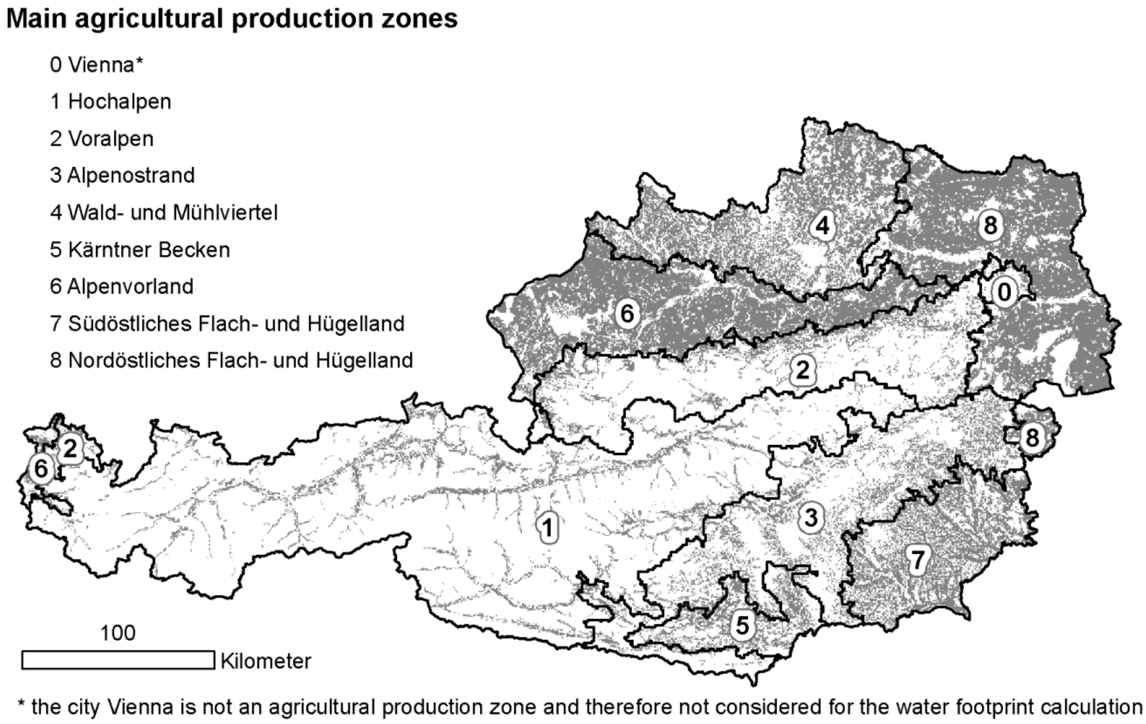

Figure 6: Main agricultural production zones with agricultural areas shaded grey

2.3.2 **Grey water**

The formula for the calculation of the grey water footprint is:

Equation 2: $WF_{grey}=L/(c_{max}- c_{nat})$

Where L (kg N; kg P) is the load emitted into waters. The maximal allowed concentration of N and P is c_{max} (kg L^{-1}) whereas c_{nat} (kg L^{-1}) expresses the ambient concentrations. The MONERIS calculation were used to determine the loads from crop production (Schilling et al., 2011) and loads carried out of by each river leaving Austria. The corresponding ambient and maximal water quality standards for each sub-catchment were taken from Deutsch et al. (2010). The resulting grey WF was summed for the entire crop production area in a similar way to the green and blue WF calculation.

2.3.3 **Water footprint of imported food items**

The water footprint of imported plant products was derived using green, blue and grey water footprints calculated by Mekonnen and Hoekstra (2010). For all imported plants worldwide averages were used. Imported animal products were calculated using the average water footprint for one unit of animal products.

3 Results

3.1 Food production and consumption in Austria

In Austria 637 kg food per capita and year is consumed, of which 52 % is animal-based and 48 % plant-based. Plant based food accounts for approximately 66 % of the consumed energy and approximately one third of the ingested protein (Table 8. Austria production does not completely meet the nutrition demands of the Austrian population but, at the same time, part of the Austrian agricultural production is not consumed in Austria and is exported. Austria is almost self-sufficient in pork and cereals, imports fish, oil seeds, fruits and vegetables amongst others, and exports beef and calf (Figure 7). Thus resources from abroad contribute to domestic consumption and domestic resources are exported into foreign countries.

Table 8: The average food consumption in Austria per capita related to mass, protein and energy.

	mass	protein	energy
	kg cap^{-1} $year^{-1}$	g cap^{-1} day^{-1}	KJ cap^{-1} day^{-1}
animal products			
beef	10.2	4.4	117
pork	34.3	15.0	413
poultry	9.5	3.8	180
other (offal, horse, sheep, goat, fallow deer)	2.8	1.0	39
eggs	11.8	2.9	209
milk	257.0	16.6	1,975
fish	5.8	1.9	66

sum animal products	331.3	45.7	3,000
plant products			
cereals	61.9	16.5	2,343
potatoes	52.7	2.1	423
oil fruits	9.7	0.5	958
fruits	58.6	1.0	316
vegetables	89.6	3.5	221
legumes	0.3	0.1	6
sugar beet	33.0	0.0	1,510
sum plant products	305.8	23.6	5,777
sum average diet	637.1	69.2	8,777

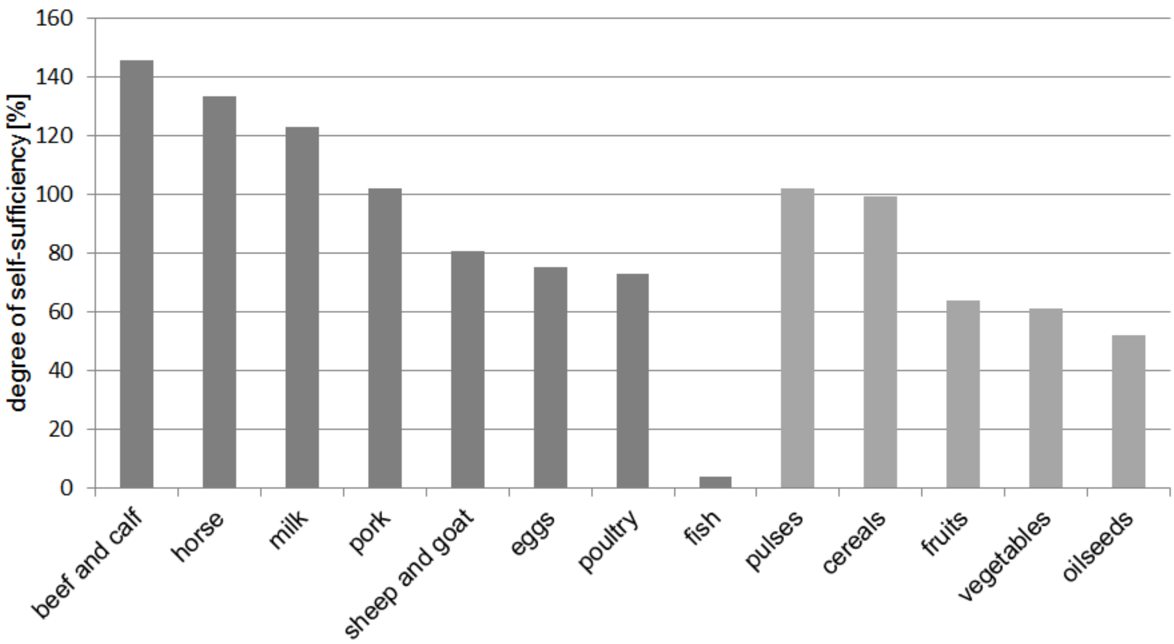

Figure 7: Degree of self-sufficiency with regards to a selection of food products. The data shows over production of cattle and the insufficient availability of other foodstuff (Statistik Austria, 2007a).

3.2 Area consumption of the Austrian diet

Austria has 1.38 million hectares of arable land (1688 m² per capita) and 1.8 million hectares of grassland (2187 m² capita^{-1}). Half of the grassland is used intensively and the other half includes less intensively used areas such as mountain pastures and meadows. Grassland is entirely utilized for grazing and fodder production. An additional 57.4 % of arable land is used for the production of animal fodder. The remaining arable land is divided into fallow land (7.5 %), industrial crops and energy production (9.1 %) and production of plant based food (26 %). In total an average of 455 m² per capita agricultural land is used for the production of plant based food and 3167 m² per capita for the production of animal based food. Based on the self-sufficient balance (Figure 7) and the average diet (Table 8) we calculated the agricultural area necessary for production of this quantity of food. Additional assumptions for production yields of food and fodder which is imported, as described in the method section, were necessary. In total 3620 m² per capita of agricultural area are needed to produce sufficient food to meet the requirements of the average Austrian diet. The majority of land is needed for the generation of animal products (2938 m² per capita) and the remaining (633 m² capita^{-1}) area is needed for the production of plant based food (Table 9).

Exported and imported food and fodder have been related to the area needed for their production. These virtual net imports and export of agricultural land are shown in Figure 8. Exported beef, calf, milk and milk products lead to a virtual net-export of grassland amounting to 466 m² per capita (21 % of the total grassland available) and a net-export of green fodder produced on arable land of 65 m² per capita. Arable land is “virtually” imported for soya based animal feedstuff (250 m² capita^{-1}) and oligenious crops (240 m² capita^{-1}). Foreign fruits (such as banana) and some types of vegetables are included under "other crops", and are responsible for 24 m² per capita of virtual import area. Rice has a negligible impact on area consumption because the domestic consumption is rather low (Figure 5).

Table 9: Area of farmed land in Austria compared to area of farmed land required to meet the nutritional demands of the Austrian population

	Area of farmed land in Austria		Area farmed land required to meet the needs of the Austrian population	
[m² capita^{-1}]	plant based food	animal based food	plant based food	animal based food
fruits and vegetables	27	0	47	0
arable land	428	980	591	1,241
meadows and pastures	0	1,101	0	877
low yielding grassland	0	1,086	0	865

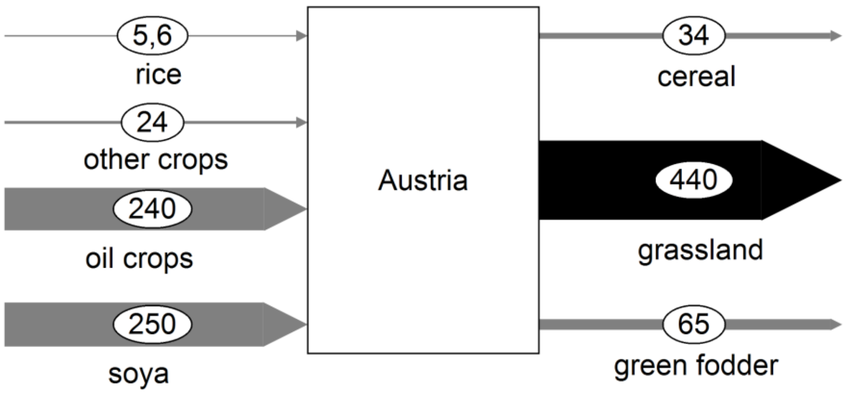

Figure 8: Austria’s virtual export and import of agricultural area

3.3 Nitrogen and phosphorus fluxes

The balance error (input minus output related to total input in %) of the processes show good results for the process “animal husbandry” (2.4 % for N, 4.6 % for P), for “plant production and agricultural soil” (-3.8 % for N, 6.3 % for P) and for “surface water” (-1.9 % for N, -5.8 % for P). The process “industry” (10 % for N, 11.2 % for P) has the highest error. Other balances are closed because a flux without available data is calculated by sum of input fluxes minus sum of output fluxes (e.g. denitrification in groundwater). Uncertainty interval estimations, as explained in the method section, lead to a distribution of uncertainty intervals of several fluxes shown in Figure 9

Figure 9: Distribution of uncertainty intervals for N and P fluxes related to the total mass flows. F-numbers are described in the supplementary material.

The uncertainty interval is drawn against the dedicated height of nutrient flux. 87 % of all fluxes have a resulting uncertainty less than ± 40 %. Fluxes with a higher uncertainty, up to ± 233 %, are fluxes of lower importance for the nutrient balances. However when investigating environmental impacts some of the fluxes with a high uncertainty interval are important. In Figure 4 and Figure 5 N and P fluxes are displayed with the dedicated uncertainty interval.

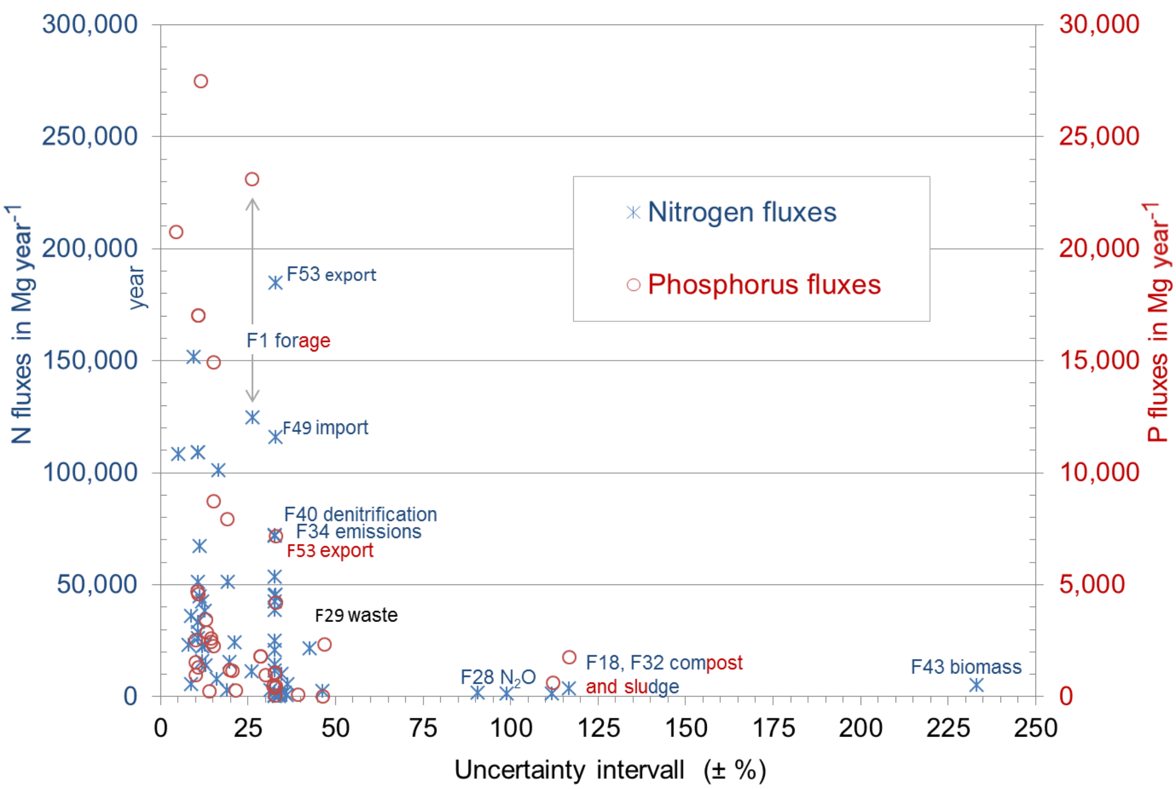

Figure 9: Distribution of uncertainty intervals for N and P fluxes related to the total mass flows. F-numbers are described in the supplementary material.

On average 2.7 kg N per capita and year in animal based and 1.7 kg N per capita and year in plant based food are consumed. In order to provide the population with these amounts the national turnover is significantly higher. When the fluxes of feedstuff and forage are combined it can be seen that fodder occupies the largest flow (27 kg N cap^{-1} year^{-1}). Forage and manure (with 19 kg N cap^{-1} year^{-1} another main flux) stay within the subsystem agriculture (processes “crop production and agricultural soil" and "animal husbandry"). Mineral fertilizer is the largest flow entering the agricultural subsystem (13 kg N cap^{-1} $year^{-1}$). Although other flows, such as emissions, are not particularly high, they play an important role regarding impacts on aquatic environment and climate. For phosphorus, the main flows are also within the subsystem agriculture (Figure 5). Imported phosphorus mineral fertilizer (2.1 kg P cap^{-1} $year^{-1}$) and feedstuff (0.42 kg P cap^{-1} $year^{-1}$) are used to supply crops, which are the basis for food supply of the population.

3.4 Import and export of nitrogen and phosphorus

We simplified the balances for nitrogen (Figure 4) and phosphorus (Figure 5) to focus on import and export of these nutrients (Figure 10 and Figure 11) to and from the considered system. Almost 19.5 kg N per cap and year are required in order to facilitate agricultural production and food supply. These inputs are realized either via fodder or other biomass, or via mineral fertilizer from the ammonia synthesis industry. Additionally 21.5 kg N per cap and year enter the system through nitrogen fixation in agricultural soils and deposition on all soils. The amount of nitrogen released into the troposphere in reactive form (NH_3, N_2O and NO_X, 7.6 kg N $capita^{-1}$ $year^{-1}$) is in roughly the same as surface water emissions leaving Austria (8.5 kg N $capita^{-1}$ $year^{-1}$). The highest losses of nitrogen out of the productive system of Austria stem from denitrification in soils, groundwater and waste water treatment plants and are released in form of N_2. All phosphorus mineral fertilizer is imported as Austria lacks phosphorus ores. A total of 91 % of the total input is bought from abroad (3.2 kg P $capita^{-1}$ $year^{-1}$). The remaining 9 % reach the soil via deposition. Phosphorus is not transferred from the troposphere to land in the same manner as nitrogen. 3 kg P $capita^{-1}$ $year^{-1}$ is accumulated in soils (~26 %), deposited in landfills (~66 %) or held back in surface waters (~8 %).

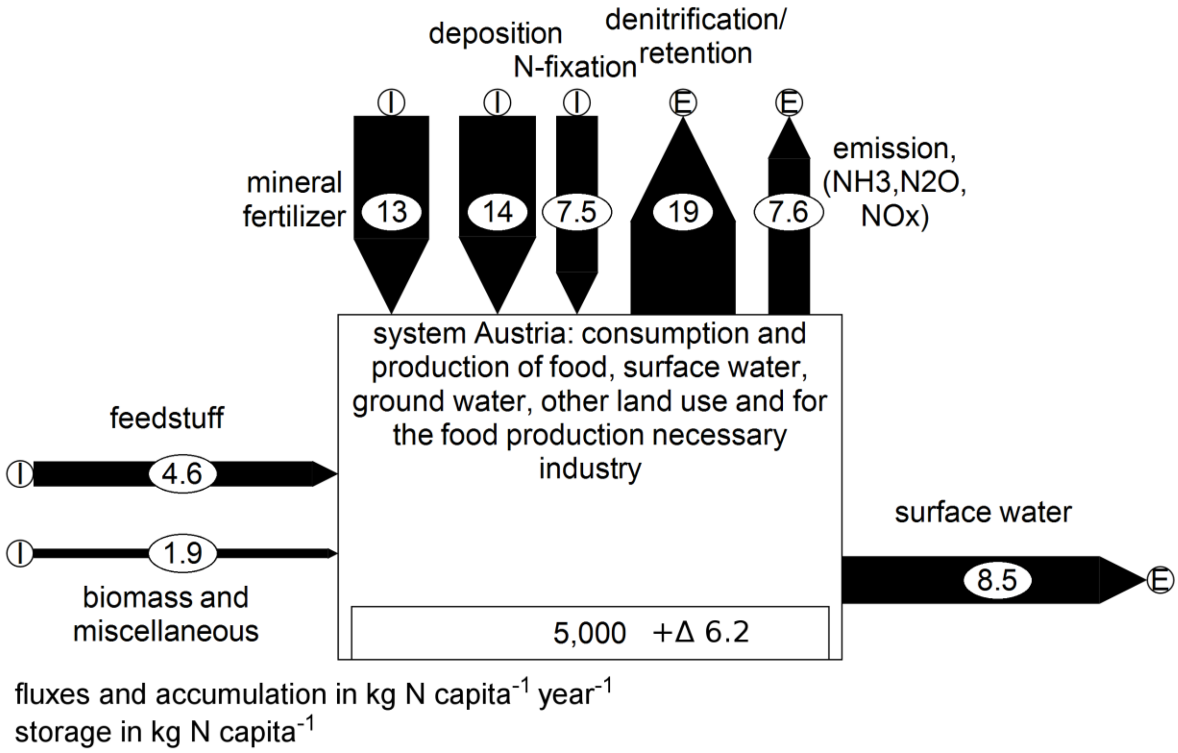

Figure 10: Net-import and net-export fluxes of nitrogen from and to Austria (kg reactive N capita^{-1} year^{-1}). Further treatment and processing of waste is not considered and therefore contained in N accumulation.

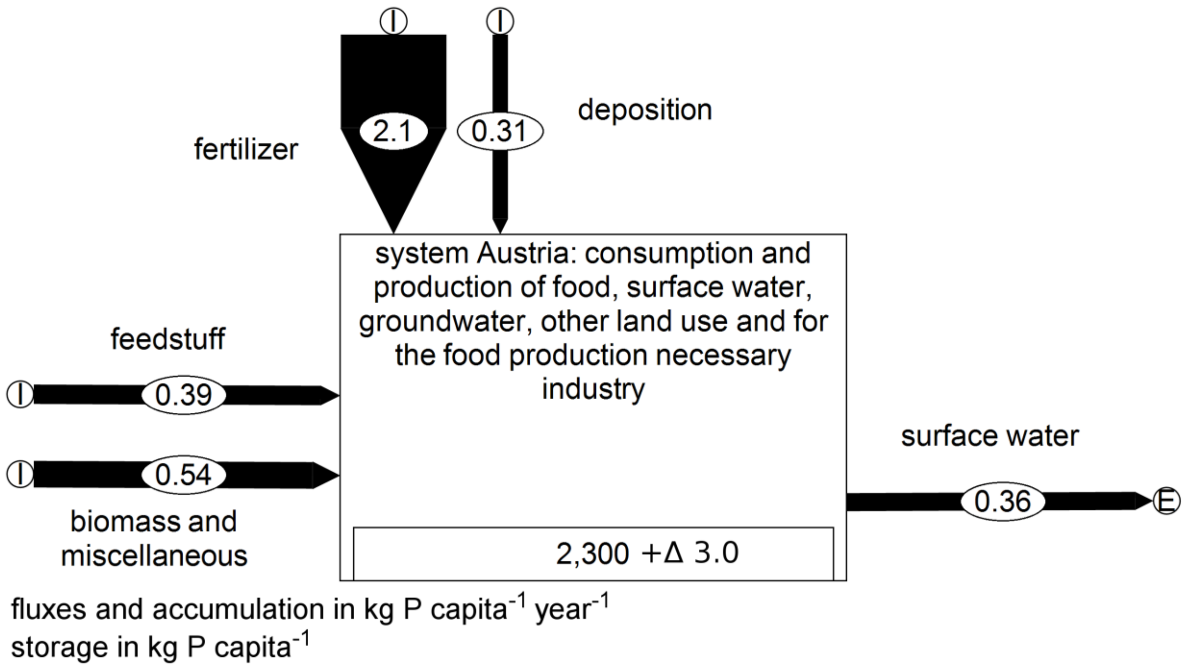

Figure 11: Net-import and net-export fluxes of phosphorus from and to Austria (kg P capita^{-1} year^{-1})

3.5 Animal vs. plant production

Animal husbandry is known to consume a lot of resources (Steinfeld et al., 2006). For the investigation of the nitrogen and phosphorus consumption we distinguished between three processes: a) animal husbandry and fodder production, b) production of plants for human nutrition on arable land, and c) production of raw materials for industry. Nearly 50 % of the applied mineral fertilizer is used for fodder production (Figure 12). Seventy-one percent of the total nitrogen input in the system (including mineral fertilizer and feedstuff) is used for animal husbandry, 21 % is used for the production of plant based food and 8 % for the production of raw materials for industry. It is notable that a similar amount of N is used for human nutrition from animal husbandry (4.5 kg N capita^{-1} year^{-1}) as it is used directly from plant based food production (4.7 kg N capita^{-1} year^{-1}).

Regarding emissions into the environment, animal husbandry is responsible for the main fluxes. For nitrogen, 95 % of the total emissions into air and 84 % of the emissions into aquatic systems from total agriculture stems from animal husbandry and fodder production. A similar result is seen for phosphorus (Figure 13). Eighty-four percent of the total P emissions from agriculture into aquatic systems originate from animal husbandry, 9 % from plant based food production and 7 % from the production of raw materials for industry. Animal husbandry consumes 58 % of the total phosphorus input into agriculture. In comparison, production of biomass to meet human nutrition needs only 29 % of the total phosphorus input. Twenty percent of the nitrogen and 54 % of the phosphorus input into animal husbandry are incorporated in fatstock, eggs and milk. A small part of phosphorus is accumulated in soils (0.63 kg P capita^{-1} year^{-1}) and can be reused for crop production as long as it is not lost by erosion or leaching. In biomass production for plant based food we find 71 % of the nitrogen and 93 % of the phosphorus input.

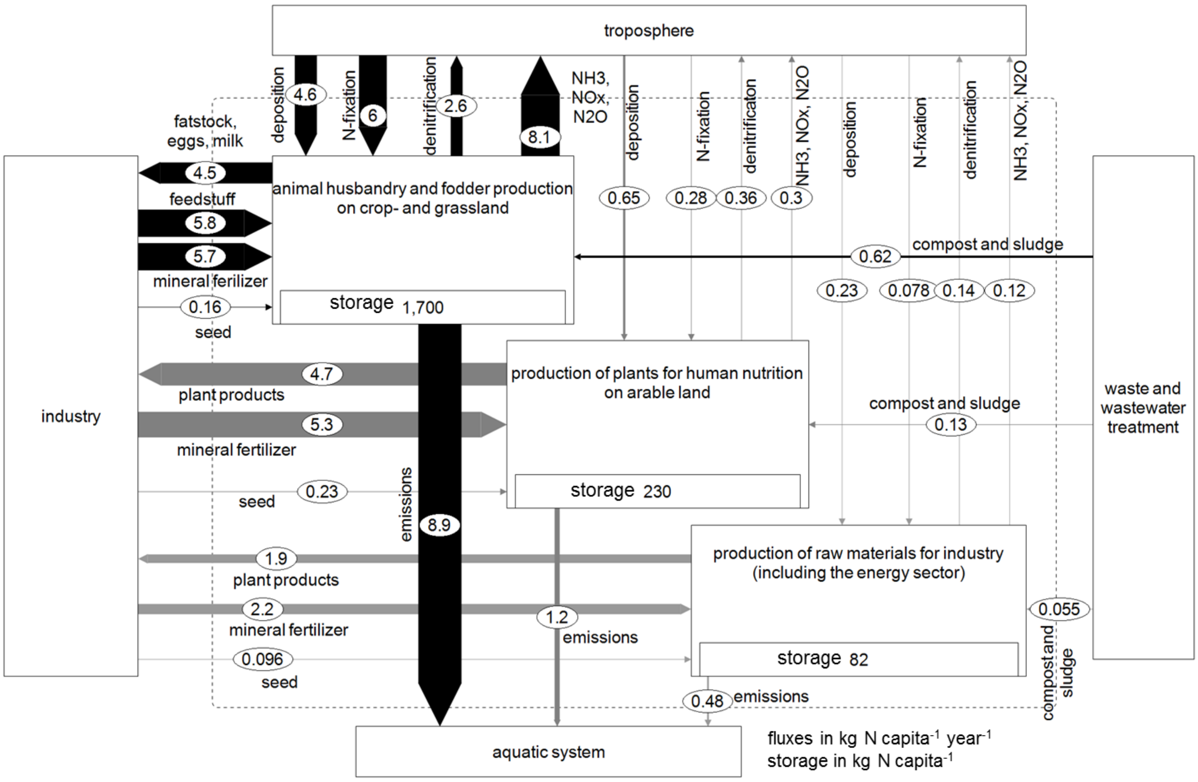

Figure 12: Nitrogen fluxes in the Agriculture system differentiated by production for animal products, production for plant products and production for industrial raw materials.

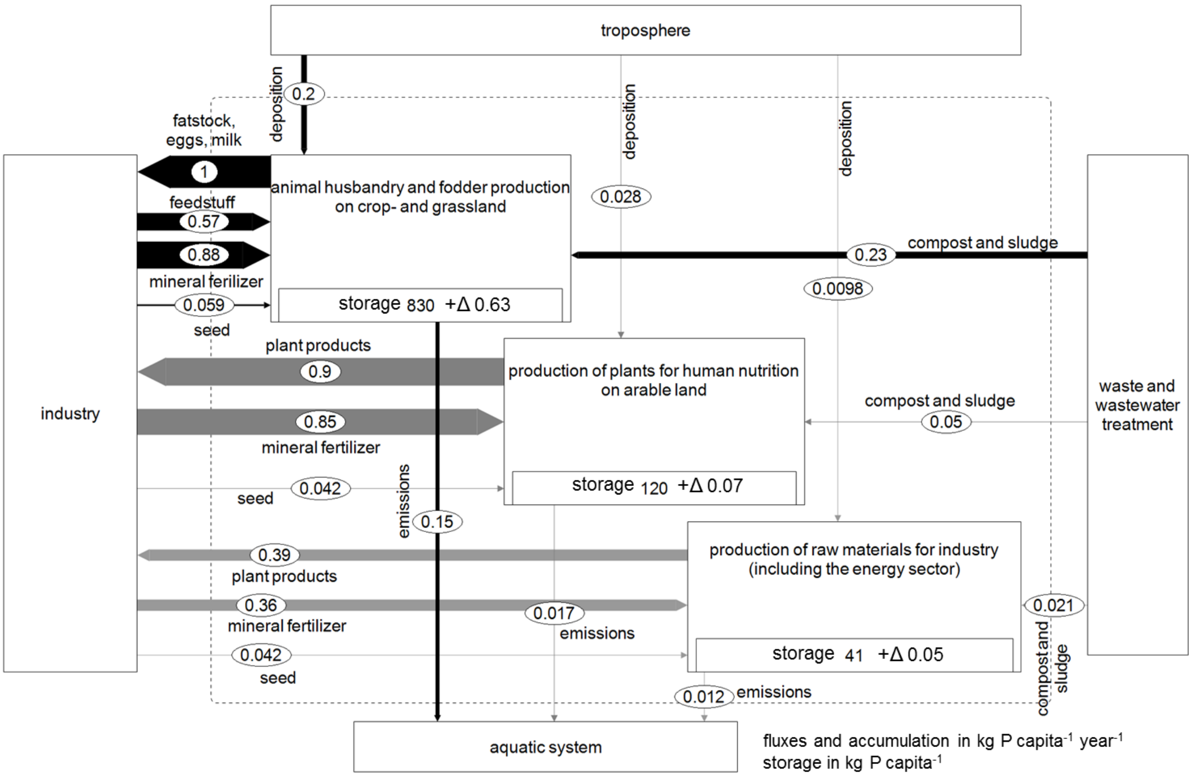

Figure 13: Phosphorus fluxes in the Agriculture system differentiated by production for animal products, production for plant products and production for industrial raw materials (accumulation is marked by Δ).

3.6 Nutrient emissions into waters

Calculations in MONERIS show that 80 % of N and 74 % of P emitted to surface water is derived from diffuse sources. In total, 80,000 Mg N per year and 4,300 Mg P per year are emitted to surface waters in Austria (Schilling et al., 2011). The nitrogen input to forest and other areas is due to deposition. By linking deposition with emissions as described in the method section, 68 % of the deposition can be allocated to animal husbandry. The allocation of the total nitrogen and phosphor emissions into surface water is shown in Figure 14. In total 60.5 % (46 % fodder production for animal husbandry plus 14,5 % deposition caused by animal husbandry) of the N emissions into waters stem from animal husbandry, 6.2 % from plant production, 2.5 % from plant production from industry and 23.4 % from point sources and urban runoff. The rest can be allocated to processes outside the scope of this work, like air pollution from traffic and industry. Point sources and urban runoff are the most important pathways for phosphorus with 38.9 % of the total P emissions. The production of fodder is responsible for 28.5 %, plant production for human nutrition is responsible for 3.2 %, plant production for industry is responsible for 2.3 %, and other land use is responsible for 27.1 % of the total P emissions.

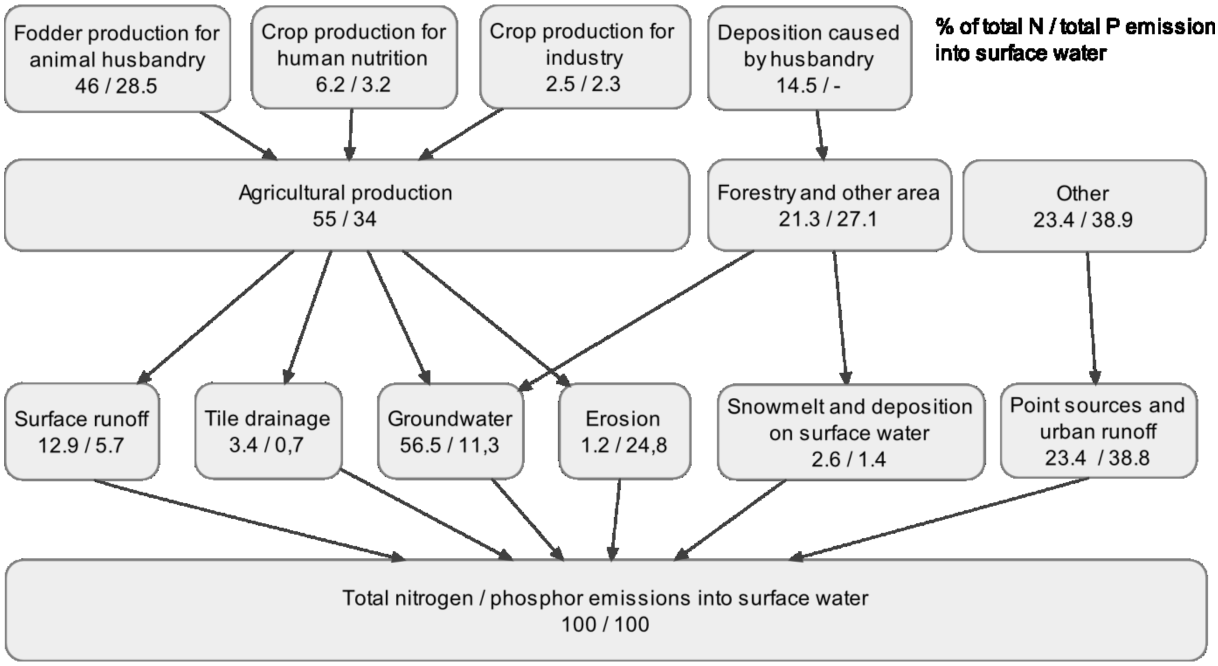

Figure 14: Nitrogen and phosphorus emissions into surface water. The contribution of agriculture and other production processes is shown. All percent values relate to total nitrogen / phosphorus emissions into surface water.

3.7 Water footprint

About 33 m³ per capita and day water reaches the land via precipitation in Austria (Kresser, 1994). The calculated water demand (expressed as WF) of all food production in Austria uses approximately half of this precipitation. The water consumed by food production and water consumed by food consumption in Austria are almost balanced (Table 10). Imported feedstuff and food is counter balanced by exported beef and other food. Green water accounts for 23 % of the total WF, grey water accounts for 77 %. Blue water makes a negligible impact on the total water footprint. Almost 87 % of the water footprint relates to the production of animal based food. When comparing the grey water footprint with the discharge of all rivers leaving Austria (net export), 43 % of the total discharge would be necessary to dilute the nutrients emitted by agricultural food production to achieve Austrian environmental quality standards defined in Deutsch et al. (2010).

Table 10: Comparison of the water footprints between the production of agricultural products in Austria and the water footprints of agricultural products consumed in Austria. Grey water from nutrition induced wastewater disposal is not included.

m^3 capita^{-1} day^{-1}	produced in Austria		consumed in Austria (in Austria and/or imported products)	
	plant based food	animal based food	plant based food	animal based food
WFP (green)	0.6	3.1	0.7	3.2
WFP (blue)	0.01	0.00	0.03	0.01
WFP (grey)	1.5	10.9	1.4	10.1
WFP (green + blue + grey)	2.1	14.0	2.1	13.3

4 Discussion and conclusion

Incorporation of various data from different sources with different quality levels lead to difficulties in uncertainty assessments. The method used for this work tries to deal with these issues. The uncertainty results are highly sensitive to the data quality assumptions and the chosen uncertainty levels. Smaller input uncertainty intervals and fine-tuned uncertainty classes would lead to lower final uncertainties. Nevertheless the method seems to be useful for including uncertainties considerations for MFA's. As most MFA's actually do not include uncertainty considerations at all (Danius and Burström, 2001), their implementation should become standard for every MFA.

The results indicate those fluxes where the data quality should be improved. Together with the intention of use (nutrient balance, environmental impact assessment) fluxes with high uncertainty intervals and relevance can be filtered. For example N_2O gas emitted from animal husbandry has a low N flux (0.2 kg N capita^{-1}

year^{-1}) but a high uncertainty (± 91 %). This flux is from high importance when looking at the climate relevance of N_2O. Whereas the mineral fertilizer input on agricultural soils is a rather well known number due the official fertilizer statistics. This is reflected by a final uncertainty interval of ± 11 %. The emissions into groundwater and surface water are not that certain (± 33 %). However in respect to water quality related questions they are from high importance.

As expected, self-sufficiency to meet the actual diet in Austria is not possible. The land demand exceeds available agricultural land resources in Austria. There is a lack of arable land in Austria, while more grassland as needed for Austrian population is available. Therefore, the production of imports is dependent on arable land outside of Austria, which is a result of high shares of animal products in the diet of Austrian population.

Arable land is a limited resource worldwide. In a world facing a growing population and increasing demand of land consumptive animal based food (OECD/FAO, 2010) the competition for especially arable land is a challenge for food security globally (Harvey and Pilgrim, 2011; Tilman et al., 2009). In this respect questions of distributive justice are inevitable. The world average for arable plus permanent land (i.e. fruit crops) per capita is 2324 m2 for the year 2006 (FAO, 2009c). In Austria there is 27 % less arable land plus permanent land available. But the Austrian yields are in general higher than the world average. For example the average wheat yield in Austria for the year 2006 was 172 % of the worldwide average (FAO, 2009c). This data suggests that Austrians are using too much arable land as they should if a worldwide equity is considered. Extensification of agricultural land use for reasons of environmental protection could deteriorate this situation. In this context the resource agricultural land should always be considered when dealing with questions related to limitations for agricultural production, environmental impacts and food consumption.

For Agricultural production N and P inputs are required. This happens in form of mineral fertilizer, fodder and other biomass. Our calculations show that 19.5 kg N per capita and year and 3.2 kg P per capita and year are brought into Austrian agriculture via these pathways. Despite the fact that animal based food only delivers one third of population's energy demands, animal husbandry requires the highest nutrient resource input. In total 71 % of the N and 58 % of the P input (mineral fertilizer, feedstuff, deposition, N fixation and miscellaneous imports) is used for animal husbandry.

Though there are other studies dealing with nitrogen and phosphorus flow analysis on a country wide scale, to the knowledge of the authors there are no studies allocating the emissions into the environment to plant and meat based food production. Likewise the distinction between land cultivation for fodder production and plant based food production is mostly not considered in detail, as for example the nutrient inputs (fertilizer, nitrogen fixation, deposition) are not allocated to the different land use purposes. Related results of this study can be summarized as follows. Animal husbandry is responsible for 60.5 % of the total N and 28.5 % of the total P emissions into surface water in Austria, production of plant based food and of industrial products for 6.2 % and 2.5 % of the total N, and 3.2 % and 2.3 % of the total P respectively. The rest of emission is related to waste water disposal and air pollution from traffic, industry and households.

With regards to water consumption, calculated as water footprint, animal husbandry is responsible for 87 % of the total food production induced water footprint. The results show that green water is not a limitation for crop growth in most of the regions of Austria. In most of the regions there is more rain water (potential green water) available than demanded by different crops. For other regions and countries green water availability and import might be a matter of importance. The most relevant WF in Austria for food production and consumption is the grey WF. For the total food consumed in Austria out of a total from 15.4 m^3 cap^{-1} day, 11.5 m^3 cap^{-1} day (75 %) are allocated to grey WF, while green and blue WF account for only 3.9 (25 %) and 0.04 m^3 cap^{-1} day (< 1 %), respectively.

In contradiction to this findings, Vanham (2013) estimated the Austrian WF of food consumption to be 3.7 m3 cap-1 day-1 (85 % green, 5 % blue, 10 % grey). These values are far below our estimations. Different system boundaries may explain some of the differences. However, the main factor is a basic difference in the calculation. Vanham (2013) calculated the WF of agricultural production and food consumption by aggregating WFs of several agricultural products out of a WF database. For standard grey WF calculations up till now only nitrogen emissions were considered (Hoekstra et al., 2011). Unspecific emission factors (10 % of applied mineral fertilizer) were utilized for the estimation of N fluxes leaching to groundwater. Following the approach they were transformed to WF-values applying generally available water quality targets for groundwater (10 mg N $liter^{-1}$).

Our approach, in contrast, includes phosphorus into the grey WF calculations. We utilized the described agricultural balance and specifically modelled nutrient emissions as well as site specific ambient water quality targets for nitrate and phosphate in surface waters as basis for the WF calculation.

These much more elaborated basis for WF estimations indicates that grey WF is significantly underestimated in standard WF-calculations as it has been performed in Vanham (2013). Improvement in the WF approach is required. It should be based on more parameter (not only nitrogen), utilizing specific emission calculations and water quality targets. Actually the water footprint network has reacted on this shortcoming and published new guidelines for grey water footprint calculations (Franke, et al., 2013).

Concluding the discussion above, our analysis shows that animal husbandry has a severe impact on resource consumption and the aquatic environment in Austria. The reasons for continual support of animal based agriculture are likely to be many and varied but two points may be significant. 1) The Austrian diet is heavily meat based; so the market requests animal based products. According to DGE (Deutsche Gesellschaft für Ernährung, i.e. German Society for Nutrition), cited in Zessner et al. (2011c) a balanced human diet should consist of about 20 % meat and egg protein, 28 % milk and fish protein and 51 % plant protein. In Austria, the diet consists of about 41 % meat and egg protein, 26 % milk and fish protein and 32 % plant protein. Changes towards a balanced diet therefore would not only improve the health status of Austrian population, but also significantly reduce environmental pressures. 2) A part of the agricultural land in Austria is most suitable as grassland. Cattle farming utilize this grassland resource for beef production. The production rate based on actual production standards exceeds domestic demands. This leads to high beef exports. In total 43 % of total produced beef is exported. Future strategies which would try to optimize the food production and supply system would have to take this regional circumstance into consideration. For instance they should consider basing relevant shares of the animal based food consumption on food produced on grassland, which actually is not the case (Statistik Austria, 2007a).

What are the benefits of considering food consumption and production, land use, water consumption, needs for nutrient resources and impacts on different environmental compartments together in one study as we have done it here? Implementing a broader view allows some basic insights into the system as prerequisite for future optimizing steps. Firstly, from our point of view it is important that the reason of production (the demand side) is included into the consideration. The driving force for agricultural production is the demand of goods. Actually this is to a main part the demand of food and to a smaller part raw material for industrial use and energy conversion. Secondly, agricultural production is limited by several factors. Main factors are land suitable for production, water availability and nutrient supply. More restrictions have to be considered in respect to protection of the environment (i.e. emissions into air and water). Optimizing only one aspect has potentially severe impacts on others. For instance, as agricultural production has tremendously impacts on environment there are a lot of studies and concepts dealing with possible measures reducing negative impacts on environmental pollution. But it is neglected that fertile agricultural soil is an essential limiting resource for food production. Others are just focusing on optimization of the efficiency of agricultural production, neglecting that the main key to efficient food supply are the demand patterns. This study delivers a basis for considering several boundary conditions for a sustainable development in food production and supply within one well aligned approach.

This basis gives us the unique opportunity to show in a next step how changes in diet habits would impact resource consumption and environmental pollution in Austria. Upcoming scenario investigations deal with different diets, different trade and agricultural production options for supply of required food as well as with related implications on resource consumption and environmental pollution.

iv Possible implications of dietary changes on environment and resources in Austria

1 Introduction

Agriculture requires vast resource inputs and impacts waters, climate and soils. In 2008, agriculture contributed 8.8 % to the total Austrian CO2 equivalent (62% for CH4, 72 % for N2O) emissions (Anderl et al., 2010). Emissions into the atmosphere are of particular interest for different reasons. Mainly climate active gases (e.g. N2O) receive attention in the ongoing discussions on agriculture and climate change. Yet, there are other impacts of non-climate active nitrous gases from agriculture on the environment (Jefferies and Maron, 1997; Vitousek et al., 1997).

Impacts on water are another challenge for agricultural activities. Especially the eutrophication potential of emitted phosphorus and nitrogen are a matter of concern (Bennett et al., 2001; Smith et al., 1999). Eighty percent of all Austrian nitrogen (N) emissions into waters stem from diffuse sources, with the highest proportion coming from agriculture (Schilling et al., 2011; Zessner et al., 2011b). An important step in implementing the European Water Framework Directive 2000/60/EC was the publication of the National River Basin Management Plan (NGP). Eleven percent of all Austrian water bodies were described as at risk of not reaching a good status for chemical or physical parameters by 2015. The NGP 2009 (BMLFUW, 2009) requests the implementation of measures to achieve the good status in all water bodies. In this context, it becomes particularly relevant to explore how nitrate concentrations in groundwater would change applying different agricultural scenarios. Nutrient emissions (especially N) from the agricultural sector are identified as main pressure on the Danube river basin and expected to rise in future without appropriate management objectives (ICPDR, 2009).

The importance of the link between human diet and health is well known (Friel et al., 2009). Federal and non-governmental organizations often attempt to raise awareness to the benefits of healthy nutrition and to support dietary change; though obesity and other health related diseases continue to increase (WHO, 2003). Another topic gaining increasing attention is the link between diet, resources consumption and environmental pollution. Animal husbandry is often associated with contributing to climate change and depleting resources (Smil, 2002; Steinfeld et al., 2006).

A predicted global shift to a meat based diet will further exacerbate the challenge of feeding a growing population of an expected 9 billion people in 2050 (UN, 2011). It will not be possible to solve this challenge solely by increasing the area of land under agricultural production. At present, more than 1.5 billion hectares of land are used worldwide for crop production (arable land and land under permanent crops) with little scope for further expansion (FAO, 2012). Minimizing food wastage and intensifying agricultural production on existing arable land are options for addressing the challenge of increased demand. However, agricultural intensification leads to further nitrogen losses into the environment (Eickhout et al., 2006). This sharpens the effect of nitrogen pollution in aquatic ecosystems such as acidification and eutrophication (Camargo and Alonso, 2006; Carpenter et al., 1998). Furthermore agricultural intensification requires an increase in other resource inputs. Some of them, like mineral phosphorus (Cooper et al., 2011), appear to be limited in the long run (some hundred years). Thus, a demand driven strategy to raise food security in the future is a dietary shift from a meat to a plant based diet (Godfray et al., 2010).

Meanwhile, a number of authors deal with the relationship of human diet patterns and their impact on the environment. Some of them examine the impact of human diet on farmers and agricultural markets (e. g. Arnoult et al., 2010; Rickard and Gonsalves, 2008), others cover the influence on water consumption. (e. g. Renault and Wallender, 2000). Material flow analyses have been calculated by varying authors for different regions showing the relationship between food production and/or food consumption and the resulting nutrient fluxes (Bleken and Bakken, 1997; Risku-Norja and Mäenpää, 2007; Zessner et al., 2010; Zessner and Lampert, 2002). However, the change in nutrient fluxes caused by a change in human diet patterns have not been investigated so far. Although some literature exists on the relationship between the land demand of different diets (Gerbens-Leenes et al., 2002; Gerbens-Leenes and Nonhebel, 2005; Meier et al., 2014) and their impacts on the environment (Meier and Christen, 2013), all of these studies use conversion factors, transferring different food types into land-use, based on an agricultural production system. The innovative aspect of our study is that required land use of a balanced diet is linked to the agricultural production potential and the nutrient requirements (nitrogen and phosphor) of agriculture in a reference period (2001-2006). By linking this nutrient supply to nutrient emissions into water, the impacts of a balanced diet on the aquatic system can be estimated. To deal with questions arising from changes in demand of agricultural products, production (conventional and organic farming) and agricultural trade, scenarios have been defined. Several scenarios are based on the relationship between diet, agricultural production, nutrient management and environmental impacts of the reference period the current knowledge of the authors, no holistically observed studies investigating the relationships between human nutrition, land and nutrient resources and impacts on the aquatic environment on a country wide scale exist so far. This paper intents to close this gap in providing a sufficient methodology and applying it for Austria as a case study.

2 Materials and methods

The first step of the investigation covered the quantification of the relationship between nutrition, agricultural production, consumption of resources and environmental impacts in Austria in the period 2001 to 2006 (the reference period). In a second step scenarios were defined to describe alternative diets along with aspects of production. This allowed the quantification of changes in resource consumption and environmental pollution for this alternative diet. In the final step, the differences between different scenarios and the reference period were calculated for comparison.

2.1 Investigating the reference period

2.1.1 Functional unit and system boundaries

The area specific system boundary was set to the national territory of Austria. The space specific system boundary, important for the material flow analysis, includes the troposphere and the groundwater. Due to data availability aspects, the average for the years 2001-2006 (the reference period) was used as the temporal dimension. One average Austrian citizen (cap) is used as the functional unit. Absolute values are related to the total population of Austria (mean population for the years 2001-2006: 8,130,515 inhabitants (Statistik Austria, 2009a). As the number of incoming foreign tourists almost balances with outgoing Austrians, tourism was neglected (Statistik Austria, 2010a, 2010b, 2009b). For the Austrian agricultural system four different branches were identified: husbandry, crop farming, fruit-growing and vegetable gardening. There was no further differentiation between these branches. However, it was differentiated between production of animal based (including fodder production) and production of plant based food. It was assumed that manure from husbandry is transported to areas where there is a lack of nutrients.

2.1.2 **Food chain system**

To determine the fluxes between food production and consumption, different data from different sources are required. The production intensity data provides average agricultural production in Austria. Additionally, information on the amount of imported and exported goods (food and agricultural products) is needed to determine the total amount of products used in Austria. Different utilizations of goods (food, feed, industry, seed and energy) have to be distinguished too. Losses occurring during processing and preparation of goods must be considered as well as the amount of food wasted in private households. Finally the average mass of food consumed needs to be determined. Supply balances for agricultural products (Statistik Austria, 2007a), official Austrian agricultural reports (BMLFUW, 2008a) and nutrition reports (Elmadfa et al., 2009a, 2009b, 1998) were the main data sources used for the investigations. The food chain system of the reference situation describes the fate of food from field to fork.

2.1.3 **Agricultural land use**

Land use and the agricultural production intensity for the reference period were derived from the official land use and harvest statistics (BMLFUW, 2008a). The agricultural production intensity is defined according to Shriar, (2000) by yields per unit time and land. Imports and exports of goods (e.g. milk, beef, feedstuff, and tropical fruits) were converted to the agricultural area needed to produce these foods. Main imports, such as soya and rice were linked to the yields of the origin country according to FAO (FAO, 2009c).

2.1.4 **Material flow analysis**

A material flow analysis (MFA) (Baccini and Brunner, 1991) was performed for nitrogen (N) and phosphorus (P). Based on mass flows and corresponding N and P concentrations complex relationships of nutrient flows were clearly expressed in “processes” and “fluxes”. A MFA-system developed by Thaler et al. (2011) was used as a basic tool for further investigation of nutrient resource consumption and nutrient losses into the environment (Figure 1). It comprises the processes “animal husbandry”, “plant production and agricultural soil”, “aquatic system”, “troposphere”, “waste and wastewater treatment” and “industry”. “Plant production” is divided into production of fodder, production of plant based food and production of raw materials for industrial use. The process “industry” contains several branches such as processing agricultural products or supporting agriculture with fertilizer, seed and feedstuff. Emissions into air were calculated using the methods from IPCC (Houghton et al., 1997) and EMEP/CORINAIR (EEA, 2006) with factors for Austria derived from the Austrian National Inventory Reports (Anderl et al., 2010; UBA, 2008). Deposition of N was linked to the sources (Anderl et al., 2010). Detailed descriptions of several processes and data sources are published in Thaler et al. (2011) (supplementary material of Thaler et al. (2014)) and Zessner et al. (2011c). The MFA models are constructed using the software STAN (Cencic and Rechberger, 2008), a development by Vienna University of Technology (free download under http://iwr.tuwien.ac.at/ressourcen).

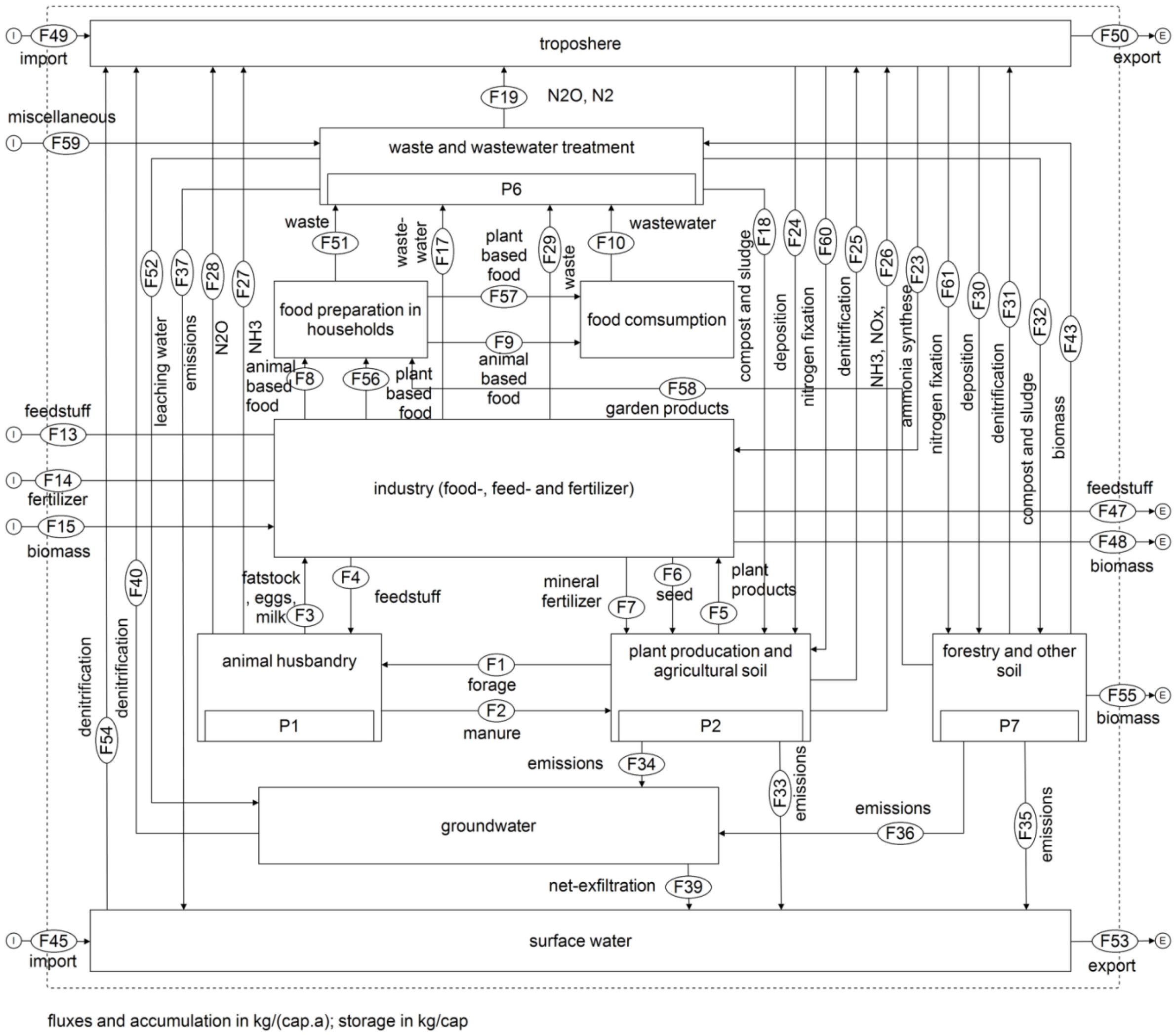

Figure 15: Developed system for the material flow analysis.

2.1.5 Nutrient emission model MONERIS

Within the frame of the MFA the “Modeling Nutrient Emissions in River Systems” (MONERIS) model (Behrendt et al., 1999) was utilized to estimate the emissions into waters (groundwater and surface water). An adapted model for Austrian conditions (Schilling et al., 2011; Zessner et al., 2011b) was used for all calculations. The MONERIS model is an empirical conceptual model. Emission loads via different pathways (groundwater, erosion, surface runoff, urban runoff, point sources and deposition) as well as retention and degradation in the surface waters are used for calculating N and P loads in river systems. The adapted MONERIS model divides

Austria in 367 different catchments (Schilling et al., 2011). It was used to estimate concentrations in groundwater and surface waters and relate them to the input pathways and sources. Validation of the model was achieved by comparing calculated river loads and concentrations to observed ones.

2.2 Scenarios

Basis for the developed scenarios was the reference period from 2001 to 2006 and therefore the scenarios are named “retrospective”. That means that these scenarios assume the same boundary conditions (e.g. population, agricultural yields and climatic conditions) as in the reference period. Changes in the system occur due to a shift in the population’s nutrition and the resulting changes in the amount of specific food produced to provide nutrition for the population.

This scenario design does not claim to make any future predictions, but highlights the impacts of a changing diet on land use and environment without dealing with uncertainties of future developments such as soil sealing, climate change, population growth, breeding progress or agricultural policies. Basic assumption for all scenarios is the realization of a balanced diet in Austria.

The scenario selection is motivated by covering the range of possible effects of changed diet habits on nitrogen and phosphorus flows and land requirements for food production. In this respect three main questions have been considered:

- Would a self-sufficient food supply in Austria be possible by implementing a balanced diet? What would be resulting effects on the environment and resource consumption?
- How would the emissions of nitrogen and phosphorus to surface and groundwater change, if organic farming would be applied on a countrywide scale?

- What would be the effects of a balanced diet in Austria when international trade (specifically export of beef and import of protein feedstuff) would not be altered compared to the reference period?

In addition to these main questions, the influence of potential alternative land-use (e.g. biomass production for energetic use) on the nutrient fluxes is investigated in specific subscenarios. The results will contribute to the ongoing discussion about the competition between bioenergy and food production (Nonhebel, 2005). A detailed analysis of these energy related results can be found in Fazeni and Steinmüller (2011).

2.2.1 **Definition of a balanced diet**

Different definitions of a healthy balanced diet exist. The DGE (German Nutrition Society) nutrition pyramid (DGE, 2005) defines a food-item-based balanced diet. The underlying basics of the nutrition recommendations are the D-A-CH nutritional reference recommendations (DGE et al., 2000) and the ten rules of balanced nutrition (DGE, 2008). The recommendations are well in line (Rademacher, 2008) with the findings of the WHO Report “Diet, nutrition and the prevention of chronic diseases“ (WHO, 2003). The balanced diet compilation suggests mass recommendations for each food group. Zessner et al. (Zessner et al., 2011a) utilized the balanced diet compilations to obtain a comprehensive comparison of the diet in the reference period and a balanced diet applied in the scenarios (Table 11). Health recommendations clearly show that less animal based food and more plant based food should be consumed. Almost 60% less meat and meat products as well as 13% more corn/rice/potatoes and 63% more vegetables should be ingested to achieve a balanced human nutrition in Austria.

Table 11 : Mass, energy and protein input for the reference situation and scenarios. (adapted from Zessner et al. (2011a))

	eaten products				energy intake				protein intake			
	scenario	reference	scenario	reference	scenario	reference	scenario	reference	scenario	reference	scenario	reference
	kg/(cap.a)		% of total consumption		kcal/(cap.a)		% of total intake		kg/(cap.a)		% of total intake	
meat and sausages	23.4	56.8	3.3	9.0	98	236	4.2	10.5	4.0	9.5	16.9	38.1
Eggs	9.5	11.8	1.3	1.9	40	50	1.7	2.2	0.9	1.1	3.7	4.3
milk and milk products	279.9	257.0	38.9	40.7	614	563	26.0	25.0	6.6	6.1	28.1	24.2
corn/rice/potatoes	129.7	114.6	18.0	18.2	895	667	38.0	29.6	9.1	6.5	38.6	26.1
Fruit	91.3	58.6	12.7	9.3	118	75	5.0	3.3	0.6	0.4	2.4	1.4
Vegetable	146.0	89.6	20.3	14.2	86	53	3.6	2.3	2.1	1.3	8.8	5.0
vegetable oil	6.8	9.7	0.9	1.5	145	250	6.2	11.1	0.4	0.2	1.7	0.7
Sugar	18.3	33.0	4.6	5.2	361	361	15.3	16.0	0.0	0.0	0.0	0.0
Total	720	631	100	100	2357	2255	100	100	23.5	25.0	100	100

For all scenarios it was assumed that Austria's population would have changed its dietary habits towards a consumption that is, on average, in line with the recommendations. This means that meat consumption is reduced in total. The relative distribution between different kinds of meat consumed for the scenarios was assumed to remain as described in the reference period, as the used guidelines do not provide recommendations on the relative distribution of different kinds of meat in the diet.

2.2.2 **Further scenario assumptions**

For all scenarios there is no change in the functional unit (Austrian citizen) and the system boundaries compared to the reference period. The performance of food processing and delivery to industry, trade and household remains also unchanged. Thus an alternative diet leads to a different demand in agricultural products, and subsequently to different agricultural production. Modifications of the amount of crop production were evenly distributed over the total agricultural area of Austria. If, for example, the total barley production is reduced by 10 %, the barley growing area is reduced by 10 % all over the country. The land use for each scenario depends on the demand of agricultural products and specific yields of each crop and each animal category. Apart from the organic farming scenario, the yields remain the same compared to the reference period. Losses within the food chain are kept constant compared to the reference period. Thus the food demand of the Austrian population caused by a balanced diet is reflected in a change of agricultural land use for food production. It was assumed that the agricultural land in Austria during the reference period is still available for agricultural activity in the scenarios. A transformation of grassland to arable land is not considered. Based on a changed food chain system the nutrient flows were determined for each scenario using the models described.

2.2.3 **Scenario definition**

Three main scenarios were developed which all presume a balanced diet, but differentiate in fulfilling the food supply requirements as demonstrated either by national agriculture alone or by import/export of agricultural goods (Figure 16).

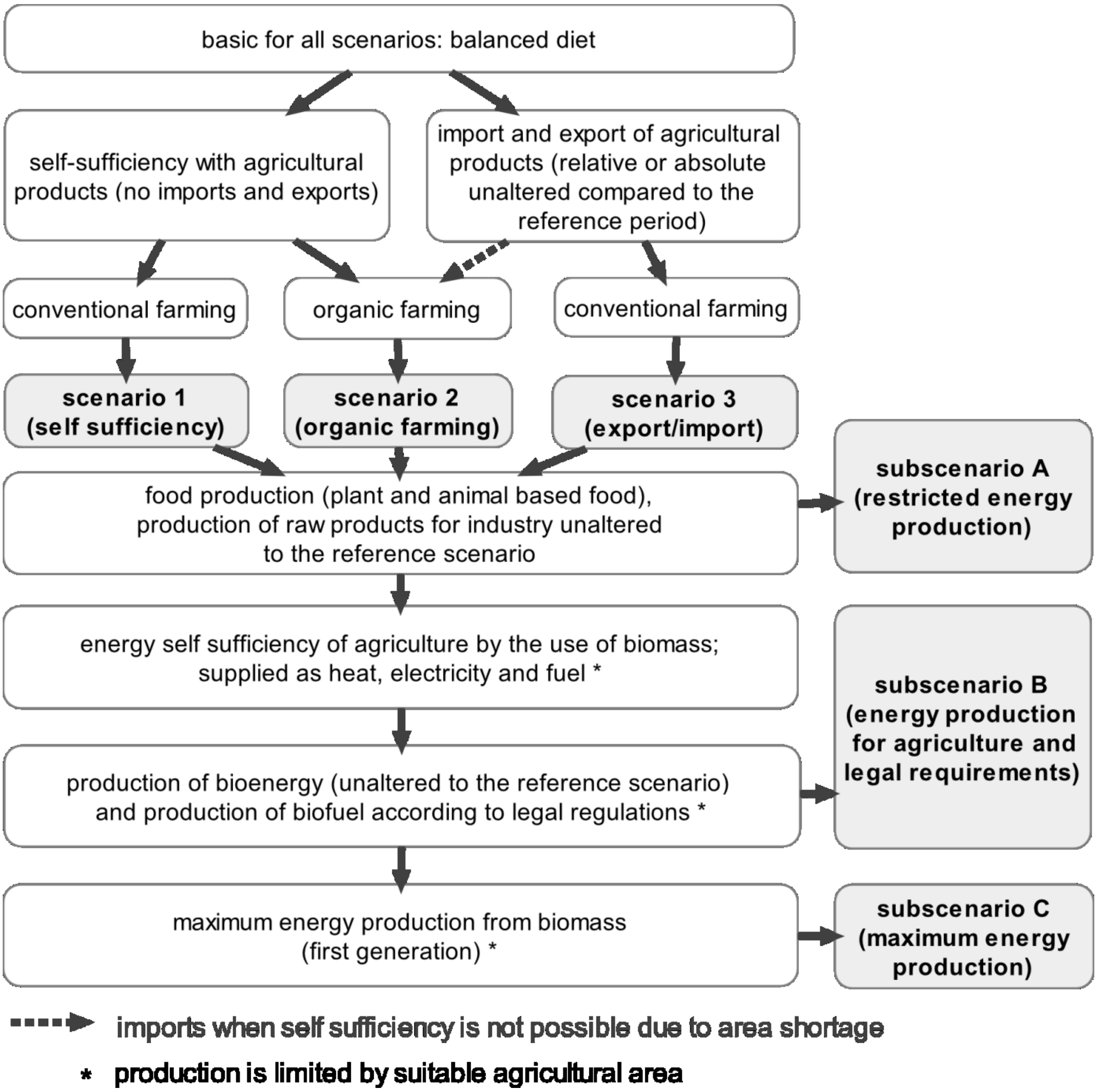

Figure 16: Definition of scenarios, subscenarios and the relationships between them.

2.2.3.1 Scenario 1 (self-sufficiency)

Scenario 1 assumes a self-sufficient food supply of the Austrian population. Resources for agricultural production, such as fuel, mineral fertilizer and plant protection products, are supposed to be imported as necessary. Industrial demands on agricultural products (e.g. for starch or citric acids) remain equal to the reference period and food consumption, according to a balanced diet, defines the necessary agricultural production. Feedstuff, food and industrial raw product imports, as demonstrated for the reference period, are replaced by domestic products and agricultural food production is adapted to the needs for a balanced diet. Where climatic or other production conditions do not allow the required plant cultivation in Austria, the goods, which would have to be imported, are replaced by domestic products having the same nutritional value. Rice was substituted with cereals, exotic fruits with a domestic fruit mix and durum wheat with common wheat. The amount of sea fish recommended for a healthy balanced diet due to their favorable content of n-3 fatty acids is significantly higher than the actual consumption in Austria. Austria has no access to the sea, domestic aquaculture is limited and only marine fish feedstuff has a high content of n-3 fatty acids (Turchini and Francis, 2009). Thus fish was substituted with rape, walnut and flaxseed containing the alpha-Linolenic acid, as they are proposed to be a crucial dietary source of n-3 fatty acids (Barceló-Coblijn and Murphy, 2009).

2.2.3.2 Scenario 2 (organic farming)

The fundamental difference to Scenario 1 is that Scenario 2 assumes organic farming to be applied on a countrywide scale. Self-sufficient food supply was assumed in the same way as in scenario 1. In case of organic farming the ban on easy soluble mineral fertilizer and synthetic pesticides results in yields that are significantly lower than conventional farming for most of the plants cultivated (in average 28% lower yields). Crop yields were estimated based on literature (BMLFUW, 2008a; Diepolder and Raschbacher, 2010; Kratochvil, 2003; Lackner, 2008)). Lower daily weight gains in livestock were accounted by reducing yields of animal products by 10% (Freyer and Dorninger, 2008). If self-sufficient food supply is not possible due the lower yields imports of demanded fodder (protein-rich concentrate) is assumed.

Relative production volumes of different crops were slightly amended. Perennial forage crops were partly replaced by intensive grassland and catch crops. Thus slight shifts in feedstuff composition from the reference period were assumed. As rape is very difficult to grow in an organic farming system, it was replaced with sunflowers.

In organic farming, the nitrogen supply is achieved by cultivation of nitrogen fixing legumes. Production of catch crops (alfalfa as the main crop) was assumed for this purpose. Currently most organic farms do not need to fertilize the soils with P mineral fertilizer, because past excessive P mineral fertilizer application has led to an accumulation of phosphorus (Lindenthal, 2000). As the pool of plant available P in the soil decreases in the long run, organic farms need to fertilize with P to maintain yields. In organic farming only soft ground rock phosphate is allowed as mineral P fertilizer (European Commission, 2008). Dependent on type of soils, cropping system and other factors a different portion of the soft ground rock phosphate is soluble. Hence it is impossible to predict the effectiveness of fertilization (Zapata and Roy, 2004). Thus mineral P fertilization was assumed to remain the same as for conventional farming.

2.2.3.3 Scenario 3 (export/import)

In Scenario 3 the imports and exports of goods (food, feedstuff) are considered. Imports which can be linked to food supply (meat, grain and other plant products) are changed relative to the change in diet. For instance, if fruit consumption increases by 50 %, an increase of tropical fruits by 50 % was assumed. Exports of meat and plant products were assumed to be the same as during the reference period. Export of offal is linked to the domestic meat production and is changed relative to the domestic meat production. Fish was treated differently, because the marine environment suffers from overfishing (Dayton et al., 1995) and aquaculture does not ease the situation (Naylor et al., 2000). Thus the consumption of fish remained the same as in the reference period. Similar to the approach in scenario 1 fish was substituted with vegetable oils containing the alpha-Linolenic acid. Agricultural products used by industry were also unaltered compared to the reference period.

2.2.3.4 Subscenarios

Due to the diet shift less agricultural area is needed for production. In case the available area is not needed to compensate lower agricultural intensity (Scenario 2), it might be used otherwise. Three different subscenarios investigate different options of using these areas either for energy production or for natural succession/landscape preservation.

2.2.3.4.1 Subscenario A (restricted energy production)

In this sub-scenario animal and plant based food is produced. The production of raw products for industry (including biofuel production) remains the same as in the reference period. Natural succession is assumed for agricultural area not needed for these purposes.

2.2.3.4.2 Subscenario B (energy production for agriculture and legal requirements)

The first goal of Subscenario B is to supply agriculture with energy (heat, electricity and fuel). Biofuel is produced from oilseeds, heat and electricity are produced from anaerobic fermentation of biomass from maize and grassland. The second goal of Subscenario B is the production of energy in the same amount as in the reference period, and in addition to meet existing legal requirements. A blending quota of bioethanol and biodiesel to gas and diesel is defined in the directive 2003/30/EC (Cox and Chrisochoidis, 2003). Maize and wheat (50:50) were assumed as the raw material for ethanol production and oil seeds were assumed as the raw material for biodiesel production. Natural succession is assumed for the agricultural area not needed in these scenario assumptions.

2.2.3.4.3 Subscenario C (maximum energy production)

The last subscenario aims at maximizing the energy production on all agricultural land areas not used for food production. Only first generation technologies were assumed for energy production. Grassland being not utilized in the other subscenarios is used for biogas production in Subscenario C. Low yielding permanent grassland (e.g. mountain pastures) is not considered for energy production due the low yields and exposition of land. Available arable land is utilized for oilseed production and further biodiesel is refined.

3 Results

3.1 **Land use**

1580 m² cap^{-1} arable land and 2190 m² cap^{-1} grassland are available in Austria. Approximately 50 % of the grassland is low yielding permanent grassland. Domestic production describes the Austrian agricultural land used for production; domestic consumption describes the total agricultural land necessary for the production of agricultural products consumed in Austria. Several scenarios do not use the entire agricultural area that is available in the reference period.

3.1.1 **Reference period**

While in total 3770 m² cap^{-1} agricultural area is utilized for agricultural production in Austria (Figure 17), only 3600 m² cap^{-1} agricultural land is necessary for domestic consumption (Figure 18). Nonetheless, there is not enough arable land available to reach self-sufficient food supply, by applying the diet from the reference period.

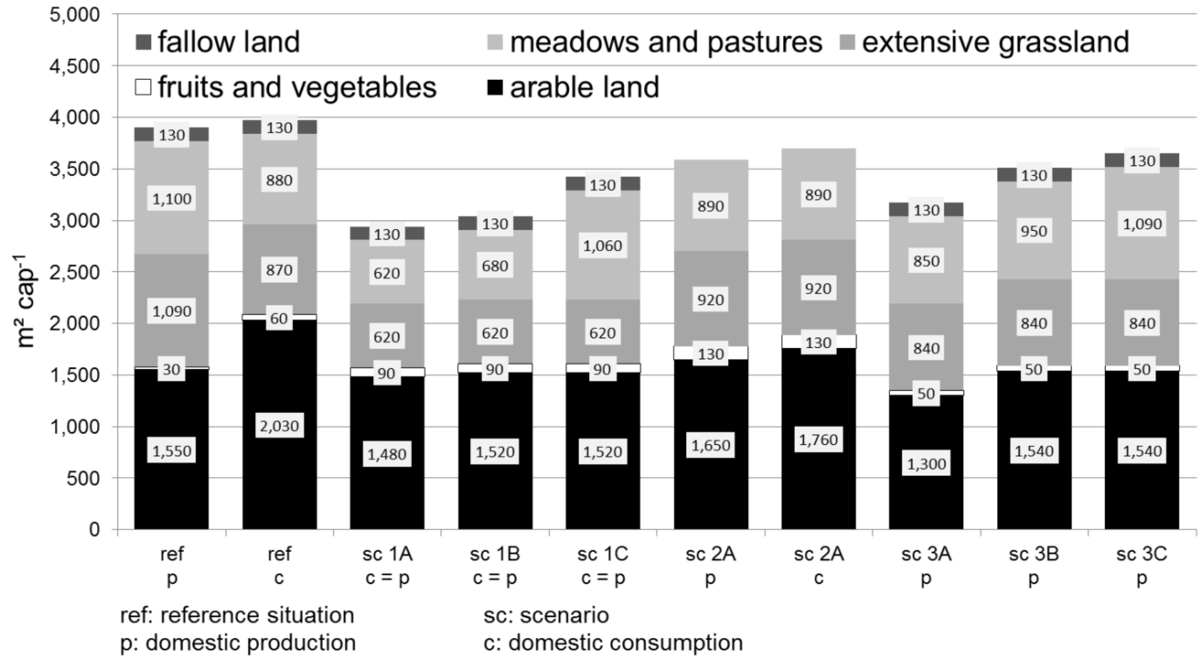

Figure 17: Land use for domestic production (p) and domestic consumption (c) for the reference situation and several scenarios.

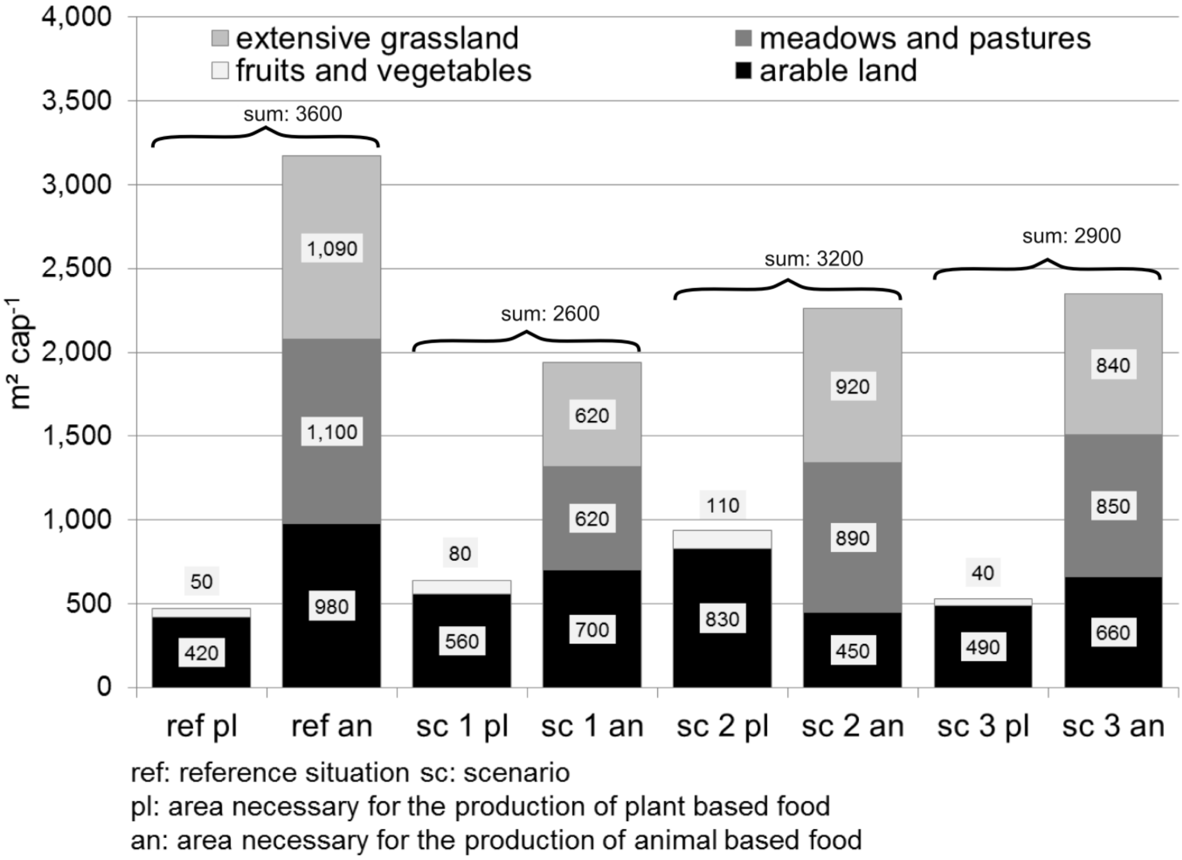

Figure 18: Distinction between land-use of animal and plant based food related to the average diet.

Considering net imports and net exports of several crops leads to a shortage of approximately 420 m² cap^{-1} of arable land (Figure 19). The reason for this is the livestock focused agriculture, that demands fodder produced on arable land. More than 80 % of agricultural land is used for animal husbandry (Figure 18). In contrast to the shortage of arable land, agricultural grassland exceeds the requirements for domestic consumption. In the reference period beef and milk, mainly produced in grassland intensive regions, is not only produced for the domestic consumption, but for export as well.

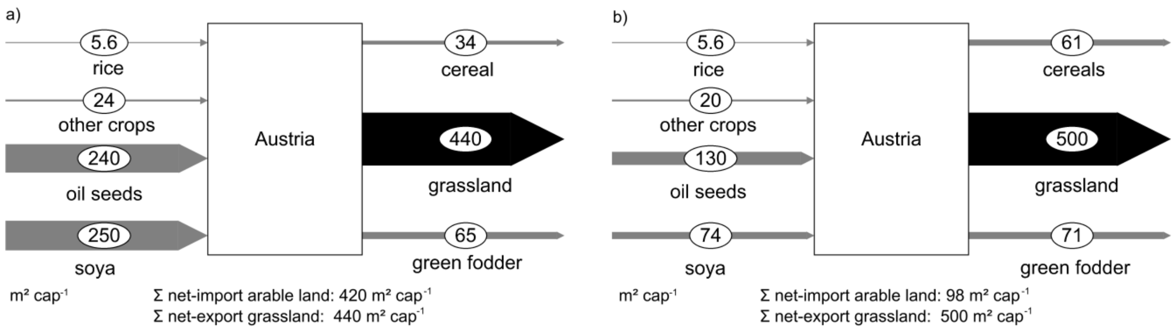

Figure 19: Net-imported and net-exported virtual agricultural land in the a) reference period and b) scenario 3A.

3.1.2 Scenario 1 A (Self sufficiency with restricted energy production)

There would be enough area to supply the Austrian population with food produced in Austria, if a balanced diet was applied. The self-sufficiency Scenario 1A (Figure 17) indicates that 2803 m² cap^{-1} (1240 m² cap^{-1} grassland, 1481 m² cap^{-1} arable land, 82 m² cap^{-1} land for fruits and vegetables) agricultural land is needed to fulfill the demands defined for this scenario. 2600 m² cap^{-1} agricultural land is used for the production of food and 74 % of this area is needed for the production of animal based food (Figure 18).Furthermore 5 m² cap^{-1} arable land and 947 m² cap^{-1} grassland is not needed for agricultural production, but available for alternative use.

3.1.3 **Scenario 2 A (Organic farming with restricted energy production)**

If Austrian agriculture was changed to organic farming, self-sufficiency would not be easily achievable, even if the diet shifted in line with health recommendations. Also the use of actual fallow land (128 m² cap^{-1}) will not stop the import of protein feedstuff, although the imports decrease considerably compared to the reference period. A virtual import of 110 m² cap^{-1} protein feedstuff (soya) is imported in this scenario. In total, 3400 m² cap^{-1} agricultural land is needed in the organic farming scenario (20 % more agricultural land as compared to the Scenario 1 A), 3200 m² cap^{-1} of this amount is used for agricultural food production (Figure 17). The higher area demand of Scenario 2 compared to Scenario 1 is caused by the lower yields of organic farming.

3.1.4 **Scenario 3 A (Export/Import with restricted energy production)**

In scenario 3A, 2900 m² cap^{-1} are used for agricultural food production (3180 m² cap^{-1} are under agricultural production in total) (Figure 17 and Figure 18), i.e. 590 m² cap^{-1} of Austrian agricultural area are available for other purposes (plus 150 m² cap^{-1} fallow land). The grassland in use increases compared to Scenario 1, because the exported beef, milk and milk products are mainly produced in grassland intensive regions. The area of arable land used in Austria decreases due to imports. Respective protein feedstuff and oil seeds are imported. In total, 500 m² cap^{-1} of grassland are virtually exported and 98 m² cap^{-1} arable land are virtually imported (Figure 19). The free area available for bioenergy production covers 230 m² cap^{-1} arable land and 490 m² cap^{-1} grassland

3.1.5 **Possible use of free area in subscenarios B and C**

The sub scenarios differ according to the amount of land used for the cultivation of bioenergy crops. Byproducts of energy production (e.g. protein rich byproduct from ethanol production) are used as fodder. Thus the necessary area needed for fodder production decreases. Figure 20 highlights the land use for bioenergy production for several sub scenarios. Arable land is the most suitable land for bio-energy production, but the availability is limited; thus the potential for the production of biofuels is rather low. Scenario 3 (export/import) has the highest potential for bioenergy production. In Scenario 3B (energy production to meet the needs of agriculture and to meet the legal requirements) and 3C (maximum energy production) 211 m^2 cap^{-1} arable land are used for oil seeds (biofuel production). On arable land, (though dependent on the natural production conditions) different crops can be grown and used for different procedures of energy production. On grassland, energy production is limited to biogas production (considering first generation energy production). Only grassland with the capacity to be intensively farmed is considered for biogas production, because low yielding permanent grassland (e.g. alpine pastures) has a very low biomass production per area. The highest potential of free grassland is offered in Scenario 1C (self-sufficiency with maximum energy production). In Scenario 2 (organic farming), alfalfa is grown to supply the crops with nitrogen. Alfalfa and catch crops can also be used for biogas production and are responsible for the relatively high bio-energy production of Scenario 2 (organic farming) (see Figure 16). In the absence of additional arable land or grassland suitable for intensive farming the output from Scenario 2C (organic farming with maximum energy production) equals that from Scenario 2B (energy production for agriculture and legal requirements).

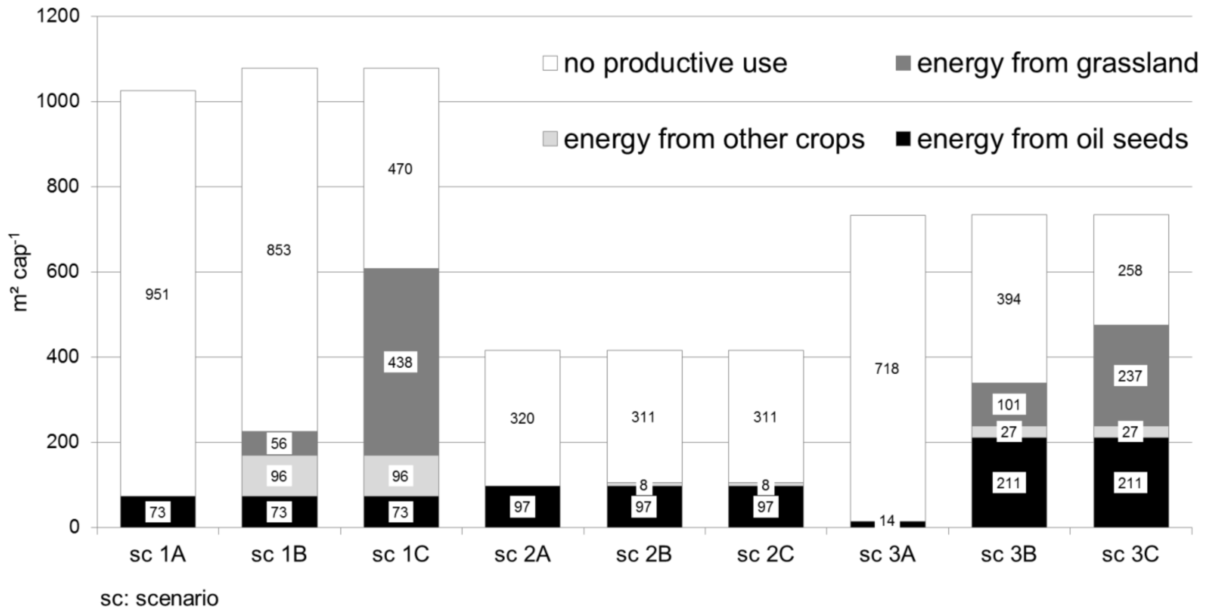

Figure 20: Different possible use of available agricultural area under several scenarios.

3.2 **Nutrient balances**

The work on nutrient resources and emissions is a detailed balance including all important fluxes as described in the method section. For several scenarios the N and P fluxes are shown in Appendix A. An important indicator for potential impact on waters is the nutrient surplus. To calculate the nutrient surplus all nutrient inputs on the land (except NH_3-losses after application) are summed and the output via crop products (fodder, crops) is subtracted. In Table 12 all N and P surpluses on fertilized agricultural land are displayed. The fertilized agricultural land comprises arable land minus fallow land plus intensive grassland plus meadows cut once a year. Clearly Scenario 2A has the lowest surplus for N and P.

Table 12: N and P surplus for several scenarios in relation to fertilized agricultural land for each scenario and per inhabitant

surplus on fertilized land	reference period	1A	1B	1C	2A	3A	3B	3C
N kg ha^{-1} yr^{-1}	58	47	50	51	38	54	54	57
N % (ha^{-1} yr^{-1})	100	81	85	87	65.1	92.2	93	98.7
N kg cap^{-1}	16	11	10	12	11	14	14	12
P kg ha^{-1} yr^{-1}	2.0	1.5	1.5	1.7	1.3	1.8	1.7	1.7
P % (ha^{-1} yr^{-1})	100	75	77	85	67.2	89.5	85	87.4
P kg cap^{-1}	0.6	0.3	0.3	0.4	0.4	0.5	0.5	0.4

Figure 21 shows the N and P fluxes of the agricultural systems for the reference period and Scenario 1A (self sufficiency with restricted energy production) and 1C (self sufficiency with maximum energy production). In both scenarios the fluxes of the process “animal husbandry” are the same. They reflect the lower animal based food intake demanded by a healthy balanced diet, compared to the reference period. Applying the Subscenario 1C leads to higher input fluxes into the process “plant production and agricultural soil” compared to the Scenario 1A. Though, the input summed up into the process “plant production and agricultural soil” are lower than in the reference period, some fluxes in Scenario 1C surpass the reference period level. Biogas production in Scenario 1C leads to biogas residue fertilizers on agricultural land. Higher emissions into the troposphere and into waters result. A slightly higher P accumulation in soils can also be noticed; however the P accumulation is already very low in the reference period (+0.4 kg P cap^{-1}).

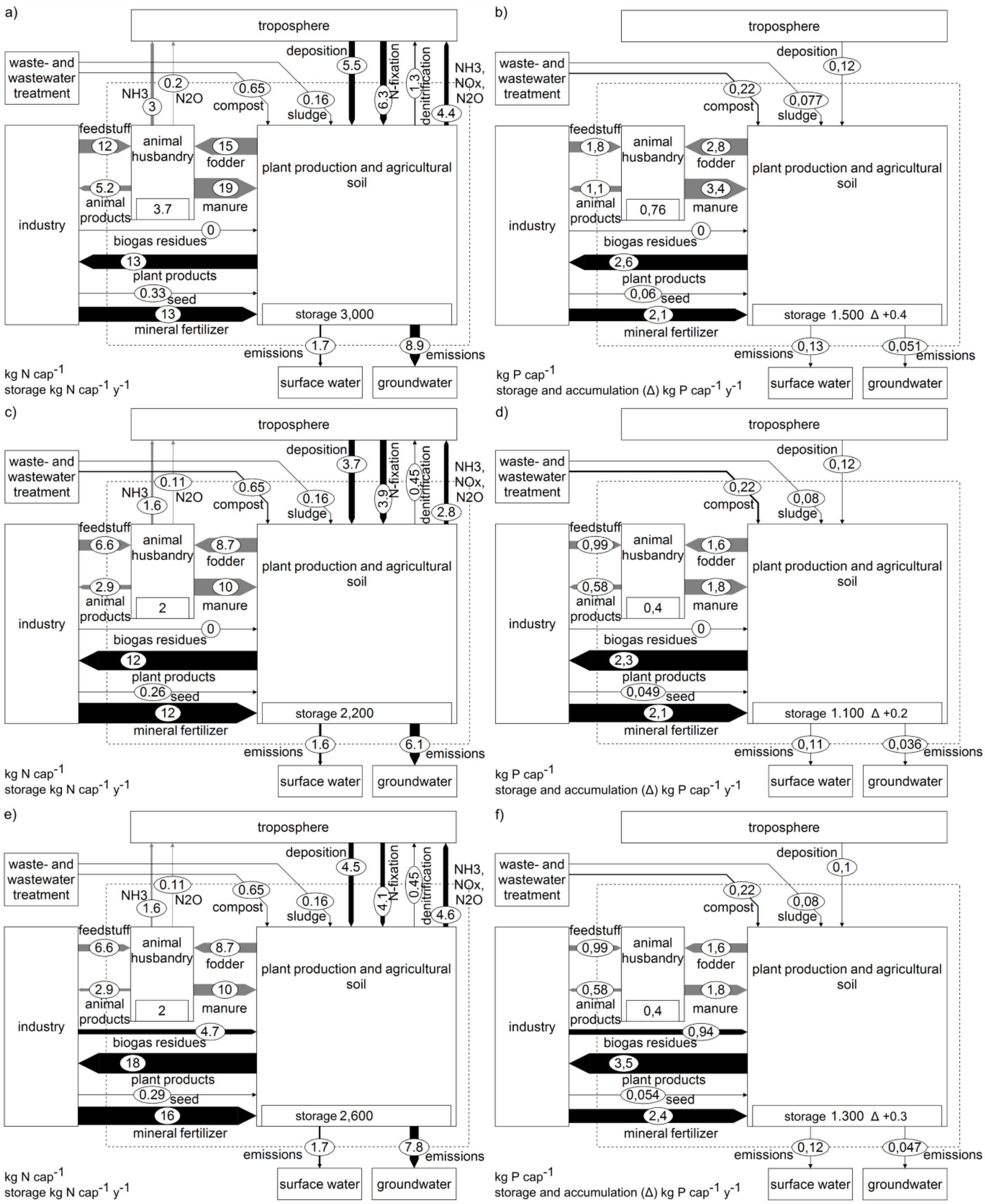

Figure 21: N and P fluxes for the system agriculture containing the two processes "plant production and agricultural soil" and "animal husbandry". The reference period (a,b), scenario 1A (c,d) and 1C (e,f) are displayed.

3.2.1 **Net import of N and P**

In Figure 22 and Figure 23 the required supply of N and P embedded in feedstuff, mineral fertilizer and other biomass inputs into Austrian agriculture are shown. In the reference situation 18 kg N and 2.8 kg P per capita and year are needed for supply. Regulations for organic agriculture prevent the application of mineral N fertilizer, and due to the constraints of the scenario definitions for Scenario 2 (organic farming) only 1.9 kg N per capita and year is imported as protein feedstuff. For Scenario 1 (self-sufficiency) and Scenario 3 (export/import) it is obvious that as more agricultural area is used the requirement of mineral fertilizer increases. For P it is similar, plus P mineral fertilizer is also used for Scenario 2 (organic farming). P cannot be synthesized from plants and must be supplied using external sources. The necessary P mineral fertilizer fluctuates between the different scenarios but for all, except for Scenario 1 A and 3 A (self-sufficiency and export/import with restricted energy production), it is higher than in the reference situation. The reasons for this are the lower imports of feedstuff and other biomass imports.

When feedstuff, mineral fertilizer and other biomass imports are summed up, all scenarios have lower P and N requirements than the reference period. Compared to the reference situation the agriculture in Scenario 1A (self-sufficiency with restricted energy production) has 37 % lower N and 25 % lower P net-imports. The relative difference from Scenario 1A (self-sufficiency with restricted energy production) and Scenario 3A (export/import with restricted energy production) to the reference situation shows clearly how a changing diet influences the N and P net-imports. A changing diet leads to less N (between -37 % and -27 %) and less P (between -25 % and -20 %) net imports (feedstuff, mineral fertilizer, other biomass) to Austria.

While Figure 22 and Figure 23 concentrate on products traded by humans,
Table 13 displays total N and P inputs into agriculture. Additional to feedstuff, mineral fertilizer and other biomass imports, N fixation and deposition of N and P are considered. Including several N and P inputs for Scenario 1A (self-sufficiency with restricted energy production) and 3A (export/import with restricted energy production), the import of N decreases between 26 % and 18 % and for P about between 20 % and 16 % compared to the reference period. In Scenario 2 (organic) no N fertilizer is imported, but when looking at the total N input in agriculture it is on the same level as Scenario 1A (self-sufficiency with restricted energy production) due the higher N fixation of legumes.

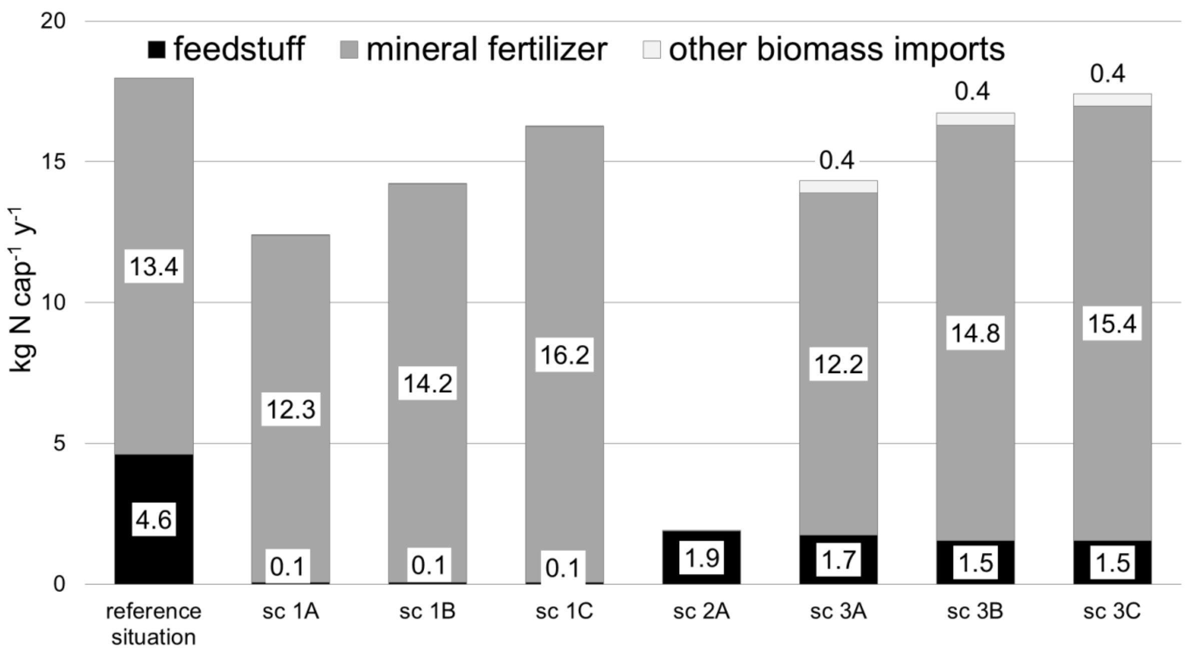

Figure 22: Net import of N embedded in feedstuff, mineral fertilizer and other biomass.

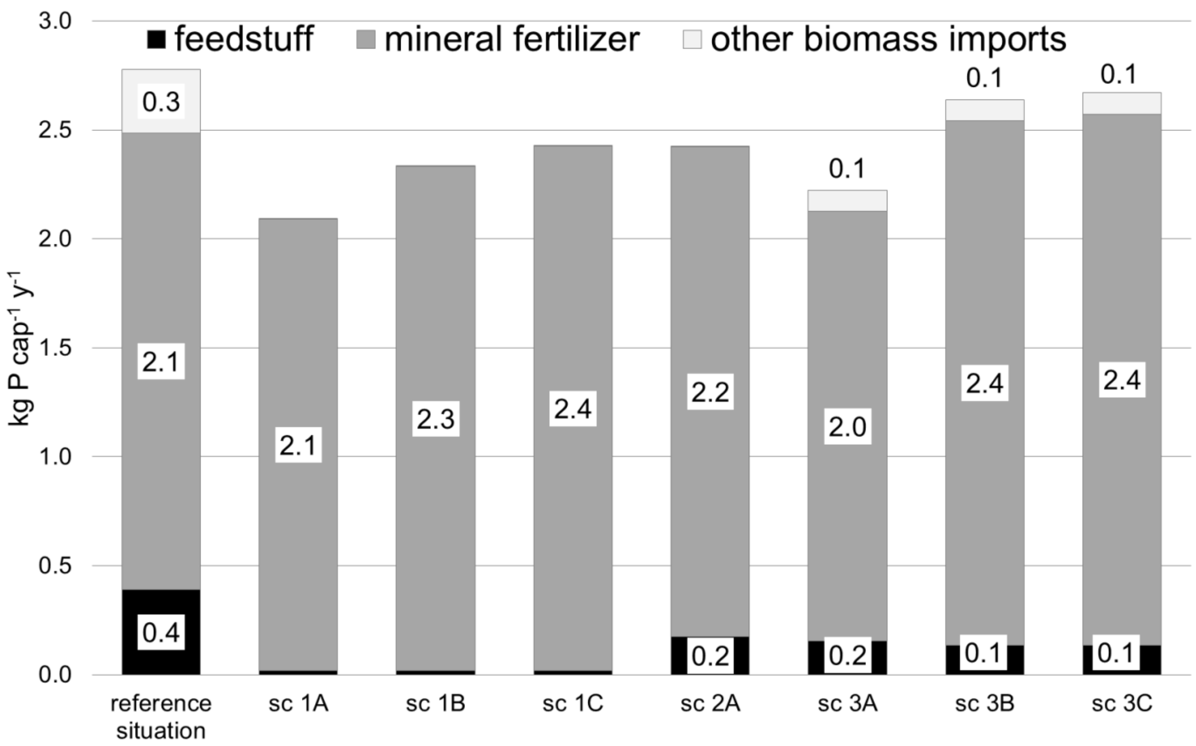

Figure 23: Net import of P embedded in feedstuff, mineral fertilizer and other biomass.

Table 13: Import and exports of N and P for several scenarios and the described system.

	reference situation	sc 1A	sc 1B	sc 1C	sc 2A	sc 3A	sc 3B	sc 3C
import in kg N and P cap^{-1} y^{-1}								
Deposition	14 / 0.3	13 / 0.3	13 / 0.3	13 / 0.3	13 / 0.3	13 / 0.3	13 / 0.3	13 / 0.3
feedstuff net import	5 / 0.4	0 / 0	0 / 0	0 / 0	2 / 0.1	2 / 0.2	2 / 0.1	2 / 0.1
mineral fertilizer	13 / 2.1	12 / 2.1	14 / 2.3	16 / 2.4	0 / 1.7	12 / 2	15 / 2.4	16 / 2.5
other biomass imports	2 / 0.5	0 / 0.3	0 / 0.3	0 / 0.3	0 / 0.3	1 / 0.4	1 / 0.4	1 / 0.4
N fixation	8 / 0	5 / 0	5 / 0	5 / 0	15 / 0	6 / 0	6 / 0	6 / 0
sum import	41 / 3.3	30 / 2.7	32 / 2.9	35 / 3	30 / 2.4	34 / 2.8	37 / 3.2	37 / 3.3
export in kg N and P cap^{-1} y^{-1}								
emissions (NH_3, NO_x,N_2O)	8 / 0	4 / 0	5 / 0	6 / 0	5 / 0	5 / 0	6 / 0	6 / 0
net export through rivers	8 / 0.4	7 / 0.3	7 / 0.4	8 / 0.4	7 / 0.4	7 / 0.3	8 / 0.4	8 / 0.4
denitrification/retention	19 / 0.2	16 / 0.1	17 / 0.2	17 / 0.2	17 / 0.2	17 / 0.1	18 / 0.2	19 / 0.2
sum export	35 / 0.4	28 / 0.3	29 / 0.4	31 / 0.4	29 / 0.4	30 / 0.3	32 / 0.4	33 / 0.4

3.2.2 Emissions into waters and change of NO_3 concentrations in groundwater

In the reference period, 116,000 Mg N per year are net-exported via rivers from Austria. This equals 8.5 kg N per capita per year. Scenario 1A and 2 (self-sufficiency with restricted energy production and organic farming) have the lowest N net-exports via rivers (minus 15 % compared to the reference situation). Scenario 3A (export/import with restricted energy production) has 11 % lower N net-exports via rivers. The lower emissions per area of Scenario 2 (organic farming) are compensated by the larger land area demand for organic farming. Scenario 2 has 21 % less emissions into waters than scenario 1 for each 1 ha of agricultural areas yet the area demand is 20 % higher than in Scenario 1. The net-export of P via rivers does not change in the same magnitude as that for N. For Scenario 3A (export/import with restricted energy production), 6 % less P is exported via rivers compared to the reference period; for Scenario 1A (self-sufficiency with restricted energy production) 5 % less exported P can be expected.

The frequency of exceedance for all 369 catchments for average modeled NO_3 concentrations in groundwater is shown for several scenarios (Figure 24). 25 mg NO_3 l^{-1} (50 % of the limit value) as the average concentration in a catchment indicates a risk of regional exceedance of the limit value in the groundwater (Gabriel et al., 2011). In the scenarios the situation improves. Due to the lower intensity of organic agriculture in Scenario 2 the lowest numbers of catchments exceed the groundwater limit value of 25 mg NO_3 l^{-1}. From the perspective of abatement of erosive P-emissions into surface waters it would be beneficial to install riparian buffer zones (Mander et al., 1997) utilizing free agricultural land. A total of around 27,000 hectares (equals 34 m² cap^{-1}) would be needed (calculated with CORINE land cover data (ETC/LUSI, 2010) and river network data, (Universität fur Bodenkultur, 2007) using a geographic information system) to install a 30 m buffer strip for all streams with arable and permanent land use nearby in Austria. By utilizing agricultural land no longer needed for production in this respect, nutrient emissions into waters could be further lowered.

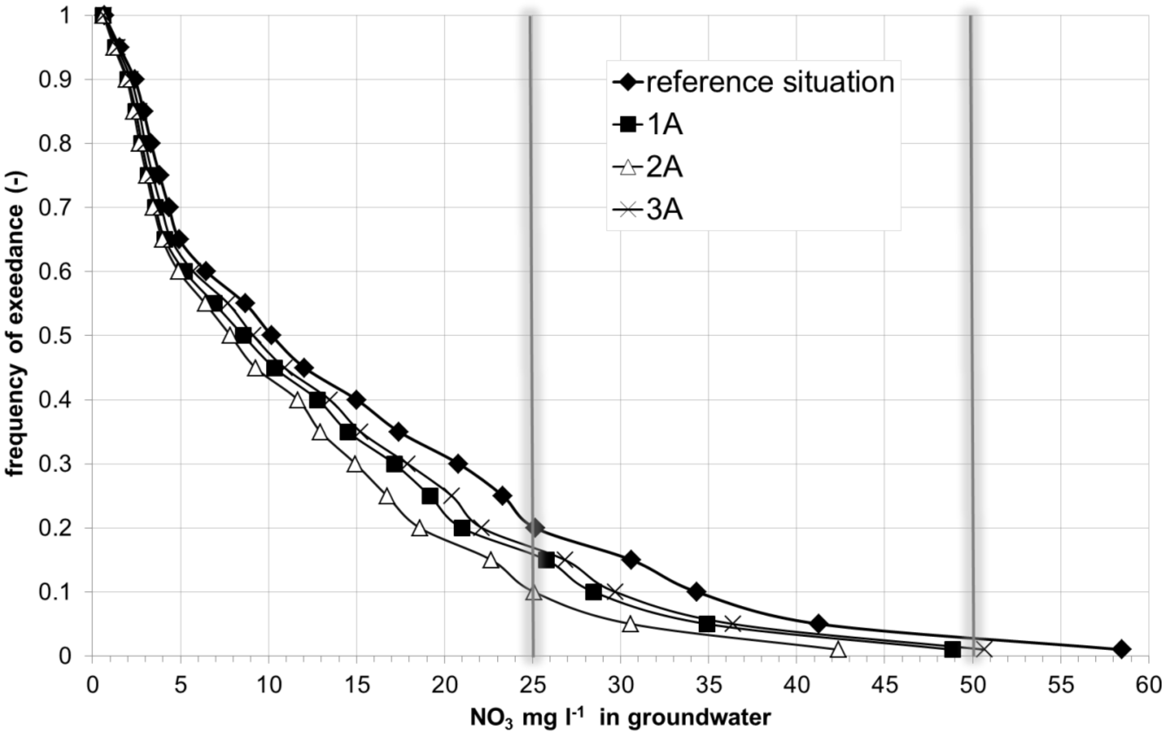

Figure 24: Frequency of exeedance of average modeled NO_3 concentrations in groundwater

3.2.3 Emissions into atmosphere

Nitrogen is transported via the atmosphere and deposited on forest land, agricultural land and open water. N deposited on land raises the N surplus and leads to higher N leaching. The emissions of N gases into the atmosphere can be seen in Figure 25 for several scenarios. Agriculture emits less nitrous gases in several scenarios than in the reference period. In the reference period manure management is responsible for 88 % of the total N emissions into the atmosphere.

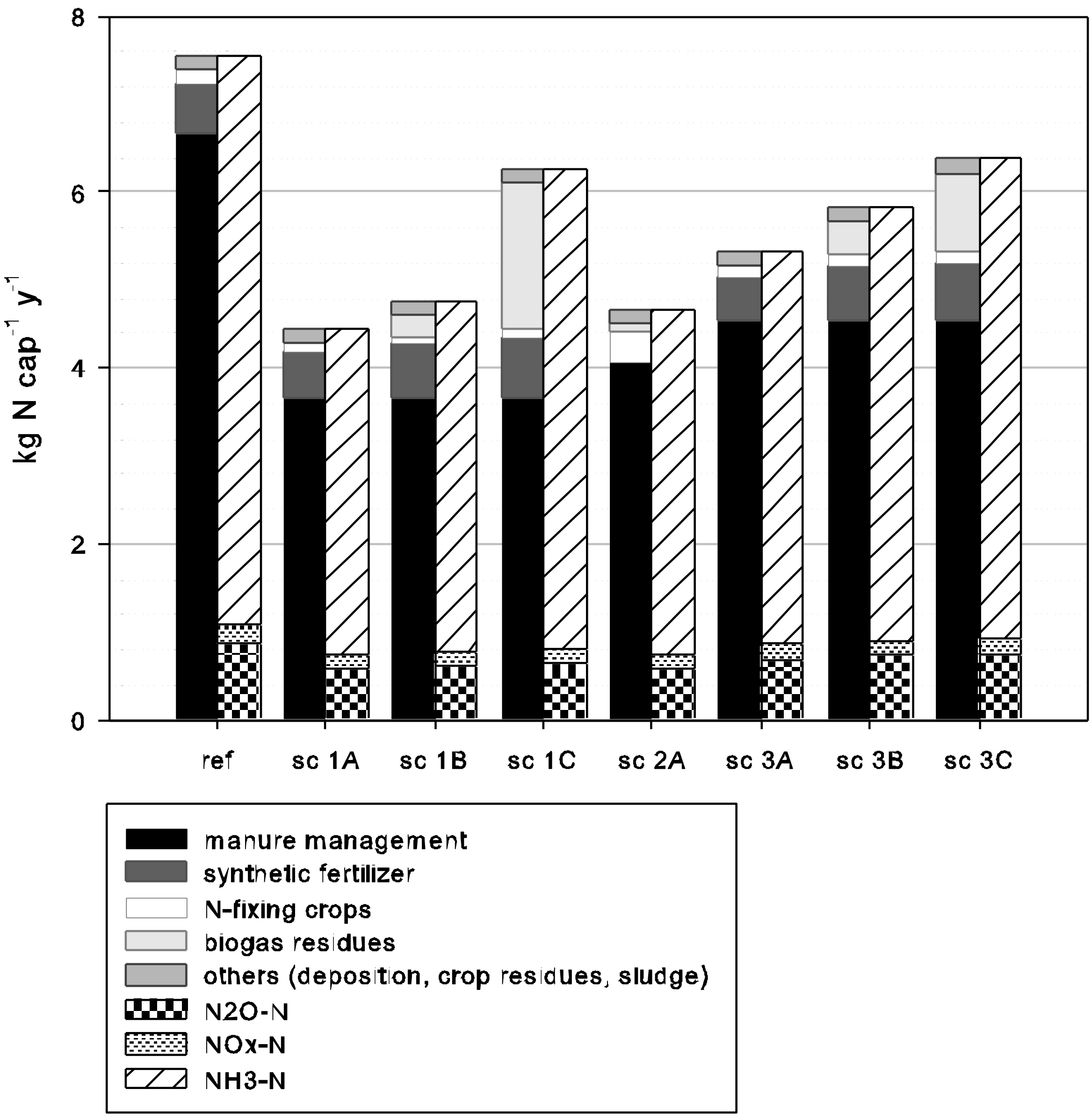

Figure 25: Agricultural emissions into atmosphere distributed between different sources and differentiated between gases are shown. Emission contains NH_3-N, N_2O-N and NO_X-N gases.

Actually the fraction of nitrous gases caused by animal husbandry is even higher when including fodder production on agricultural land. Scenario 1A (self-sufficiency with restricted energy production), the scenario with the lowest agricultural output, has emissions of N that are 41 % below the reference period (Table 14). The fraction of manure management is 82 % lower than in the reference period. It is noticeable that the fraction of manure management decreases substantially when bioenergy is produced, because spreading of biogas slurry leads to emissions of NH_3 and N_2O as well. A reduction in animal husbandry, with a coincidental increase in bioenergy production, will reduce N-emissions into air from agriculture. Figure 12 shows that it is mainly NH_3 that is reduced when applying different scenarios.

Table 14: Emissions into atmosphere in total and as a percentage for several scenarios and the reference situation (ref).

kg N cap^{-1} y^{-1} / % of sum	ref	1A	1B	1C	2A	3A	3B	3C
manure management	6.7 / 88	3.7 / 82	3.7 / 77	3.7 / 59	4.1 / 87	4.5 / 85	4.5 / 78	4.5 / 71
synthetic fertilizer	0.6 / 8	0.5 / 12	0.6 / 13	0.7 / 11	0 / 0	0.5 / 10	0.6 / 11	0.7 / 10
N-fixing crops	0.1 / 2	0.1 / 2	0.1 / 2	0.1 / 2	0.3 / 7	0.1 / 2	0.1 / 2	0.1 / 2
biogas residues	0 / 0	0 / 0	0.2 / 5	1.6 / 26	0.1 / 2	0 / 0	0.4 / 6	0.9 / 14
others (deposition, crop residues, sludge)	0.2 / 2	0.2 / 4	0.2 / 4	0.2 / 3	0.2 / 3	0.2 / 3	0.2 / 3	0.2 / 3
emissions total	7.6 / 100	4.4 / 100	4.8 / 100	6.3 / 100	4.7 / 100	5.3 / 100	5.8 / 100	6.4 / 100
comparison between scenarios in %								
reduction compared to ref	0	-41	-37	-17	-38	-29	-23	-16

3.3 Main findings

Applying a balanced diet in Austria involves the following main impacts:

- Land use:
  - The demand for agricultural land is reduced by 30 % compared to the reference period.
  - Arable land, as the more limited land resource compared to grassland, is significantly reduced.
  - Self-sufficiency with food (agricultural land) is only likely when a balanced diet is applied.
- Nutrient inputs:
  - The quantity of P needed for agricultural production is reduced by 20 % to 25 %.
  - With regards to the inevitable limitation in P resources, a balanced diet

can contribute to more efficient use of P.

- Lower N inputs (between -37 % and -27 %) to agricultural production implies that less energy demand and less reactive N is released into the environment.

- Nutrient exports and N concentrations in groundwater:
  - Nutrient loads exported via rivers from Austria decrease by between 15 % and 11 % for N and by 5 % to 6 % for P. Additional measures (e.g. buffer stripes) on land no longer required for food production would further reduce P-emissions into waters.
  - Between 30 % and 40 % lower emission of N into the atmosphere compared to agricultural emissions in the reference period, especially from animal husbandry.
  - Because N concentrations in groundwater are strongly related to land use, the concentrations change according to the land use intensity. The organic farming scenario (2A) with the lowest N surplus on agricultural land leads to the lowest N concentrations in groundwater.

4 Discussion

Applying a balanced diet in Austria has several effects on, resources and the environment. The assessment of nutrition, agricultural production and resulting effects on resource consumption and environmental pollution in the reference period (2001 - 2006) highlights that Austria is currently heavily dependent on imports of feed and food from other countries. By adopting a balanced diet in Austria a decrease in agricultural land demand could be realized, compared to the reference period. Our work shows that a shift towards a balanced diet leads to 2600 $m^2\ cap^{-1}$ agricultural land (52 % of which is for arable land and permanent crops) to be required for food supply in contrast to 3600 $m^2\ cap^{-1}$ in the reference period. Gerbens-Leenes et al.

(2002) estimated the average land demand of an average diet in the Netherlands to be 1448 m² cap^{-1}. They assessed the land demand of an Austrian diet to be 4% higher (Gerbens-Leenes and Nonhebel, 2005). The difference between previous work and the results shown in this paper can be explained by considering the different agricultural systems in the two countries, plus the various methodological differences (e.g. the inclusion or exclusion of waste). Whereas the average wheat yield is 8.9 Mg ha^{-1} in the Netherlands (Gerbens-Leenes et al., 2002), it amounts to 5.2 Mg ha^{-1} in Austria (BMLFUW, 2008a). This means that 170 % of the land utilized in the Netherlands is needed in Austria to reach the same total wheat yield. However, this difference is not as high for all agricultural crops and livestock systems. But there are other production limitations in Austria. In contrast to the Netherlands, roughly 60% of Austria is located in the Alps. Thus a high proportion of the agricultural land is pastoral land with low production capabilities. We assert that a holistic view on the food chain system of a country is essential to estimate land demand and environmental impacts of diet for a specific region or country.

In this work, retrospective scenarios were used to assess the impacts of a change to a balanced diet. Hence, no future optimizations of the agricultural production process were assumed. Austrian agriculture is neither land nor nutrient resource optimized from an environmental point of view. Whereas the focus in this paper was on the diet change issue, optimized production could lead to a further reduction of impacts on the environment (Schröder et al., 2011). Keeping ruminant animals on grassland without or with less concentrates from arable land would result in lower arable land demand. As described, there are different possible options for the use of agricultural land that is not needed for food production in case of dietary changes. Depending on the use of this available area, the positive environmental effects of a change in diet could be increased. From the perspective of abatement of erosive P-emissions into surface waters it would be beneficial to install riparian buffer zones (Mander et al., 1997) utilizing free agricultural land. A total of around 27,000 hectares (equals 34 m^2 cap^{-1}) would be needed (calculated with CORINE land cover data (ETC/LUSI, 2010) and river network data, (Universität fur Bodenkultur, 2007) using a geographic information system) to install a 30 m buffer strip for all streams with arable and permanent land use nearby in Austria. By utilizing agricultural land no longer needed for production in this respect, nutrient emissions into waters could be further lowered. Another option is the reduction of the agricultural intensity (fertilizer application) in groundwater sensible areas. However, the arable land demand of food production would increase. In this context further research is necessary to investigate the optimization potential for keeping cattle only on grassland Reducing concentrates (e.g. grain) in cattle feeding regimes would reduce the arable land demand for fodder production. Above all, the balanced diet adjusted to meet the natural resources available in Austria (higher portion of beef instead of pork and broilers), is the general framework of an agricultural optimization.

In literature, the competition for agricultural land, especially arable land, is seen as an ongoing challenge for food security globally (Harvey and Pilgrim, 2011; Tilman et al., 2009). Thus it has to be considered that not the whole agricultural land is and will be available for food production purposes. To deal with this aspect all scenarios meet the demand for agricultural products in industry and renewable energy according to the reference period production level. However, the outcome does not consider the future competition for land. An equitable allocation of agricultural land to different purposes is not in the focus of this article, but another important question.

There is an ongoing debate, if organic farming could feed the world or not (Badgley et al., 2007; Badgley and Perfecto, 2007; Connor, 2008). Whereas this is not the topic of this contribution, it clearly highlights, how difficult and vulnerable the modeling of an organic farming scenario is. Consequently, this scenario involves higher uncertainties compared to conventional farming scenarios (1 and 3). Generally the different design of Scenario 2 compared to the other scenarios has to be considered, when interpreting the results. Whereas the conventional farming scenarios (1 and 3) are based on a broad data basis of the actual agricultural system (reference period), Scenario 2 is designed using data from literature and applying them to available production resources and conditions. So far, no countrywide organic farming system exists. Thus every study dealing with organic farming systems on a national level has to cope with this limitation.

A limitation of this study is the lack of socio-economic analysis. The existing agricultural system as presented in the reference period is more or less optimized for economic aspects. The scenarios are constructed using the available land resources to fulfill the food requirement of a balanced diet and socio-economic aspects are not considered. However, it is not the purpose of this study to implement a change in diet, but to highlight the possible impacts on land demand and nutrient fluxes in Austria. In a globalized world it is not likely and reasonable to introduce a self-sufficient food supply or to install a countrywide organic farming system. However, based on our methodology and results further socio-economic investigations can be made.

5 Conclusion

There is a basic demand for a change in diet which is argued because of health care considerations. Benefits for the environment could be the result. Resource efficiency of food production would significantly increase. The local environment would benefit, if land (not required for food production) is used for a reduction in the intensity of agricultural production. If free resources (area, nutrients) are used for additional bioenergy production, the environmental gain would be less significant.

In respect to nitrogen organic farming has benefits for the local water bodies due to the lower intensity (lower nutrient surpluses), but not for the supra regional one (Black Sea in case of Austria). Lower yields lead to higher area demands and therefore the summed up emissions into waters would stay almost the same compared to conventional farming. Area wide organic farming in Austria without a diet change is not possible without huge imports of food from other countries. We conclude that only a diet change gives us the freedom to choose a significant increase of organic farming production system or other strategies for agricultural intensity reduction. The paper clearly shows that it is important to choose a suitable reference indicator. For food related investigations one inhabitant (one average diet) should be the reference indicator, as the basic task is to nourish the population. In conclusion, we may postulate that a beneficial diet change seems to be a very simple measure, but extremely difficult to implement; though it seems there are no satisfying alternatives to a less resource demanding diet in the future on a global scale. Reducing resource consumption, impacts on climate and waters demands measures not only on the supply but on the demand side. From our point of view local diet recommendations may help in transferring the food system in a more environmental friendly system without losing production capacity. These recommendations should implement the local resource availability, the environmental needs, socioeconomic aspects as well as health requirements. The possible result of such diets could be that in regions with plenty of grassland, meats from ruminants have a higher portion than in other regions with mainly arable land. This could be one step in reducing the complexity of the whole food supply system by implementing local relationships.

However great demand for research in tight cooperation with nutritional, agricultural, environmental and socioeconomic scientists exists.

v How human diet impacts on waters and resources

1 Introduction

Agriculture and water are tightly linked together. Enough water at the right time is necessary to achieve high yields. The predicted growth of the world population will have significant impacts on food production and agricultural water demand for evapotranspiration (Steduto, 2011). Water quality is also affected by nutrients released from fertilizer application. Eutrophication of rivers and coastal areas is to a large extent caused by the intensity of agricultural activity in the catchments. Human diet is a driving force for water and land requirements for food production but also on fertilizer losses to the waters. This paper is based on results of a trans-disciplinary research project (Zessner et al., 2011c) on the relationship between human diet, food production, resource consumption, water quality impacts and human health effects.

This contribution concentrates on the relationship between

- food consumption (diet) and agricultural production,
- the resulting mass flows of nitrogen (N) and phosphorus (P) and
- their impact on the aquatic environment,
- agricultural area requirements
- nitrogen emissions to the atmosphere

in a clearly defined region. This method was applied to Austria as a case study where the actual situation (scenario 0) is compared to a scenario 1 characterized by an average diet of the Austrian population. The actual diet with its elevated level of meat consumption as common in most of the developed countries is not in agreement with a balanced healthy diet according to the recommendations of nutrition experts (DGE, 2008).

2 Methods

The basis of all investigations is a complete analysis of the relevant material flows for agricultural products, fertilizers and the import and exports of all relevant goods and all relevant processes for the characterization of scenario 0. Scenario 0 defines the reference period. Changing the average diet has influence on the agricultural production and several other processes described in scenario 0. One essential prerequisite for the calculation of scenario 1 was that the main quantitative relationships are the same as in the reference period. Exceptions had to be specified and justified. Thus the efficiency of agricultural production of a specific crop, the efficiency of food processing and the losses within the food chain are kept on the scenario 0 level. Data for the whole food supply chain of scenario 0 are taken from various statistical databases (Thaler et al., 2011; Zessner et al., 2011c). The resulting food supply chains are the basis for the N and P balances and area requirement calculations. As functional unit we chose one average Austrian inhabitant. Absolute values were converted using the total Austrian population (mean population of the years 2001-2006: 8,130,515 inhabitants).

Starting point for scenario 1 are the requirements for nutrition, derived from health care considerations. The German Nutrition Society publishes product-based diet recommendations (DGE, 2008) described in Zessner et al. (Zessner et al., 2011a). The recommendations are well in line with the findings of the WHO Report “Diet, nutrition and the prevention of chronic diseases“ (WHO, 2003). The basic assumption for scenario 1 was that the Austrian population fulfills these recommendations on average, which significantly deviates from the nutrition habits under reference conditions. Based on the relation between produced and consumed food, the necessary agricultural area and the utilities needed for agricultural production in the reference situation can be calculated. If export and import situations are defined and the amounts of food needed for the supply with a recommended nutrition is known, the agricultural area and utilities required in the scenarios can be calculated.

The material flow analysis (MFA) (Baccini and Brunner, 1991) was the method used for calculation of the N and P balances. The main principle of the MFA is the conservation of mass. Complex relationships of material flows can be expressed with clearly defined “processes” and “fluxes” between them. One of the first steps of a MFA is the definition of the system boundaries. For the application of the method to Austria the horizontal system boundary is the national territory of Austria; the vertical system boundaries include the groundwater and the troposphere. As temporal dimension an average over the years 2001-2006 for the reference situation was taken. For the calculation of N and P fluxes it is practical to first calculate mass flows and then calculate the final fluxes with corresponding N and P concentration factors.

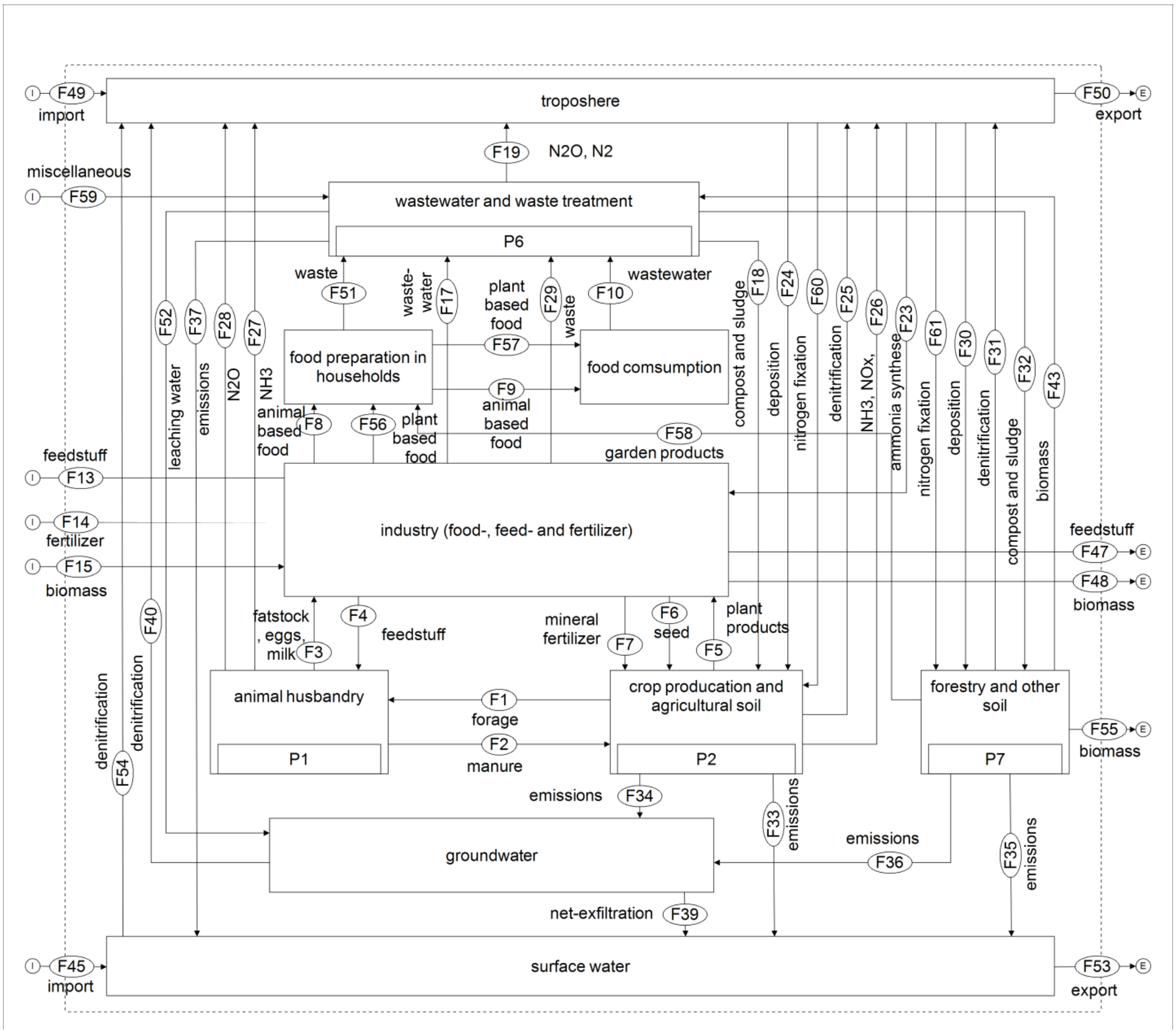

Figure 26: Developed system for the material flow analysis.

The developed system, shown in Figure 26, is the basic tool for further investigations regarding resource consumption, import and export of resources and emissions (losses) of nutrients into waters and the troposphere. It comprises the important processes “animal husbandry”, “crop production and agricultural soil”, “groundwater”, “surface water”, “troposphere” and “food consumption”. Processes like “industry”, “food preparation in households” and “forestry and other soil” are necessary to map the whole system.

Emissions into waters were calculated using the MONERIS (Modeling Nutrient Emissions in River Systems) model (Behrendt and Opitz, 1999). MONERIS is an empirical conceptual model for the quantitative description of the different pathways (groundwater, erosion, surface runoff, urban runoff, point sources and deposition) of N and P. Point sources as well as diffuse sources are included. C. Schilling et al. (2011) adapted the MONERIS model for Austrian conditions. This adapted model was used for the N and P balance and for the calculation of concentrations in groundwater. Due to data availability the scenario 0 calculations are based on 5 year average of the data for the period 2001-2006. The scenario 1 describes the consequence of a diet change of the whole population for the same period of time without changing any other condition in order to clearly demonstrate the effect of nutritional habits only. It was assumed for the comparison that agriculture has adapted to the average diet of the population for scenario 1.

3 Results for Austria

The Austrian agriculture was treated as one farming unit with cultivation of crops and animals adapted to the regional peculiarities and sustainable operation regarding humus balance and recycling of organic substance (manure). For scenario 1 it was assumed that the agricultural area remains unchanged (also the division between grass and arable land) and only the mode of cultivation was adapted to the consequences of the changes of the diet.

4 Agricultural area and mode of cultivation

The agricultural area necessary for the production of the actual in Austria consumed food is on average 3620 m² per inhabitant (cap). 640 m²/cap are used for the production of plant based food and 2980 m²/cap for animal based food. The production of an equivalent nutrition value (J) of animal based food needs ~7.5 times more area than plant based food. There are various imports and exports within the actual Austrian food and fodder supply system. Imports and exports of agricultural products can be converted into equivalent land areas for Austrian conditions. Actually Austria is “importing” 421 m²/cap of arable land for plant products and “exporting” 460 m²/cap of grassland for beef and milk (Figure 27).

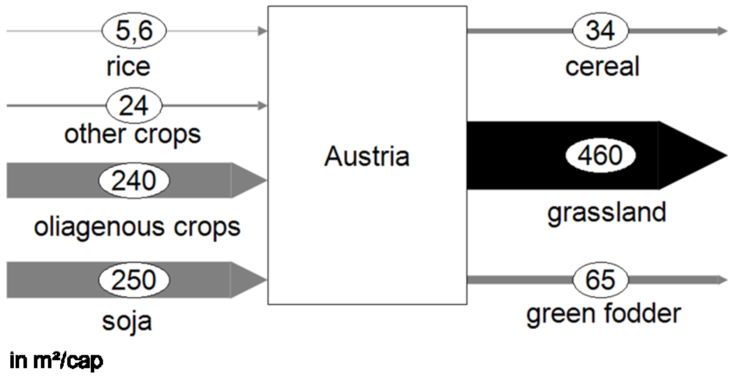

Figure 27: Imported and exported agricultural areas hided in agricultural products in scenario 0

Recommended healthy diet (scenario 1) would result in a ~60 % reduction of meat and meat product consumption as compared to actual state (scenario 0). For scenario 1 the required agricultural area for food production could be reduced to 2600 m²/cap or a reduction by 30 % (Figure 28). Animal fodder production area would decrease while area for cereal-, vegetable- and fruit-production would increase. As a consequence ~20 % of the agricultural area could be used for other production, assumed imported food and fodder are adapted to the recommended diet and the amount of exported food stays unaltered (diet change only in Austria). Due to the increased demand of cereals and the decrease of grassland requirements, the required arable land area would remain on a higher level than the grassland. Though self-sufficiency (agricultural land) in Austria would be possible applying a balanced diet, as recommended by the DGE (2008).

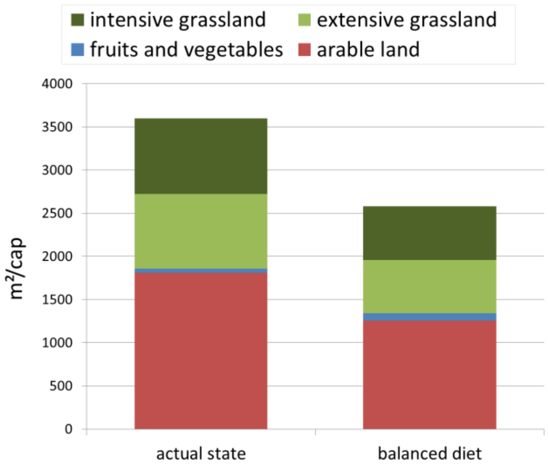

Figure 28: area demand for an actual (scenario 0) and a balanced diet (scenario 1).

5 Nutrient emissions

A detailed mass flow balance for nitrogen (N) and phosphor (P) was performed to gain insight into resource consumption and emissions (losses) to waters and the atmosphere. For scenario 0 8.5 kg N/cap/a is exported via rivers leaving Austria. In scenario 1 the export of nitrogen compounds would decrease by 11 % (Figure 29). For (mainly particulate) phosphorus the reduction would only be 6 % (Figure 30). Both effects are positive for eutrophication abatement in the Black Sea. Reduction of nitrogen compound discharge can be classified as relevant, for phosphorus the effect is less pronounced. Complementary management options, as erosion protection, can be more efficient.

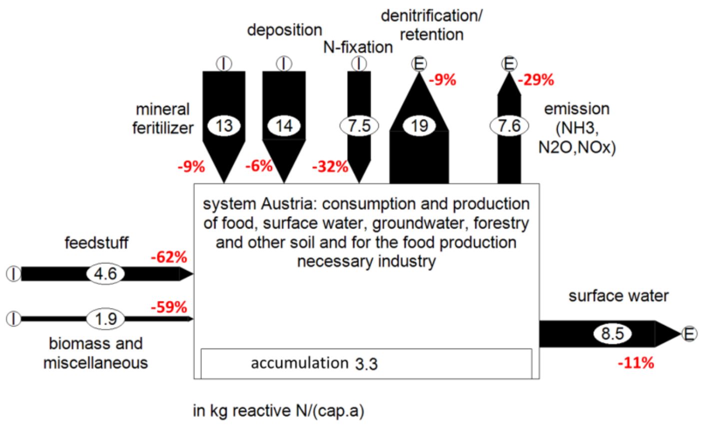

Figure 29: imports and exports of nitrogen in Austria for scenario 0 and the changes in scenario 1 expressed in percent.

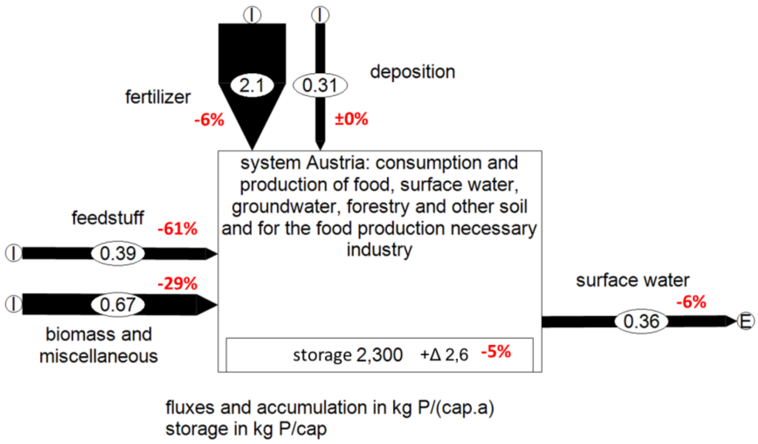

Figure 30: imports and exports of phosphorus in Austria for scenario 0 and the changes in scenario 1 expressed in percent.

6 Nitrate emissions to groundwater

Especially for drinking water supply high nitrate (NO_3) concentrations in groundwater represent a thread in several regions and there is a clear relationship between agricultural production and nitrogen losses to the groundwater, which also strongly depend on the regional climatic conditions. Figure 31 illustrates the difference in exceeding a certain nitrate concentration in 367 groundwater catchment areas. From experience it can be derived that the target value of 50 mg NO_3/L can only be reliably met if the mean concentration does not exceed 20 mg NO_3/L (Gabriel et al., 2011). A balanced diet would reduce the amount of catchments exceeding the quality standard. But the advancement is not great. In catchments where water quality standards cannot be fulfilled there is mainly intensive agriculture on arable land. As the diet change will have little influence on arable land under cultivation the effect is relatively low. Diet change alone cannot solve the groundwater nitrate problem.

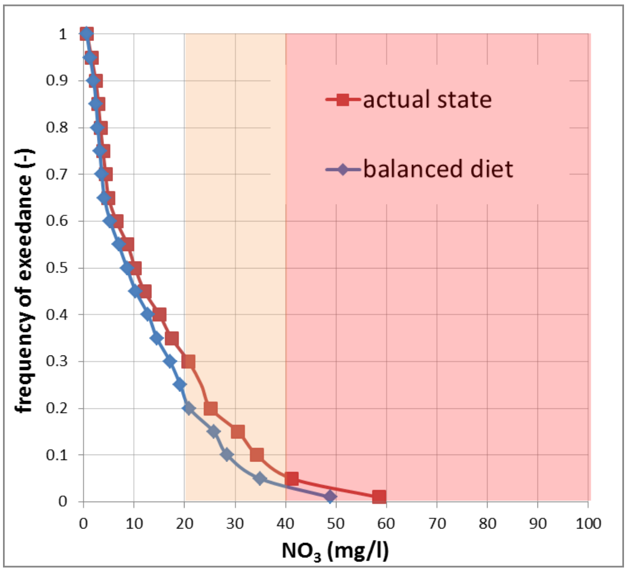

Figure 31: nitrate concentrations in catchment areas and the change in scenario 1.

7 Ammonia emissions to the atmosphere

Ammonia emissions from agriculture to the atmosphere have a strong influence on the continental transport of diffused nitrogen fertiliser loads by wind and precipitation. Especially in Alpine regions enhanced precipitation runoff transfers these loads to the rivers and hence to the seas. Ammonia emissions from agriculture decrease by 30 % in scenario 1 compared to scenario 0. This results in lower nitrogen surpluses and lower nitrogen leachate to waters.

8 Conclusions

Actual diet especially in developed countries is not balanced regarding the recommended healthy nutrition as it contains too much animal products causing negative health effects. The developed methodology allows assessing in detail the consequences of changing the nutrition habits of a population in a defined region to a balanced diet for an adapted agriculture, its mode of crop production, the land area requirements and the nutrient flows. The consequences for agricultural water consumption could also be included but this was not assessed in the study. For the comparison of the two diet scenarios all other regional or local situations were assumed to remain unchanged.

Application of the method to Austria shows a 30 % reduction of agricultural land requirements for food production by changing nutritional habits to a healthy balanced diet. Nitrogen export via rivers would be decreased by 11 %. If all neighboring countries would follow the same change the effect would increase to 16 % due to reduced air transport of ammonia from manure management. Mainly particulate Phosphorus export through rivers would decrease by only 6 %. The diet change would also result in a reduced fertilizer input by 6 % to agriculture which is relevant especially for the limited resource phosphorus. The combination of material flow analysis, nutrient emission model and statistical input data determines the reference state. By changing some input data (changing diet) several independent processes changes. Thus the impacts of changing nutrition patterns can be investigated for a well-defined region.

vi Overall conclusions

1 Main findings

The main findings are structured according to the chapters of the thesis:

Considerations on methodological challenges for water footprint calculations (Thaler et al., 2012a)

- The calculation approach for the green and blue water footprint of sugar beets, where soil moisture deficit at harvest time is not considered, leads to an overestimation of blue water. The widely used approach for the calculation of green and blue water for crops does not suit the actual applied irrigation water.
- Utilizing different sets of standards as reference for required water quality targets has an insignificant influence on the grey water footprint for sugar beet factories with an adequate treatment. For sugar beet factories with a low level of treatment the choice of reference standard for grey water footprint calculation has a decisive influence of the results. Therefore, the largest proportion of the water footprint would not be the green water footprint (evapotranspiration of rainwater), but rather the grey water footprint caused by the discharge of waste water.

Impacts of human nutrition on land use, nutrient balances and water consumption in Austria (Thaler et al., 2014)

- It is possible to derive a balanced material flow analysis for nitrogen and phosphorus including human nutrition, agriculture and environment.
- Based on an uncertainty investigation of the MFA, derived environmental indicators can better be interpreted and further research needs can be easier formulated.

- Austria is almost self-sufficient in pork and cereals, imports fish, oil seeds, fruits and vegetables among others, and exports beef and calf. Thus resources from abroad contribute to domestic consumption and domestic resources are exported into foreign countries.
- Grassland is entirely utilized for grazing and fodder production. An additional 57.4 % of arable land is used for the production of animal fodder. The remaining arable land is divided into fallow land (7.5 %), industrial crops and energy production (9.1 %) and production of plant based food (26 %). In total an average of 455 m^2 per capita agricultural land is used for the production of plant based food and 3167 m^2 per capita for the production of animal based food.
- In total 3620 m^2 per capita of agricultural area are needed to produce sufficient food to meet the requirements of the average Austrian diet. The majority of land is needed for the generation of animal products (2938 m^2 per capita) and the remaining (633 m^2 per capita) area is needed for the production of plant based food.
- On average 2.7 kg N $capita^{-1}$ $year^{-1}$ in animal based and 1.7 kg N $capita^{-1}$ $year^{-1}$ in plant based food are consumed. In order to provide the population with these amounts the national turnover is significantly higher. When the fluxes of feedstuff and forage are combined it can be seen that fodder occupies the largest flow (27 kg N $capita^{-1}$ $year^{-1}$). Forage and manure (with 19 kg N $capita^{-1}$ $year^{-1}$ another main flux) stay within the subsystem agriculture (processes ‘‘crop production and agricultural soil’’ and ‘‘animal husbandry’’). Mineral fertilizer is the largest flow entering the agricultural subsystem (13 kg N $capita^{-1}$ $year^{-1}$).

- Seventy-one percent of the total nitrogen input in the system (including mineral fertilizer and feedstuff) is used for animal husbandry, 21 % is used for the production of plant based food.
- Regarding emissions into the environment, animal husbandry is responsible for the main fluxes. For nitrogen, 95 % of the total emissions into air and 84 % of the emissions into aquatic systems from total agriculture stems from animal husbandry and fodder production. A similar result is seen for phosphorus (Fig. 10). Eighty-four percent of the total P emissions from agriculture into aquatic systems originate from animal husbandry, 9 % from plant based food production and 7 % from the production of raw materials for industry.
- In total 60.5 % (46 % fodder production for animal husbandry plus 14.5 % deposition caused by animal husbandry) of the total Austrian N emissions into waters stem from animal husbandry, 6.2 % from plant production, 2.5 % from industry and 23.4 % from point sources and urban runoff.
- Point sources and urban runoff are the most important pathways for phosphorus with 38.9 % of the total P emissions. The production of fodder is responsible for 28.5 %, plant production for human nutrition is responsible for 3.2 %, plant production for industry is responsible for 2.3 %, and other land use is responsible for 27.1 % of the total P emissions.
- The calculated water demand (expressed as WF) of all food production in Austria uses approximately half of the yearly precipitation in Austria.
- Green water accounts for 23 % of the total WF, grey water accounts for 77 %. Blue water makes a negligible impact on the total water footprint. Almost 87 % of the water footprint relates to the production of animal based food.
- When comparing the grey water footprint with the discharge of all rivers leaving Austria (net export), 43 % of the total discharge would be necessary to

dilute the nutrients emitted by agricultural food production to achieve Austrian environmental quality standards.

Possible implications of dietary changes on environment and resources in Austria (Thaler et al., 2015)

- Linking the derived MFA System to agricultural production potential allows the development of different scenarios by changing human nutrition and accordingly agricultural production. Hence environmental impacts can be modelled.

Applying a balanced diet in Austria involves the following main impacts:

- There is not enough arable land available to reach self-sufficient food supply without changing the actual diet. Self-sufficiency with food (agricultural land) is only likely when a balanced diet is applied.
- The demand for agricultural land is reduced by 30 % compared to the reference period.
- With regards to the inevitable limitation in P resources, a balanced diet can contribute to more efficient use of P (the quantity of P needed for agricultural production is reduced by 20 % to 25 %).
- Lower N inputs (between -37 % and -27 %) to agricultural production implies less energy demand and that less reactive N is released into the environment.
- Nutrient loads exported via rivers from Austria decrease by between 15 % and 11 % for N and by 5 % to 6 % for P. Additional measures (e.g. buffer stripes) on land no longer required for food production would further reduce P-emissions into waters.
- Between 30 % and 40 % lower emission of N into the atmosphere compared

to agricultural emissions in the reference period, especially from animal husbandry.

- Because N concentrations in groundwater are strongly related to land use, the concentrations change according to the land use intensity. The organic farming scenario (2A) with the lowest N surplus on agricultural land leads to the lowest N concentrations in groundwater.

How human diet impacts on waters and resources (Thaler et al., 2012b)

- The developed methodology allows assessing in detail the consequences of changing the nutrition habits of a population in a defined region to a balanced diet for an adapted agriculture, its mode of crop production, the land area requirements and the nutrient flows.
- Nitrogen export via rivers would be decreased by 11 % when applying a balanced diet. If all neighboring countries would follow the same change the effect would increase to 16 % due to reduced air transport of ammonia from manure management.

2 Discussion

What are the benefits of considering food consumption and production, land use, water consumption, needs for nutrient resources and impacts on different environmental compartments together as it was done here? Implementing a broader view allows some basic insights into the system as prerequisite for future optimizing steps. Firstly, from my point of view it is important that the reason of production (the demand side) is included into the consideration. The driving force for agricultural production is the demand of goods. Actually this is to a main part the demand of food and to a smaller part raw material for industrial use and energy conversion. Nevertheless, the second aspect deserves increasing attention as the demand on bio-energy production is increasing. Secondly, agricultural production is limited by several factors. Main factors are land suitable for production, water availability and nutrient supply. More restrictions have to be considered in respect to protection of the environment (i.e. emissions into air and water). Optimizing only one aspect has potentially severe impacts on others. For instance, as agricultural production has tremendously impacts on environment there are a lot of studies and concepts dealing with possible measures reducing negative impacts on environmental pollution. But it is neglected that fertile agricultural soil is an essential limiting resource for food production. Others are just focusing on optimization of the efficiency of agricultural production, neglecting that the main key to efficient food supply are the demand patterns. This work delivers a basis for considering several boundary conditions for a sustainable development in food production and supply within one well aligned approach.

This basis gives the unique opportunity to show how changes in diet habits would impact resource consumption and environmental pollution in Austria. The local environment would benefit, if land (not required for food production) is used for a reduction in the intensity of agricultural production. If free resources (area, nutrients) are used for additional bioenergy production, the environmental gain would be less significant.

In respect to nitrogen organic farming has benefits for the local water bodies due to the lower intensity (lower nutrient surpluses), but not for the supra regional one (Black Sea in case of Austria). Lower yields lead to higher area demands and therefore the summed up emissions into waters would stay almost the same compared to conventional farming. Area wide organic farming in Austria without a diet change is not possible without huge imports of food from other countries. We conclude that only a diet change gives us the freedom to choose a significant increase of organic farming production system or other strategies for agricultural intensity reduction. The work clearly shows that it is important to choose a suitable reference indicator. For food related investigations one inhabitant (one average diet) should be the reference indicator, as the basic task is to nourish the population. In conclusion, it is postulated that a beneficial diet change seems to be a very simple measure, but extremely difficult to implement; though it seems there are no satisfying alternatives to a less resource demanding diet in the future on a global scale. Reducing resource consumption, impacts on climate and waters demands measures not only on the supply but on the demand side seems inevitable. Connecting diet recommendations with sustainability would possibly work by implementing local diet recommendations (e.g. nations or regions). These recommendations should implement the local resource availability, the environmental needs as well as health requirements. This could lead to a changed demand transferring the food production system to a more environmental friendly system without losing production capacity. The possible result of such diets could be that in regions (must be clearly defined) with plenty of grassland, meats from ruminants have a higher portion than in other regions with mainly arable land. This could be one step in reducing the complexity of the whole food supply system by (re)implementing local relationships. However a tight cooperation between nutritional, agricultural, environmental and socio-economic scientists is inevitable.

3 References

Allan, J.A., 2003. Virtual Water-the Water, Food, and Trade Nexus: Useful Concept or Misleading Metaphor? Water International 28, 106–112.

Allan, J.A., 1993. Fortunately there are substitutes for water otherwise our hydro-political futures would be impossible. ODA 13–26.

Allen, R.G., Pereira, L.S., Raes, D., Smith, M., 1998. Crop evapotranspiration-Guidelines for computing crop water requirements-FAO Irrigation and drainage paper 56. FAO, Rome 300.

Amon, B., Fröhlich, M., Weißensteiner, R., Zablatnik, B., Amon, T., 2007. Tierhaltung und Wirtschaftsdüngermanagement in Österreich (No. GZ LE.1.3.2/0066-II/1/2005). Wien.

Anderl, M., Freudenschuß, A., Friedrich, A., Köther, T., Kriech, M., Kuschel, V., Muik, B., Pazdernik, K., Poupa, S., Schodl, B., Stranner, G., Schwaiger, E., Seuss, K., Weiss, P., Wieser, M., Zethner, G., 2010. Austria's National Inventory Report 2009 - Submission under the United Nations Framework Convention on Climate Change and under the Kyoto Protocol (No. REP-0265). Umweltbundesamt, Vienna.

Arnoult, M.H., Jones, P.J., Tranter, R.B., Tiffin, R., Traill, W.B., Tzanopoulos, J., 2010. Modelling the likely impact of healthy eating guidelines on agricultural production and land use in England and Wales. Land Use Policy 27, 1046–1055. doi:10.1016/j.landusepol.2010.02.001

AWI, 2009. Bundesanstalt für Agrarwirtschaft: DATEN UND FAKTEN [WWW Document]. URL http://www.agraroekonomik.at/index.php?id=datenfakten&L=1%20%20%25...d%2Ffiles%2Fid1.txt%3F%3F%2F%3Fpag%3D&K=0 (accessed 10.20.09).

Baccini, P., Brunner, P.H., 1991. Metabolism of the Anthroposphere. Springer-Verlag, New York.

Bach, M., Frede, H.G., 2005. Assessment of Agricultural Nitrogen Balances for Municipalities–Example Baden-Wuerttemberg (Germany). E-WAter 15.

Badgley, C., Moghtader, J., Quintero, E., Zakem, E., Chappell, M.J., Aviles-Vazquez, K., Samulon, A., Perfecto, I., 2007. Organic agriculture and the global food supply. Renewable Agriculture and Food Systems 22, 86–108.

Badgley, C., Perfecto, I., 2007. Can Organic Agriculture Feed the World? Renewable Agriculture and Food Systems 22, 80–86. doi:10.1017/S1742170507001986

Barceló-Coblijn, G., Murphy, E.J., 2009. Alpha-linolenic acid and its conversion to longer chain n−3 fatty acids: Benefits for human health and a role in maintaining tissue n−3 fatty acid levels. Progress in Lipid Research 48, 355–374. doi:10.1016/j.plipres.2009.07.002

Behrendt, H., Huber, P., Kornmilch, M., Opitz, D., Schmoll, O., Scholz, G., Uebe, R., 1999. Nutrient emissions into river basins of Germany (TEXTE 23/00). Berlin.

Behrendt, H., Opitz, D., 1999. Retention of nutrients in river systems: Dependence on specific runoff and hydraulic load. Hydrobiologia 410, 111–122.

Benedictow, A., Fagerli, H., Gauss, M., Jonson, J.E., Nyíri, Á., Simpson, D., Tsyro, S., Valdebenito, A., Valiyaveetil, S., Wind, P., 2009. Transboundary acidification, eutrophication and ground level ozone in Europe in 2007 - EMEP Status Report 1/2009.

Bennett, E.M., Carpenter, S.R., Caraco, N.F., 2001. Human impact on erodable phosphorus and eutrophication: A global perspective. Bioscience 51, 227–234. doi:10.1641/0006-3568(2001)051[0227:HIOEPA]2.0.CO;2

Bleken, M.A., Bakken, L.R., 1997. The nitrogen cost of food production: Norwegian society. Ambio 26, 134–142.

BMLFUW, 2009. Nationaler Gewässerbewirtschaftungsplan 2009 (No. BMKFUW-UW.4.4.3/0011-I/4/2010). Bundesministerium fur Land-und Forstwirtschaft Umwelt und Wasserwirtschaft, Wien.

BMLFUW, 2008a. Grüner Bericht 2001 bis 2008. Bundesministerium für Land- und Forstwirtschaft, Umwelt und Wasserwirtschaft, Abteilung II 5, Wien.

BMLFUW, 2008b. Kommunale Abwasserrichtlinie der EU - 91/271/EWG - Österreichischer Bericht 2008. Bundesministerium für Land- und Forstwirtschaft, Umwelt und Wasserwirtschaft - Sektion VII, Wien.

BMLFUW, 2007. INVEKOS-Datenpool des BMLFUW.

BMLFUW, 2006. Bundesabfallwirtschaftsplan 2006. Bundesministerium für Land- und Forstwirtschaft, Umwelt und Wasserwirtschaft, Abteilung VI/3, Wien.

BMLFUW, 2001. Bundesabfallwirtschaftsplan 2001. Bundesministerium für Land- und Forstwirtschaft, Umwelt und Wasserwirtschaft, Abteilung VI/3, Wien.

Brown, K.F., Messem, A.B., Dunham, R.J., Biscoe, P.V., 1987. Effect of drought on growth and water use of sugar beet. Journal of Agricultural Science 109, 421–435.

Buzby, J.C., Wells, H.F., Vocke, G., 2006. Possible implications for US agriculture from adoption of select dietary guidelines. Washington, DC: US Department of Agriculture.

Camargo, J.A., Alonso, Á., 2006. Ecological and toxicological effects of inorganic nitrogen pollution in aquatic ecosystems: A global assessment. Environment International 32, 831–849. doi:10.1016/j.envint.2006.05.002

Carpenter, S.R., Caraco, N.F., Correll, D.L., Howarth, R.W., Sharpley, A.N., Smith, V.H., 1998. Nonpoint pollution of surface waters with phosphorus and nitrogen. Ecological Applications 8, 559–568.

Cencic, O., Rechberger, H., 2008. Material flow analysis with software STAN. Journal of Environmental Engineering and Management 18, 3–7.

Chapagain, A.K., Hoekstra, A.Y., 2004. Water footprints of nations, Value of Water Research Report Series No. 16. UNESCO-IHE, Delft, The Netherlands.

Chapagain, A.K., Hoekstra, A.Y., Savenije, H.H.G., Gautam, R., 2006. The water footprint of cotton consumption: An assessment of the impact of worldwide consumption of cotton products on the water resources in the cotton producing countries. Ecological Economics 60, 186–203.

Chapagain, A.K., Orr, S., 2009. An improved water footprint methodology linking global consumption to local water resources: A case of Spanish tomatoes. Journal of Environmental Management 90, 1219–1228.

Connor, D.J., 2008. Organic agriculture cannot feed the world. Field Crops Research 106, 187.

Cooper, J., Lombardi, R., Boardman, D., Carliell-Marquet, C., 2011. The future distribution and production of global phosphate rock reserves. Resources, Conservation and Recycling 57, 78–86. doi:10.1016/j.resconrec.2011.09.009

Cotula, L., Vermeulen, S., Leonard, R., Keeley, J., 2009. Land Grab Or Development Opportunity? Agricultural investment and international land deals in Africa. IIEE/FAO/IFAD, London/Rome.

Cox, P., Chrisochoidis, M., 2003. Directive 2003/30/EC of the European Parliament and of the Council of 8 May 2003 on the promotion of the use of biofuels or other renewable fuels for transport. Official Journal of the European Union 46, 42–46.

Craig, I.P., 2006. Comparison of precise water depth measurements on agricultural storages with open water evaporation estimates. Agricultural Water Management 85, 193–200.

Dabrowski, J.M., Murray, K., Ashton, P.J., Leaner, J.J., 2009. Agricultural impacts on water quality and implications for virtual water trading decisions. Ecological Economics 68, 1074–1082.

Danius, L., Burström, F., 2001. Regional material flow analysis and data uncertainties: can the results be trusted, in: Proceedings of 15th International Symposium on Informatics for Environmental Protection, Zurich (Switzerland). Metropolis Verlag, Marburg, pp. 10–12.

Dayton, P.K., Thrush, S.F., Agardy, M.T., Hofman, R.J., 1995. Environmental effects of marine fishing. Aquatic Conservation: marine and freshwater ecosystems 5, 205–232.

De Boer, J., Helms, M., Aiking, H., 2006. Protein consumption and sustainability: Diet diversity in EU-15. Ecological Economics 59, 267–274. doi:doi: DOI: 10.1016/j.ecolecon.2005.10.011

Deutsch, K., Haunschmid, R., Kreuzinger, N., Prinz, H., 2010. Leitfaden zur typspezifischen Bewertung gemäss WRRL - Allgemein physikalisch-chemische Parameter in Fliessgewässern. BMLFUW - Abt. VII 1, Wien.

Deutsch, K., Haunschmid, R., Kreuzinger, N., Prinz, H., 2008. Leitfaden zur typspezifischen Bewertung der allgemein physikalisch-chemischen Parameter in Fließgewässern gemäß WRRL. Bundesministerium für Land- und Forstwirtschaft, Umwelt und Wasserwirtschaft - Sektion VII, Wien.

DGE, 2008. Vollwertig essen und trinken nach den 10 Regeln der DGE, Deutsche Gesellschaft für Ernährung. ed. aid Infodienst, Bonn.

DGE, 2005. Die Dreidimensionale Lebensmittelpyramide. DGE info 4/2005, 56–57.

DGE, ÖGE, SGE, SVE, 2000. D-A-CH-Referenzwerte für die Nährstoffzufuhr. Umschau/Braus, Frankfurt.

Diepolder, M., Raschbacher, S., 2010. Leistungsfähiges Grünland und Verzicht auf mineralische Düngung - LfL. Bayerische Landesanstalt für Landwirtschaft Institut für Fischerei Starnberg, Freising.

Doorenbos, J., Kassam, A.H., 1979. Yield response to water, FAO irrigation and drainage paper 33. Food and Agriculture Organisation, Rome.

EEA, 2006. EMEP/CORINAIR Emission Inventory Guidebook - 2006 (No. 11/2006). EEA (European Environment Agency).

Eickhout, B., Bouwman, A.F., van Zeijts, H., 2006. The role of nitrogen in world food production and environmental sustainability. Agriculture, Ecosystems & Environment 116, 4–14. doi:10.1016/j.agee.2006.03.009

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

10.1016/j.jclepro.2006.04.003

Elmadfa, I., Burger, P., Derndorfer, E., Kiefer, I., Kunze, M., König, J., Leimüller, G., Manafi, M., Meci, Papathanasiou, V., Rust, P., Vojir, F., Wagner, K.H., Zarfl, B., 1998. Österreichischer Ernährungsbericht 1998. Department of Nutritional Sciences of the University of Vienna, Wien.

Elmadfa, I., Freisling, H., König, J., Blachfelner, J., others, 2009a. Austrian Nutrition Report 2003 - English Summary. Department of Nutritional Sciences of the University of Vienna, Vienna.

Elmadfa, I., Freisling, H., Nowak, V., Hofstädter, D., others, 2009b. Österreichischer Ernährungsbericht 2008. Department of Nutritional Sciences of the University of Vienna, Wien.

EMEP, 2010. emep Convention on Long-range Transboundary Air Pollution [WWW Document]. URL http://webdab.emep.int/Unified_Model_Results/AN/userguide_frame.html (accessed 2.5.10).

EMEP, 2009. EMEP Status Report 1/09 (No. EMEP Report 1/2009). Norwegian Meteorological Institute.

EPA, 1995. Compilation of air pollutant emission factors. Volume I: Stationary point and area sources. Office of air quality planning and standards, Office of air and radiation, USA.

ETC/LUSI, 2010. Corine Land Cover 2000 raster data - version 13 (02/2010) - Datasets — EEA.

European Commission, 2008. Commission Regulation (EC) No 889/2008 of 5 September 2008 laying down detailed rules for the implementation of Council Regulation (EC) No 834/2007 on organic production and labelling of organic products with regard to organic production, labelling and control. Official Jounal of the European Union 1–84.

European Commission, 2006. Integrated Pollution Prevention and Control: Reference Document on Best Available Techniques in the Food, Drink and Milk Industries.

European Parliament and Council, 2000. Directive 2000/60/EC of the European Parliament and of the Council of 23 October 2000 establishing a framework for Community action in the field of water policy.

Fachbeirat für Bodenfruchtbarkeit und Bodenschutz, 2006. Richtlinien für die sachgerechte Düngung.

FAO, 2012. FAO statistiacl Yearbook 2012, FAO statistiacl Yearbook. FAO, Rome, Italy.

FAO, 2009a. The state of food and agriculture 2009 : livestock in the balance. Food and Agriculture Organization of the United Nations, Rome.

FAO, 2009b. CROPWAT 8.0. Rome.

FAO, 2009c. FAOSTAT.

FAO, 2004a. Global map of monthly precipitation - 10 arc minutes.

FAO, 2004b. Global map of monthly reference evapotranspiration - 10 arc minutes.

Fazeni, K., Steinmüller, H., 2011. Impact of changes in diet on the availability of land, energy demand, and greenhouse gas emissions of agriculture. Energy, Sustainability and Society 1, 6. doi:10.1186/2192-0567-1-6

Franke, N.., Boyacioglu, H., Hoekstra, A.Y., 2013. Grey water footprint accounting: Tier 1 supporting guidelines, Value of Water Research Report Series No. UNESCO-IHE, Delft, the Netherlands.

Freyer, B., Dorninger, M., 2008. Bio-Landwirtschaft und Klimaschutz in Österreich - Aktuelle Leistungen und zukünftige Potentiale der Ökologischen Landwirtschaft für den Klimaschutz in Österreich. Wien.

Friel, S., Dangour, A.D., Garnett, T., Lock, K., Chalabi, Z., Roberts, I., Butler, A., Butler, C.D., Waage, J., McMichael, A.J., Haines, A., 2009. Public health benefits of strategies to reduce greenhouse-gas emissions: food and agriculture. The Lancet 374, 2016–2025. doi:16/S0140-6736(09)61753-0

Gabriel, O., Kovacs, A., Thaler, S., Zessner, M., Hochedlinger, G., Schilling, C., Windhofer, G., 2011. Stoffbilanzmodellierung auf Einzugsgebietsebene als Grundlage für Bewirtschaftungspläne und Maßnahmenprogramme. (No. Forschungsbericht). Institute for water quality management Vienna University of Technology, Vienna.

Galler, J., 2009. Wirtschaftsdünger Anfall, Lagerung, Verwertung, Umwelt - Praxisratgeber.

Gerbens-Leenes, P.W., Hoekstra, A.Y., 2009. The water footprint of sweeteners and bio-ethanol from sugar cane, sugar beet and maize, Value of Water Research Report Series No. 38. UNESCO-IHE, Delft, the Netherlands.

Gerbens-Leenes, P.W., Nonhebel, S., 2005. Food and land use. The influence of consumption patterns on the use of agricultural resources. Appetite 45, 24–31. doi:10.1016/j.appet.2005.01.011

Gerbens-Leenes, P.W., Nonhebel, S., Ivens, W.P.M.F., 2002. A method to determine land requirements relating to food consumption patterns. Agriculture, Ecosystems & Environment 90, 47–58. doi:doi: DOI: 10.1016/S0167-8809(01)00169-4

Godfray, H.C.., Beddington, J.R., Crute, I.R., Haddad, L., Lawrence, D., Muir, J.F., Pretty, J., Robinson, S., Thomas, S.M., Toulmin, C., 2010. Food Security: The Challenge of Feeding 9 Billion People. Science 327, 812–818. doi:10.1126/science.1185383

Götz, B., 1998. Stickstoffbilanz der oesterreichischen Landwirtschaft nach den Vorgaben der OECD: aktualisiert und erweiterte Fassung. Berichte (Austria); Umweltbundesamt.

Grieser, J., Gommes, R., Cofield, S., 2006. New gridded maps of Koeppen's climate classification.

Harvey, M., Pilgrim, S., 2011. The new competition for land: Food, energy, and climate change. Food Policy 36, Supplement 1, S40–S51. doi:10.1016/j.foodpol.2010.11.009

Hedbrant, J., Sörme, L., 2001. Data vagueness and uncertainties in urban heavy-metal data collection. Water, Air, & Soil Pollution: Focus 1, 43–53.

Hoekstra, A.Y., Chapagain, A.K., 2008. Globalization of water: sharing the planet's freshwater resources. Blackwell Publishing, Malden, Oxford, Victoria.

Hoekstra, A.Y., Chapagain, A.K., Aldaya, M.M., 2009. Water Footprint Manual: State of the art 2009. Water Footprint Network.

Hoekstra, A.Y., Chapagain, A.K., Aldaya, M.M., Mekonnen, M.M., 2011. The Water Footprint Assessment Manual. Earthscan, London, Washington DC.

Hoekstra, A.Y., Hung, P.Q., 2002. Virtual water trade: A quantification of virtual water flows between nations in relation to international crop trade. Value of Water Research Report Series No. 11. Delft, The Netherlands: IHE.

Houghton, J.T., Meira Filho, L.G., Lim, B., Tréanton, K., Mamaty, I., Bonduki, Y., Griggs, D.J., Callander, B.A. (Eds.), 1997. Revised 1996 IPCC Guidelines for Natinal Greenhouse Gas Inventories, Vol. 1: Reporting Instructions, Vol. 2: Workbook, Vol. 3: Reference Manual. Intergovernmental Panel on Climate Change,.

ICPDR, 2009. Danube River Basin District Management Plan (No. IC / 151). ICPDR, Vienna.

Isermann, K., Isermann, R., 1998. Food production and consumption in Germany: N flows and N emissions. Nutrient Cycling in Agroecosystems 52, 289–301.

Jefferies, R.L., Maron, J.L., 1997. The embarrassment of riches: atmospheric deposition of nitrogen and community and ecosystem processes. Trends in Ecology & Evolution 12, 74–78. doi:10.1016/S0169-5347(96)20125-9

Keyzer, M., Merbis, M., Pavel, I., Vanwesenbeeck, C., 2005. Diet shifts towards meat and the effects on cereal use: can we feed the animals in 2030? Ecological Economics 55, 187–202. doi:10.1016/j.ecolecon.2004.12.002

Kratochvil, R., 2003. Betriebs-und regionalwirtschaftliche Aspekte einer grossflächigen Bewirtschaftung nach den Prinzipien des Ökologischen Landbaus am Beispiel der Region Mostviertel-Eisenwurzen. Universität für Bodenkultur Wien.

Kresser, W., 1994. Wasserbilanz für das österreichische Bundesgebiet 1961-90. Mitteilungsblatt des Hydrographischen Dienstes in Österreich 72, 1–3.

Kroiss, H., Zessner, M., Deutsch, K., Schaar, W., Kreuzinger, N., 1998. Nährstoffbilanzen der Donauanrainerstaaten-Erhebungen für Österreich. TU-Wien, Institut f\ür Wasserg\üte und Abfallwirtschaft.

Lackner, M., 2008. Sozialökologische Dimensionen der österreichischen Ernährung - Eine Szenarienanalyse. Social Ecology Working Paper 103, 1–66.

Leinweber, P., Turner, B.L., Meissner, R., 2002. Phosphorus, in: Haygarth, P.M., Jarvis, S.C. (Eds.), Agriculture, Hydrology, and Water Quality. CABI, Oxon, New York, pp. 29–55.

LFL, 2008. Basisdaten für die Ermittlung des Düngebedarfs; für die Umsetzung der Düngeverordnung.

Lindenthal, T., 2000. Phosphorvorräte in Böden, betriebliche Phosphorbilanzen und Phosphorversorgung im biologischen Landbau.

Mander, Ü., Kuusemets, V., Lõhmus, K., Mauring, T., 1997. Efficiency and dimensioning of riparian buffer zones in agricultural catchments. Ecological Engineering 8, 299–324. doi:10.1016/S0925-8574(97)00025-6

Meier, T., Christen, O., 2013. Environmental Impacts of Dietary Recommendations and Dietary Styles: Germany As an Example. Environmental Science & Technology 47, 877–888. doi:10.1021/es302152v

Meier, T., Christen, O., Semler, E., Jahreis, G., Voget-Kleschin, L., Schrode, A., Artmann, M., 2014. Balancing virtual land imports by a shift in the diet. Using a land balance approach to assess the sustainability of food consumption. Germany as an example. Appetite 74, 20–34. doi:10.1016/j.appet.2013.11.006

Mekonnen, M.M., Hoekstra, A.Y., 2010. The green, blue and grey water footprint of crops and derived crop products (No. Research Report Series No. 47), Value of Water. UNESCO-IHE Institute for Water Education, Twente.

Naylor, R.L., Goldburg, R.J., Primavera, J.H., Kautsky, N., 2000. Effect of aquaculture on world fish supplies. Nature 405, 1017–1024.

New, M., Lister, D., Hulme, M., Makin, I., 2002. A high-resolution data set of surface climate over global land areas. Climate research 21, 1–25.

Nonhebel, S., 2005. Renewable energy and food supply: will there be enough land? Renewable and Sustainable Energy Reviews 9, 191–201. doi:10.1016/j.rser.2004.02.003

Obernosterer, R., Reiner, I., 2003. Stickstoffbilanz Österreich “. Beitrag der Abfallwirtschaft zum Stickstoffhaushalt Österreichs. Villach.

OECD, 2012. Water quality and agriculture : meeting the policy challenge., OECD Studies on water. OECD Publishing, Paris.

OECD/FAO, 2010. Agricultural Outlook, 2010-2019: Highlights, Agricultural Outlook. Paris.

Rademacher, C., 2008. Die Dreidimensionale Lebensmittelpyramide. Ernährungs Umschau 1/08, 44–50.

Renault, D., Wallender, W.W., 2000. Nutritional water productivity and diets. Agricultural Water Management 45, 275–296. doi:doi: DOI: 10.1016/S0378-3774(99)00107-9

Rickard, B.J., Gonsalves, J.L., 2008. How would compliance with dietary recommendations affect revenues for agricultural producers? Food Policy 33, 422–433. doi:doi: DOI: 10.1016/j.foodpol.2008.01.006

Risku-Norja, H., Mäenpää, I., 2007. MFA model to assess economic and environmental consequences of food production and consumption. Ecological Economics 60, 700–711. doi:10.1016/j.ecolecon.2006.05.001

Schadauer, K., Büchsenmeister, R., Hauk, E., Russ, W., Frank, G., 2004. Ergebnisse der Österreichischen Waldinventur 2000 - 2002 [WWW Document]. URL http://web.bfw.ac.at/i7/Oewi.oewi0002?geo=0 (accessed 2.9.10).

Schilling, C., Zessner, M., Kovacs, A., Hochedlinger, G., Windhofer, G., Gabriel, O., Thaler, S., Parajka, J., Natho, S., 2011. Stickstoff- und Phosphorbelastungen der Fließgewässer Österreichs und Möglichkeiten zu deren Reduktion. Österreichische Wasser- und Abfallwirtschaft 63, 105–116.

Scholten, W., 2009. The water footprint of sugar and sugar-based ethanol (Master). University of Twente, Enschede, The Netherlands.

Schröder, J.J., Smit, A.L., Cordell, D., Rosemarin, A., 2011. Improved phosphorus use efficiency in agriculture: A key requirement for its sustainable use. Chemosphere 84, 822–831. doi:10.1016/j.chemosphere.2011.01.065

Shriar, A.J., 2000. Agricultural intensity and its measurement in frontier regions. Agroforestry Systems 49, 301–318. doi:10.1023/A:1006316131781

Smil, V., 2002. Worldwide transformation of diets, burdens of meat production and opportunities for novel food proteins. Enzyme and Microbial Technology 30, 305–311. doi:doi: DOI: 10.1016/S0141-0229(01)00504-X

Smith, V.H., Tilman, G.D., Nekola, J.C., 1999. Eutrophication: impacts of excess nutrient inputs on freshwater, marine, and terrestrial ecosystems. Environmental Pollution 100, 179–196. doi:10.1016/S0269-7491(99)00091-3

Son, Y., 2001. Non-symbiotic nitrogen fixation in forest ecosystems. Ecological Research 16, 183–196. doi:10.1111/j.1440-1703.2001.00385.pp.x

Statistik Austria, 2010a. Ankünfte und Nächtigungen im Tourismus-Kalenderjahr (2000 bis 2009).

Statistik Austria, 2010b. Reisegewohnheiten der Inländerinnen und Inländer von 1990 bis

2009.

Statistik Austria, 2010c. Landwirtschaftliche Haupt- und Kleinproduktionsgebiete Österreichs.

Statistik Austria, 2009a. Statistik des Bevölkerungsstandes - Revidierte Ergebnisse für 2002 bis 2008.

Statistik Austria, 2009b. Urlaubs- und Geschäftsreisen der Inländerinnen und Inländer.

Statistik Austria, 2009c. Futtermittelaufkommen und -Verteilung 2001-2006; unveröffentlicht (unpublished).

Statistik Austria, 2007a. Versorgungsbilanzen für tierische und pflanzliche Produkte 2001 bis 2006.

Statistik Austria, 2007b. Durchschnittliche Lebend- und Schlachtgewichte 2006.

Steduto, P., 2011. Water, food and agriculture; challenges and responses., in: Symposium "Future of the European Waters." Presented at the Symposium "Future of the European Waters," Budapest.

Steinfeld, H., Gerber, P., Wassenaar, T.D., Castel, V., de Haan, C., 2006. Livestock's long shadow: environmental issues and options. FAO.

Thaler, S., Zessner, M., Bertrán de Lis, F., Kreuzinger, N., Fehringer, R., 2012a. Considerations on methodological questions of the water footprint calculations. Water Science and Technology 65.7, 1258–1264.

Thaler, S., Zessner, M., Katerina, S., Helmut, K., 2013. How human diet impacts on waters and resources. Water Science & Technology: Water Supply.

Thaler, S., Zessner, M., Mayr, M.M., Haider, T., Kroiss, H., Rechberger, H., 2014. Impacts of human nutrition on land use, nutrient balances and water consumption in Austria. Sustainability of Water Quality and Ecology 1-2, 24–39. doi:10.1016/j.swaqe.2014.04.003

Thaler, S., Zessner, M., Mayr, M.M., Haider, T., Kroiss, H., Wagner, K.H., Ruzicka, K., 2011. Der Einfluss von Ernährungsgewohnheiten auf die Nährstoffbilanz Österreichs. ÖWAV Heft 5-6, 117–128.

Thaler, S., Zessner, M., Schilling, K., Kroiss, H., 2012b. How human diet impacts on waters and resources, in: Proceedings IWA World Water Congress. Presented at the World Water Congress & Exhibition, IWA Publishing, Busan, Korea.

Thaler, S., Zessner, M., Weigl, M., Rechberger, H., Schilling, K., Kroiss, H., 2015. Possible implications of dietary changes on nutrient fluxes, environment and land use in Austria. Agricultural Systems 136, 14–29. doi:10.1016/j.agsy.2015.01.006

Tilman, D., Socolow, R., Foley, J.A., Hill, J., Larson, E., Lynd, L., Pacala, S., Reilly, J., Searchinger, T., Somerville, C., Williams, R., 2009. Beneficial biofuels - The food, energy, and environment trilemma. Science 325, 270–271.

Turchini, G.M., Francis, D.S., 2009. Fatty acid metabolism (desaturation, elongation and β-oxidation) in rainbow trout fed fish oil- or linseed oil-based diets. British Journal of Nutrition 102, 69–81.

UBA, 2008. Austria's National Inventory Report (IIR)2008 - Submission under the UNECE Cionvention on Long-range Transboundary Air Pollution (No. REP-0133). Umweltbundesamt, Vienna.

UN, 2011. World Population Prospects: The 2010 Revision [WWW Document]. Population

Division of the Department of Economic and Social Affairs of the United Nations Secretariat. URL http://esa.un.org/unpd/wpp/index.htm, (accessed 5.4.11).

Universität fur Bodenkultur, U. fur B., 2007. Hydrologischer Atlas Österreichs, 3/2007 ed. Bundesministerium fur Land- und Forstwirtschaft, Umwelt und Wasserwirtschaft.

Utset, A., Mart'ınez-Cob, A., Farré, I., Cavero, J., 2006. Simulating the effects of extreme dry and wet years on the water use of flooding-irrigated maize in a Mediterranean landplane. Agricultural Water Management 85, 77–84.

Utset, A., Velicia, H., del R'ıo, B., Morillo, R., Centeno, J.A., Mart'ınez, J.C., 2007. Calibrating and validating an agrohydrological model to simulate sugarbeet water use under mediterranean conditions. Agricultural Water Management 94, 11–21.

Vanham, D., 2013. The water footprint of Austria for different diets. Water Sci. Technol. 67, 824–830. doi:10.2166/wst.2012.623

Vitousek, P.M., Aber, J.D., Howarth, R.W., Likens, G.E., Matson, P.A., Schindler, D.W., Schlesinger, W.H., Tilman, D.G., 1997. Human alteration of the global nitrogen cycle: sources and consequences. Ecological applications 7, 737–750.

WFN, 2010. Waterfootprint.org: Water footprint and virtual water [WWW Document]. URL http://www.waterfootprint.org/?page=files/home (accessed 3.16.10).

WHO, 2003. Diet, nutrition and the prevention of chronic diseases - Report of a Joint WHO/FAO Expert Consultation (No. 916), WHO Technical Report Series. World Health Organization, Geneva.

ZAMG, 2011. Zentralanstalt für Meteorologie und Geodynamik (ZAMG) - Klima, Phänologie [WWW Document]. Phänologie Auswertungen Diagramme. URL http://zacost.zamg.ac.at/phaeno_portal/ (accessed 5.19.11).

Zapata, F., Roy, R.N., 2004. Use of phosphate rocks for sustainable agriculture, FERTILIZER AND PLANT NUTRITION BULLETIN. FAO, Rome.

Zessner, M., Helmich, K., Thaler, S., Weigl, M., Wagner, K.H., Haider, T., Mayr, M.M., Heigl, S., 2011a. Ernährung und Flächennutzung in Österreich. Österreichische Wasser- und Abfallwirtschaft 63, 95–104.

Zessner, M., Kovacs, A., Schilling, C., Hochedlinger, G., Gabriel, O., Natho, S., Thaler, S., Windhofer, G., 2011b. Enhancement of the MONERIS Model for Application in Alpine Catchments in Austria. International Review of Hydrobiology 96, 541–560.

Zessner, M., Lampert, C., 2002. The use of regional material balances in water quality management. Urban Water 4, 73–83. doi:10.1016/S1462-0758(01)00054-1

Zessner, M., Steinmüller, H., Wagner, K.H., Krachler, M.M., Thaler, S., Fazeni, K., Helmich, K., Weigl, M., Ruzicka, K., Heigl, S., Kroiss, H., 2011c. Gesunde Ernährung und Nachhaltigkeit – Grundlagen, Methodik und Erkenntnisse eines Forschungsprojektes in Rahmen des proVISION Programmes des BMWF. ÖWAV 63, 87–94.

Zessner, M., Thaler, S., Ruzicka, K., Natho, S., Kroiss, H., 2010. Considerations on the importance of nutrition habits for the national nitrogen balance of Austria. Water Science and Technology 62, 21–27.

Zethner, G., Götz, B., Amlinger, F., 2000. Qualität von Komposten aus der getrennten Sammlung (No. M-133). Umweltbundesamt, Wien.

vii Appendix

Appendix A: data

3.1 Definition of nutrient fluxes

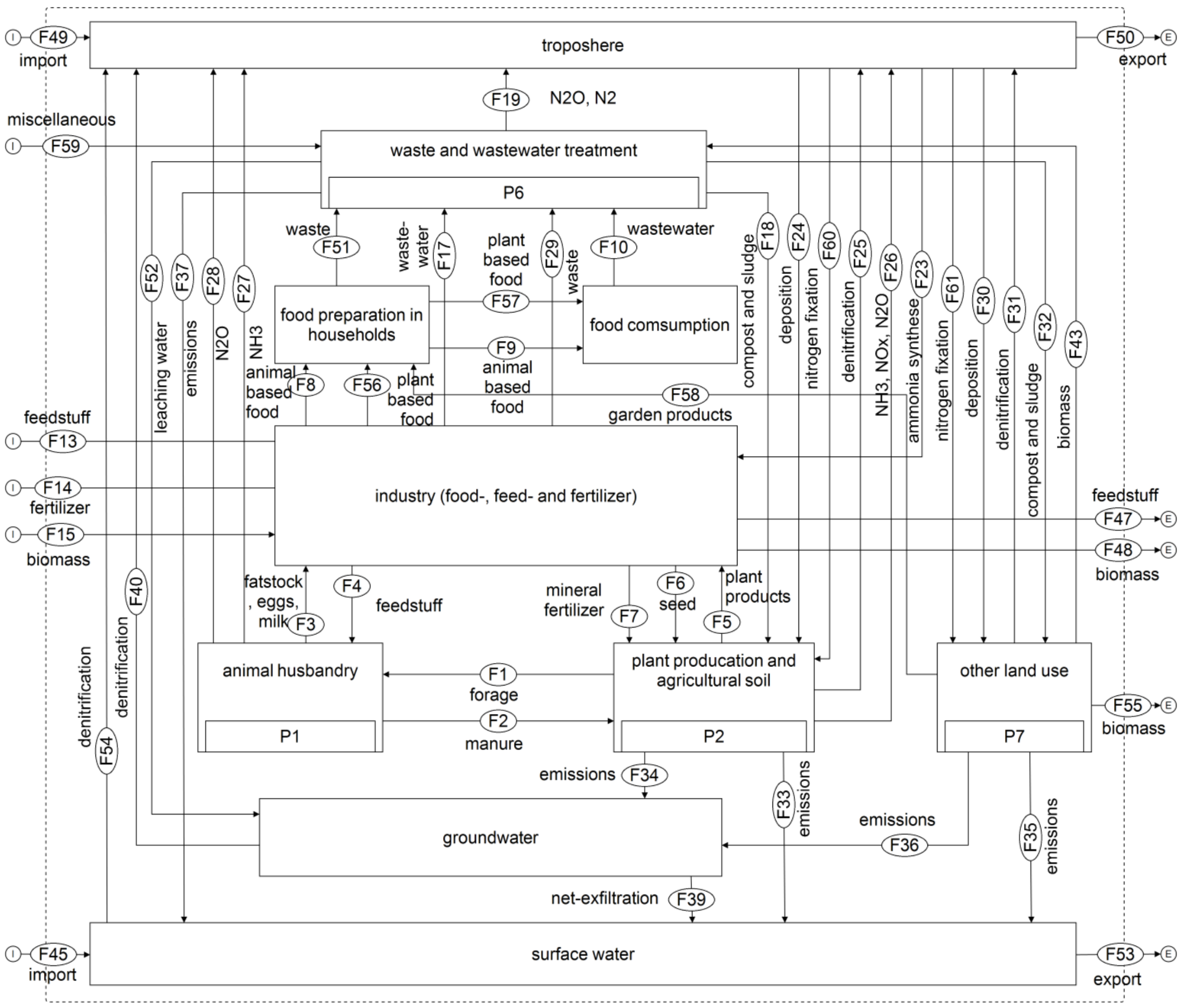

Figure 32: Material Flow System with numbered fluxes

Table 15: Definition of nutrient fluxes, corresponding with Figure 32 showing their location in the MFA system

flux number	flux name	from process	to process	data sources and comments	concentration values used, table number in chapter 1.4
F1	forage	plant production and agricultural soil	animal husbandry	(BMLFUW, 2008a)	19
F2	manure	animal husbandry	plant production and agricultural soil	(BMLFUW, 2008a; UBA, 2008)	-
F3	fatstock, eggs, milk	animal husbandry	industry	(Amon et al., 2007; BMLFUW, 2008a; Fachbeirat für Bodenfruchtbarkeit und Bodenschutz, 2006; Statistik Austria, 2007a, 2007b)	18
F4	feedstuff	industry	animal husbandry	(Statistik Austria, 2009c)	18,21
F5	plant products	plant production and agricultural soil	industry	(BMLFUW, 2008a)	18
F6	seed	industry	plant production and agricultural soil	(AWI, 2009)	18
F7	mineral fertilizer	industry	plant production and agricultural soil	(BMLFUW, 2008a)	-
F8	animal based food	industry	food preparation in households	(Statistik Austria, 2007b)	17
F9	animal based food	food preparation in households	food consumption	(Elmadfa et al., 2009b, 1998; Statistik Austria, 2007b)	17
F10	wastewater	food consumption	waste and wastewater treatment	(= F57 plus F9) no accumulation or loss of nutrients in the human body is assumed	-
F13	feedstuff	import	industry	(Statistik Austria, 2009c)	20,21
F14	fertilizer	import	industry	(Statistik Austria, 2009c)	-
F15	biomass	import	industry	(Statistik Austria, 2009c)	18
F17	wastewater	industry	waste and wastewater treatment	(BMLFUW, 2008b; Kroiss et al., 1998)	-
F18	compost and sludge	waste and wastewater treatment	plant production and agricultural soil	(BMLFUW, 2006, 2001; Obernosterer and Reiner, 2003; Zethner et al., 2000)	24
F19	N2O,N2	waste and wastewater treatment	troposphere	(BMLFUW, 2008b)	-
F23	ammonia synthesis	troposphere	industry	= F7	-
F24	deposition	troposphere	plant production and agricultural soil	(Benedictow et al., 2009; EMEP, 2010)	-
F25	denitrification	plant production and agricultural soil	troposphere	calculation based on Behrendt et al. (1999)	-
F26	NH3, NOx, N2O	plant production and agricultural soil	troposphere	calculation based on UBA(2008) ; EEA (2006)	-
F27	NH3	animal husbandry	troposphere	calculation based on UBA(2008) ; EEA (2006)	-
F28	N2O	animal husbandry	troposphere	calculation based on UBA(2008)	-
F29	waste	industry	waste and wastewater treatment	(BMLFUW, 2008b; Kroiss et al., 1998)	25
F30	depostion	troposphere	other landuse	(Benedictow et al., 2009; EMEP, 2010)	-
F31	denitrification	other landuse	troposphere	calculation based on Behrendt et al. (1999)	-
F32	compost and sludge	waste and wastewater treatment	other landuse	(BMLFUW, 2001, 2001; Obernosterer and Reiner, 2003; Zethner et al., 2000)	24
F33	emissions	plant production and agricultural soil	surface water	MONERIS model(Schilling et al., 2011; Zessner et al., 2011b)	-
F34	emissions	plant production and agricultural soil	groundwater	MONERIS model(Schilling et al., 2011; Zessner et al., 2011b)	-
F35	emissions	other landuse	surface water	MONERIS model(Schilling et	-

				al., 2011; Zessner et al., 2011b)	
F36	emissions	other landuse	groundwater	MONERIS model(Schilling et al., 2011; Zessner et al., 2011b)	-
F37	emissions	waste and wastewater treatment	surface water	MONERIS model(Schilling et al., 2011; Zessner et al., 2011b)	-
F39	net-exfiltration	groundwater	surface water	MONERIS model(Schilling et al., 2011; Zessner et al., 2011b)	-
F40	denitrification	groundwater	troposphere	=F36+F34+F52-F39	-
F43	biomass	other landuse	waste and wastewater treatment	(BMLFUW, 2006, 2001; Zethner et al., 2000)	24
F45	import	import	surface water	MONERIS model(Schilling et al., 2011; Zessner et al., 2011b)	-
F47	feedstuff	industry	export	(Statistik Austria, 2009c)	20
F48	biomass	industry	export	(Statistik Austria, 2009c)	18
F49	import	import	troposphere	(EMEP, 2009)	-
F50	export	troposphere	export	(EMEP, 2009)	-
F51	waste	food preparation in households	waste and wastewater treatment	=F8+F56+F58-F57-F9	-
F52	leaching water	waste and wastewater treatment	groundwater	(BMLFUW, 2006)	-
F53	export	surface water	export	MONERIS model(Schilling et al., 2011; Zessner et al., 2011b)	-
F54	denitrification	surface water	troposphere	MONERIS model(Schilling et al., 2011; Zessner et al., 2011b)	-
F55	biomass	other landuse	export	(Schadauer et al., 2004)	23
F56	plant based food	industry	food preparation in households	(Statistik Austria, 2007a)	16
F57	plant based food	food preparation in households	food consumption	(Elmadfa et al., 2009a, 1998; Statistik Austria, 2007a)	16
F58	garden products	other landuse	food preparation in households	(Statistik Austria, 2007a)	16
F59	miscellaneous	import	waste and wastewater treatment	(Kroiss et al., 1998)	-
F60	nitrogen fixation	troposphere	plant production and agricultural soil	(AWI, 2009; BMLFUW, 2008a; Götz, 1998; LFL, 2008; UBA, 2008)	-
F61	nitrogen fixation	troposphere	other landuse	(Son, 2001)	-

3.2 N and P concentrations and range

Table 16: N and P concentration part 1

food consumption	lower limit N in %	upper limit N in %	lower limit P in %	upper limit P in %
beef	3,2	3,5	0,32	0,45
pork	3	3,2	0,32	0,45
sheep and goat	2,5	3,5	0,32	0,45
horse	2,5	3,5	0,32	0,45
offal	2,1	3	0,27	0,34
poultry	1,7	2,1	0,18	0,21
other meat	2,5	3,5	0,32	0,45
eggs	1,6	2	0,13	0,2
raw milk	0,3	0,5	0,0	0,1
fish	3	3	0,14	0,3
cereals	1,5	2	0,25	0,35
rice	1,20	1,20	0,12	0,22

potatos	0,30	0,40	0,05	0,10
oil seed	0,00	0,00	0,00	0,00
fruit	0,10	0,10	0,01	0,02
vegetable	0,40	0,40	0,07	0,13
pulses	3,64	3,64	0,48	0,48

Table 17: N and P concentrations part 2

production, import and export (slaughtered)	lower limit N in % fresh matter	upper limit N in % fresh matter	lower limit P in % fresh matter	upper limit P in % fresh matter
cattles	3,20	3,80	1,00	1,00
pork	2,60	3,10	0,63	0,63
sheep and goat	2,50	3,50	1,00	1,20
horse	2,50	3,50	1,00	1,20
offal	2,10	3,00	0,27	0,34
poultry	1,70	2,10	0,18	0,21
other meat	2,50	3,50	1,00	1,20
eggs	1,60	2,00	0,13	0,20
raw milk	0,50	0,60	0,09	0,10
fish	3,00	3,00	0,14	0,30
wheat	1,81	2,30	0,33	0,35
spelt	1,50	2,00	0,33	0,35
rye	1,50	2,00	0,33	0,35
barley	1,20	1,65	0,33	0,35
oat	1,50	2,00	0,33	0,35
maize	1,51	1,80	0,28	0,35
triticale	1,50	2,00	0,33	0,35
mixed corn	1,50	2,00	0,33	0,35
durum wheat	1,81	2,30	0,33	0,35
rice	1,20	1,20	0,12	0,22
potato	0,30	0,40	0,05	0,10
fruit	0,10	0,10	0,01	0,02
vegetable	0,40	0,40	0,07	0,13
wine, juices	0,25	0,25	0,04	0,04
sugarbeet	0,18	0,18	0,04	0,04
brewer`s barley	1,20	1,65	0,33	0,35
rape	2,00	3,35	0,50	0,79
spring swede rape	0,35	0,35	0,05	0,05
sunflower	2,91	2,91	0,70	0,70
soya	4,40	4,40	0,48	0,48
flax	3,50	3,50	0,52	0,52
oil pumkin	2,00	5,00	0,50	0,70
poppy	2,00	5,00	0,50	0,70
grain peas	3,60	3,60	0,48	0,48

field bean	4,10	4,10	0,52	0,52

Table 18: N and P concentrations part 3

softwood	lower limit N in %	upper limit N in %	lower limit P in %	upper limit P in %
roots	0,700	0,800	0,045	0,055
branches	0,300	0,600	0,033	0,033
leaves	1,300	1,400	0,070	0,070
tree trunk	0,070	0,100	0,013	0,013
hardwood	lower limit N in %	upper limit N in %	lower limit P in %	upper limit P in %
roots	0,700	1,000	0,045	0,063
branches	0,300	0,500	0,044	0,044
leaves	1,000	1,500	0,080	0,100
tree trunk	0,300	0,500	0,014	0,014

Table 19: N and P concentrations part 4

by products (fodder) from	lower limit N in %	upper limit N in %	lower limit P in %	upper limit P in %
milling	2,6	3,1	0,8	1,3
brewery	0,5	0,7	0,0	0,1
distillery	0,2	8,0	0,0	2,1
starch production	5,5	9,0	0,1	0,9
sugar industry	1,6	1,8	0,0	0,1
oil production	6,5	7,7	0,5	0,7

Table 20: N and P concentrations part 5

frodder from	lower limit N in %	upper limit N in %	lower limit P in %	upper limit P in %
marine animals	9,6	9,6	3,0	4,0
terrestrial animals	9,6	9,6	2,0	3,0
animal fats and oil	0,0	0,0	0,02	0,02
raw-milk	3,8	4,6	0,7	0,8
milk powder	0,4	0,5	0,1	0,1
whey	1,0	1,0	0,5	0,5

Table 21: N and P concentrations part 6

livestock	lower limit N in %	upper limit N in %	lower limit P in %	upper limit P in %
cattle	2,5	3,5	0,6	0,6
pig	2,1	2,6	0,5	0,5
horse	2,5	3,5	0,6	0,6

sheep	2,5	3,5	0,6	0,6
goat	2,5	3,5	0,6	0,6
poultry	1,7	3,5	0,5	0,6

Table 22: N and P concentrations part 7

fodder	lower limit N in %	upper limit N in %	lower limit P in %	upper limit P in %
fodder from grassland				
meadows	2,2	2,2	0,4	0,4
pastures	2,2	2,2	0,4	0,4
low yielding meadows	1,3	1,3	0,3	0,3
low yielding pastures	1,8	1,8	0,3	0,3
alpine pasture and meadows	1,3	1,3	0,3	0,3
fodder from arable land (concentrate fodder is not included)				
clover	0,6	0,6	0,1	0,1
alfalfa	0,6	0,7	0,1	0,1
grass-clover	0,5	0,5	0,1	0,1
temporary grassland	0,5	1,8	0,1	0,3
other field forage	0,6	0,6	0,1	0,1
corn silage	0,2	0,4	0,1	0,1
fodder maize	0,2	0,4	0,1	0,1
fodder beet	0,2	0,4	0,0	0,0

Table 23: N and P concentrations part 8

compost	lower limit N in %	upper limit N in %	lower limit P in %	upper limit P in %
source marterial				
garden, park and cemetery biomass	1,0	7,0	1,3	2,2
other source (marked, household)	7,0	8,6	1,3	2,2

Table 24: N and P concentrations part 9

waste	lower limit N in %	upper limit N in %	lower limit P in %	upper limit P in %
non-recyclable waste	0,0	0,0	0,1	0,1
bio-waste	0,7	1,0	0,1	0,2
recovered paper	0,1	0,2		
waste glass	0,0	0,0		
waste wood	0,1	0,2	0,0	0,0

Table 25: N and P concentrations part 10

waste from industry	lower limit N in %	upper limit N in %	lower limit P in %	upper limit P in %
food production	0,7	1,0	0,1	0,2
production of fat	0,7	1,0		
slaughtering	0,3	0,4		
skin and leather waste	3,4	12,0	0,2	0,4
other waste from processing of agricultural products	0,3	0,7		
plastic and rubber waste	1,4	2,5		
organic solvent	0,3	0,6		
textile waste	0,1	4,0		
wood and paper	0,1	0,3	0,0	0,0

3.3 Yield and head of animals

Table 26: yields (AMA, 2010; BMLFUW, 2008a; Statistik Austria, 2011)

	yield ($Mg\ ha^{-1} year^{-1}$)
wheat	5,2
spelt	5,2
rye	3,9
barley	4,5
oat	4,0
maize	10,9
other cereals	1,8
durum	4,3
potato	30,7
rape	2,7
sunflower	2,6
soya	2,5
flax	2,0
fruit mix	48,8
vegetable mix	62,5
pulses	2,6
sugarbeet	10,0
triticale	4,8
mixed grain	3,9
walnut	4,5
cultivated grassland	5,2
extensive grassland	0,8
field forage	8,1

corn silage	12,5

Table 27: head of animals in Austria (BMLFUW, 2008a)

	head
young cattle	1.083.994
dairy cows	557.437
other bovines	407.569
fattening pigs	1.212.774
breeding pigs	330.027
piglets and young pigs (<50 kg)	1.694.576
sheeps	374.265
goats	55.939
horses	85.237
chicken	12.113.609
other poultry	670.664
farmed game	40.647

average years 2001-2006

3.4 Crop production area

Table 28: Agricultural area used for production of different crops in Austria

crops	ha
wheat	265.465
durum	15.056
spelt	4.854
rye	42.300
barley	203.374
oat	32.265
triticale	35.941
mixed grain	9.627
other cereals	4.015
maize	170.367
pulses	44.012
potato	22.133
sugarbeet	43.598
rape	44.772
sunflower	26.874
other oilfruits	23.067
soya	18.350
field forage	252.902
other crops	19.137
cultivated grassland	895.141
extensive grassland	883.220

fallow land	103.740
sum	3.160.212

average years 2001-2006
(BMLFUW, 2008a)

3.5 Data for Water Footprint Calculation

Table 29: Parameters used for different crops for water footprint calculation

	Kc ini	Kc mid	Kc end	Initial stage [days]	Dev. Stage [days]	Mid stage [days]	Late stage [days]	planting/green up date
wheat	0,7	1,15	0,3	130	70	70	25	15.Oct
rye	0,3	1,15	0,25	130	60	60	40	01.Oct
barley	0,3	1,15	0,25	130	70	70	25	01.Oct
oat	0,3	1,15	0,25	40	30	40	20	01.Apr
triticale	0,3	1,15	0,3	130	70	70	25	15.Oct
maize	0,3	1,2	0,5	30	40	50	30	15.Apr
potato	0,5	1,15	0,75	30	35	50	30	01.Apr
rape	0,35	1,15	0,35	130	58	59	29	15.Sep
sunflower	0,35	1,15	0,35	25	35	45	25	01.May
soya	0,4	1,15	0,5	20	25	75	30	01.May
flax	0,35	1,1	0,25	25	35	50	40	15.Apr
grain peas	0,5	1,15	0,3	35	25	30	20	15.Apr
broad bean	0,5	1,15	0,3	15	25	25	15	01.May
sugarbeet	0,35	1,2	0,7	50	42	55	50	02.Apr
corn silage	0,3	1,2	0,5	25	40	45	30	15.Apr
clover	0,4	0,95	0,4	10	15	75	35	15.Apr
seeded pastures	0,95	1,05	1	10	15	75	35	15.Mar
cultivated grassland	0,4	0,95	0,4	10	15	90	60	15.Apr
extensive grassland	0,3	0,75	0,75	10	20	10	100	15.Apr
apple	0,6	0,95	0,75	60	90	100	20	01.Mar
strawberry	0,6	0,95	0,75	60	90	100	20	01.Mar
apricot	0,4	0,85	0,75	20	40	120	90	01.Mar
string bean	0,5	1,05	0,9	20	30	30	10	01.Mar
carrots	0,7	1,05	0,95	30	50	90	30	01.Mar
tomatos	0,6	1,15	0,8	35	40	50	30	20.May
onions	0,7	1,05	0,75	20,35	110	45	40	01.Mar
pumpkin	0,5	0,95	0,75	25	35	35	25	15.Jun
cabbage	0,7	1,05	0,95	40	60	50	15	15.May
salat	0,7	1	0,95	35	50	20	45	01.Mar

Data sources: own compilation based upon data from Chapagain and Hoekstra (2004) and ZAMG (2011)

<u>Abbreviations:</u>

Kc ini	crop coefficient during the initial growth stage [-]
Kc mid	crop coefficient during the mid-season growth stage [-]
Kc end	crop coefficient at end of the late season growth stage [-]
Initial stage	duration of initial growth stage in days
Dev. stage	duration of the transition from initial to mid-season growth stage in days
Mid stage	duraction of mid-season growth stage in days
Late stage	duration of the transition from mid-season to the late season growth stage (harvest) in days
planting/green up date	average green up date based upon phenological observations
ETo	reference crop evapotranspiration [mm day-1]
ETc	crop evapotranspiration under standard conditions [mm day-1]

The parameter shown here are in combination with ETo the basis for the calculation of ETc. ETc is necessary for the calculation of the crop water requirement for each growth stage. In combination with precipitation data and soil moisture storage the irrigation demand is calculated. The calculations were performed using the CROPWAT 8.0 programm of the FAO (FAO, 2009b). This programm is based upon the work from Allen et al. (1998). ETo and precipitation data:

Spatial data from FAO (2004a, 2004b) were used to extract for each agricultural production area the montly precipiation and ETo data. The data published by the FAO are processed climate data from the Climate Resarch Unit (CRU) published in New et al. (2002).

Appendix B: results and intermediate results

3.6 Agricultural land use

Table 30: Agricultural used land for several scenarios and different purposes.

	production for				
$m^2\ cap^{-1}$	plant based food	animal based food	bio energy	raw material for industry	no use
reference situation -- domestic production					
arable land	416	980	23	128	
fruits	14	0	0	5	
vegetables	12	0	0	0	
productive grassland	0	1,101	0	0	
low yielding grassland	0	1,086	0	0	
fallow land					128
sum	443	3,168	23	133	128
reference situation -- domestic consumption					
arable land	568	1,241	73	151	
fruits	25	0	0	8	
vegetables	23	0	0	0	
productive grassland	0	877	0	0	
low yielding grassland	0	865	0	0	
fallow land					128
sum	616	2,983	73	159	128
scenario 1A -- domestic consumption = domestic production					
arable land	560	697	73	151	
fruits	45	0	0	12	
vegetables	37	0	0	0	
productive grassland	0	624	0	0	
low yielding grassland	0	616	0	0	
fallow land					128
sum	642	1,937	73	163	128
scenario 1B -- domestic consumption = domestic production					
arable land	560	630	182	151	
fruits	45	0	0	12	
vegetables	37	0	0	0	
productive grassland	0	624	56	0	
low yielding grassland	0	616	0	0	
fallow land					128
sum	642	1,870	238	163	128
scenario 1C -- domestic consumption = domestic production					
arable land	560	630	182	151	
fruits	45	0	0	12	
vegetables	37	0	0	0	
productive grassland	0	624	438	0	
low yielding grassland	0	616	0	0	
fallow land					128
sum	642	1,870	621	163	128
scenario 2A -- domestic production					
arable land	832	447	105	269	
fruits	64	0	0	16	
vegetables	45	0	0	0	
productive grassland	0	885	0	0	
low yielding grassland	0	920	0	0	
fallow land					0
sum	941	2,252	105	285	0
scenario 2A -- domestic consumption					

arable land	832	557	105	269	
fruits	64	0	0	16	
vegetables	45	0	0	0	
productive grassland	0	885	0	0	
low yielding grassland	0	920	0	0	
fallow land					0
sum	941	2,361	105	285	0
scenario 3A -- domestic production					
arable land	487	662	14	139	
fruits	22	0	0	7	
vegetables	20	0	0	0	
productive grassland	0	854	0	0	
low yielding grassland	0	842	0	0	
fallow land					128
sum	530	2,358	14	147	128
scenario 3B -- domestic production					
arable land	502	659	238	141	
fruits	22	0	0	7	
vegetables	20	0	0	0	
productive grassland	0	854	101	0	
low yielding grassland	0	842	0	0	
fallow land					128
sum	544	2,355	339	148	128
scenario 3C -- domestic production					
arable land	502	659	238	141	
fruits	22	0	0	7	
vegetables	20	0	0	0	
productive grassland	0	854	237	0	
low yielding grassland	0	842	0	0	
fallow land					128
sum	544	2,355	475	148	128

3.7 N and P fluxes

Table 31: N and P fluxes for the system agriculture containing the two processes "plant production and agricultural soil" and "animal husbandry".

kg N cap^{-1} y^{-1} and kg P cap^{-1} y^{-1}		ref	sc 1A	sc 1B	sc 1C	sc 2A	sc 3A	sc 3B	sc 3C
Animal husbandry									
source process	input								
plant production and agricultural soil	fodder	15 / 2.8	9 / 1.6	9 / 1.6	9 / 1.6	11 / 2	12 / 2.2	12 / 2.2	12 / 2.2
industry	feedstuff	12 / 1.8	7 / 1	7 / 1	7 / 1	5 / 0.7	7 / 1	7 / 1	7 / 1
destination process	output								
plant production and agricultural soil	manure	19 / 3.4	10 / 1.8	10 / 1.8	10 / 1.8	11 / 2	13 / 2.3	13 / 2.3	13 / 2.3
industry	animal products	5 / 1.1	3 / 0.6	3 / 0.6	3 / 0.6	3 / 0.6	3 / 0.7	3 / 0.7	3 / 0.7
troposphere	NH_3-N	3 / -	2 / -	2 / -	2 / -	2 / -	2 / -	2 / -	2 / -
troposphere	N_2O-N	0.2 / -	0.1 / -	0.1 / -	0.1 / -	0.1 / -	0.1 / -	0.1 / -	0.1 / -
storage	animals	4 / 0.8	2 / 0.4	2 / 0.4	2 / 0.4	2 / 0.4	3 / 0.5	3 / 0.5	3 / 0.5
sum input		27 / 4.7	15 / 2.6	15 / 2.6	15 / 2.6	16 / 2.7	19 / 3.2	19 / 3.2	19 / 3.2

sum output		27 / 4.5	15 / 2.4	15 / 2.4	15 / 2.4	16 / 2.6	19 / 3	19 / 3	19 / 3
plant production and agricultural soil									
source process	input								
animal husbandry	manure	19 / 3.4	10 / 1.8	10 / 1.8	10 / 1.8	11 / 2	13 / 2.3	13 / 2.3	13 / 2.3
industry	biogas residues	0 / 0	0 / 0	1 / 0.1	5 / 0.9	1 / 0.1	0 / 0	1 / 0.2	2 / 0.5
waste and wastewater treatment	sludge	0 / 0.1	0 / 0.1	0 / 0.1	0 / 0.1	0 / 0	0 / 0.1	0 / 0.1	0 / 0.1
waste and wastewater treatment	compost	1 / 0.2	1 / 0.2	1 / 0.2	1 / 0.2	1 / 0.2	1 / 0.2	1 / 0.2	1 / 0.2
industry	mineral fertilizer	13 / 2.1	12 / 2.1	14 / 2.3	16 / 2.4	0 / 1.7	12 / 2	15 / 2.4	16 / 2.5
industry	seed	0.3 / 0.1	0.3 / 0	0.3 / 0.1	0.3 / 0.1	0.2 / 0	0.3 / 0.1	0.3 / 0.1	0.3 / 0.1
troposphere	deposition	6 / 0.1	4 / 0.1	4 / 0.1	4 / 0.1	4 / 0.1	4 / 0.1	5 / 0.1	5 / 0.1
troposphere	N-fixation	6 / -	4 / -	4 / -	4 / -	14 / -	5 / -	5 / -	5 / -
destination process	output								
animal husbandry	fodder	15 / 2.8	9 / 1.6	9 / 1.6	9 / 1.6	11 / 2	12 / 2.2	12 / 2.2	12 / 2.2
industry	plant products	13 / 2.6	12 / 2.3	13 / 2.7	18 / 3.5	9 / 1.7	11 / 2.1	14 / 2.8	14 / 3.1
surface water	emissions	2 / 0.1	2 / 0.1	2 / 0.1	2 / 0.1	2 / 0.1	2 / 0.1	2 / 0.1	2 / 0.1
groundwater	emissions	9 / 0.1	6 / 0	7 / 0	8 / 0	6 / 0	7 / 0	8 / 0	9 / 0
troposphere	NH_3, N_2O, NO_x emissions	4 / -	3 / -	3 / -	4 / -	3 / -	3 / -	4 / -	4 / -
troposphere	denitrification	1.3 / 0	0.5 / 0	0.7 / 0	0.4 / 0	0.2 / 0	0.7 / 0	1.1 / 0	1.3 / 0
storage	soil	2966 / 1483	2248 / 1124	2321 / 1161	2608 / 1304	2152 / 1076	2427 / 1214	2681 / 1341	2783 / 1391
sum input		45 / 6	31 / 4.3	34 / 4.7	41 / 5.6	30 / 4.1	35 / 4.7	40 / 5.4	42 / 5.8
sum output		45 / 5.6	31 / 4.1	34 / 4.5	41 / 5.3	30 / 3.9	35 / 4.5	40 / 5.1	42 / 5.4

3.8 **Water Footprint Calculations**

Table 32: Effective Rainfall

mm yr^{-1}	planting/ green up date	Hochalpen	Voralpen	Alpenostrand	Wald- und Mühlviertel	Kärntner Becken	Alpenvorland	Südöstliches Flach- und Hügelland	Nordöstliches Flach- und Hügelland
wheat	15.Okt	469,2	534,7	499,1	485,5	518,2	534,5	504,8	380,6
rye	01.Okt	341,8	397,6	369,8	393,4	386,6	397,5	414,1	307,4
barley	01.Okt	370	431,5	401,3	395,8	420,3	431,6	410,8	305,6
oat	01.Apr	275,6	327,5	304,5	306,3	322,9	328,3	329,7	237,3
triticale	15.Okt	469,2	534,7	499,1	485,5	518,2	534,5	504,8	380,6
maize	15.Apr	371,8	431	405,7	367,7	427,9	434,1	406,3	278,6
potato	01.Apr	373	441,2	410,6	374,2	434,3	441,6	423,2	274,3

rape	15.Sep	282,8	320,5	299,5	317,1	309,5	319,8	327,6	260
sunflower	01.Mai	325	378,5	354	339,6	373,2	378,5	375,7	260,1
soya	01.Mai	403,8	467,7	438,2	404,2	461,3	467,7	453,1	267,3
flax	15.Apr	340,8	400,3	373,4	385,6	394,4	400,4	424	290,8
grain peas	15.Apr	180,7	221	203,8	212,7	216,9	221,5	223,4	169,4
broad bean	01.Mai	194,1	234	216,8	226,2	230,5	234,7	240,3	175,7
sugarbeet	02.Apr	442,2	503	475,2	429	499,1	505,9	490,5	337,5
corn silage	15.Apr	350,1	411,3	383,6	355,8	405,4	411,5	388,3	268,3
clover	15.Apr	316,8	375,8	349,3	372,2	369,6	376	399,3	293,7
seeded pastures	15.Mär	346,6	414,1	384,2	382,2	407	414,8	400,1	272,9
cultivated grassland	15.Apr	390,4	456,5	426,3	452,6	449,4	456,5	484,2	345,6
low yielding grassland	15.Apr	273,4	322,8	300,5	319,9	317,6	322,8	342,7	285,4
apple	01.Mär	504,1	564,8	532,8	546,8	555,8	564,7	598,8	458,7
strawberry	01.Mär	504,1	564,8	532,8	546,8	555,8	564,7	598,8	458,7
apricot	01.Mär	504,2	571,6	537,5	568,1	562,2	571,6	606,7	451,8
string bean	01.Mär	143,5	172,8	159,6	161,4	168,5	172,6	166,8	128,9
carrots	01.Mär	490,1	568,8	535,5	506,2	564,2	569,8	552,6	372,7
tomatos	20.Mai	375,6	417,3	398,3	365,1	416,8	422,1	423,1	298,3
onions	01.Mär	492,2	572,2	535,2	524	563,1	572	585,1	394,1
pumpkin	15.Jun	243,5	272,6	257,8	259,1	269,3	272,3	287,4	216,4
cabbage	15.Mai	378,2	424	399,8	391,7	418,3	424	447,5	318,9
salat	01.Mär	326	387,8	360,1	368,7	381,1	388,3	395,9	283,7

Table 33: Actual water demand by crops

mm yr^{-1}	planting/ green up date	Hochalpen	Voralpen	Alpenostrand	Wald- und Mühlviertel	Kärntner Becken	Alpenvorland	Südöstliches Flach- und Hügelland	Nordöstliches Flach- und Hügelland
wheat	15.Okt	471,4	537,2	501,5	532,8	520,7	537	568,9	617,9
rye	01.Okt	341,8	397,6	369,8	393,4	386,6	397,5	424,7	459,9
barley	01.Okt	377,4	439,9	409,2	435,4	428,6	440	469,2	508,2
oat	01.Apr	276,8	328,9	305,9	325,7	324,3	329,7	349,8	378,6
triticale	15.Okt	471,4	537,2	501,5	532,8	520,7	537	568,9	617,9
maize	15.Apr	378,5	441,5	412,7	437,7	435,2	441,5	467,7	507,8
potato	01.Apr	373	441,2	410,6	437	434,3	441,6	469,1	508,6
rape	15.Sep	282,8	320,5	299,5	317,1	309,5	319,8	342,7	371,2
sunflower	01.Mai	325	378,5	354	375,3	373,2	378,5	400,7	435
soya	01.Mai	403,8	467,7	438,2	463,9	461,3	467,7	494,8	537,2
flax	15.Apr	344,2	404,1	377	400,5	398,2	404,3	428,5	464,9
grain peas	15.Apr	180,7	221	203,8	218,7	216,9	221,5	235,6	254,8
broad bean	01.Mai	197,6	238	220,5	235,6	234,5	238,7	252,8	273,3
sugarbeet	02.Apr	444,4	507,7	477	504	500,9	507,7	537,5	583,9
corn silage	15.Apr	359,5	421,8	393,6	418,1	415,7	422	447,1	485,1
clover	15.Apr	316,8	375,8	349,3	372,2	369,6	376	399,3	432,7
seeded pastures	15.Mär	346,6	414,1	384,2	409,3	407	414,8	444,1	480,1
cultivated grassland	15.Apr	392,5	458,4	428,2	454,5	451,4	458,5	486,2	527,5
low yielding grassland	15.Apr	283,7	334,4	311,5	331,4	329	334,4	354,9	385
apple	01.Mär	506	566,7	534,6	563,6	557,5	566,6	600,6	651,6
strawberry	01.Mär	506	566,7	534,6	563,6	557,5	566,6	600,6	651,6
apricot	01.Mär	506	573,4	539,3	569,9	563,9	573,4	608,5	660
string bean	01.Mär	149	179,4	165,7	176,9	175	179,3	194,9	210,4
carrots	01.Mär	496,6	580,8	542,2	574,9	571,2	580,6	618,9	670,8
tomatos	20.Mai	380,8	426,6	402,7	424,3	421,1	426,5	450,1	489,4
onions	01.Mär	498,7	578,9	541,7	573,3	569,8	578,8	616,5	668,2
pumpkin	15.Jun	250,4	279	264,1	277,4	275,6	278,7	294,1	320,1
cabbage	15.Mai	382,5	427,9	403,6	425,7	422	427,8	451,5	490,6
salat	01.Mär	329,2	391,5	363,6	386,8	384,7	392	419,2	452,9

Table 34: Soil moisture deficit at harvest

mm yr^{-1}	planting/ green up date	Hochalpen	Voralpen	Alpenostrand	Wald- und Mühlviertel	Kärntner Becken	Alpenvorland	Südöstliches Flach- und Hügelland	Nordöstliches Flach- und Hügelland
wheat	15.Okt	2,2	2,5	2,4	47,3	2,5	2,5	64,1	197,3
rye	01.Okt	0	0	0	0	0	0	10,6	152,5
barley	01.Okt	7,4	8,4	7,9	39,5	8,3	8,4	58,3	122,5
oat	01.Apr	1,2	1,4	1,3	19,4	1,4	1,4	20,1	141,3
triticale	15.Okt	2,2	2,5	2,4	47,3	2,5	2,5	64,1	197,3
maize	15.Apr	6,5	10,5	7	70	7,3	7,3	61,3	149,2
potato	01.Apr	0	0	0	22,9	0	0	22,9	34,4
rape	15.Sep	0	0	0	0	0	0	15,1	111,2
sunflower	01.Mai	0	0	0	35,8	0	0	25	134,9
soya	01.Mai	0	0	0	59,7	0	0	41,7	114,8
flax	15.Apr	3,5	3,8	3,7	15	3,8	3,8	4,5	134,1
grain peas	15.Apr	0	0	0	5,9	0	0	12,2	85,4
broad bean	01.Mai	3,5	4	3,8	9,4	4	4	12,5	97,6
sugarbeet	02.Apr	2,2	4,7	1,8	75,1	1,8	1,8	47	126,4
corn silage	15.Apr	9,4	10,5	9,9	62,3	10,3	10,4	58,8	136,9
clover	15.Apr	0	0	0	0	0	0	0	139
seeded pastures	15.Mär	0	0	0	27,2	0	0	44	167,1
cultivated grassland	15.Apr	2,1	1,9	1,9	2	1,9	1,9	2	141,9
low yielding grassland	15.Apr	10,3	11,6	11	11,5	11,4	11,5	12,2	99,6
apple	01.Mär	1,9	1,8	1,8	16,8	1,7	1,8	1,9	112,8
strawberry	01.Mär	1,9	1,8	1,8	16,8	1,7	1,8	1,9	112,8
apricot	01.Mär	1,8	1,8	1,8	1,9	1,7	1,8	1,8	128,2
string bean	01.Mär	5,5	6,7	6,2	15,5	6,5	6,7	28,1	81,5
carrots	01.Mär	6,6	12	6,8	68,7	7	10,9	66,3	138,1
tomatos	20.Mai	5,3	9,3	4,3	59,1	4,3	4,4	27,1	111,1
onions	01.Mär	6,5	6,7	6,5	49,3	6,7	6,8	31,4	154,1
pumpkin	15.Jun	6,9	6,4	6,2	18,4	6,3	6,4	6,7	103,7
cabbage	15.Mai	4,4	3,8	3,8	34	3,7	3,8	3,9	91,6
salat	01.Mär	3,2	3,7	3,5	18,1	3,6	3,7	23,3	169,1

Table 35: Calculated irrigation demand

mm yr^{-1}	planting/ green up date	Hochalpen	Voralpen	Alpenostrand	Wald- und Mühlviertel	Kärntner Becken	Alpenvorland	Südöstliches Flach- und Hügelland	Nordöstliches Flach- und Hügelland
wheat	15.Okt	0	0	0	0	0	0	0	40
rye	01.Okt	0	0	0	0	0	0	0	0
barley	01.Okt	0	0	0	0	0	0	0	80
oat	01.Apr	0	0	0	0	0	0	0	0
triticale	15.Okt	0	0	0	0	0	0	0	40
maize	15.Apr	0	0	0	0	0	0	0	80
potato	01.Apr	0	0	0	40	0	0	23	200
rape	15.Sep	0	0	0	0	0	0	0	0
sunflower	01.Mai	0	0	0	0	0	0	0	40
soya	01.Mai	0	0	0	0	0	0	0	155
flax	15.Apr	0	0	0	0	0	0	0	40
grain peas	15.Apr	0	0	0	0	0	0	0	0
broad bean	01.Mai	0	0	0	0	0	0	0	0
sugarbeet	02.Apr	0	0	0	0	0	0	0	120
corn silage	15.Apr	0	0	0	0	0	0	0	80
clover	15.Apr	0	0	0	0	0	0	0	0
seeded pastures	15.Mär	0	0	0	0	0	0	0	40
cultivated grassland	15.Apr	0	0	0	0	0	0	0	40
low yielding grassland	15.Apr	0	0	0	0	0	0	0	0
apple	01.Mär	0	0	0	0	0	0	0	80
strawberry	01.Mär	0	0	0	0	0	0	0	80
apricot	01.Mär	0	0	0	0	0	0	0	80
string bean	01.Mär	0	0	0	0	0	0	0	0
carrots	01.Mär	0	0	0	0	0	0	0	160
tomatos	20.Mai	0	0	0	0	0	0	0	80
onions	01.Mär	0	0	0	0	0	0	0	120
pumpkin	15.Jun	0	0	0	0	0	0	0	0
cabbage	15.Mai	0	0	0	0	0	0	0	80
salat	01.Mär	0	0	0	0	0	0	0	0

<u>Explaination:</u>

effective rainfall	is defined as precipitation used by the plants
actual water demand by crop	the sum of water actual used by the crop (when no water limitation occurs)
soil moisture deficit at harvest	is definied as soil moisture at harvest (calculated) minus soil moisture at planting date (assumed to be 100 % of soil field capacity)
calculated irrigation demand	is calculated as actual water demand minus effective rainfall minus soil moisture deficit at harvest; it is assumed that the soil moisture deficit is filled up during winter precipitation and therefore green water (Thaler et al., 2012)

Appendix C: Authorship

Chapter ii of this thesis is based on the paper “Considerations on methodological challenges for water footprint calculations” by Simon Thaler, Matthias Zessner, Fátima Bertrán de Lis, Norbert Kreuzinger, Fehringer Roland, Water Science and Technology 65(7), (2012) 1258-1264.

The contribution of Simon Thaler to this paper was:

- concept and method development
- data preparation in GIS
- literature research
- calculations
- paper writing

Chapter iii of this thesis is based on the paper “Impacts of human nutrition on land use, nutrient balances and water consumption in Austria” by Simon Thaler, Matthias Zessner, Maria Magdalena Mayr, Tamara Haider, Helmut Kroiss, Helmut Rechberger, Sustainability of Water Quality and Ecology 1-2, (2014), 24-39.

The contribution of Simon Thaler to this paper was:

- concept and method development
- literature research
- data collection and preparation
- performance of material flow analysis
- model simulations
- paper writing

Chapter iv of this thesis is based on the paper “Possible implications of dietary changes on environment and resources in Austria” by Simon Thaler, Matthias Zessner, Martin Weigl, Helmut Rechberger, Katerina Schilling, Helmut Kroiss, Agricultural Systems 136, (2015), 14–29.

The contribution of Simon Thaler to this paper was:

- concept and method development
- literature research
- scenario development
- data collection and preparation
- performance of material flow analysis
- model simulations
- paper writing

Chapter v of this thesis is based on the paper “How human diet impacts on waters and resources” by Simon Thaler, Matthias Zessner, Katerina Schilling, Helmut Kroiss, Water Science & Technology: Water Supply, 13(6), 1419-1424.

The contribution of Simon Thaler to this paper was:

- concept and method development
- data collection and preparation
- performance of material flow analysis
- model simulations
- paper writing