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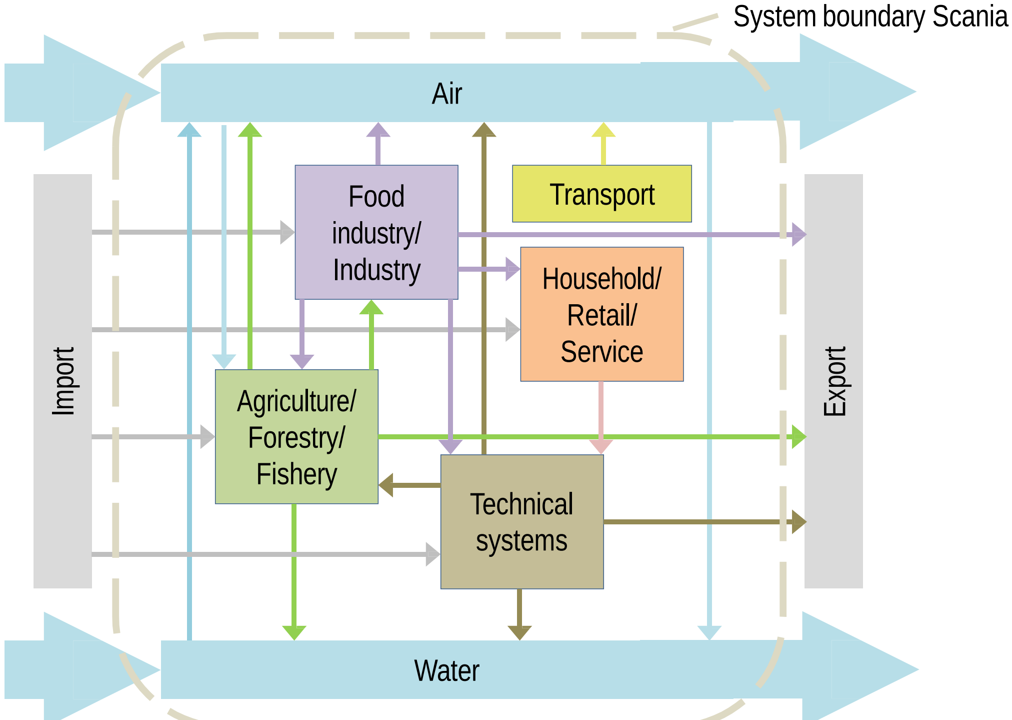

Nitrogen flow in Scania

– Substance flow analysis on a regional level

Johanna Hellstrand

Master's thesis

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Author: Johanna Hellstrand

Supervisor: Mats Johansson, Ecoloop
Co-supervisor: David Gustavsson, VA SYD
Examiner: Håkan Jönsson, Department of Energy and Technology, SLU

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Preface

This thesis is part of a project called *SuNha or later…* (SuNha - Sustainable urban Nitrogen handling), i.e. sooner or later we need to have sustainable nitrogen management in our society. The project was developed by David Gustavsson and funded by Sweden Water Research in Scania. The purpose of *SuNha or later…* is to explore effects and methods for recycling the urban nitrogen flow. One part of the project is a substance flow analysis for nitrogen. This is it.

The thesis work was carried out at Ecoloop, Stockholm, with Mats Johansson as supervisor. Parallel to this thesis a similar flow analysis for phosphorus in Scania was conducted by Linnea Seweling, Stockholm university. Seweling's report is called *Phosphorus flow in Scania - A substance flow analysis (Swedish: Fosforflöden i Skåne - En substansflödesanalys)* (Seweling, 2015) and the report is, at the time of writing, still in progress.

Johanna Hellstrand

June 2015

Abstract

In this thesis, the flows of reactive nitrogen (N_r) in Scania were investigated and quantified. The thesis was also intended to form a basis for comparison between the urban nitrogen flow and other flows of nitrogen within Scania. The management of nitrogen in society has disturbed the natural nitrogen cycle. This is linked to a series of environmental problems such as eutrophication, acidification, global warming and smog.

The method used was Substance Flow Analysis (SFA) for N_r. For calculation and flow charts Scania was divided into three subsystems; air, water and society. The society was divided into five sectors; agriculture/forestry/fishery, food industry/industry, household/retail/service, technical systems and transport. After that flows within the subsystems was identified, which could then be quantified by data collection and calculations.

The results showed that emissions to air mainly come from agriculture, transport and combustion. Agriculture contains the largest N_r flows, consisting of mineral fertilizer, deposition and nitrogen fixation. In agriculture, animal production creates an internal flow in the form of manure and feed from agricultural land. Scania has a large food production, where animal products, slaughtered animals, imported material and crops act as raw materials. A large proportion of the produced food is exported; resulting in a large outflow of N_r. Transport gives rise to a big part of the air emissions within Scania. A surplus of N_r in soil and water give rise to leakages to the surrounding seas. The relatively large urban nitrogen flow in Scania contributes to water discharges down-stream, energy consumption at WWTPs and N_r pollution up-stream. Only a small amount of the urban nitrogen flow is reused on agricultural land. There is a potential of increasing the reuse by installing urine-separating toilets. Another way of improving N_r management could be to eat less protein, i.e. give less N_r load into WWTP.

The conclusions are that Scania leaks N_r to air, water and soil. The nitrogen management generally needs to be improved to become sustainable and there is a great potential for improvements of the urban nitrogen flow by either changing the wastewater systems and/or changing the diets of the people living in Scania.

Sammanfattning

I detta examensarbete har Skånes flöden av reaktivt kväve (N_r) undersökts och kvantifierats. Examensarbetet avsåg även att utgöra en grund för jämförelse mellan det urbana kväveflödet och andra kväveflöden inom Skåne. Hanteringen av kväve i samhället har rubbat den naturliga kvävecykeln. Detta är kopplat till en rad miljöproblem, exempelvis övergödning, försurning, global uppvärmning och smog.

Metoden som användes var substansflödesanalys (SFA) för N_r. För beräkning och flödesbilder delades Skåne in i tre delsystem; luft, vatten och samhälle. Sedan delades samhället in i fem sektorer; jordbruk/skogsbruk/fiske, livsmedelsindustri/industri, hushåll/handel/service, tekniska system och transporter. Efter det identifierades flöden inom delsystemen, som sedan kunde kvantifieras genom datainsamling och beräkningar.

Resultaten visade att utsläppen till luft främst kommer från jordbruk, transporter och förbränning. Jordbruket innehåller de största flödena, bestående av mineralgödsel, deposition och kvävefixering. Inom jordbruket skapar djurproduktionen ett internt flöde i form av stallgödsel och foder från jordbruksmark. Skåne har en stor livsmedelsproduktion, där animaliska produkter, slaktade djur, importerat material och grödor fungerar som råvaror. En stor del av den producerade maten exporteras, vilket ger ett stort utflöde av N_r. Transport ger upphov till en stor del av utsläppen i luften inom Skåne. Ett överskott av N_r i mark och vatten ger upphov till läckage till de omgivande haven. Det relativt stora urbana kväveflödet i regionen bidrar till utsläpp i vatten nedströms, hög energianvändning vid reningsverken samt kväveföroreningar uppströms. Endast en liten mängd av det urbana kväveflödet återanvänds på jordbruksmark. En potentiell förbättring är att installera urinsorterande toaletter, vilket skulle kunna öka återanvändningen av det urbana kväveflödet. Andra sätt att förbättra hanteringen av N_r kan vara att minska kvävebelastning till reningsverken genom att äta mindre protein.

Slutsatserna är att Skåne läcker N_r till luft, vatten och mark. Kvävehanteringen behöver i allmänhet förbättras i Skåne för att bli hållbar och det finns en stor potential i att förbättra det urbana kväveflödet antingen genom att ha urinsorterande toaletter och/eller genom förändrad kost på de skånska matborden.

Populärvetenskaplig sammanfattning

Får vi en bättre framtid om vi byter toalett och diet?

Hur kväve hanteras i samhället idag är både ineffektivt, kontraproduktivt och miljöförstörande. Blir kvävehanteringen bättre med urinsorterande toaletter eller kostförändringar?

Reaktivt kväve (N_r) är former av kväve som på olika sätt kan reagera med sin omgivning, till skillnad mot icke-reaktiv kvävgas (N_2) som upptar 80 % av volymen i atmosfären. Mänskligheten har börjat pumpa ut N_r genom djurproduktion, odling av baljväxter, tillverkning av mineralgödsel samt genom förbränning av fossila bränslen och biomassa. N_r är kopplat till en rad miljöproblem där ett axplock är; övergödning, marknära ozon, smog, försurning, ozonförtunning och global uppvärmning. Enligt forskare är den planetära gränsen för kväve redan nådd, vilket betyder att planeten inte längre kan kompensera för den hantering av kväve som vi har, utan effekterna kan vara katastrofala och oförutsedda. Och som grädde på moset står produktion av mineralgödsel för ca 2 % av världens energianvändning. För att ytterligare påvisa kvävehanteringens ineffektivitet i samhället visar det sig att det finns en nästan helt outnyttjad kväveresurs i toalettavfallet, som allt som oftast går till spillo genom energikrävande processer i reningsverken som skapar N_2, utsläpp till vatten och slam. Ungefär 20 % av N_r i inflödet till reningsverken hamnar i slammet, som kanske sprids på åkermark. Kan vi förbättra vår kvävehantering här? Eftersom urin innehåller mycket kväve och dieten påverkar mängd kväve i toalettavfallet – blir kvävehanteringen bättre med urinsorterande toaletter eller kostförändringar? För att kunna svara på detta behövs kunskap om mängd N_r som finns i samhället och hur stora eller små flödena är. Därför gjordes en substansflödesanalys för N_r i Skåne. Resultatet ses i bilden till höger. Det visar sig att det är mest N_r i omlopp inom jordbruket, där det finns ett stort inflöde av mineralgödsel, stora interna flöden av foder och stallgödsel samt stora utsläpp till vatten och luft. Flöden in och ut ur hushåll och handel är det urbana kväveflödet där N_r i intagen mat hamnar i toalettavfallet, mestadels i urinen. Mängden N_r i den skånska urinen motsvarade 16 % av mängden N_r i mineralgödsel i skånska jordbruket. I bilden visar den lilla pilen mellan avfallshantering och jordbruk, Skånes återvinning av N_r. Den ser försvinnande liten ut jämfört med de andra pilarna i jordbruket och det urbana flödet ut ur hushåll och handel. Om man skulle ta skåningarnas urin och återföra denna till åkermark skulle återvinningen av det urbana flödet kunna öka med 900 % i Skåne. Dessutom skulle energianvändningen i reningsverken minska och i och med ett minskat behov av mineralgödsel skulle även mindre energi behövas i tillverkningen av denna. Negativa effekter är att urin som gödsel ökar försurnings- och övergödningspotentialen. Utsläpp till vatten torde vara oförändrat eftersom reningsverk följer de krav som ställs. Ett annat förslag är att skåningarna skulle äta mindre protein vilket skulle leda till mindre mängd intagen N_r och därmed en mindre mängd N_r som hamnar i toaletten. Detta skulle kunna minska energianvändningen i reningsverken. Om man dessutom minskar på mängden animaliskt protein skulle effekterna även kunna vara uppströms i och med minskad djurproduktion. Så vad byter du helst, toalett eller diet?

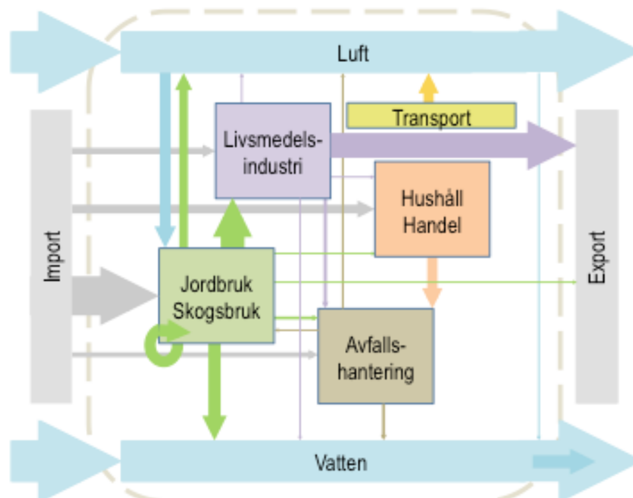

Bild. Resultatet av substansflödesanalysen för Skåne.

Acronyms

ha	Hectare (10,000 m^2)
MFA	Material flow analysis
N	Nitrogen
N_r	Reactive nitrogen
PE	Person Equivalent - average amount of emission in wastewater that one person produces per day
SFA	Substance flow analysis
WWTP	Wastewater treatment plant

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1 Introduction

Nitrogen gas (N_2) occupies almost 80% of in the volume of the atmosphere. Its reactive forms (N_r) are essential nutrients for plants, which make it crucial for feeding humans (Sutton et al., 2013). The production of fertilizers, cultivation of legumes, combustion of fossil fuels and biomass has led to intensification of N_r flows. N_r is partly responsible for acidification, eutrophication, global warming and ozone depletion (Sutton et al., 2013).

The anthropogenic impact on the natural nitrogen cycle has already exceeded the planetary boundary for humanity to operate safely (Rockström et al., 2009; Steffen et al., 2015). The disturbance of the nitrogen cycle is affecting the environment, health and economy and the production of fertilizer when turning N_2 into N_r is energy demanding (Sutton et al., 2013).

The nitrogen content food is directly connected to protein content and about 16% of the protein is nitrogen (Danius, 2002; Swedish Food Agency, 2015). According to Danius and Burström (2001), essentially all consumed quantity of N_r ends up in urine and faeces and then enters wastewater management. This makes the amount of nitrogen in the toilet directly connected to the diet. About 90% of the nitrogen leaving your body will be dissolved in urine (SMED, 2006). The nitrogen in food, toilet waste and food waste is what will be referred to as the *urban nitrogen flow*.

The nitrogen in the Swedish toilet waste corresponds to 20% of the sold fertilizer and is in economic terms five times as valuable as the phosphorus in the toilet waste, when valued at the price of mineral fertilizers (Jönsson, 2011). Swedish farmers use about 13 times as much nitrogen as phosphorus and in economic terms they spend about nine times as much on nitrogen fertilizers as on phosphorus fertilizers (Jönsson, 2011).

The Swedish government has set goals for recycling of phosphorus, but no other plant nutrients have been included given quantified goals. When recycling toilet waste from the wastewater sludge the phosphorus content is enough to reach the goals for recycling phosphorus, but when more nutrients are included in the goal, such as nitrogen, source separation becomes interesting solution to reach the goals. The Swedish EPA has proposed as new goals for recycling of plant nutrients from toilet waste that at least 10% of the nitrogen and 40% of the phosphorus in Swedish wastewater should be reused on arable land (Swedish EPA, 2013).

Scania is a county in the south of Sweden. Year 2013 the population in the county was almost 1.3 million, which represents 14% of the total population in Sweden (Statistics Sweden, 2014a). Sjölunda Wastewater Treatment Plant (WWTP), in the south of Scania, receives about 1350 l/s of wastewater on average, which makes it one of Sweden's largest WWTP (VA SYD, 2014). Large investments and strategic choices in terms of nitrogen removal in Sjölunda WWTP are to be made soon.

Substance Flow Analysis (SFA) is a method of determining flows and may be a basis for making decisions in the environmental field from the perspective of improving the efficiency of material or substance flow (Huanga et al., 2012).

The material flows in cities are most often linear, which means that there is no cycling of material (Brunner & Rechberger, 2004). When the substance and material flows are analysed it gives insight to their impact on the environment, resource use, economy and society (Huanga et al., 2012). Recycling or source separation of the toilet waste could potentially have many positive consequences, such as reduced need for mineral fertilizer and reduced energy use followed by reduced climate impact. This thesis investigated the flow of N_r in Scania and examined the potential for the urban nitrogen flow compared to other flows of nitrogen within the region.

1.1 Aim and research questions

The aim was to make a substance flow analysis of reactive nitrogen (N_r) in Scania. From the substance flow analysis the impact and potential for possible changes of the urban nitrogen flow was investigated. The following research questions (RQ) were addressed:

RQ1. How big were the urban nitrogen flows in Scania in relation to other nitrogen flows?

RQ2. Is urine separation a potential improvement of the urban nitrogen flow?

RQ3. Is change in diet a potential improvement of the urban nitrogen flow?

1.2 Scope

Part of the assignment for this thesis was to use the method substance flow analysis (SFA) (Sweden Water Research, n.d.). Sörenby (2010) did a comparison between SFA and other methods for quantifying flows and stocks of phosphorus in Stockholm County and concluded that, for the purpose of mapping and quantifying flows, the SFA method is suitable. With those two reasons no further effort, to find better methods for fulfilling the purpose of this thesis, was made.

1.3 Disposition

A review of how the paper is organized is presented below:

Chapter 1. **Introduction** – the thesis is introduced and aims and research questions are presented.

Chapter 2. **Background** – a short literature review concerning the topics; the region Scania, nitrogen cycle and the human interference of the nitrogen cycle.

Chapter 3. **Methods and materials** – a description of how the master thesis was carried out.

Chapter 4. **Substance flow analysis for Scania** – the result of the substance flow analysis. Calculation, assumption and illustrations are presented.

Chapter 5. **Possible changes of urban nitrogen flow** – a literature review together with rough calculation to discuss the effects of dietary change or urine separation.

Chapter 6. **Discussion** – the results from chapter 4 and 5 is discussed.

Chapter 7. **Conclusions** – the conclusions together with suggestions for future work.

2 Background

In the first section of this chapter (2.1 Scania), the region of Scania will be introduced. In the second section (2.2 Nitrogen) nitrogen's natural cycle and the anthropogenic influence on it will be reviewed. In the third section (2.3 Methods of flow analysis) the method for substance flow analysis will be presented.

2.1 Scania

Scania is a region in the south of Sweden (Figure 1). The region has 33 municipalities and the largest cities are Malmö, Helsingborg, Lund and Kristianstad (Skane, n.d.). The population in Scania the 31st of December 2010 was 1,243,329 people (Statistics Sweden, n.d.). About 45% of the Scania area is agricultural land, and 34% of the land is productive forestland (Statistics Sweden, 2010). The region has many potential sources of plant nutrients such as WWTP, industries and agriculture and Scania is Sweden's most agriculturally intensive county (Ekologgruppen i Landskrona AB, 2010). In fact 17% of Sweden's agricultural land is located in Scania (Statistics Sweden, 2010). The share of Swedish-produced foods produced in Scania is about a quarter of the total food produced in Sweden (Jörgenson, 2013). This altogether makes the load of nutrients to streams and coastal waters potentially high.

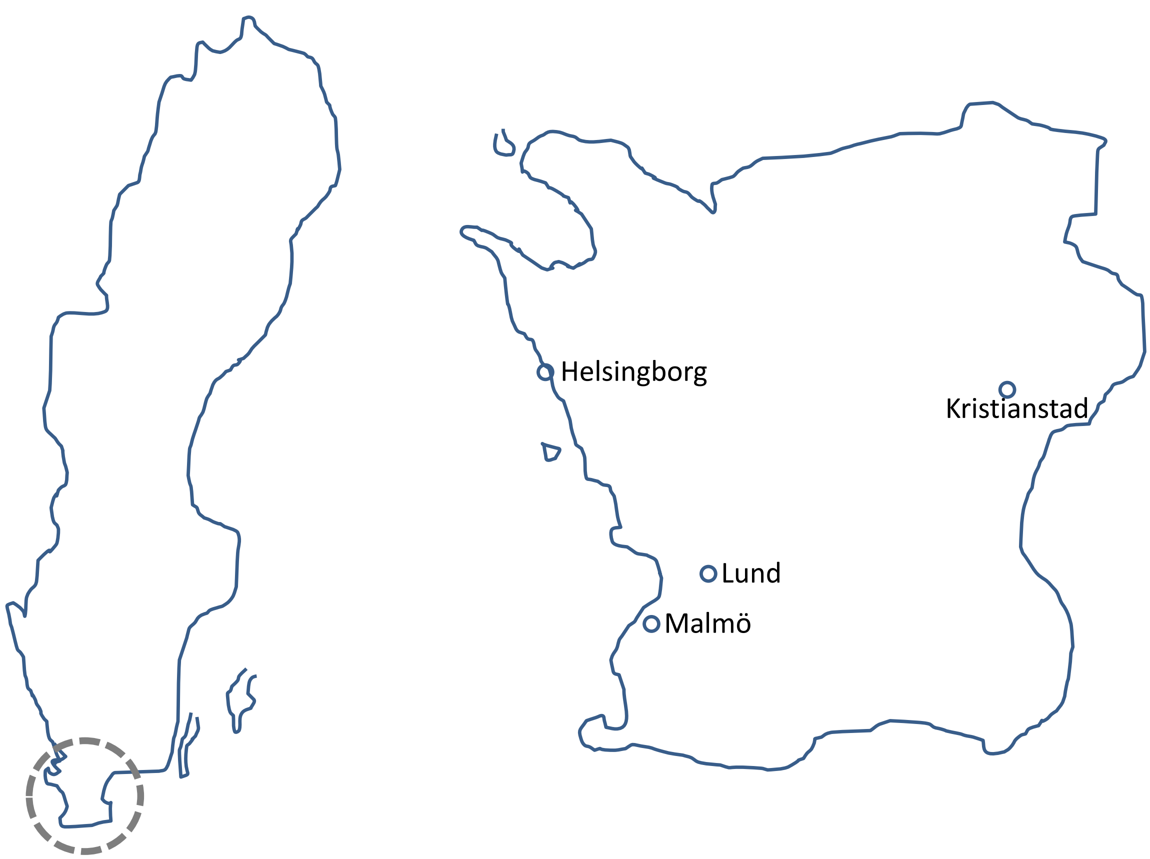


Figure 1. To the left – Sweden with a circle around Scania, to the right – the region of Scania. Sjölunda WWTP is located in Malmö.

2.2 Nitrogen

Most of the nitrogen on the planet earth is on the form of N_2.The atmosphere consists to 78% by volume of N_2. The gas is with its triple bond very stable and therefore not usable by most organisms, which instead depend on small flows of reactive nitrogen (N_r), which refers to all forms of N except for N_2 (Sutton et al., 2013).

In organic compounds, nitrogen is a building block for proteins and nucleic acids thus all organisms need it for living and growing. Nitrogen is in nature a limiting plant nutrient. There are mainly two forms that plants can take up for their metabolism; ammonium and nitrate. Animals can only utilize organic forms of nitrogen (Markov, 2015).

Atmospheric deposition, when nitrogen reaches the ground from air, is mostly in the forms of nitrate or ammonium (Statistics Sweden, 2013a). In Table 1, various forms of nitrogen are introduced.

Table 1. Different forms of nitrogen. Plant nutrients and N_r are marked with crosses in two different columns.

Chemical composition	Plant nutrient	N_r	Compound	Short facts
N_2			Nitrogen gas	78% of the volume of the atmosphere (Sutton et al., 2013).
NH_3		X	Ammonia	Could be both in gaseous forms and dissolved in water (Sutton et al., 2013).
NH_4^+	X	X	Ammonium	A salt that falls down in the rain (Sutton et al., 2013).
NO_2^-		X	Nitrite	Turns to NO_3^-.
NO_3^-	X	X	Nitrate	A plant nutrient.
NO_x		X	Mono-nitrogen oxides	The sum of the gases NO and NO_2 (Nelson, 2006).
N_2O		X	Nitrous oxide	Used as pain relieve during childbirth.

2.2.1 Nitrogen cycle

The nitrogen cycle is the shift between different forms of nitrogen. Nitrogen changes through biological, physical and geological forms. There are five major processes involved in the natural nitrogen cycle (Table 2).

Table 2. At first the four major biological processes in the nitrogen cycle, next the physical and chemical process involved in the natural nitrogen cycle, i.e. when there is no interference from humans.

Process	
Nitrogen fixation	When N_2 is fixated by legume plants such as beans, cloves etc. The bacteria Rhizobium live in symbiosis with legume plants (Markov, 2015).
Ammonification	When microorganisms break down organic nitrogen in faeces, dead plants and animals into NH_3.
Nitrification	NH_3 and NH_4 are turned to NO_3^- by different types of microorganisms (ammonia oxidizing bacteria (AOB) or ammonia oxidising archaea (AOA) and nitrite oxidizing bacteria (NOB)). They obtain energy from consuming inorganic nitrogen compound.
Denitrification	When nitrogen is removed from soil - NO_3^- is turned to N_2 or N_2O by bacteria (Markov, 2015).
Lightning	When the lightning hits, nitrogen and oxygen are combined to form NO_x, when NO_x is dissolved in precipitation it hits the surface as NO_3^- or NO_2^- and therefore provides the world with plant available nitrogen (Spradley, 2015).

The natural nitrogen cycle, i.e. with no interference from humans, involves five processes converting nitrogen between different compounds (Figure 2). The cloudlike shapes represent gaseous forms of nitrogen. The green boxes together with green arrows represent compounds available for plants. The round shapes represent the natural processes transforming nitrogen between different forms.

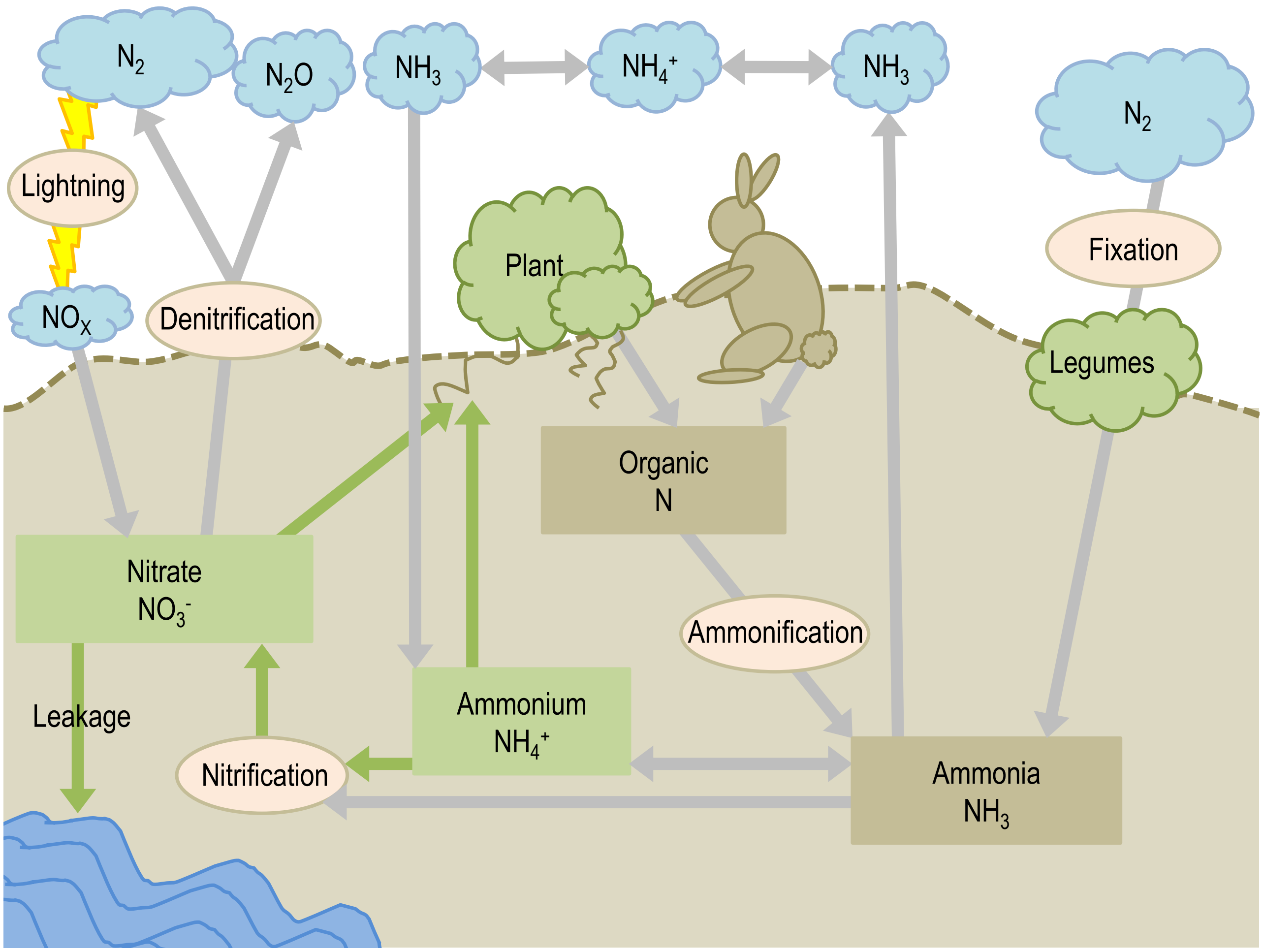


Figure 2. The natural nitrogen cycle without anthropogenic intervention. The green arrows represent forms available for plants. The five round shapes represent the natural processes transforming nitrogen between different forms. The animals produce faeces and animal matter. The cloudlike shapes represent nitrogen in gaseous forms. Nitrate leaks to watercourses. The figure is inspired by above-mentioned information.

2.2.2 Human interference – nitrogen cycle

The industrial and agricultural revolution in the 19th-20th century increased need for mineral fertilizers, which led to the development of new technology - the Haber-Bosch process – where atmospheric nitrogen (N_2) is converted to reactive form (NH_3). The process to break the bond between the two nitrogen atoms uses around 2% of the world's energy use (Sutton et al., 2013).

Mineral fertilizer is inorganic and the most commonly used nitrogen supply in Sweden (Swedish EPA, 2013). In the year of 2011, the world's nitrogen fertilizer consumption was 107.5 million tons (Heffer & Prud'Homme, 2012). According to Sutton et al. (2013), mineral fertilizer is essential for feeding half of the world's population. The meat and dairy consumption per capita has increased, which together with growing human population has led to increased use of mineral fertilizer. The use of nitrogen fertilizer has allowed the food production to grow but has at the same time saturated and overloaded the natural nitrogen cycle, which has affected both human health and the environment (Sutton et al., 2013).

Combustion of fuels has led to an increase of NO_x (Galloway et al., 2008). Nitric oxide (NO) is, together with small amounts of NO_2, formed in all combustion processes and the main source of NO_x on a global scale is combustion of fossil fuels (Figure 3) (Nelson, 2006).

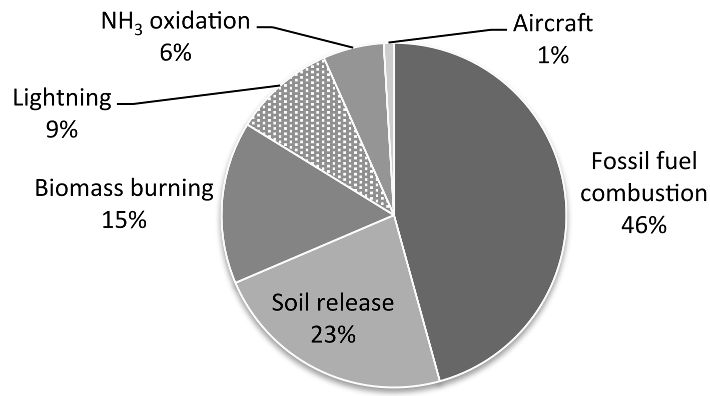


Figure 3. The different global sources' share of NO_x emissions. Soil release is volatile nitrogen release from volatile matter content. (Nelson, 2006)

The risk of phosphorus and nitrogen leaching from the soil is affected by soil type, soil treatment, crops grown, rain, irrigation and harvesting. Leaching of nitrate nitrogen is significantly larger in comparison to phosphorus (Swedish EPA, 2013).

Rockström et al. (2009) defined nine planetary boundaries within which humanity can operate safely. The nine boundaries identified are as listed below; last modified by Steffen et al. (2015):

1. Climate change
2. Changes in biosphere integrity
3. Land-system change
4. Freshwater use
5. Biogeochemical flows (originally called interference with the global phosphorus and nitrogen cycle, now more flows are included)
6. Ocean acidification
7. Atmospheric aerosol loading
8. Stratospheric ozone depletion
9. Novel entities, which can be unknown impact from new forms of existing substances

Crossing the thresholds for these boundaries could lead to irreversible and unforeseen changes of the environment. The anthropogenic impact on the natural nitrogen cycle has already exceeded the planetary boundary where humanity can operate safely (Rockström et al., 2009; Steffen et al., 2015).

The European Nitrogen Assessment (ENA) has defined five key threats from disturbances of the natural nitrogen cycle (Table 3) (Sutton et al., 2013).

Table 3. The five threats from disturbance of the natural nitrogen cycle (Sutton et al., 2013).

Threat to	N_r compound	Effects
Water quality	N_r	Eutrophication resulting in algal blooms, dead zones, contaminated water, nitrate pollution of groundwater and hypoxia.
Air quality	NH_3	Formation of particulate matter (PM) and ground-level O_3. Could result in shortening of human life and loss off agricultural crop productivity. Causes eutrophication.
	NO_X	High concentration of NO_2 and ground-level O_3.Could result in shortening of human life and loss off agricultural crop productivity. NO_2 is an irritant gas causing severe damage to lungs when inhaled. Both NO and NO_2 reduces visibility and cause acidification and eutrophication.
Greenhouse balance	N_2O	Has since the ban of chlorofluorocarbons the largest impact of stratospheric ozone depletion, which increases the risk of skin cancer, and has a large impact on global warming.
	NO_x	Contributes to tropospheric $O_{3,\text{ which}}$ reduce plants CO_2 uptake and react with methane reducing its lifetime. It thus leads to global warming and cooling.
	N_r	N_r deposition promotes plants' growth and water soluble particulate matter – both of these phenomena have a cooling effect
Ecosystem and bio-diversity	N_r	Too much nutrients threaten species adapted to little nutrients. Too little nutrients could force farmers to seek new agricultural land in sensitive areas.
Soil quality	N_r	Atmospheric deposition leads to over fertilization and acidifying soils. Shortage of N_r results in loss off fertility and erosion. Acidification tends to depleted soils and mobilize toxic metals which could harm forests and fresh-water fish

Figure 4 is an illustration of human interference of the natural nitrogen cycle. The largest impacts are combustion of fossil fuels and biomass, increased animal production, cultivation of legumes crops and production of fertilizers. The natural processes are small in comparison. The combustion of fossil fuels and burning of biomass to the left in the figure generates NO_x emissions. The livestock produces manure loaded with N_r. The cultivation of legumes crops such as soybeans and peas fixate N_2. The factory to the right turns nonreactive N_2 into chemical fertilizer, which farmers can spread on the agricultural land

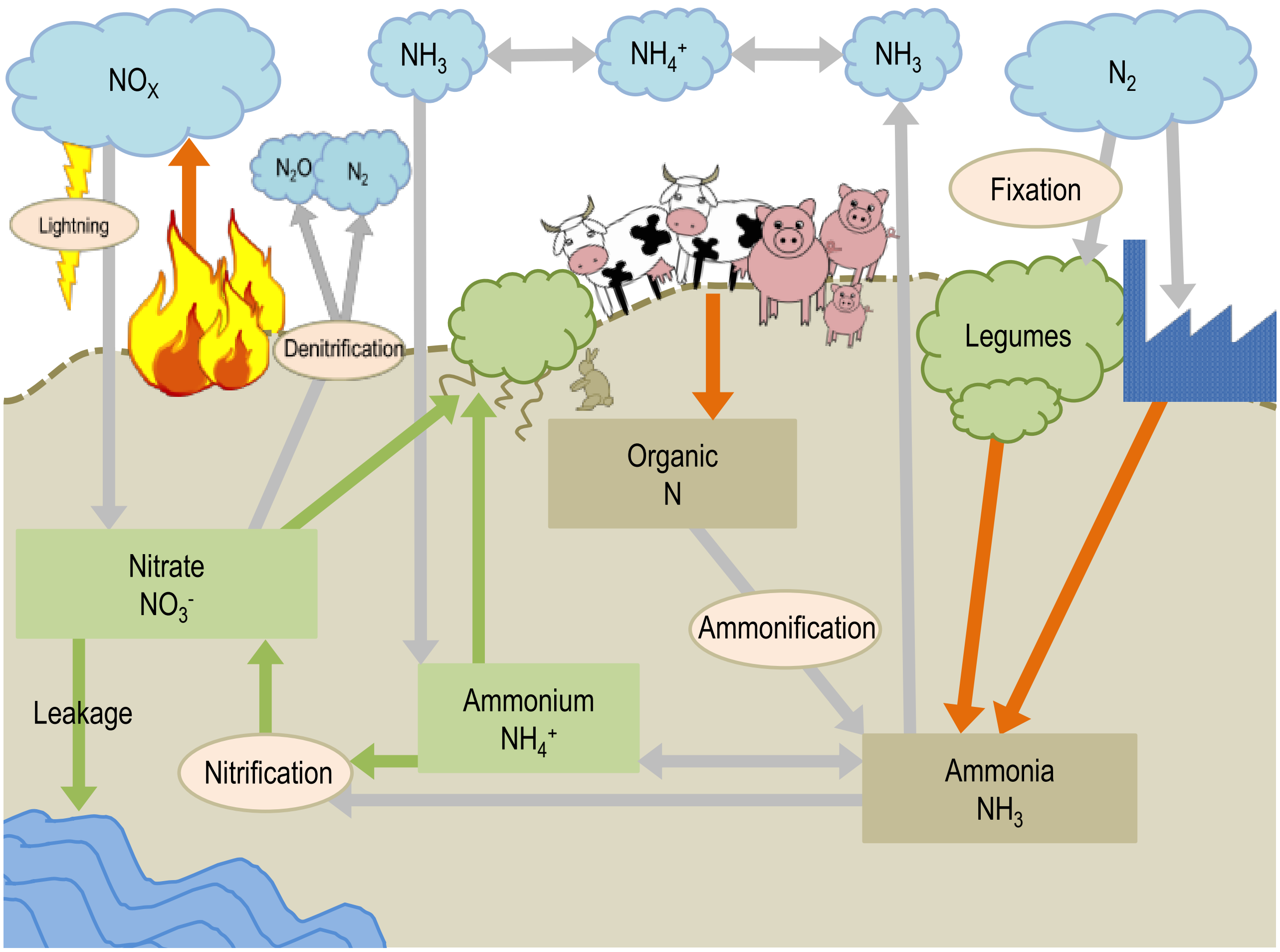


Figure 4. Human interference of the natural nitrogen cycle. The combustion of fossil fuels and biomass, increased animal production, cultivation of legumes and production of fertilizers has led to intensification of the flows of N_r. The red arrows represent the increased nitrogen loads from human interference and generate more deposition, ammonia emissions and leaking.

2.3 Methods of flow analysis

Material flow analysis (MFA) or substance flow analysis (SFA) quantifies stocks and flows of a particular material inside well-defined system boundaries (Brunner & Rechberger, 2004). Sometimes MFA and SFA are used synonymous (e.g. by Linderholm & Mattson, 2013; Brunner & Rechberger, 2004; Huang et al., 2012).

Brunner & Rechberger (2004) give the term *material* the meaning of both substances and goods. The term *substance* could be matter (composed of atoms), atoms (such as nitrogen) or chemical compounds (such as ammonium). MFA follows substances through a system irrespective of the physical or chemical appearance. With this definition nitrogen as well as fodder can be addressed as material. In this thesis the method from now on will be referred to as SFA, although some references describing the method might call it MFA.

2.3.1 Substance flow analysis

Substance flow analysis (SFA) is a method most often used for evaluating systems such as e.g. food production or waste management, but could also be used for natural systems. The method is based on the conservation of matter, which makes the results verifiable with a material balance, comparing inflows, outflows and stocks. When balancing the flows within the system the problematic or environmentally unsafe flows or stocks become visible. (Brunner & Rechberger, 2004).

SFA is well established when it comes to considering sustainable development of socio-economics and environment. It is particularly adequate when it comes to improving material or substance flows. A flow chart facilitates the assessment, comparison and verification by providing systematic information and showing efficiency of transformation processes and sources of environmental pressure, such as waste and emissions. This provides good foundation for regional planning (Huanga et al., 2012).

Linderholm et al. (2012) made a phosphorus flow chart for the Swedish food chain, including agriculture, by using the method described by Brunner & Rechberger (2004). The purpose of that particular flow analysis was to provide a basis for the Swedish EPA's mission to explore the potentials for sustainable phosphorus handling (Linderholm & Mattson, 2013).

2.3.2 Kommunlådan

Kommunlådan (Eng. municipality box) is a conceptual model for municipalities based on MFA. In the model the society is divided into three communicating subsystems: society, air and water (flow chart in Figure 5). The municipality is in contact with the rest of the world through inflows and outflows. The subsystem community is divided into twelve sectors:

1. Farming & Fishing
2. Forestry
3. Mineral Extraction
4. Industry
5. Food
6. Electricity, gas and heat production
7. Service
8. Construction
9. Real Estate
10. Transport
11. Household
12. Waste management

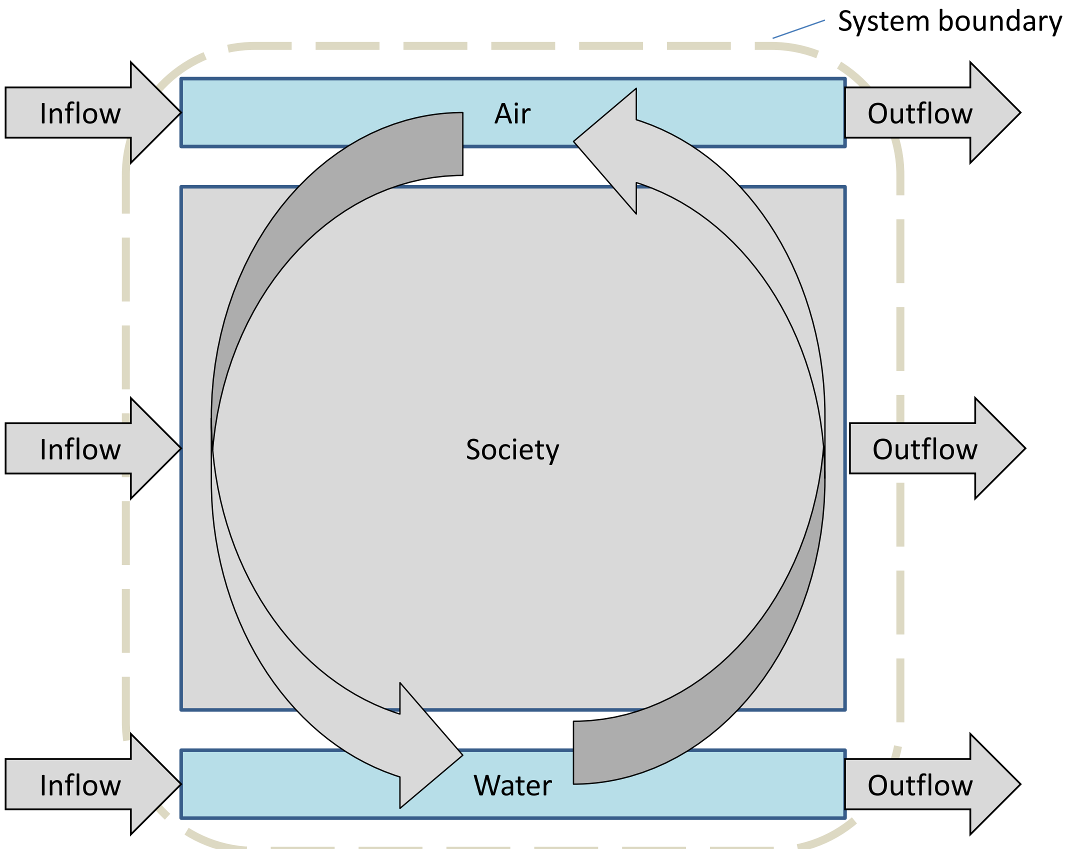


Figure 5. In Kommunlådan the community is divided into three subsystems. The figure is designed from the Swedish analogous simplified version of *Kommunlådan* from Danius & Burström (2001) with permission from Danius.

2.3.3 Similar studies using SFA for nitrogen

In Sweden there have been a few studies on nitrogen on regional and municipal level:

- In the report *Nitrogen in Västerås - Industrial Ecology and municipal environmental strategies* (Swedish: *Kväve i Västerås. Industriell ekologi och kommunala miljöstrategier)* by Danius, et al. (2002) and in the report *Nitrogen Metabolism in Västerås 1995 and 1998 Practical application of material flow analysis* (Swedish: *Kvävemetabolism i Västerås 1995 och 1998 Praktisk tillämpning av materialflödesanalys*) by Danius & Burström (2001) the authors use SFA to map flows on nitrogen in the municipality of Västerås or as the authors formulates it: a regional MFA using the method *Kommunlådan*.
- Another example is Skredsvik-Raudberget (1998) where SFA for nitrogen and phosphorus in the municipality of Stockholm is performed using the above mentioned method *Kommunlådan*.
- Johansson & Wijkmark (1995) performed a flow analysis of plant nutrients, including nitrogen, for the municipality of Nynäshamn. The report was called: *The source separating wastewater system -a step towards better resource management* (Swedish*: Det källseparerande Avloppssystemet -ett steg mot bättre resurshushållning*).

There are also national studies on nitrogen flows:

- A study of nutrient flows within the agriculture by Steineck et al. (2000).
- The flow from land to sea is described together with the sources by the Swedish EPA (1997) in the report *Nitrogen from land to sea* (Swedish*: Kväve från land till hav*).

There are also some international studies of nitrogen:

- *Substance flow analysis for nitrogen and phosphorus in Flanders* (Coppens et al., 2013)
- *NITROGEN: Strategies for resolving an urgent environmental problem* (German Advisory Council on the Environment, 2015)
- The report *The European Nitrogen Assessment Sources, Effects and Policy Perspectives* describes a continental assessment of N_r in Europe (Sutton et al., 2011)

3 Methods and materials

This chapter first describes the method and material used for the SFA in Scania. The second section describes how the literature review was carried out.

3.1 Substance flow analysis

The flow analysis was performed using SFA and based on the most relevant in- and outflows and the most important flows within the system. The method was an iterative process using the list, below as a base. The list is modified from and inspired by Brunner & Rechberger (2004), Lassen & Hansen (2000) and Huang et al. (2012):

1) Definition of substance and goals
2) System definition – system boundaries (temporal and spatial)
3) Identify flows, stocks, and processes
4) Make a flow chart
5) Mass balancing using the conservation of matter principle
6) Make the results understandable, reproducible and transparent by illustration and interpretation

The interpretation of each point on the list is presented on the following pages.

1) Definition of substance and goals

Definition of substance – the flows are calculated for reactive nitrogen (N_r). In this thesis N_r includes:

- Inorganic reduced forms such as ammonia (NH_3) and ammonium (NH_4^+)
- Inorganic oxidized forms such as mono-nitrogen oxides (NO_x), nitrous oxide (N_2O), nitrite (NO_2^-) and nitrate (NO_3^-)
- Organic compounds such as urea and proteins

Nitrogen gas (N_2) is excluded since it doesn't have an environmental impact.

Definition of goals – From section *1.1 Aim and research questions* the first part of the aim and RQ1 connects to the SFA and are together the goals for this SFA. Here part of the aim and RQ1 are presented again:

- The aim was to make a substance flow analysis of N_r in Scania.
- How were the urban nitrogen flows in Scania in relation to other regional nitrogen flows?

2) System definition – system boundaries (temporal and spatial)

The SFA was conducted with the following scope and system boundaries:

- Spatial – the region of Scania with associated air, water and land.
- Temporal – the flow of nitrogen was calculated for one year. The target year was 2010 and when possible an average for the years 2009-2011 was calculated.

Other delimitations

Activities and flows that could potentially have a large impact on the result of the SFA are listed below. An investigation of these unknown flows might be relevant but in this study they were neglected or not considered because of the time frame for this study.

- Biological fixation on other land than agricultural land
- Denitrification and nitrification on natural land
- Constructed wetlands and their effects
- Paper mills and chemical factories in Scania could have potential large flows of nitrogen
- There are more fish farms today than in 2010
- Only food waste is considered. – No other waste such as garden waste, pinecones, leaves, plastics, furniture etc.
- The cultivation of vegetable seed and plants, in this study only cereals, peas and potatoes etc. were included
- Urea and ammonia to incineration plants
- Import and export of waste both from other countries and other counties. Each municipality is responsible for their own waste planning and to export waste to another municipality, if it is e.g. more profitable and in line with their goals, is very likely to occur
- Stormwater

Other delimitations of the SFA will be mentioned together with the calculated flows.

3) Identify flows, stocks, and processes

By examining how other authors and reports have implemented the SFA for municipalities, regions and countries, e.g. literature mentioned in section *2.3.3 Similar studies using SFA for nitrogen*; the flows, stocks and processes within the system boundaries were discovered.

4) Make a flow chart

In this SFA, Scania is divided into three subsystems; air, water and society. The society is divided into five sectors according to Table 4 where each sector of the society is described.

Table 4. Description of the three subsystems; society, air and water. Society is divided into five sectors.

Sub-system	Sector	Description	Examples of flows containing N
Air		Deposition from air come from emissions within and outside of Scania e.g. from transportation and incineration plants. Emissions to air come from transportation, combustion and agricultural activities	NH_3, N_2O, NO_x
Society	Agriculture	Inside this box the flows for cultivating, farming and harvesting is found.	Fertilizer, manure, animals, crops
	Forestry	Flows for managing and harvesting forests.	Fertilizer, wood
	Fishing	Fishing performed by Scanian fishers.	Fish
Society	Food industry	The food industry such as slaughterhouses.	Live animals, food waste, food products
	Industry	Other industry than food industry such as chemical industry.	Emissions to air and water
Society	Households	Involves eating and excretion via the wastewater system.	Food, waste, wastewater
	Service	Restaurants, school kitchens, or other large scale catering establishments.	Food, waste
	Retail	Household purchase their food in grocery stores.	Food products, food waste
Society	Technical systems	Including wastewater system, incineration plants, and treatment of biological waste - the technical systems needed for waste, wastewater and energy distribution.	Wastewater, household waste, fuel, NO_x
Society	Transport	This box contains all transportation within Scania e.g. transport by boat for fishing or working machinery.	NO_x
Water		This box contains emissions to water from the other boxes within Scania and also emissions to the sea across the system boundary.	Leakage from On-site sanitation, discharges from WWTP, leakage from fields

The flow chart for Scania was inspired by *Kommunlådan* (Ref; see Figure 5). Between the subsystems and sectors nitrogen is flowing in various forms and across the system boundary there is import and export of goods as well as inflows and outflows through air and water (Figure 6).

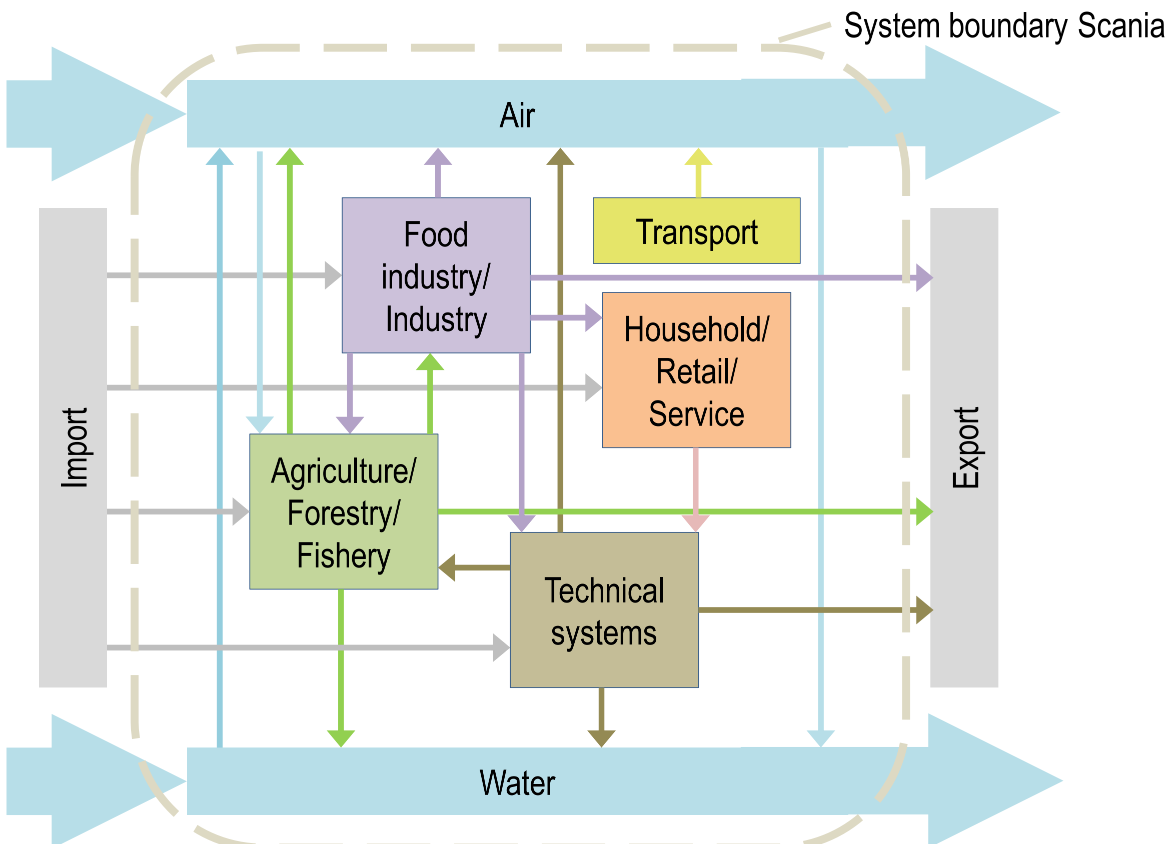


Figure 6. A schematic diagram of Scania's nitrogen flows between the three subsystems air (top), society (five sectors in the middle) and water (bottom). The subsystem society is divided into five sectors, which have nitrogen flows between them in forms of e.g. food or waste. Across the system boundary the import and export of goods as well as inflows and outflows with water and air are illustrated. The arrows/flows have the same colour as the box they stem from.

In the next few pages a further discussion of the flows for each subsystem will follow. Some flows are internal inside of Scania i.e. they stem from and/or go to another sector or subsystem in Figure 6 above.

The flow charts show identified flows. In chapter 4, Substance flow analysis for Scania, the number of identified flows or processes might differ from the ones presented in this chapter. This could either be a result of setbacks in obtaining data or it could be that an assessment has been made with the conclusion that the flow is too small to allocate resources on it.

Air

In Scania there is deposition and nitrogen fixation from air to land together with emission to air from land and processes within society (Figure 7). There is deposition from air both to land and water. Processes within society e.g. combustion or waste management cause emissions to air in the form of NO_x, N_2O and/or NH_3. Land includes all different types of land inside of Scania, e.g. agricultural land, built-up land and forestland etc.

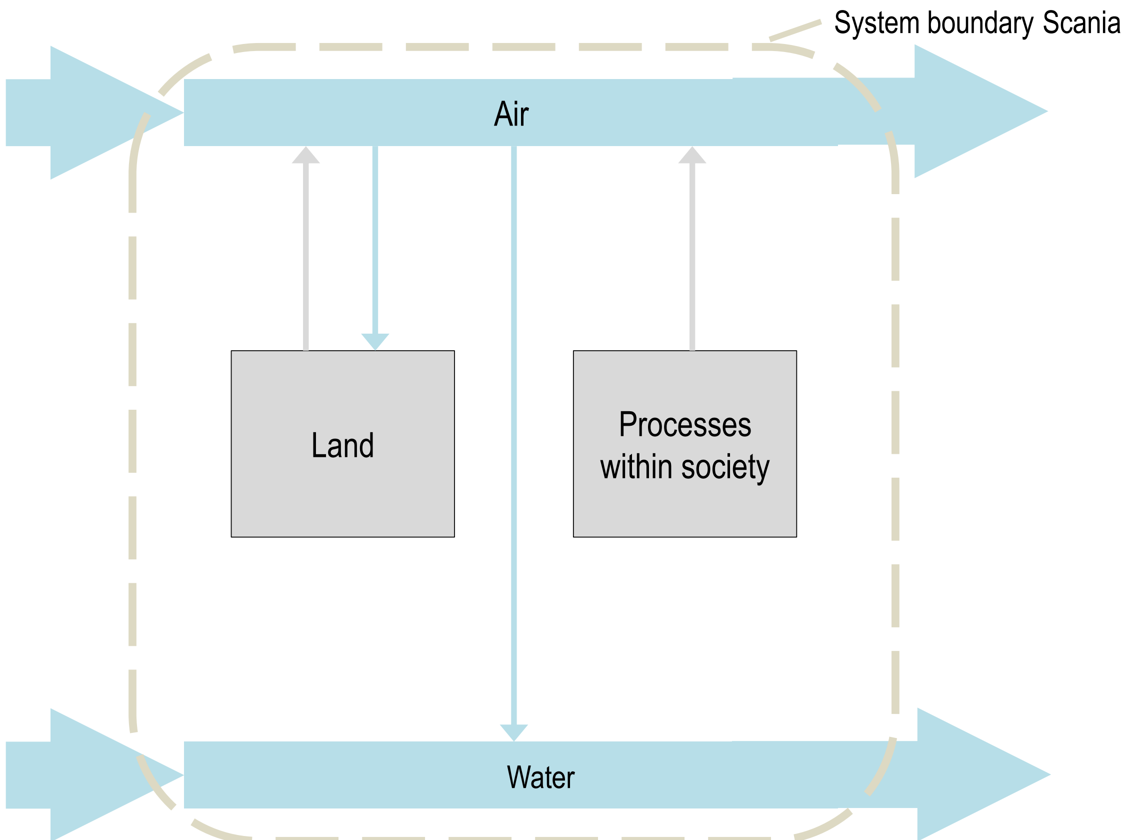


Figure 7. Flows from air to land and water are deposition and fixation. Flows from land to air are NH_3 and N_20 emissions. Flows to air are emissions from different processes within society such as combustion and industrial processes.

Agriculture/Forestry/Fishery

Agricultural land and animal production are divided into two boxes (Figure 8). Leakage and emissions from animal manure are allocated to the agricultural land. Sludge is both WWTP sludge and digestate from biogas production. Emissions from working machinery, fishing boats and other transports are allocated to the sector Transport in Figure 12. Animal products include e.g. fish, egg and milk.

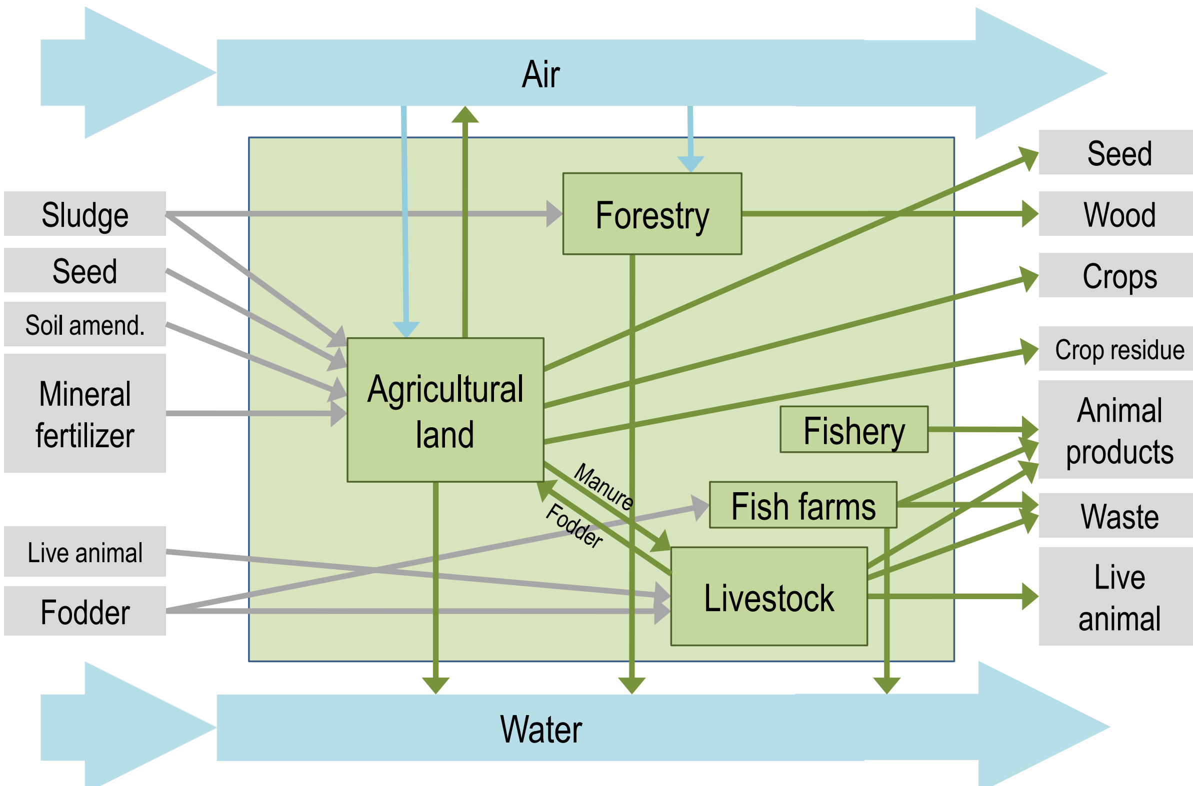


Figure 8. The nitrogen flows in Agriculture/Forestry/Fishery. The flows between Agricultural land and Livestock are internal flows.

Food Industry/Industry

The food industry is divided into food industry and slaughterhouse (Figure 9). Into the slaughterhouse live animals enter on the left hand side, get slaughtered and then become an inflow to food industry for further refining. Wastewater from industries can be treated in two ways – on site and at WWTPs, when treated on-site the discharges are directly into water, which is represented by arrows to the water. Imported material is foodstuff from outside of Scania.

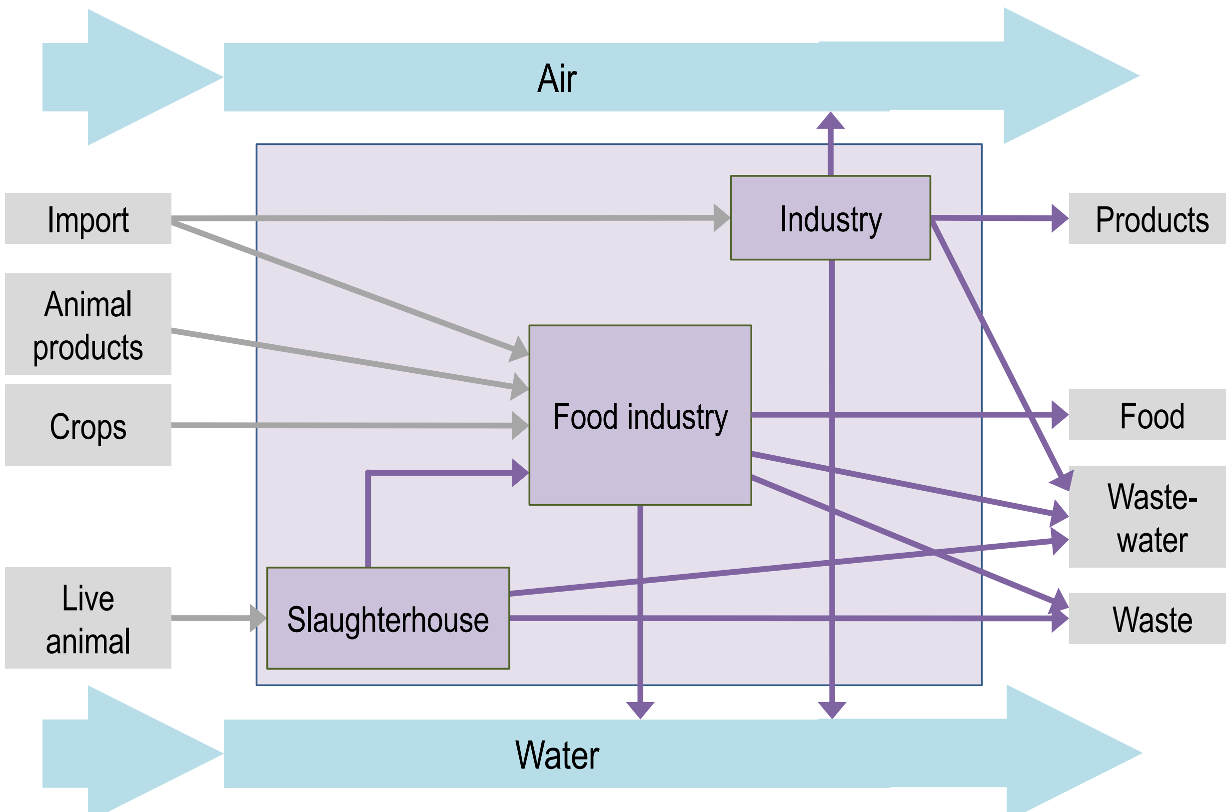


Figure 9. The flows within the sector food industry/industry.

Household/Retail/Service

The sector Household/retail/service involves human consumption of food, and excretion plus food waste caused by this consumption (Figure 10). Some meals are assumed to be consumed at restaurants and other types of commercial kitchens such as nursing home.

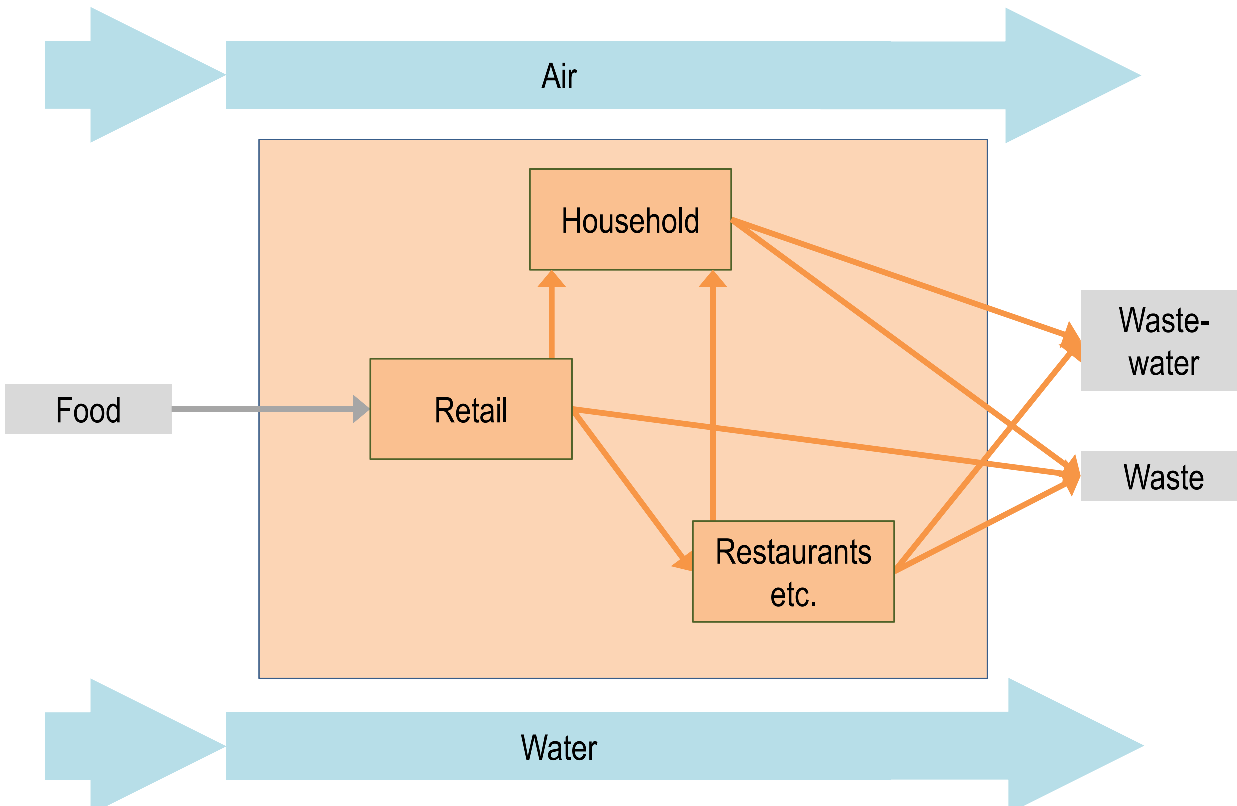


Figure 10. The flows within the sector household/retail/service.

This sector (Figure 10) is simplified when it comes to purchase of food for the different members of society. There are wholesalers as an intermediary between producers and restaurants and caterers. Here all actors distributing food are put together in one box. Waste arising from residents, such as toilet waste and food waste, are inflows in in the sector Technical systems below

Technical systems

Figure 11 includes the technical systems needed for waste, wastewater and energy distribution. Other sewage treatment is sewage treatment not included in WWTP (larger than 2 000 PE) and on-site sanitation (less than 200 PE).

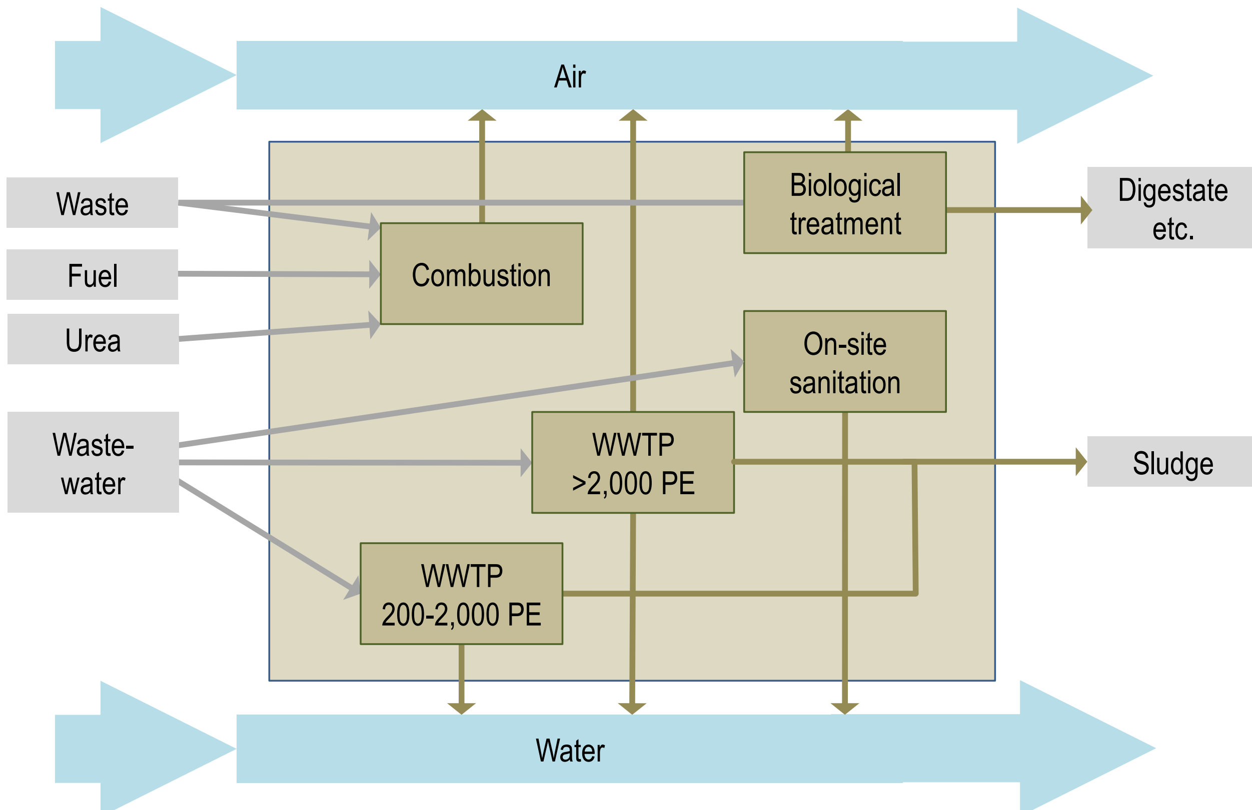


Figure 11. The flows within the sector technical systems.

Transport

Figure 12 shows emissions from different kinds of transportation. The emissions to air consists e.g. of NO_x. This sector in society consists of transportation within all other sector, e.g. residents moving between household and work, working machinery, transportation of goods, public transport etc. Fuel is excluded since it is assumed not to contain any N_r.

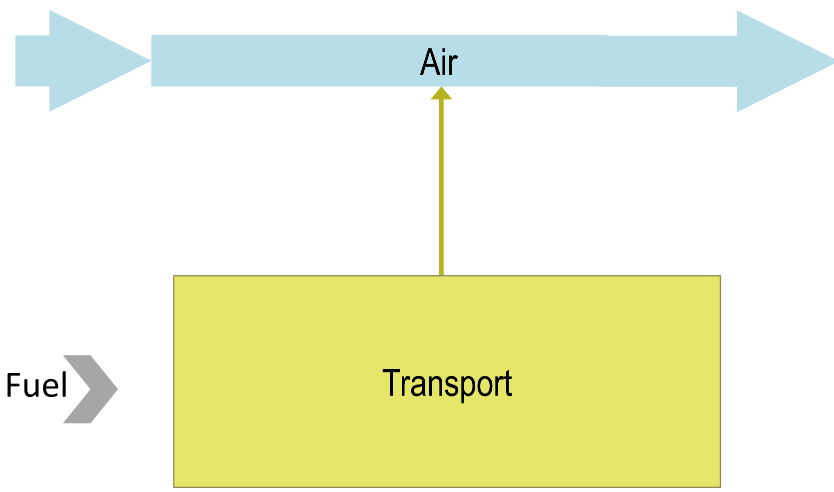


Figure 12. The flows for this sector are emissions to air from transportation within Scania.

Water

Three different seas are surrounding Scania (Figure 13).

Figure 13. Kattegat, Öresund Strait and Baltic Sea surrounding Scania.

Figure 14 shows an illustration of the different sectors, within society, leaking nitrogen into water.

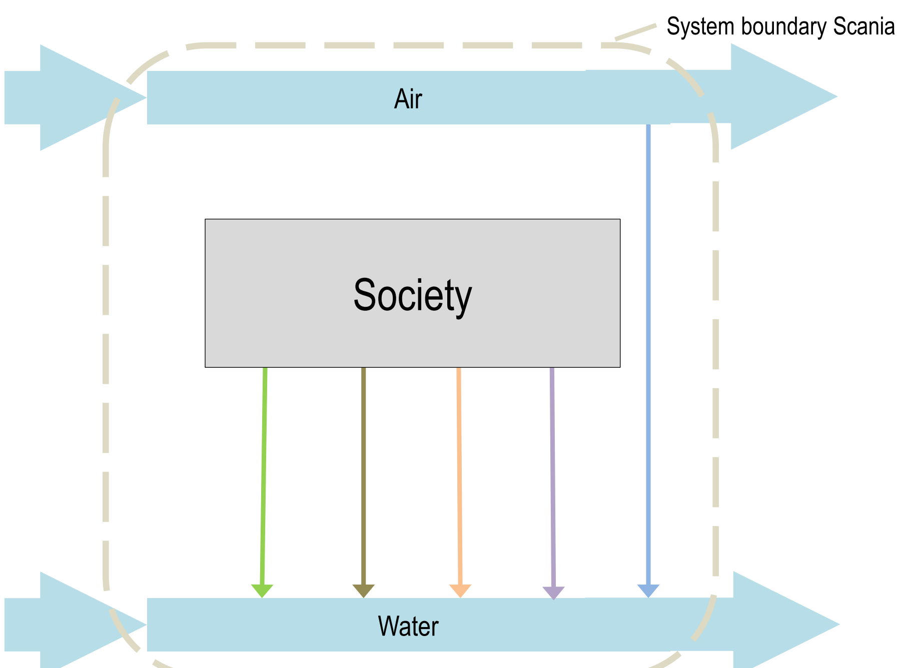


Figure 14. The society and possible leakage and emissions into water. The arrow between air and water is deposition to lakes and watercourses.

Quantifying the flow charts

For calculation and storage of data Excel was used. Calculations in this sheet will not be a part of this report although parts of calculations are presented in chapter 4, Substance flow analysis for Scania. Data collection was carried out through two main approaches; statistical data and personal contacts guiding towards data (Table 5).

Table 5. Main approaches for collection of data.

Approach	Description
Statistics	The massive search for data was mainly conducted via search on the internet. The main sources of data came from the following domains: - Statistics Sweden (Swedish: Statistiska centralbyrån, SCB) - Swedish Environmental Protection Agency (EPA) (Swedish: Naturvårdsverket) - Swedish Board of Agriculture (Swedish: Jordbruksverket) - Swedish University of Agricultural Sciences (SLU)
Expert judgement and contacts with experts	Many people were contacted, over the phone and via email, to guide and give advice towards where data could be obtained. Mainly people in County Administrative Board[A] of Scania and authors of relevant reports were contacted. Advice from supervisor Mats Johansson also led to contacts with persons who could hand out important information. For nitrogen fixation by leguminous crops an expert on SLU was interviewed over the phone.

5) Mass balancing using the conservation of matter principle

In order to get as good results as possible, controls of the calculations were made through tallying, and comparing inflows and outflows. When it differed tremendously between the in- and outflow extra effort has been devoted to investigate the cause. Mass balancing is hard to perform on all processes within Scania, since some processes converts N_r to N_2 and vice versa.

6) Make the results understandable, reproducible and transparent by illustration and interpretation

In chapter 4, Substance flow analysis for Scania, the results of the SFA are presented by using illustrations. To make the results reproducible and transparent a lot of information is located in Tables in section 4.1-4.7. In section 4.8 *Quantified flow charts for society, air and water* the quantified flowcharts with some additional information is presented. In section *4.9 Nitrogen flows in Scania – the flow chart* the quantified flow chart for Scania is presented. In the last section *4.10 Data uncertainties – the evaluation* the flows are evaluated. In chapter *6 Discussion* – the results are interpreted. In chapter *7 Conclusion*, the results of the SFA are discussed and conclusions from the SFA together with the conclusions for RQ2, RQ3 and for the thesis are arrived at.

[A] County Administrative Board (Länsstyrelse in Swedish) is a government agency in each county in Sweden.

Uncertainty of data

Another way of displaying transparency is to evaluate the uncertainty in the data. Here follows different methods to evaluate uncertainty in data:

- The article *Systematic Evaluation of Uncertainty in Material Flow Analysis* (Laner et al., 2014) distinguishes the different sources of uncertainties in MFA and a five-step framework for uncertainty handling is provided.
- The report *Regional material flow analysis and data uncertainties: Can results be trusted?* (Danius & Burström, 2002) gives a method for calculating an interval to determine the reliability of the collected data.
- The report *Data Vagueness and uncertainties in urban heavy-metal data collection* (Hedbrant & Sörme, 2000) discusses uncertainties in MFA for heavy metal data and suggests a method for estimating uncertainties by using factors to multiply or divide with data. This method is used in the article *Phosphorus Flows to and from Swedish Agriculture and Food Chain* (Linderholm et al., 2012).
- In the report *Data uncertainties in material flow analysis Local case study and literature survey* (Danius, 2002) the author discusses and analyses the influence of data uncertainties.
- The evaluation method *Relatively certain*, *relatively uncertain* and *uncertain* (Swedish: *Relativt säker*, *relativt osäker* och *osäker*) according to Sörenby (2010) uses three categories to evaluate uncertainty of data. The method uses colour to illustrate the uncertainty; green for *Relatively certain*, yellow for *relatively uncertain* and red for *uncertain.*

In this thesis the method by Sörenby (2010) is chosen for showing the certainty/uncertainty of the results. It is an illustrative method, communicating uncertainty in a simple way, using colour. For advanced calculations, models, decision making or for following trends over years, it is advisable to choose one of the above-mentioned method to back up the results and the following discussion. Within the time frame for this study, the Sörenby method was found suitable.

The method divides the flows into three categories; *relatively certain* in green, *relatively uncertain* in yellow and *uncertain* in red (Table 6).

Table 6. Method for evaluation of data according to Sörenby (2010).

	Requirements
Relatively certain	⇨ Reliable statistics ⇨ If two references are used both must be trustworthy ⇨ If different calculations/methods confirm similar calculated value
Relatively uncertain	⇨ Less reliable statistic/method ⇨ Two references are used and one is not trustworthy
Uncertain	⇨ Calculations build upon unreliable statistics/data ⇨ No available statistics ⇨ The calculation is uncertain but can still be an important rough estimate on size and information about the flow.

3.2 Literature review

A literature review was conducted for the information in chapter 2 Background, the substance flow analysis (RQ1), possible changes of urban nitrogen flow the impact and effect of possible changes (RQ2 & RQ3).

Search engines used:

- Scopus – a database containing abstracts and citations for academic journal articles concerning i.e. environmental technique, natural science and technology.
- Primo – the search engine of SLU's library.
- Unisearch – the search engine of Linköping's University's library.
- Google– a web search engine listing information in order of relevance. The ranking is based on an algorithm hidden from the public eye.

Keywords used: Substance/material flow analysis, nitrogen cycle, dietary change, urine separation, source separation

4 Substance flow analysis for Scania

This chapter is devoted to the last item on the list – *6) Make the results understandable, reproducible and transparent by illustration and interpretation*. Here the results of the SFA, including assumptions, calculations and illustrations of the different flows will be displayed. First some reading instructions. The interpretation of the results will mainly be located in chapter *7. Discussion*.

In the following sections (4.1-4.7) the N_r flows inside each box within the system boundary of Scania are quantified in a variety of different tables (Table 9-Table 54). The reason for this excessive amount of tables is that the author wants to show that there are many ways to calculate and sometimes more than one source of data. Therefore the author raises a note of caution to those readers with limited amount of time. If reader has no interest in calculations or assumptions they are recommended to go directly to the two last sections (4.8-4.9). In section 4.8 the quantified flowcharts for the three subsystems are displayed, including flow charts for the five sectors of society. In section 4.9 all the flows are put together in a flowchart for Scania. The last section 4.10 of this chapter is an evaluation of data uncertainties in the SFA. First some general data used in the SFA is presented. After that the three subsystems are presented starting with air.

Food manufacturers use a general conversion factor 6.25 for all food groups for calculation on protein content based on nitrogen content (National Food Agency, 2015a). For different kind of food there are different factors, this together with protein content gives the N_r content (Table 7). This has been the general approach for calculating N_r content in organic compounds.

Table 7. Conversion factors from National food administration (2015a) and protein content from The Food Database (Swedish: livsmedelsdatabasen) (National Food Agency, 2015b).

Food	Conversion factor	Protein content	N_r content
Soybeans	7.71	34.00%	0,044%
Wheat flour	5.83	8.47%	0,015%
Meat	6.25	19.19%	0,031%
Rice	5.95	7.80%	0,013%

In a number of cases it has not been possible to find data for the region of Scania, but only data on a national level. In Table 8, different scaling methods, used for different sectors and areas, are presented.

Table 8. Scaling factors used in this report.

Scaling factors	Explanation
13.2%	Part of Swedish population living in Scania (Statistics Sweden, n.d.).
24.0%	Part of Swedish food production located in Scania, in economical terms (Jörgenson, 2013)
17.0%	Part of Swedish agricultural land located in Scania (Statistics Sweden, 2010)
15.0%	Part of food in Sweden stemming from Scanian food production (Jörgenson, 2013)

4.1 Air

4.1.1 Atmospheric deposition and nitrogen fixation

The atmospheric deposition is distributed over different land types. The total area of Scania is 1,130,197 ha (Statistics Sweden, 2010) and the land has different applications (Figure 15).

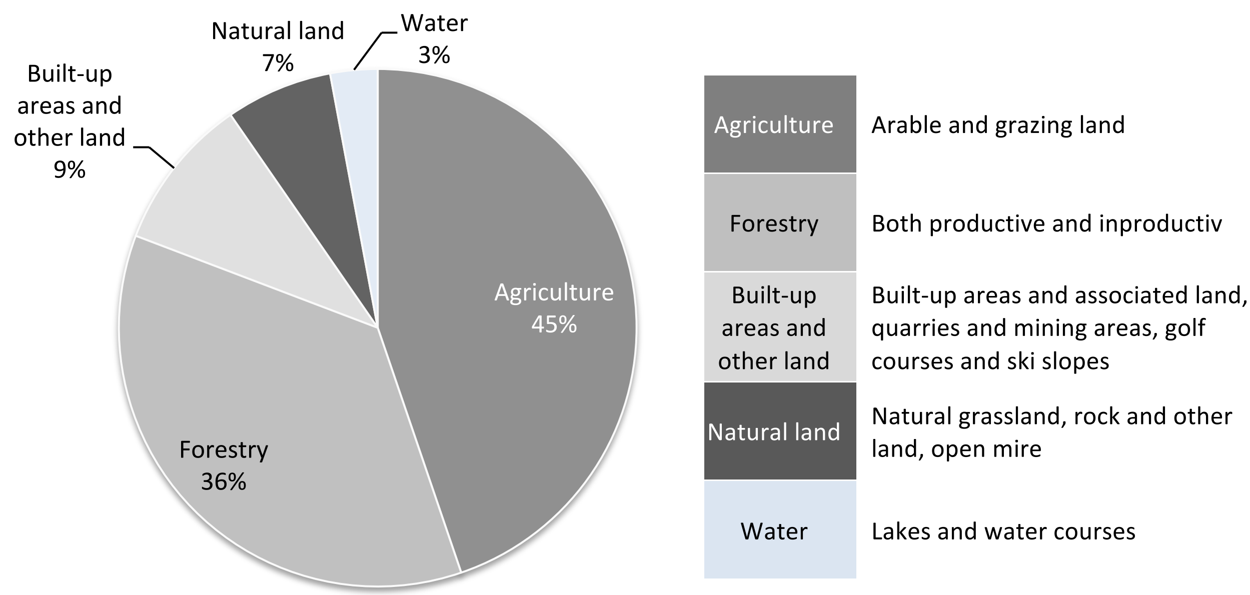


Figure 15. Distribution of different land types from Statistics Sweden (2010). Categorized by the author,

An average value the deposition was used for the three agricultural production areas[B], from Statistics Sweden (2013a), which equalled 10 kg/ha.

The ability of different leguminous crops for nitrogen fixation was obtained through an expert judgement by Carlsson pers. (2015) – with a disclaimer that uncertainties are large. Expert judgement together with Statistics Sweden for ha of different crops (Statistics Sweden, n.d. b) gave the resulting 5,121 tonnes.

[B] The three agricultural production areas are introduced in Figure 16 below.

The different land types and the calculated deposition of nitrogen (10 kg/ha) and nitrogen fixation gave the result according to Table 9.

Table 9. Final values for deposition. Nitrogen fixation in agriculture is added in the column to the right with value from Table 17.

	Deposition N_r $[tonne]$	Fixation N_r $[tonne]$
Agriculture	5,060	5,121
Forestry	4,070	-
Built-up areas and other land	1,084[C]	-
Natural land	755	-
Water	333	-
Sum	**11,302**	**5,121**
Total sum (deposition + fixation)	**16,423**	

4.1.2 Emissions to air

RUS stands for Regional Development and Cooperation in the environmental system (Swedish: Regional Utveckling och Samverkan i miljömålssystemet). RUS is a collaborative body with the task to support, guide and coordinate the County Administrative Boards and other regional efforts in Sweden (RUS, n.d. b). On RUS's webpage you find the national emission database. The emissions retrieved from the database were divided into different sectors (e.g. transport, industrial processes, energy supply, and agriculture); the data was divided into the different sectors and given in tonnes of NO_x, N_2O and NH_3.

NO_x, N_2O and NH_3 are converted into tons of N-equivalents using information in Table 10. The most important N_r compounds formed during combustion is NO. Small amounts of NO_2 are also formed, usually 5-10% of the total NO_x (Nelson, 2006). Here the assumption that 10% of formed amount is NO_2 and the rest is the NO.

Table 10. When diverting the data for NO_x, N_2O and NH_3 into N-equivalents the following weights for the elements were used.

NO_x	$[u]$	N_r weight [%]	N_2O	$[u]$	N_r weight [%]	NH_3	$[u]$	N_r weight [%]
N	14	-	N	14	-	N	14	-
O	16	-	O	16	-	H	1	-
NO	30	46%	N_2O	44	64%	NH_3	16	82%
NO_2	46	30%						
NO_x	32[D]	44%[E]						

[C] From which 92.2% is Built-up land and associated land, which correspond to 1,000 tonnes deposition on Built-up land.

[D] Weight of NO_x in this report is calculated using 10% of NO_2 and 90% of NO: $0.1 * 46 + 0.9 * 30 = 31.6 \approx 32$

[E] N-equivalent from NO_x using weight percentage 44% from calculation: $\frac{14}{31.6} = 44\%$

The emissions to air in N-equivalents are presented in Table 11 calculated from values for the different compounds from Table 10.

Table 11. Final values for N_r emissions to air. Data downloaded from the national emission database (RUS, n.d. a).

	NO_x N_r $[tonne]$	N_2O N_r $[tonne]$	NH_3 N_r $[tonne]$	Sum N_r $[tonne]$
Energy supply	1,541	141	93	**1,775**
Industrial processes	327	8	80	**415**
Transportation	9,055	69	342	**9,465**
Solvent use	-	30	-	**30**
Agriculture	-	1,650	6,350[F]	**8,000**
Waste and WWTP	-	34	88	**122**
Sum	**10,921**	**1,906**	**6,952**	**19,809**

4.2 Agriculture, forestry and fishing

4.2.1 Agricultural land

Sedimentary soil and rocks in the south and the Baltic shield with rocks in the north, has concentrated Scanian agricultural land to the south-western parts of Scania, while forestland is more prevalent in the north-east (Ekologgruppen i Landskrona AB, 2010). Streams in the north are therefore usually less loaded with nutrients per unit area than southerly Scanian streams.

As mentioned in section *2.1 Scania*, Scania is a county with lots of agricultural activities. Scania is also the region in Sweden where the spreading of WWTP sludge is most common, about 13,000 tons of sludge (dry matter) was spread on Scanian agricultural land in 2010 (Swedish EPA, 2013). A balance for nitrogen has been calculated by Statistics Sweden (2013a) for agricultural land using the *soil surface gross method* (OECD and Eurostat, 2007). The balance is calculated for eight agricultural production regions covering Sweden. Three of those regions are located in Scania but all of them are extending outside (Figure 16).

[F] A mean value from RUS and Table 19. : $\frac{6{,}143+6{,}556}{2} = 6{,}350\ tonnes$

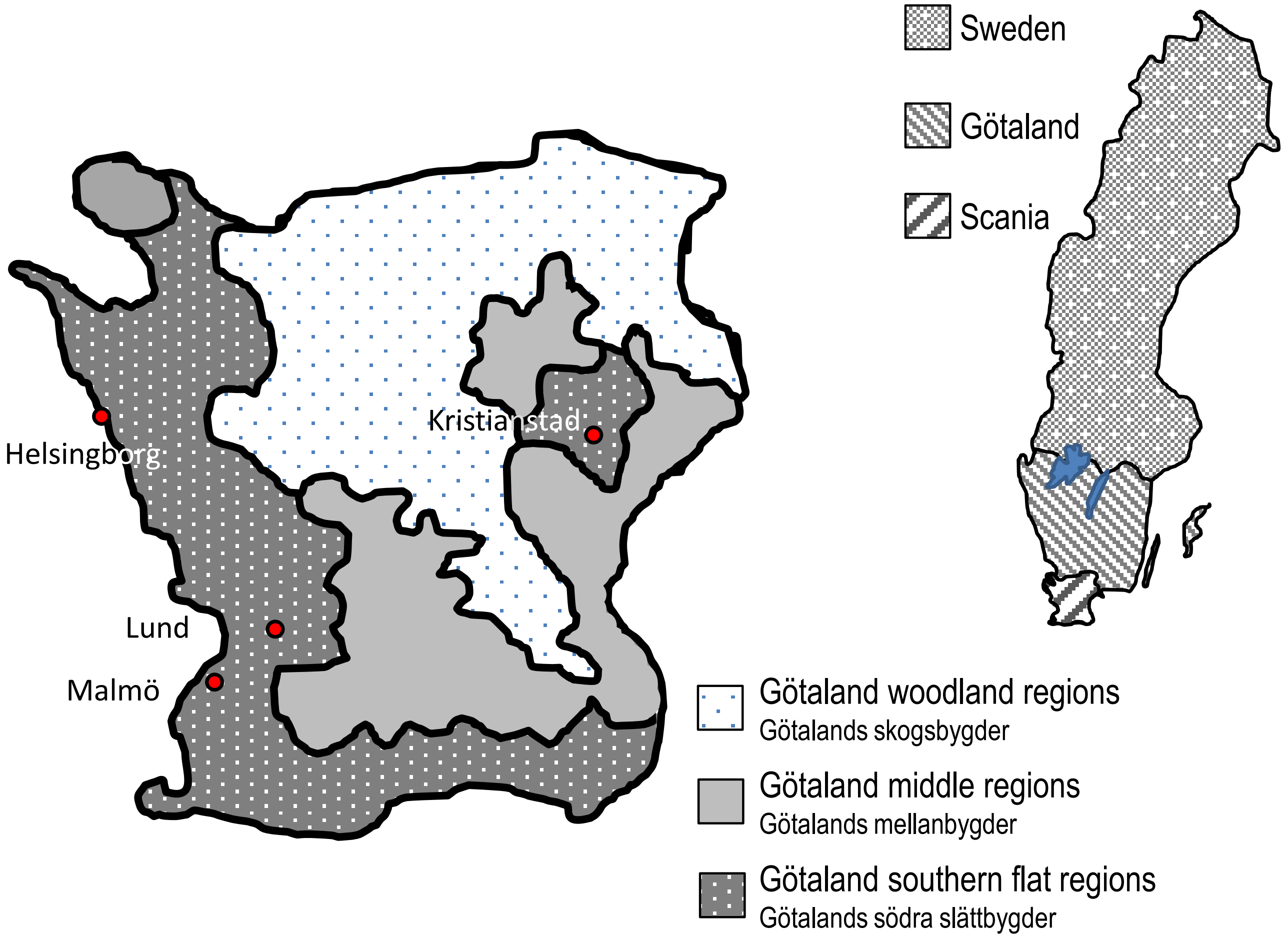


Figure 16. To the left, Scania is divided into the three agricultural production regions. To the right, you find Sweden with Götaland with Scania at the very bottom. Figure is drawn from figures in Statistics Sweden (2011a)

The N_r inputs to the agricultural production regions are mineral fertilizer, soil amendments, manure, seed, deposition, WWTP sludge and biological fixation. Outputs are yield and harvested plant residues. The difference between input and output shows a surplus[G] of nitrogen. The surplus contributes to ammonia volatilisation, leaching, denitrification and stock changes in soil. In *gross balance* losses of ammonia and leaching are taken into account by separate calculation (Statistics Sweden, 2013a).

Above-mentioned balancing was used for filling in the unknown flows in this sector. Whenever balancing was used to make assumption for Scania figures from year 2011 were used.

[G] For Sweden 2011 the total input was 115 kg/ha and the output was 81 kg/ha (Statistics Sweden, 2013a).

Manure

For calculating the manure from Scanian livestock two approaches are used together with a small discussion on the reliability of data. The two approaches are presented in the list below:

1. The first approach is a calculation for manure using data for different livestock from Danius & Burström (2001) (Table 12).
    a. Discussions on the reliability of first approach – the values from Danius & Burström (2001) are compared with different values from Steineck et al. (2000) (Table 13).
2. The second approach is a mean value for the three agricultural production areas (Table 14).

The final value for manure will be an average between approach 1 and 2. Manure from horses are discussed separately below and added in the final values for manure at the end (Table 15).

Table 12. First approach -manure from livestock, values from Danius & Burström (2001).

	Live animals in June 2010[H]	**Times Replaced á year**	**N_r in Manure**[I] $\left[\frac{kg}{year,animal}\right]$	**N_r** $[\boldsymbol{tonne}]$
Boars	928	1	29	27
Sows in production	42,794	1	29	1,241
Swine, 20 kg and over	249,231	2[J]	9	4,486
Swine, under 20 kg	113,389	1	9	1,021
Cows for milk production	38,905	1	117	4,552
Cows for the rearing of calves	36,631	1	63	2,308
Heifers, bulls and steers	70,537	1	47	3,315
Calves, under 1 year	69,531	1	22	1,530
Rams and ewes	27,424	1	12	329
Lambs	30,388	1	12	365
Hens, 20 weeks or older	1,079,949	1	0.27	292
Hens, intended for egg production	182,911	2.2[K]	0.64	258
Broilers	1,946,037	7[L]	0.29	3,950
Turkey	72,864	7[M]	0.29	148
Sum				**23,820**

The values for manure in Danius & Burström (2001) do not agree with the data Steineck et al. (2000) (Table 13). This might suggest that values from Danius & Burström (2001) are

[H] Number of animals from 2010 in June (Swedish Board of Agriculture & Statistics Sweden, 2011).
[I] N_r content in manure (kg/year) for different livestock was most based on Danius & Burström (2001).
[J] A swine in the meat production lives about 6 months before it is ready to be slaughtered (Djurens rätt, n.d.).
[K] A hen intended for egg production is ready for laying eggs after about 20 weeks (Steineck et al., 2000).
[L] Life length expectance of a broiler is 1/7 years (Steineck et al., 2000).
[M] Turkey is assumed to live, eat and excrete as a broiler.

overestimated, except for sows and hens, where the values instead are underestimated. Danius & Burström (2001) have for swine, hens and broilers used higher numerical values.

Table 13. Manure - different values from Danius & Burström (2001) compared to Steineck, et al. (2000).

	Steineck, et al. (2000) $N_r \left[\frac{kg}{year,animal}\right]$	Danius & Burström (2001) $N_r \left[\frac{kg}{year,animal}\right]$	$\left[\frac{Danius\ \&\ Burström}{Steineck\ et\ al.}\right]$
Sow	45.00	29.00	64%
Swine, 20 kg and over	5.30	9.00	170%
Hens, 20 weeks or older	1.47	0.27	18%
Hens, intended for egg production	0.12	0.64	533%
Broilers	0.10	0.29	290%

When using a mean value for the agricultural production areas, the N_r supply from mineral fertilizer and manure for the year 2011 equals according to Table 14. Manure from grazing is based on grazing periods, e.g. a milk cow is assumed to be in a stable 38% of the time. (Statistics Sweden, 2013a)

Table 14. Second approach for manure - calculated values for manure using an average for the three agricultural production areas.

	N_r $[tonne]$	Part of total manure[N]
Manure (stable)	16,157	72%
Manure (during grazing)	6,283	28%
Sum	**22,440**	**100%**

Since horses are not part of the animal production but rather used for leisure the calculations are made separately. According to Svensson pers. (2015) the horse manure on Vingåker's Rider association (Swedish: Vingåkers Ryttarförening) is collected by a local farmer who spreads it on the agricultural land. When no farmer collects the horse manure it is gathered by the municipal waste treatment (ibid). Horses on a riding school are inside the stable more than horses owned by private citizen (ibid).

According to Pafvelsson pers. (2015) a horse is outside 50% of the time, i.e. half of the horse manure is excreted during grazing. It is usual that the plant nutrients arising in stable are not collected by any farmer and spread on agricultural land (ibid.). In this study it is assumed that at least half of the horse manure is placed on agricultural land, either during grazing or spread by a farmer.

The year of 2010 the number of horses in Scania was 52,400 (Swedish Board of Agriculture, 2010). A grown 500 kg horse with one hour of exercise a day eats and excretes 47.6 kg N_r per year (Swedish Board of Agriculture, 2013a). This equals the final value for horse manure according to calculation below:

$$52{,}400 * 47.6 = 2{,}494{,}000\ kg = 2{,}494\ tonnes$$

[N] Calculated by the author.

When comparing calculated value for manure from Table 12 with the calculated value from Table 14 they look quite similar and an average for those two calculated values is used (Table 15). It is assumed that the produced manure ends up on either an acre or during grazing, except for half of the horse manure, which is assumed to go to municipal waste management.

Table 15. Final values for the manure.

Flows		N_r $[tonne]$
Manure	An average from calculations above: $$\frac{23{,}820 + 22{,}440}{2} + 0.5 * 2{,}494 = 24{,}377\ tons$$	23,377

Mineral fertilizer

Two different data from Statistics Sweden was obtained for mineral fertilizer and manure (Table 16). The manure is in the table to show that the total input of mineral fertilizer and manure are alike from the two data.

Table 16. Mineral fertiliser from Statistics Sweden (2014) and the three agricultural production areas. Manure is in the table for comparing total input of fertilizer from the two data sources.

Flows		N_r $[tonne]$
Scania	Sweden statistics gave mean value for the N_r supply kg/ha over the years 2008-2011 from mineral fertilizer used in Scania (Statistics Sweden, 2014b). This together with area for agricultural land (Statistics Sweden, 2010) gave the total calculated value of N.	
	Mineral fertilizer	32,673
	Mineral fertilizer and manure	17,468
	Sum	**50,141**
Three agricultural production areas	When using a mean value for the agricultural production areas the N_r supply from mineral fertilizer and manure for the year 2011 equals according to below. Manure from grazing is based on grazing periods, e.g. a milk cow is assumed to be in a stable 38% of the time. (Statistics Sweden, 2013a)	
		N_r $[tonne]$
	Mineral fertilizer	27,676
	Manure (total)	22,440
	Sum	**50,116**

Since there is only one value for mineral fertilizer in Scania, that value is used, i.e. 32,673 tonnes of mineral fertilizer.

WWTP Sludge

Almost half of the produced WWTP sludge in Scania was spread on Agricultural land. Scanian WWTPs produced 26,650 tonnes sludge was produced in 2010. An average for the N_r content was 44 g per kg dry sludge. This corresponds to 1,131 tonnes of nitrogen. The distribution of the usage of sludge is shown in a pie chart (Figure 17) (Swedish EPA and Statistics Sweden, 2012).

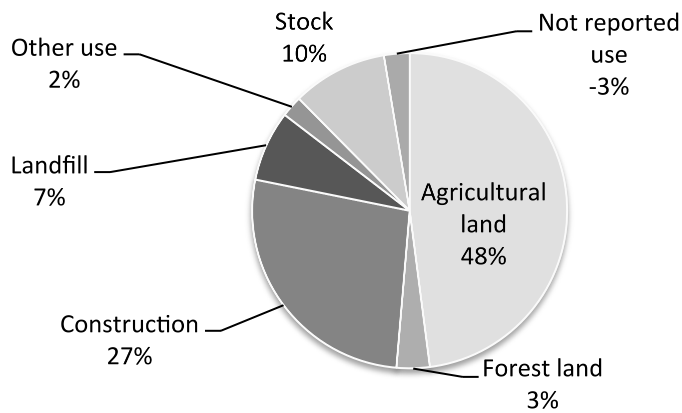


Figure 17. Where the total amount of N_r in sludge (1,131 tonnes) ended up in Scania 2010. About half is spread in on agricultural land and forestland the rest (518 tonnes) is used on other land including 117 tonnes of stock. (Swedish EPA and Statistics Sweden 2012).

Final values for inflows agricultural land

The final values for N_r entering agricultural land are according to Table 17. The seed is in the table because the same amount is assumed to be used the next year.

Table 17. Final values for N_r flows into agricultural land are in total 68,408 tonnes.

Flows		**N_r $[tonne]$**
Mineral fertilizer	Using the value for Scania in Table 16.	32,673
Manure	Using manure from Table 15.	24,377
WWTP sludge	The total sludge production from Scanian WWTP contained 1,131 tons of nitrogen and from this 48% was spread on agricultural land (Figure 16).	572
Seed	An average for the three agricultural production areas from Statistics Sweden (2014b) gave an N_r supply from seed of 1,3 kg/ha for 2011, or 598 tonnes in total. This is assumed to be an internal flow within Scania i.e. the seed is not imported.	598
Soil amendment	Soil amendment could be digestate from biogas production. It is mostly different kinds of substrates used in ecological production. (Statistics Sweden, 2013a) Calculated from an average of the amount of soil improvement for the three agricultural production areas year 2011. The mean value 2 kg/ha, together with the area of the agricultural land (Statistics Sweden, 2010) gave the calculated value of N.	898
N fixation	Values from Table 9. When using the average from the three agricultural areas the corresponding result is 4,189 tonnes of nitrogen.	5,121
Deposition	Deposition of nitrate and ammonium is in the soil balance calculated by SMHI based on atmospheric data and weather, including bot wet and dry deposition. The different agricultural production areas were assigned a value based on their geographical location. The deposition is without contributions from domestic agriculture (Statistics Sweden, 2013a) Here is an average of the three agricultural production areas calculated – 10 kg/ha was used. This together with the total agricultural area in Scania (Statistics Sweden, 2010) gave the result.	5,060
Sum		**68,408**

Outflows agricultural land

Emission from agriculture to air was found in the national emission database (Table 18).

Table 18. Emissions from agriculture. The data from RUS (n.d. a) were given in tons of N_2O and NH_3 per year. For more information on method for calculation go to section 4.1.2 Emissions to air page 28.

Emissions arising from	**NH_3** N_r [$tonne$]	**N_20** N_r [$tonne$]
Cow manure	2,650	170
Pig manure	1,438	29
Horse manure	404	42
Chicken manure	566	12
Sheep manure etc.	96	7
Cultivation of organogenic soils	0	109
Other agricultural activities	1,402	1,281
Total	**6,556**	**1,650**

In Figure 18 the leakage and NH_3 losses from the three agricultural production areas are illustrated in a chart.

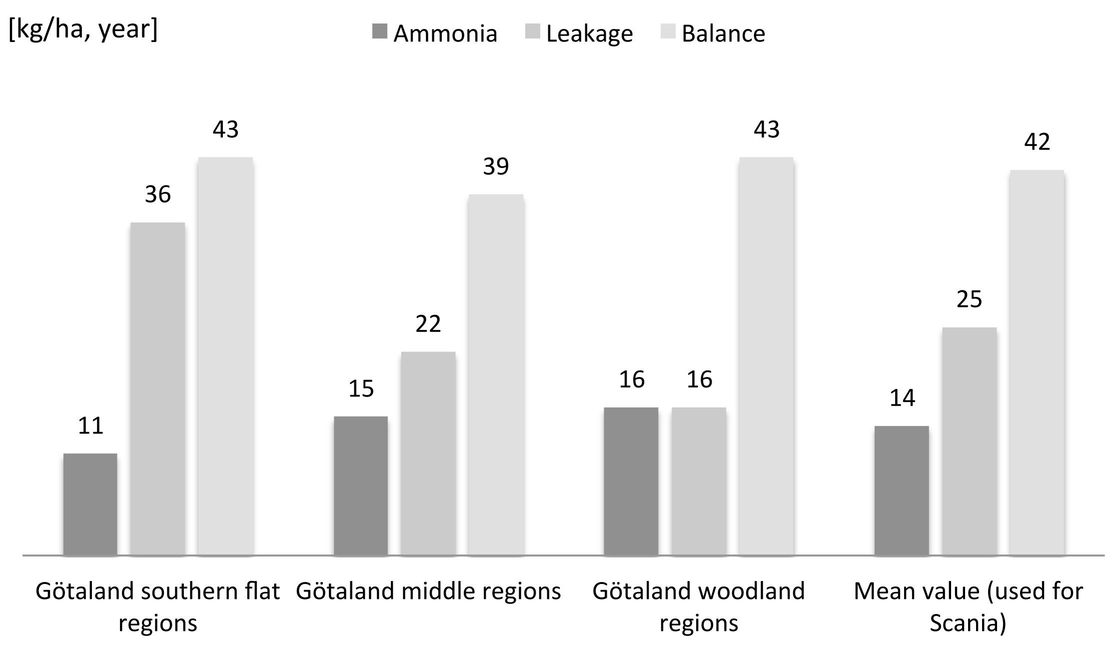


Figure 18. Ammonia losses and leakage together with balance (kg/ha, year). Balance is input (mineral fertilizer, manure etc.) minus output (yield and harvested plant residue). This is for the year 2011. (Statistics Sweden, 2013b)

Since two values for NH_3 losses were found, an average for the two will be used. The outflows from agricultural land include harvest, crop residue, NH_3, leakage and N_2O (Table 19).

Table 19. Final values for N_r flows out of agricultural land are in total 68, 807 tonnes.

Flows		**N_r [$tonne$]**
Harvest	Total Harvest, tons by region, crop and year gave the harvest in ton (Statistics Sweden, 2015a). Three different approaches was used for calculation of N_r content in harvest: • Using N_r content in different crops from Steineck, et al. (2000) gave the total calculated value of N: 53,017 ton. • Using Swedish National Food Agency's food database for protein content plus the conversion factor 5,7 or 6,25 (National Food Agency, 2015b) depending on type of crop gave the total calculated value of N: 52,202 ton. • Using the a mean value for the three agricultural production areas over the years 2009 and 2011 the yield was 91 kg/ha which gave total calculated value of N: 40,692 ton An average for the three numerals was used: $\frac{53{,}017 + 52{,}202 + 40{,}692}{3} = 48{,}637\ tonnes$	48,637
Crop residues	Crop residues (straws and tops) leaving the field used for energy or other purposes (Statistics Sweden, 2013a). Using the mean value for the three agricultural production areas gave 3 kg/ha.	1,346
NH_3	The losses of ammonia in the balance for nitrogen by Statistics Sweden (2013) is calculated from data from CLRTAP (Convention on Long-Range Transboundary Air Pollution) and takes into account different manure, losses from ventilation, storage and ventilation. The manure production is calculated from number of livestock and their production of milk and manure including losses from permanent pasture. For the ammonia losses in Scania the figures in Figure 18 was used, together with the area for agricultural land 2010 (Statistics Sweden, 2010). $438{,}800 * 14 = 6{,}143{,}000\ \text{kg} = 6{,}143\ tonnes$ This result compares well to data from RUS (n.d. a) Table 18: An average from the two figures is used according to below: $\frac{6{,}143 + 6{,}556}{2} = 6{,}350\ tonnes$	6,350
Leakage	Data from Figure 18 was used, together with the area for agricultural land 2010 (Statistics Sweden, 2010). $438{,}800 * 25 = 10{,}824{,}000\ \text{kg} = 10{,}824\ tonnes$ No other data for this was obtained.	10,824
N_2O	Data from RUS (n.d. a) from Table 18.	1,650
Sum		**68,807**

4.2.2 Livestock

In this section the in- and outflows from animal production is presented. The emissions from animal manure were allocated to the agricultural land. For all calculations a N_r content in of 2,9%[O] is used.

Outflows from livestock

The live weight for different livestock is used to calculate the outflow from the livestock box entering slaughterhouses (Table 20).

Table 20. Live weights for different livestock.

	Live weight $[kg]$
Cattle	487
Veal	122
Horse	487
Sheep and lambs	52.5
Goats	39
Swine	129
Broiler	1.9

To determine the fraction of livestock exiting the livestock box, i.e. slaughtered Scanian livestock from Scanian animal production, two different approaches were used:

1. First approach is using scaling from slaughtered livestock in Sweden (Table 21), i.e. a certain amount of the total slaughtered animals in Sweden are assumed to be produced in Scania.
2. Second approach for slaughtered Scanian livestock, is based upon number of live animals in Scania and a factor taking into account the lifetime of the animals (Table 22). The reason for using expected lifetime is because of e.g. a broiler lives about 1/7 of a year (Steineck et al., 2000) and the statistics for number of livestock is for June 2015. If using only statistics for June, there are probably a lot of animals left out of the calculations.

An average of the two approaches will be used.

[O] 2.9% is the percentage used for calculation nitrogen content in animals by Danius & Burström (2001). The number is also obtained if using protein content 18% and the conversion factor 6.25 to calculate the nitrogen content$\left(\frac{18\%}{6.25} = 2{,}91\%\right)$.

Table 21. First Approach - slaughtered Scanian livestock. Calculated from scaling total amount of slaughtered animals in Sweden. The calculations are without consideration to import and export to Sweden.

	Slaughtered Sweden[P]	**Scanian share**[Q]	**Live weight N_r $[tonne]$**
Cattle	424,506	15%	898
Veal	26,639	15%	14
Horse	3,845	15%	8
Sheep and lambs	254,635	11%	43
Goats[R]	490	11%	0.06
Swine	2,936,240	27%	2,932
Broiler	78,507,000	23%	994
Sum			**4,888**

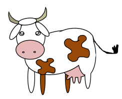
Table 22. Second Approach – slaughtered Scanian livestock. Based on number of livestock in June 2010 (Statistics Sweden, 2011b) and lifetime of livestock. When no data was found a dotted line will appear: "…".

	Live animals	**Lifetime $[year]$**		**Slaughtered animals**	**Live weight N_r $[tonne]$**
Boars	928	3	Cattle	78,318	1106
Sows in production	42,794	3[S]	Veal	69,531	246
Swine, 20 kg and over	249,231	0,5	Horse	…	
Swine, under 20 kg	113,389	…	Sheep and lambs	64,995	99
Cows for milk production	38,905	5[T]	Goats	…	
Cows for the rearing of calves	36,631	…	Swine	512,726	1918
Heifers, bulls and steers	70,537	1	Broiler[U]	15,212,256	838
Calves, under 1 year	69,531	1			
Rams and ewes	27,424	6,5[V]			
Lambs	30,388	1			
Hens, 20 weeks or older	1,079,949	1[W]			
Hens, intended for egg production	182,911	…			
Broilers	1,946,037	1/7[X]			
Turkey	72,864	1/7			
Sum					**4,206**

[P] Numbers of slaughtered livestock in Sweden are from Swedish Board of Agriculture (2014b), except for broilers where data is downloaded from Statistics Sweden (2011b).
[Q] Based on a report calculating Scanian part of Swedish animal production in economic terms (Jörgenson, 2013), except from sheep and lambs which are based on animals in Scania compared to Sweden (Statistics Sweden, 2011b).
[R] The number of goats is based on the assumption that they are as prevalent in Scania as sheep and lambs.
[S] The sow becomes unproductive after 3 years (Djurrättsalliansen, n.d.).
[T] The average age of a dairy cow is 5 years (Soldala School, n.d.).
[U] Turkeys are added to broilers, although they probably are heavier and might live longer.
[V] A mean value for expected lifetime for rams and ewes are 5-8 years (Wikipedia, 2015b): $\frac{5+8}{2} = 6,5$
[W] Egg production from a hen starts to run out after a year (Wikipedia, 2014).
[X] A broiler is replaced 7 times á year when it is ready to hit the slaughterhouse (Steineck et al., 2000).

The outflows from the livestock box contain flows of milk, egg, dead animal, manure, and live animals (Table 23).

Table 23. Final values for N_r flows out of livestock are in total 31,764 tonnes.

Flows		**N_r $[tonne]$**
Milk 	From the Cow Control (Swedish: kokollen) a Scanian milk cow produced 9,390 kg and 9,473 of ECM[Y] milk a year for 2009 and 2011 respectively. An average for the two years was used. Number of milk cows from Swedish Board of Agriculture & Statistics Sweden (2011) was 38,905 in June 2010. Protein content for milk (3.51%) from National Food Administration (2015b) and together with conversion factor for milk (6.38) National Food Administration (2015a).	2,024
Egg	Swedish Board of Agriculture & Statistics Sweden (2011) gave number of hens and tons of produced egg in Sweden, total 111,000 tonnes from which 86,200 tonnes passed through the wholesale. Based on number of egg layers (hens older than 20 weeks) in Scania divided by total number of hens in Sweden it was assumed that 20% of Swedish egg production was located in Scania. This gave total N_r content in egg: 429 tons. From which 22% $\left(1-\frac{86.2}{111}=22\%\right)$ do not pass through the wholesale. Eggs in wholesale: $$429-429*0.22=333\ tonnes$$	429
Dead animal – destruction	Dead animals heading for destruction are probably used for energy recovery and year 2010 about 63,500 tons of dead animal were destructed in Sweden (Jenssen et al., 2011). If assuming that 21% of animal production in Sweden is located in Scania together with N_r content 2.9% for dead meat the N_r flow was calculated.	387
Manure	Using manure from Table 15.	24,377
Live animal	An average from two approaches (Table 21 and Table 22) gave the live animal flow according to calculation below: $$\frac{4{,}206+4{,}888}{2}=4{,}547\ tonnes$$	4,547
Sum		**31,764**

Inflows to livestock

Two approaches were also used for calculating the fodder ingested by Scanian livestock.

1. The first approach for estimating amount of fodder was to use the sum from Table 23, i.e. what comes out of animal production in the shape of milk, dead animals or manure etc. should also be what enters in the shape of fodder (31,764 tonnes)
2. The second approach was to find data for how much the different livestock consumed individually using values for fodder and manure in Table 24 together with number of livestock from Table 22. The second approach is summated in Table 25.

An average from the two values will be used.

[Y] ECM = energy corrected milk. Calculated from kg milk according to the equation (Cow Control, n.d.):
$$milk[\boldsymbol{kg}]*0.25+fett[\boldsymbol{kg}]*12.2+protein[\boldsymbol{kg}]*7.7=ECM[\boldsymbol{kg}]$$

Table 24. Steineck, et al. (2000) has values for fodder and manure for sow, swine (30-115 kg) and different kinds of hens.

	Fodder $N_r \left[\frac{kg}{year,animal}\right]$	**Manure** $N_r \left[\frac{kg}{year,animal}\right]$	**Part of N_r in manure**[Z]
Sow	45.00	24.00	53%
Swine	5.30	2.90	55%
Hens, 20 weeks or older	1.47	1.05	71%
Hens, intended for egg production	0.12	0.09	72%
Broilers	0.10	0.05	51%

These animals in Table 24 are either growing, producing egg or piglets. Using the manure from Table 15 the fodder could be calculated (Table 25). For those animals that are assumed not to grow are eating what they are producing, i.e. the N_r content in fodder is the same as in the manure – 100%. Calves, lambs and lightweight swine are assumed to accumulate N_r as swine (20 kg and over), i.e. for these animals the ammonia losses from stable and manure is neglected.

Table 25. Fodder second approach. Based on live animals, manure and amount of N_r in fodder ending up in manure.

	Manure[AA] **N_r $[tonne]$**	**N_r in manure**[10]	**Fodder N_r $[tonne]$**
Boars	27	100%	27
Sows in production	1,238	53%	2,320
Swine, 20 kg and over	4,474	55%	8,176
Swine, under 20 kg	1,018	55%	1,860
Cows for milk production	4,539	…[BB]	6,563
Cows for the rearing of calves	2,301	100%	2,301
Heifers, bulls and steers	3,306	100%[CC]	3,306
Calves, under 1 year	1525	55%	2,788
Rams and ewes	328	100%	328
Lambs	364	55%	665
Hens, 20 weeks or older	291	71%	407
Hens, intended for egg production	257	72%	358
Broilers	3,939	51%	7,660
Turkey	148	51%	287[DD]
Sum	**23,754**		**37,046**

[Z] Part of N_r in manure compared to amount of N_r in fodder, i.e. the other part is stored in the body of the growing or lactating animal.

[AA] The manure is downsized based on the average value for manure in Table 15. The average value was lower than the value for manure. The calculated value for manure is multiplied by the factor 0.997 $\left(\frac{23,754}{23,820} = 0,997\right)$.

[BB] Milk cows were treated different adding milk to the manure and assuming that as fodder, excluding gestation once a year. Calculated from milk and manure: $2,024 + 4,539 = 6,563$.

[CC] This means that NH_3 losses and N_r content in the calve is neglected

[DD] Turkeys are assumed to be broilers.

The average value and finally chosen value for fodder consumed by Scanian livestock, is calculated (Table 26).

Table 26. Final value for N_r flow into livestock, i.e. fodder, is an average of two approaches with some added horse manure.

Flows		N_r $[tonne]$
Fodder – consumed by livestock	A mean value for the different values in Table 23 and Table 25 will be used. A compensation for the horse fodder (2,494 tons) is added. $$\frac{31{,}764 + 37{,}046}{2} = 34{,}094\ tonnes$$ Half of the horse manure was excluded in one of the calculations and fully excluded in the other: $$34{,}094 + \frac{2{,}494 + \frac{2{,}494}{2}}{2} = 35{,}964\ tonnes$$	35,964

21% of Swedish animal production is assumed to be in Scania, based on number of livestock in Scania divided by number of livestock in Sweden. Calculated from import of fodder to Sweden (Linderholm & Mattson, 2013) gave the result 3,628 tonnes. Fodder not imported from abroad is assumed to be produced on Scanian acres:

$$35{,}964 - 3{,}628 = 32{,}336 \text{ tonnes}$$

No data was found on live animal entering the Scanian system boundary into Scanian animal production.

4.2.3 Forestry

In the statistics for the different counties in Sweden from Swedish Forest Agency (2014) there is a ”–” for Scania which means there is nothing to report about fertilizer used in forestry. It seems like the N_r removal (harvesting of forest) is compensated by deposition in southern Sweden (Swedish Forest Agency, 2014).

Swedish Forest Agency does not recommend nitrogen fertilization on forestland in Scania. The reason for that is nitrogen rich soils generally, to this, nitrogen falls downs via precipitation. Additional nitrogen fertilization would lead to potentially high amounts of nitrogen leaching from forestland to waterways (Näslund, 2015).

Deposition, WWTP sludge and fertilizer reaching Scanian forestland are 4,101 tonnes in total (Table 27).

Table 27. Final values for N_r flows into forestry.

Flows		N_r $[tonne]$
Deposition	From section *4.1.1 Atmospheric deposition and nitrogen fixation* (page 27) the deposition over forestland is 4,070 tonnes.	4,070
WWTP sludge	Values from Figure 17 (page 34).	41
Fertilizer	Not recommended (Näslund, 2015).	0
Sum		**4,101**

In Table 28 the N_r flows out of forestland is presented.

Table 28. Final values for N_r flows out of forestry.

Flows		N_r $[tonne]$
Wood[EE]	Quantity of forest harvested over the years 2008-2010 (average) was (Swedish Forest Agency, 2012) 475,660 tonnes in total, of which 64,600 tons was Grot (abbreviation of branches and tree tops). Using nitrogen content for aspen tree, (0,1% (Strömberg & Solvie, 2012)§.	476
	N_r $[tonne]$	
	Grot: 65	
	Harvested wood excluding grot: 411	
Leakage	Nitrogen leaching happens to a limited extent from all forestland. On average the leakage of N_r could be 1-2 kg N/ha, year. Over 90% of the leakage occurs from growing forest, while a smaller part is caused by forestry measures. (Näslund, 2015) Here 1.5 kg/ha, year is used in the calculation. Area of productive and not productive forestland from Statistics Sweden (2010). $407{,}000 * 1{,}5 = 610{,}000\ kg = 610\ tonnes$	610
Sum		**1,086**

4.2.4 Fishery

The emissions from fishery from ships and boats are included under section *4.5 Transport*. In Table 29 the N_r content in fish fished by Scanian fishers is displayed together with assumptions about the outflow.

Table 29. Final values for N_r flow in fishery.

Flows			N_r $[tonne]$
Fish	County board statistics (länsstatistik) showed cached fish in kg (County Board Statistics, 2015). This together with protein content for raw fish (National Food Agency, 2015b) and N_r content (National Food Agency, 2015a)		370
Fish	Anon. pers. (2015) made an expert's judgement about the destiny of the fish.		
	Exported directly	45%	
	Processed in Scania	25%	
	Frozen (and then exported)	30%	

4.2.5 Fish farms

There are six fish farms and three sport facilities with some smaller breeding activities. Of the six farms; two are recirculating the water to 95%, one is a large land-based eel cultivation and three are dam-based cultures. Two mussel farms on experimental level are run by the City of Malmö (County Board Statistics, 2015). With that information no further effort was made for determining these nitrogen flows.

[EE] Calculation for tonnes of harvested wood in Scania and grot are performed by Seweling (2015).

4.3 Food industry and industry

Due to the time frame of this SFA the Scanian industry was not an area of interest since other parts of the sectors was assumed to be of greater impact, i.e. assumed to involve larger nitrogen flows, and therefore had more attention from the author in the search for data, although some negligible data for wastewater was obtained (Table 30).

Table 30. N_r out industry

Flow		N_r $[tonne]$
Wastewater	From paper mills and chemical factories (Swedish EPA, n.d.)	64
Emissions to air	From Table 11 including industrial processes and solvent use.	445
Sum		**509**

A lot of effort was put into calculating N_r flows in food industry and slaughterhouses. Since slaughterhouse produces an inflow to food industry the data from the two boxes will be presented together below. First data and calculations will be presented for food industry and slaughter-houses. Then a calculation for the waste in this sector is presented. At last a summation with final values will be presented.

4.3.1 Food industry

In Scania, a major part of Sweden's largest food producers are found, which is because of the agriculture (County Board of Scania, n.d.). Statistics Sweden has data on the amount of goods that Swedish industry produces. The data is divided into KN-codes and could be given in tons or litres. It is the quantity that is manufactured and sold by the producer (Statistics Sweden, n.d. a) and it is given in Table 31.

Table 31. Produced food in food industry.

Flow		N_r $[tonne]$
Produced food	Calculations with data from Statistics Sweden was made with the following assumptions: - The data gives sold amount from the food industry. It could be produced the year before. For this no consideration was taken in to account. - N content used in calculations could be found in - Appendix A – Nitrogen content for KN-codes. Here it is assumed that chapter 1-22 (KN-code) are part of the food industry. - In economical terms 24% of Sweden's food industry is located in Scania (Jörgenson, 2013). One litre of food or drink etc. was assumed to weigh one kg. With those assumptions the food production in Scania could be calculated.	24,451

4.3.2 Slaughterhouse

In Table 32 the weights used for calculations in Scanian slaughterhouses is presented. For all calculations a nitrogen content of 2,9%[FF] is used.

Table 32. Weights for different livestock.

	Carcass weight $[kg]$	N_r per carcass $[kg]$
Cattle	268[GG]	7.80
Veal	67[HH]	1.90
Horse	268[II]	7.80
Sheep and lambs	19[JJ]	0.60
Goats	14	0.40
Swine	90[KK]	2.60
Broiler	1.38[LL]	0.04

The nitrogen content in slaughtered animals in Scanian slaughterhouses could be calculated by using number of slaughtered animals in Scania (Table 33). The live weight is calculated, since the difference between live weight and carcass (mostly head and intestine, but also skin) is the arising waste from slaughterhouses.

Table 33. Slaughtered animals in Scania. Based on actually slaughtered animals, which probably includes imported animals. The calculated value from goats is to small to be in the table.

	Slaughtered animals in Scania[MM]	Slaughtered in Scania – live animals N_r $[tonne]$	Slaughtered in Scania – carcass N_r $[tonne]$
Cattle	64,419	910	501
Veal	8,857	31	17
Horse	631	9	5
Sheep and lambs	28,399	43	16
Goats	33	-	-
Swine	1,325,450	4,942	3,459
Broiler	18,056,610	1,000	720
Sum		**6,936**	**4,718**

[FF] 2.9% is by Danius & Burström (2001). Also obtained if using a protein content 18% and conversion factor 6.25 (18%/6.25=2,91%).
[GG] For cattle the weight was received via mail from Swedish Board of Agriculture.
[HH] Veal is assumed to weigh one quarter of a cow.
[II] Horse is assumed to weigh as a cow.
[JJ] Sheep and lambs are assumed to weigh as the most common lamb in Sweden (City Gross, n.d.).
[KK] Swine weights are received via mail from Swedish Board of Agriculture.
[LL] The broiler's weight is calculated from live weight and 72% carcass weight from live weight (Wariss, 2000).
[MM] The number of slaughtered animals are from Swedish board of Agriculture (2014b), data for Broilers was missing, 23% of Sweden's slaughtered broilers was assumed to be slaughtered in Scania (Table 21)

These animals in Table 33 are probably not all Scanian livestock since the animal producer is likely to send her animals to the slaughterhouse that pays the most. Scanian inflow to slaughterhouse is 4,547 tonnes (average from Table 21 and

Table 22). This makes the imported livestock to Scanian slaughterhouse according to calculation below:

$$6{,}936 - 4{,}545 = 2{,}389\ tonnes$$

4.3.3 Waste – food industry and slaughterhouses

First total food waste from slaughterhouses (Table 34) and food industry (Table 35) will be presented. After that the assumptions about usage or destiny for the food waste will be presented (Table 36).

The food waste from slaughterhouses are the difference between live weight and carcass e.g. intestines and heads (Table 34).

Table 34. Food waste slaughterhouse is based on live weight and carcass weight from Table 33.

Livestock	N_r $[tonne]$
Cattle	410
Veal	14
Horse	4
Sheep and lambs	28
Goats	0.02
Swine	1,483
Broiler	280
Sum	**2,218**

Food waste from food industry is based on a report - *From farm to table* (Swedish: Från Jord till bord) - a SMED report (Jenssen et al., 2011) - where the authors studied the environmental reports from companies. They developed key indicators for food waste in different sub-sectors of the food industry. The nitrogen content was assumed to be the same as in purchased food (2.9%[NN]).

[NN] The nitrogen content in food waste was calculated with the assumptions: Protein content as in purchased food (18%) and the conversion factor (6.25) together give the nitrogen content in food waste 2.9%

In Table 35 the food waste in the food industry is presented.

Table 35. Food waste from food industry calculated from key indicators. The key indicators for food waste are developed for different sub-sector, not to be confused with what in this report is called subsystems (air, society and water) or sectors of society (5 sectors e.g. food industry/industry)

Sub-sector	SNI-code[OO]	Number of employees[PP]	Food waste $\left[\frac{kg}{person}\right]$ [QQ]	N_r $[tonne]$
Slaughter houses and charcuterie	10.1	2,131	2,500	155
Seafood	10.2	112	200	1
Fruit, vegetables and beverages	10.3	2,660	8,100	628
	11.0	462		109
	10.4	177		3
Oils, cheese and ice cream	10.511	155	500	2
	10.520	88		1
Milk	10.519	397	2,100	24
Flour and (animal) fodder	10.6	449	4,800	63
	10.9	211		30
Sugar production	10.81	475	1,200	17
Bakeries	10.7	2,504	1,900	139
Other food	10.82	184	8,800	47
	10.83	196		50
	10.84	503		129
	10.85	489		125
	10.86	39		10
	10.89	96		25
Sum				**1,557**

In Table 36 waste destination for both slaughterhouse and food industry are presented. Table 35 presented the calculated value of 155 tonnes food waste from slaughterhouse and charcuteries. These numbers seem very low compared to calculated values based on live weight and carcass weight. This calculated value is assumed to be included in the food waste from slaughterhouses and are therefore excluded ($1{,}556 - 155 = 1{,}401$ tonnes).

[OO] The SNI-code for the different sub-sectors was obtained via contact with one of the authors of the report.
[PP] The number of employees in for the different sub-sectors was obtained via e-mail with Sweden statistics.
[QQ] Key indicators for waste per employee was developed for 9 different sub-sectors with similar waste by Jensen et al. 2011

Table 36. Waste from food industry and slaughterhouses. Below – where food waste from the food industry could go to or be used as according to the column to the left (Jenssen et al., 2011).

	Destination (Jenssen et al., 2011)	**From slaughterhouses N_r [$tonne$]**	**From food industry[RR] N_r [$tonne$]**	**Sum N_r [$tonne$]**
Fodder	53%	1,176	743	**1,918**
Anaerobic digestion	28%	621	392	**1,013**
Combustion	11%	244	154	**398**
Other recycling	2%	44	28	**72**
Discharge into water	6%	133[SS]	84	**217**
Sum	**100%**	**2,218**	**1,401**	**3,619**

4.3.4 Food industry and slaughterhouse – final values

Wastewater, food waste and produced food equal the outflow from food industry (Table 37).

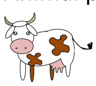
Table 37. Final values for outflows in food industry.

Flows		**N_r [$tonne$]**
Wastewater	Wastewater food industry showed different result depending on origin of data. 1. The calculated value was 84 tonnes according to Table 36 above and 2. the reports value of 771 tonnes according to Swedish EPA's database *"utsläpp i siffor"* containing discharges from companies with environmental hazardous activities, here discharge from food industry (Swedish EPA, n.d.). Since reported data should be more reliable than assumed data. The reported data is used.	771
Food waste	Excluding waste in wastewater from calculations in Table 36, since reported values was chosen the other value is subtracted to avoid double counting: $1{,}401 - 84 = 1{,}317$ tonnes	1,317
Produced food	Total amount of produced food from Table 31.	24,451
Sum		**26,539**

[RR] Excluding food waste from slaughter houses and charcuteries 1,556-155=1,401
[SS] Similar to reported amount: 131 tonnes (Table 39)

Final values for inflows in food industry are presented below. The total inflow is the sum from wastewater, food waste and produced food exiting food industry from Table 37 above. Here mass balancing has been used for assumptions about the inflows to food industry (Table 38).

Table 38. Final values in food industry. The sum at the bottom equals the inflow.

Flows		N_r $[tonne]$
Harvest	Total harvest (48,637 tons), fodder (assumed to eat from the harvest although some part of the energy supply is fulfilled during grazing, 35,964 tonnes) and imported fodder (3,628 tons) and seed assumed to be used the year after (598 tons) $$48{,}637 - 35{,}964 + 3{,}628 - 598 = 15{,}703 \text{ tonnes}$$	15,703
Animal products 	Milk (2,024 tons), egg (333 tonnes, 429*0.22 don't pass through wholesale) and fish (203 tonnes) $$2{,}024 + 333 + 203 = 2{,}560$$	2,560
Carcass from slaughterhouses	Values from Table 33. Chapter 2 in the KN-.codes is mostly already slaughtered animals when reading description of the codes (Statistics Sweden, 2015b).	4,718
Imported material (excluding live animals)	$$\text{Inflow to food industry} - \text{harvest} - \text{animal products} - carcass$$ $$26{,}539 - 15{,}703 - 2{,}560 - 4{,}718 = 3{,}475\ tonnes$$	3,558
Sum		**26,539**

The outflows from slaughterhouse are wastewater, waste (mainly head and intestines) and carcass (entering food industry) (Table 39). Since wastewater is assumed to be part of the waste it is subtracted from other waste exiting the slaughterhouse.

Table 39. Final values for slaughterhouses.

Flows		N_r $[tonne]$
Wastewater	To WWTP (Swedish EPA, n.d.)[TT] – similar to calculated value (133 tonnes in Table 36) Reported value is chosen rather than calculated value.	131
Waste	Calculated from live animals and carcass (2,218 tonnes) from table Table 34: $$2{,}218 - 131 = 2{,}087$$	2,087
Food into food industry.	Calculated from slaughter data and carcass weights 4,718 tonnes	4,718
Sum		**6,936**

[TT] From industries according to Swedish EPA's database "Utsläpp i siffror" containing discharges from companies with environmental hazardous activities, here discharge to WWTPs from slaughterhouses, 131 tonnes.

4.4 Households, service and retail

Two different approaches for human excretion into the wastewater were collected.

1. The first approach is based on food intake and food waste ending up in greywater or flushed down the drain (Table 40)
2. The second approach for human excretion is found in literature (Table 41).

One of the approaches will be chosen.

Table 40. First Approach - N_r load per person into the toilet. Based on food intake and food waste into the wastewater.

	$N_r \left[\frac{g}{person,day}\right]$	$N_r \left[\frac{kg}{person,year}\right]$	$N_r \left[\frac{tonnes}{Scania,year}\right]$
Consumed food – Based on food diaries kept for the year 2010/11 the protein content in food was obtained (National Food Agency 2012).	12.9	4.7	5,844
Food waste in greywater – Year 2014 an average Swede threw away 26 kg of food into the greywater; this was 23% of the total food waste (Sörme et al., 2014). - Total food waste waste in solid collection per person in Sweden the year 2010 was 72 kg (Jenssen et al., 2011). - With the same proportion (23%) of food waste in greywater as 2014, this makes the foodwaste in greywater 22 kg/person for 2010. - If using the same weight percentage for protein as in purchased food (18%) and the conversion factor 6.25 the N_r load can be calculated. - A small amount will leave the body in the forms of nails, skin and sweat (Skredsvik-Raudberget 1998). This will not be taken into account. - No literature on any other N_r ending up in the greywater has been found. The greywater is assumed to be according to the food waste in the grey water according to 22 kg per person and year, which is 0.63 kg N_r per person and year.	1.7	0.63	783
Sum	**14.6**	**5.3**	**6,627**

Table 41. Second approach - N_r load per person into the toilet found in in other reports. Second approach is based on human N_r load from a report from Swedish EPA (1995)

	$N_r\left[\frac{g}{person,day}\right]$	$N_r\left[\frac{kg}{person,year}\right]$	$N_r\left[\frac{tonnes}{Scania,year}\right]$
Urine	11	4.0	4,992
Faecal	1	0.5	454
Grey water	1.5	0.4	681
Sum	**13.5**	**4.9**	**6,127**

In this study the first approach is used. The approach builds upon the fact that the nitrogen you eat also leaves your body. The nitrogen you eat if you are an adult person leaves your body and ends up in the wastewater (Swedish EPA, 1995). Since data for first approach is more up to date it appears more reasonable to choose these data. For Scania this makes a total difference of 500 tonnes (6,627 tonnes - 6,127 tonnes = 500 tonnes) of N_r depending on chosen approach.

4.4.1 Household, restaurants etc.

The statistical data for purchased amount of food and food waste was could not be separated into household and restaurants etc. The waste and wastewater from this sector are treated in Technical systems, where you also find fuel for small scale heating.

In Table 42 the flows into household and restaurants etc. are presented.

Table 42. Final value for flow of N_r with food to households.

Flows		$N_r\ [tonne]$
Purchased food	The data is based on direct consumption i.e. on the quantities available for consumption in retail or large scale catering establishment, waste occurring after purchase is not considered. The protein purchase is 112 g/person, day (Swedish Board of Agriculture, 2013b). This is the same as 41 kg/person, year. The weight percentage for protein in purchased food is 18 % (calculated Swedish Board of Agriculture (2013b)) and the conversion factor 6.25 the N_r load can be calculated. $\frac{41 * 0,18 * 1,243,329}{6.25} = 8,132,000\ kg = 8,132\ tonnes$	8,132

Total inflow for household and restaurant is according to the outflow, which includes total waste for household and restaurants etc. (Table 43).

Table 43. Final values for household and restaurants etc. These are the outflows.

Flows		N_r $[tonne]$
Wastewater	Based on food intake (from The second approach for human excretion is found in literature (Table 41). One of the approaches will be chosen. Table 40) gives the total N_r load. $1{,}243{,}329 * 5.3 = 6{,}627{,}000\ kg = 6{,}627\ tonnes$	6,627
Food waste – to biological treatment	In Scania 43,800 tonnes of food waste was collected from households and similar activities such as hotels and restaurants (Avfall Sverige, 2011). With the assumption that wasted food has the same nutritional content as purchased food the nitrogen content was calculated: $43{,}800 * 2.9\% = 1{,}275$ tonnes	1,275
Food waste – to incineration plants	In this report it is assumed that food waste not heading for biological treatment goes to incineration plants inside of Scania. Food waste based on purchased and consumed food, when counting backwards give this result: $8{,}132 - 6{,}627 = 1{,}505$ tonnes When counting backwards from purchased food (8,132 tonnes), food waste in wastewater and eaten food (6,627 tonnes) and collected food waste (1,275 tonnes): $8{,}132 - 6{,}627 - 1{,}275 = 230\ tonnes$ Total food waste in solid collection in Sweden from households and similar activities is 72 kg per person and year; this is without food waste flushed down the drain (Jenssen et al., 2011). This together with above mentioned assumptions (2.9%[UU] nitrogen content) for N_r content gave the calculated value: $72 * 1{,}243{,}329 * 2.9\% = 2{,}608{,}000\ kg = 2{,}608\ tonnes$ If using total food waste (2,608 tonnes) and subtracting the food waste to biological treatment (1,275 tonnes): $2{,}608 - 1{,}275 = 1{,}333\ tonnes$	1,333
Sum		**9,235**

The difference between total amount of purchased food (8,132 tonnes) and total food waste (9,235 tonnes), could be either that the nitrogen content in food waste is overrated or that the hotels and restaurants are included in the collected food waste, which also could include eating and waste producing tourists. It could also be that the purchased amount doesn't fully include all food.

The sum of the outflow in Table 43 and the purchased food in Table 42 does not agree. The difference is calculated:

$$9{,}235 - 8{,}132 = 1{,}103\ tonnes$$

[UU] This might be overestimated since inevitable food waste, such as peels and bones, potentially has lower protein content.

This calculation using the conservation of matter principle gives a value (1,103 tonnes), which is added as an inflow in the household and restaurant etc. above.

4.4.2 Retail

Jensen et al. (2011) developed key indicators (kg waste/employee) for food waste per employee in grocery stores. The number of employees in Scanian grocery stores in 2010 was obtained via e-mail with Sweden statistics. Same assumption for N_r content is made here as in Table 43, i.e. 2.9%. Table 44 shows both in- and outflows. The sum at the bottom equals the inflow to retail.

Table 44. Final values in retail.

Flows					**N_r $[tonne]$**
Food waste – grocery stores		Food waste $\left[\frac{kg}{employee}\right]$	Employees	N_r $[tonne]$	261
	Food waste - together with other household waste	374	9,534	104	
	Food waste - separate collection	565	9,534	157	
	Sum	**939**	**9,534**	**261**	
Food	Purchased food from Table 42.				9,235
Sum					**9,496**

The food waste in retail is assumed to go to combustion, i.e. in the normal garbage bag.

4.5 Technical systems

4.5.1 Wastewater treatment

Data is obtained for WWTPs with activity number 90.10, i.e. WWTPs with more than 2,000 PE (>2,000 PE). Number of people living with one-site sanitation was obtained from (Stockholm County Board, 2013) based on a SMED technology survey of on-site sanitation in 2011. The gap in between those two data sources was assumed to be filled by smaller wastewater managements systems (200-2,000 PE). Table 45 presents the nitrogen load based number persons connected to the different wastewater treatment systems. The nitrogen loads are calculated from N_r load per person (14.6 g/person, day) from Table 40.

Table 45. N_r load from Scanians was divided into three different wastewater treatment categories.

Human load	Persons	N_r $[tonne]$
>2,000 PE	991,901	5,291
200-2,000 PE	136,930	730
On-site sanitation (with 65% home presence in parenthesis)	114,498	611 (397)
Sum	**1,243,329**	**6,632**

From industries according to Swedish EPA's database *"Utsläpp i siffror"* (Eng. quantified emissions) containing discharges from companies with hazardous activities (Table 46). Waste sites and landfills will be in the allocated to combustion in the calculated values and illustrations.

Table 46. Discharges into water and to WWTPs from Swedish EPA (n.d.).

Type of industry	N_r to water $[tonne]$	N_r to WWTP $[tonne]$
Papermills	64	-
Food industry	250	521
Slaughterhouses	-	131
Chemical factory	-	4
Waste sites and landfills	19	-
Energy supply	-	3
Sum	**333**	**659**

In Table 47 the calculated values and assumptions for wastewater treatment technologies is presented.

Table 47. Final values for inflows to different wastewater treatment technologies.

Flows		N_r $[tonne]$
>2,000 PE[VV]	WWTP with activity number 90.10, an extract from the Swedish Environmental Reporting Portal (Svenska miljörapporteringsportalen) gave total influent load of 5,398 tonnes. From Table 45 based on numbers of connected people the influent load from inhabitants should be 5,291 tonnes. The difference is calculated: $5{,}398 - 5{,}291 = 107\ tonnes$ These 107 tonnes could be from industries. The 107 tonnes, from other wastewater than from residents, could also be higher since inhabitants might use toilets not connected to >2,000 PE WWTP.	5,398
200-2,000 PE	Influent load from those with on-site sanitation and 65% home presence (Table 45): $611 - 397 = 214$ tonnes These 214 tonnes are residents using toilets outside their homes. Influent load from industries is 659 tonnes (Table 46). Here subtracted the influent load to WWTP >2000 PE. These 107 tonnes are assumed to be influent load to >2,000 PE WWTP. Calculation below gives the influent load from industries to 200-2,000 PE WWTP: $659 - 107 = 552\ tonnes$ Total nitrogen load from inhabitants with on-site sanitation (214 tonnes) and industries (552 tonnes) and inhabitants connected to 200-2,000 PE WWTP (730 tonnes, Table 45): $214 + 552 + 730 = 1{,}496\ tonnes$	1,496
On-site sanitation	From Table 45 based on numbers of connected people with 65% home presence.	397
Sum		**7,291**

To quantify leakage of nitrogen from on-site sanitation the SMED technology survey of on-site sanitation in 2011 has been combined with statistics from the Swedish Statistics 2013 in a project (Stockholm County Board, 2013). They assume that 65% of the N_r load is allocated to on-site sanitation (65% home presence).

[VV] Data for WWTPs with activity number 90.10 – WWTP with more than 2 000 PE. The data was received via mail and is an extract from the Swedish Environmental Reporting Portal (Svenska Miljörapporteringsportalen).

About 9.2% (114,498 persons) of Scania's population has on-site sanitation (Stockholm County Board, 2013). This applied with assumptions for N_r load (5.3 kg/person, year) give N_r in and out (Table 48).

Table 48. On-site sanitation. Data from Stockholm County Board (2013).

Treatment technology	On-site sanitation[WW] $[persons]$	N_r removal efficiency	Load 65%[XX] home-presence N_r $[tonne]$	Leakage 65%[RR] home-presence N_r $[tonne]$
Soil infiltration	45,153	30%	157	110
Sand filter bed	22,483	25%	78	58
Sand filter bed and phosphorus removal	219	30%	1	1
Septic tank	23,244	10%	81	73
Greywater treatment	21,256	28%	74	53
Prefabricated wastewater treatment plant	2,095	40%	7	4
Chemical and biological treatment plant	48	25%	-	-
Sum	**114,498**		**397**	**299**

In Table 49 the calculated values for wastewater management is presented.

Table 49. The final outflows from wastewater management.

Flows		N_r $[tonne]$
WWTP >2000 PE	From the Swedish Environmental Reporting Portal [YY]	1,480
WWTP 200-2,000 PE[ZZ]	$1{,}496 * (1 - 0.4) = 898$ tonnes	898
One-site sanitation	From Table 48.	299
Sludge	From Figure 17, total sludge production from WWTP	1,131
Emissions to air	From Table 11.	122
Sum		**3,930**

4.5.2 Combustion

Statistics Sweden provides data the amount of fuel used in Scania in MWh fuel (Statistikdatabasen, n.d.). The data is divided into gas and solid fuel, and additionally into renewable and non-renewable (Table 50).

[WW] With the assumption: People registered on a property also live there
[XX] Stockholm County Board (2013) used a 65% home presence which gave N_r load of 9,7 g/day, person, which gave the total N_r load 282.6 tonnes for on-site sanitation.
[YY] Swedish Environmental Reporting Portal (Svenska miljörapporteringsportalen).
[ZZ] If using a 100% home presence, a N_r removal efficiency of 40%.

Table 50. N_r in fuel for solid fuels (Statistikdatabasen, n.d.).

Flows					**N_r $[tonne]$**
Fuel to district heating	Values for MWh from (Statistikdatabasen, n.d.). For non-renewable, a heating value for black coal was used, 28-36 MJ/kg (Swedish Energy Agency, 2010). A mean value for lower and upper value was used below. For renewable a heating value for wood fuel was used (Wikipedia, 2015a). The nitrogen content is median value for a mix of paper, plastic and wood from The Fuel Handbook 2012 (Strömberg & Solvie, 2012).				4,681
		Mean value 2009-2011 $[MWh]$	Heating value $\left[\frac{MJ}{kg}\right]$	N_r [% of TS]	
	Renewable (solid)	585,322	32	1%	
	Non-renewable (solid)	2,704,173	24,2	1%	
Fuel to electricity	Same values and references as for district heating.				
		Mean value 2009-2011 $[MWh]$			1,299
	Renewable (solid)	172,283			
	Non-renewable (solid)	742,671			
Fuel -for small scale heating	Including small scale heating for houses, apartment buildings, cottages, industry and construction, activities in the public sector and other services. With same assumptions as above.				
				N_r $[tonne]$	2,922
	Renewable (solid)			2,154	
	Non-renewable (solid)			768	
Sum					**8,902**

NO_x, N_2O and NH_3 emissions to air from combustion are presented in section *4.1 Air*. No data for use of urea or ammonia was obtained.

4.5.3 Biological treatment

The soil amendment used on agricultural land could possibly be a by-product from biogas production. 898 tonnes of soil amendment was used 2010. Table 51 below presents the food waste collected from household and food waste from food industry that could possibly be used in biogas production. Some farmers have biogas production using manure, this was not considered.

Table 51. Final values for biological treatment.

From		**N_r $[tonne]$**
Household	Values from Table 43	1,275
Food industry	From food waste in food industry assumed to be used in for anaerobic digestion from Table 36.	1,013
Sum		**2,288**

The sum from biogas production (2,288 tonnes) is much higher than the soil amendment used on agricultural land (898 tonnes). When biogas is produced from protein rich substrates NH_3 is produced (Nilsson, 2010), which means that some part of N_r entering biogas production might go to air. This is not considered.

4.6 Transport

Table 52 presents emissions to air from transport. For more information on calculation method for NO_x, NH_3 and N_2O to N-equivalents, please go to section *4.1 Air*.

Table 52. Final values for N_r emissions from transportation.

	International[AAA] N_r $[tonne]$	Working machinery[BBB] N_r $[tonne]$	Scanian[CCC] N_r $[tonne]$	Total N_r $[tonne]$
NO_x	3,896	1,162	3,997	**9,055**
NH_3	2	1	340	**343**
N_2O	-	16	53	**69**
Sum	**3,898**	**1,179**	**4,390**	**9,467**

4.7 Water

A surplus of nitrogen within Scania leads to leakage into the sea. For this two different data can be discussed:

1. First data[DDD]– the calculation method by SLU together with SMHI (Swedish Meteorological Institute) the supply of nitrogen to the Kattegat, Öresund Strait and Baltic Sea (Table 53). Method used in data basis:
    a. Data Basis - The supply of nitrogen to the coast (Swedish: Dataunderlag - Tillförsel av kväve till kusten)
    b. Calculation of the N_r load are from rivers and streams into the sea
2. Second data– the data is a summation of leakage, emission and deposition to water from sections 4.1-4.1 above, i.e. a summation of all other flows of N_r into water (Table 54).

Both data will be discussed and illustrated in flow charts further on.

Table 53. N_r supply to the sea from SLU together with SMHI (Miljömål, n.d.).

	2009 N_r $[tonne]$	2010 N_r $[tonne]$	2011 N_r $[tonne]$
Kattegat	2,115	3,304	3,838
Öresund strait	2,156	3,792	4,223
Baltic Sea	3,940	5,437	6,981
Mean values over the years 2009-2011 from are summated: $3,068 + 3,390 + 5,453 = 11,929$ tonnes			
Sum		**11,929**	

[AAA] International aviation and maritime transport - This sector includes emissions on Scanian waters and in Scanian airspace of international aviation and shipping. (RUS, n.d. a)

[BBB] Working machinery, including working machinery used in agriculture, scooters and quads (RUS, n.d. a)

[CCC]Scanian transport includes passenger cars, light trucks, heavy trucks and buses, mopeds and motorcycles, domestic civilian shipping (including motorboats), domestic air traffic and other transport. (RUS, n.d. a)

[DDD] Data source found by Seweling (2015).

Table 54. N_r leakage and emission to water from all sectors. Deposition directly to water is presented at the very at the bottom.

From	N_r $[tonne]$
Agricultural land (Figure 15)	10,824
Forest land (Figure 15)	610
Wastewater from food industries (Figure 16)	250
Wastewater from industries (Figure 16)	64
Leakage from waste sites and landfills (Figure 26)	19
Leakage from on-site sanitation (Figure 26)	299
Discharges WWTP >2,000 PE (Figure 26)	1,480
Discharge WWTP 200-2000 PE (Figure 26)	898
Deposition to lakes and watercourses (Section 4.1.1)	333
Sum	**14,777**

This calculated value is higher than the sum from Table 53.

4.8 Quantified flow charts for society, air and water

In this section all the flowcharts for the three subsystems is presented. The last section is a table containing all flows (Table 55). Background data and information about references and calculations for each subsystem are found above in section 4.1-4.7.

4.8.1 Air – three quantified flow charts and four pies

First a composition of four pie charts showing different distributions of emissions is presented (Figure 25). Then a flow chart of emissions to air is displayed (Figure 20), after that of a flowchart of deposition on land and fixation to agriculture (Figure 26). The last flowchart (Figure 27) is a merge of the two first, showing both inflows and outflows of airborne emissions.

The Scanian air pollution is mainly NO_x from transport, but also N_2O and NH_3 emissions from agriculture (Figure 25). At the bottom the contribution by the different sectors to N_r pollution is shown. Technical systems include the emissions from WWTP, waste management and incineration plants.

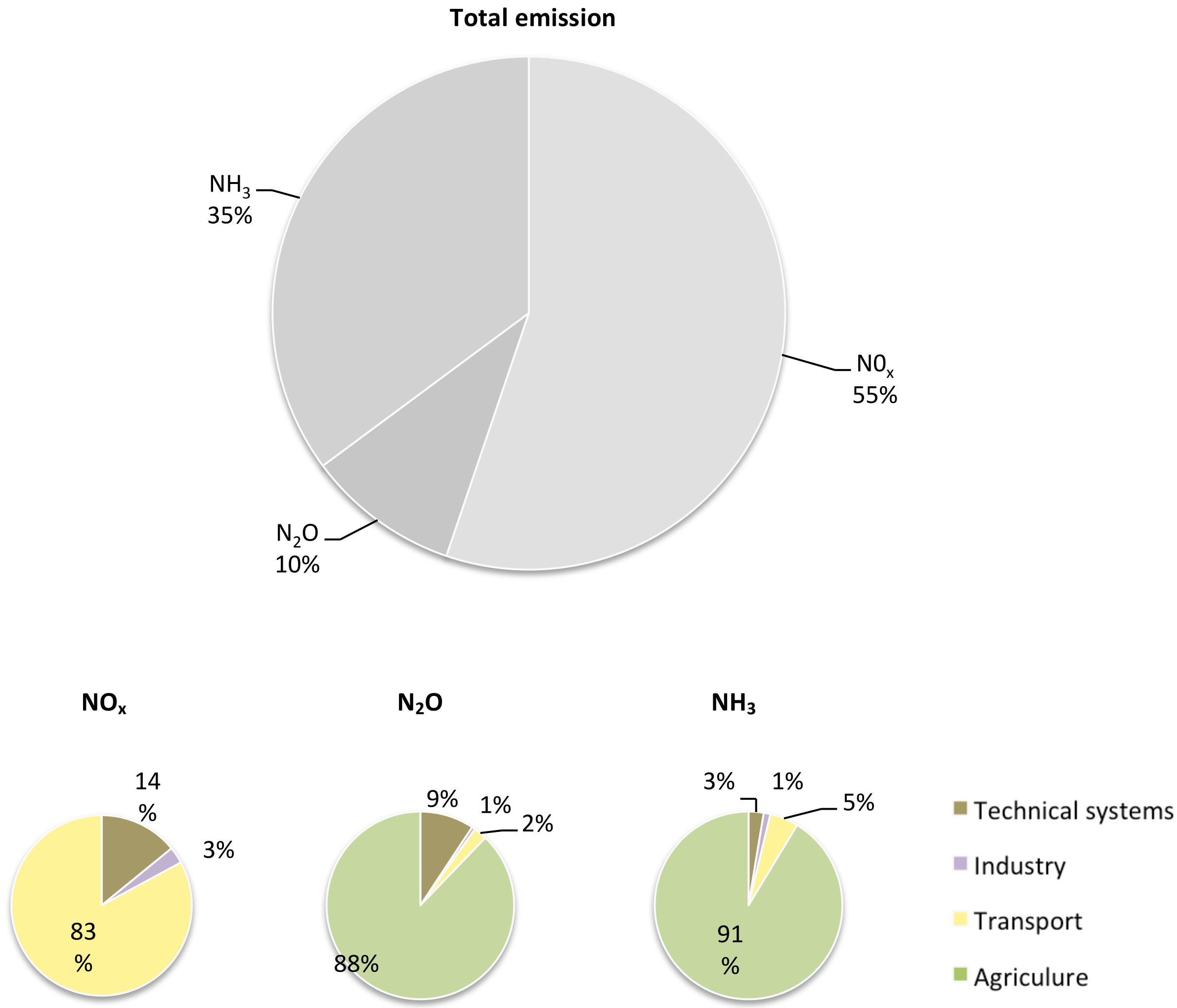


Figure 19. Distribution of NO_x, N_2O and NH_3 from emissions to air. The three bottom pie charts show the contribution of the different sectors to each N_r gas pollution.

The emissions from society are mainly from Agriculture and Transport (Figure 20). Calculated values are here presented with some modifications; technical system is waste and wastewater put together with NO_x emissions from combustion i.e. energy supply. Industry includes industrial processes and solvent use.

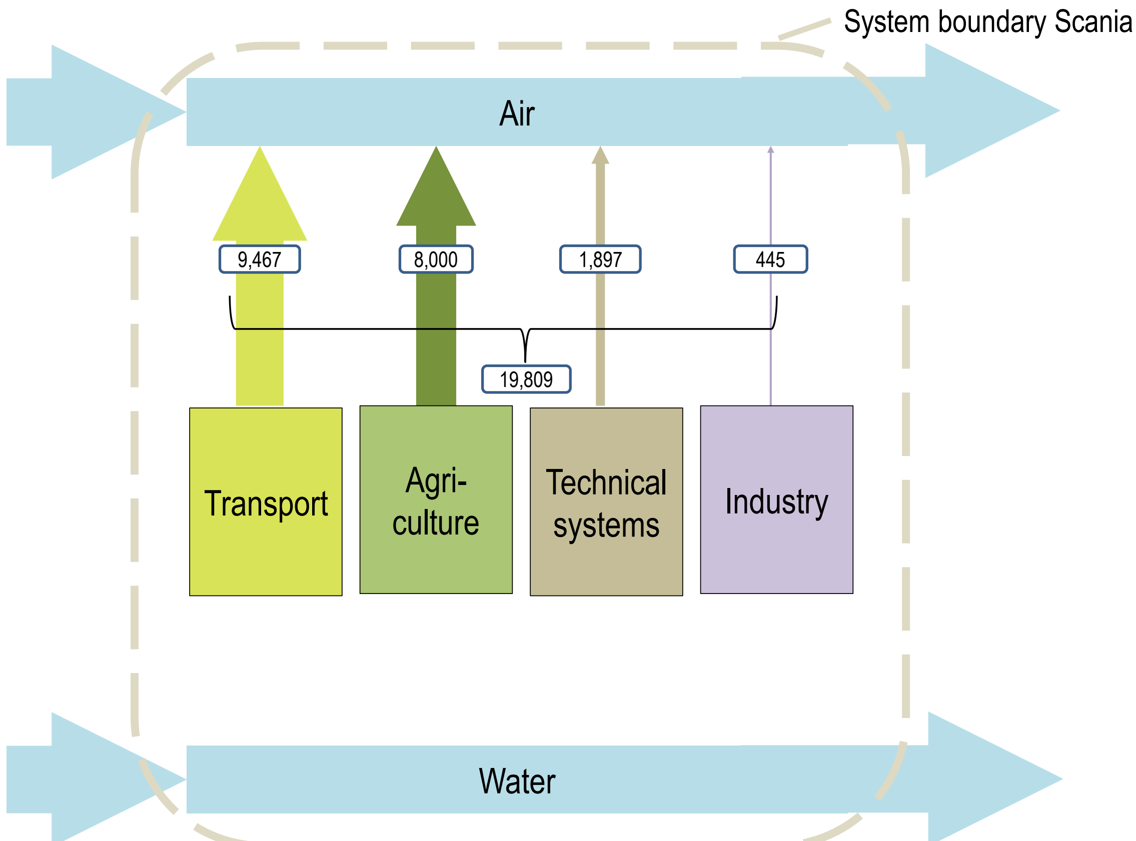


Figure 20. Emissions to air from all sectors except Household/Retail/Service for which no data was found. Emissions from waste management were allocated to technical systems. The arrows are scaled with respect to size. Unit is in tonnes of N_r.

The atmospheric deposition, which is distributed over different land types, and nitrogen fixation on agricultural land, is in total 16,423 tonnes (Figure 21). Agricultural land contains grazing land. The deposition is calculated at 10 kg/ha from Statistics Sweden (2013a) from Table 17. A small amount deposits directly in water. The areas are from Statistics Sweden (2010). The nitrogen fixation (Table 17) is in lighter colour to the left. Total deposition in Scania is total 11,302 tonnes. The inflow to agricultural land, deposition and fixation, is in total 10,181 tonnes.

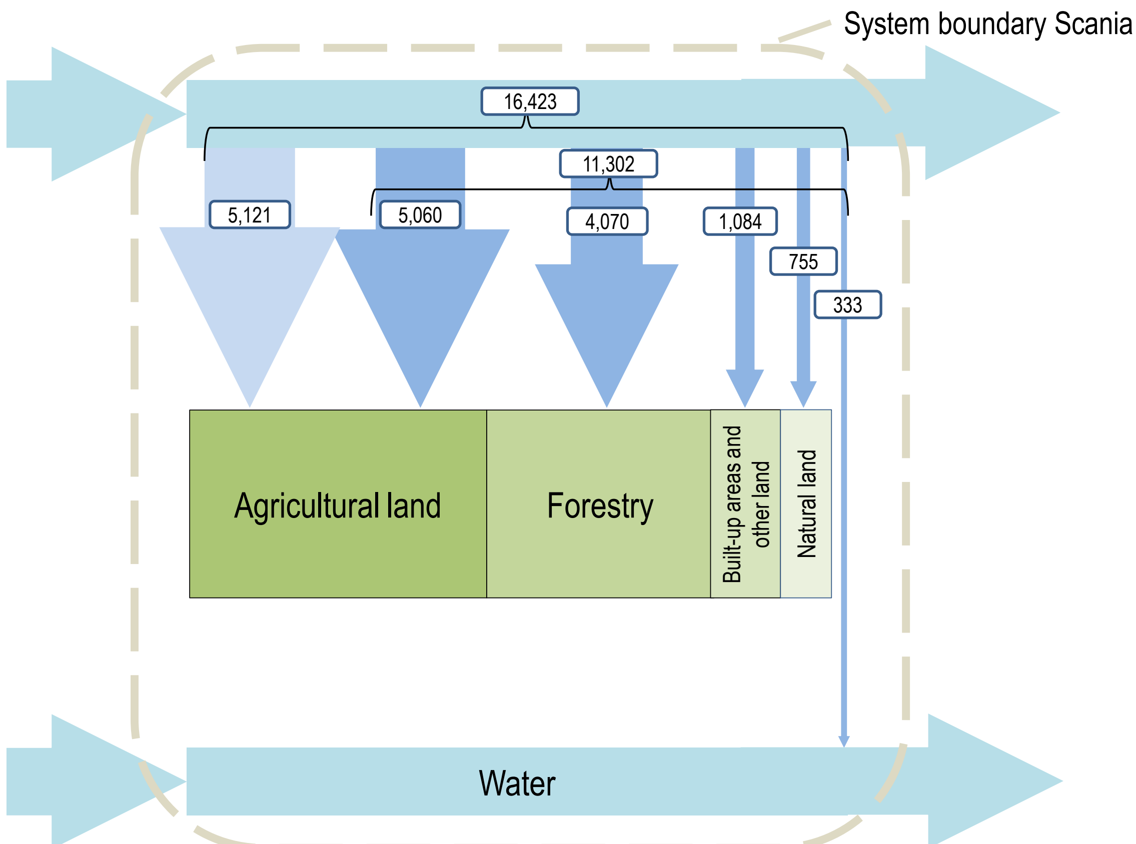


Figure 21. Atmospheric depositions (darker colour) distributed over different land types and water within Scania. The nitrogen fixation on agricultural land is to the left (lighter colour). The arrows are scaled with respect to size. Unit is in tonnes of N_r.

A summary of the subsystem air shows that Scania pollutes more than the region receives; net emissions to air are 3,845 tonnes (Figure 22). The deposition over the two land kinds; natural land (755 tonnes) and built-up land (1,084 tonnes) are put together with deposition on water (333 tonnes) with the total value of 2,172 tonnes.

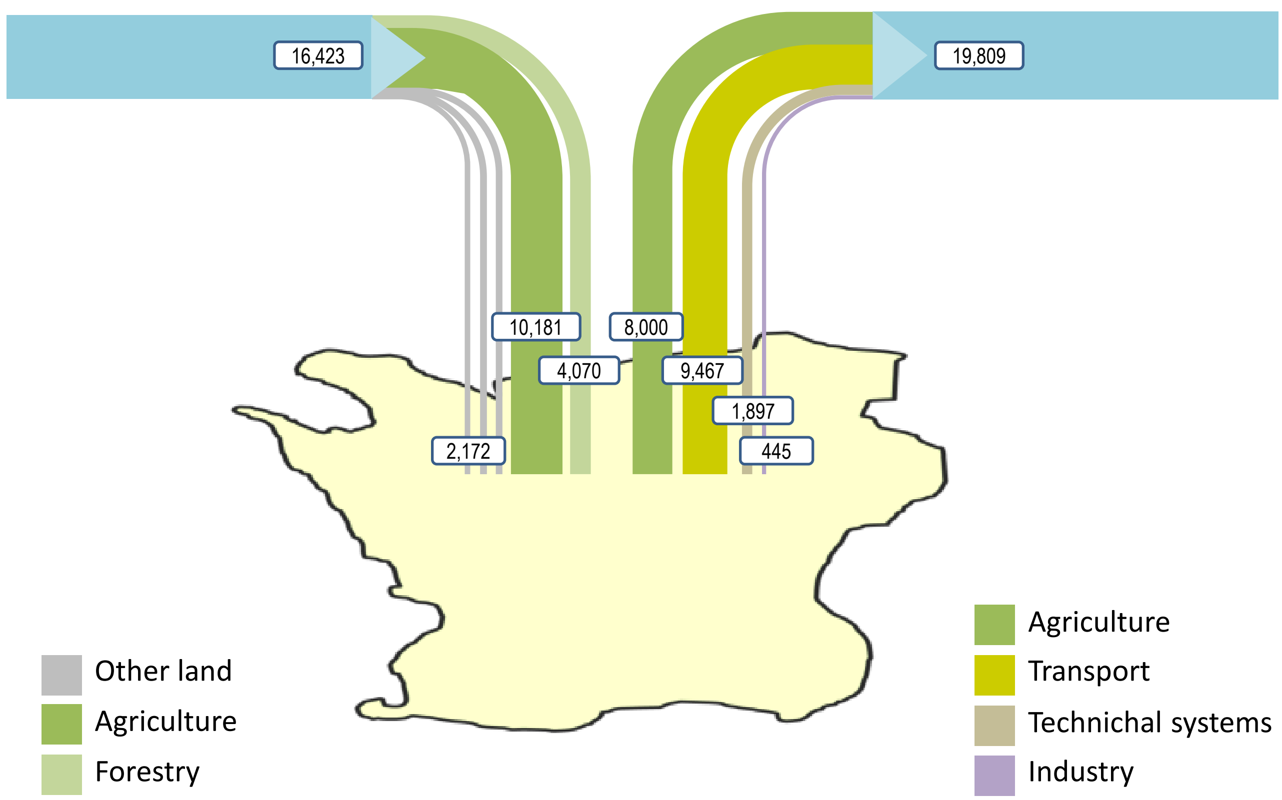


Figure 22. To the left, deposition and nitrogen fixation on other land, Agriculture and Forestry. To the right NO_x, NH_3 and N_20 emissions from Agriculture, Transport, Technical systems and Industry. Other land contains Built-up land and other land, natural land and water. The arrows are scaled with respect to size. Unit is in tonnes of N_r.

4.8.2 Agriculture, forestry and fishing – the quantified flow chart

This sector contains large internal flows and large import and export (Figure 23). The calculated value for seed is also assumed to be the same next year, i.e. it stays in Scania. Live animals were not determined which is illustrated with a dotted line. Imported fodder is from outside of Sweden and the rest is assumed to be an internal flow from acres and grazing land to livestock. Back to agricultural land goes the manure produced by livestock. All emissions from manure are allocated to arable and grazing land within the agricultural land box. The fish farms are excluded since they are assumed to have little effect on N_r leakage (explained in 4.2.5 Fish farms above). The waste includes dead animals for destruction (387 tonnes) and horse manure (1,247 tonnes). The flow from air to Agricultural land includes deposition (5,060 tonnes) and fixation (5,121 tonnes), which in total equals 10,181 tonnes. The flow in opposite direction is NH_3 (6,350 tonnes) and N_2O (1,650 tonnes) in total 8,000 tonnes. Total use of sludge in this sector is spread on agricultural land (572 tonnes) and forestland (41 tonnes) was in total 598 tonnes. Total leakage to water from agricultural land (10,824 tonnes) and forestland (610 tonnes) was in total 11,434 tonnes.

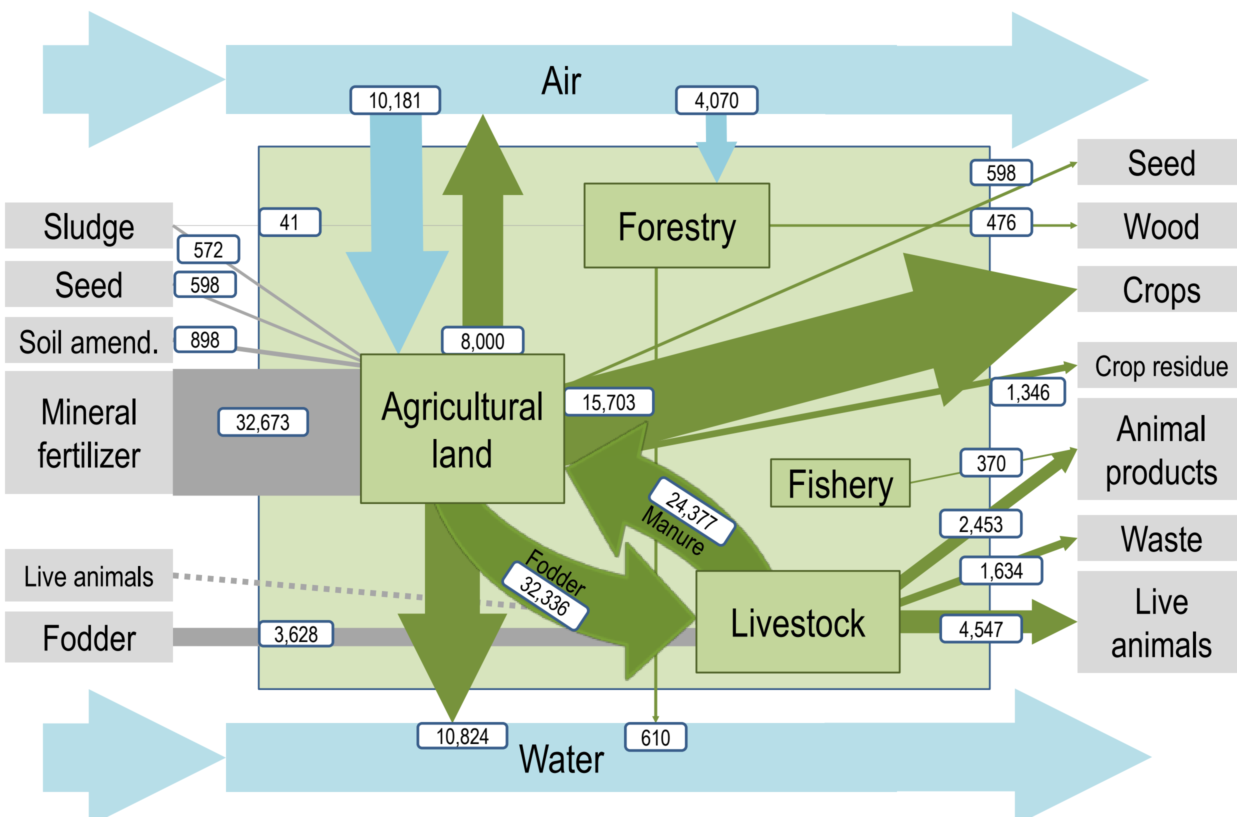


Figure 23. Quantified flow chart for Agriculture/Forestry/Fishery. The arrows are scaled with respect to size. Unit is in tonnes of N_r. Dotted lines are unknown data. Manure and fodder are not scaled for aesthetic reasons.

4.8.3 Food industry and industry – the quantified flow chart

The quantified and scaled flows within the sector Food industry/Industry contain mostly food (Figure 24). Since industry wasn't an area of interest due to timeframe and assumptions no data for material input was found, which is illustrated by dotted lines. Imported material to food industry was obtained using the conservation of matter principle, or backwards counting. Imported crops are harvest from Scania after fodder and seed have been subtracted. Animal products contain eggs, milk and fish. Live animal is both Scanian and imported animals. The carcasses from slaughtered animals are an input to food industry. Animal products include egg (333 tonnes), milk (2,024 tonnes) and fish (203 tonnes). Total Scanian input in this sector is live animal (4,547), crops (15,703) and animal products (2,560) that make a total of 22,810 tonnes.

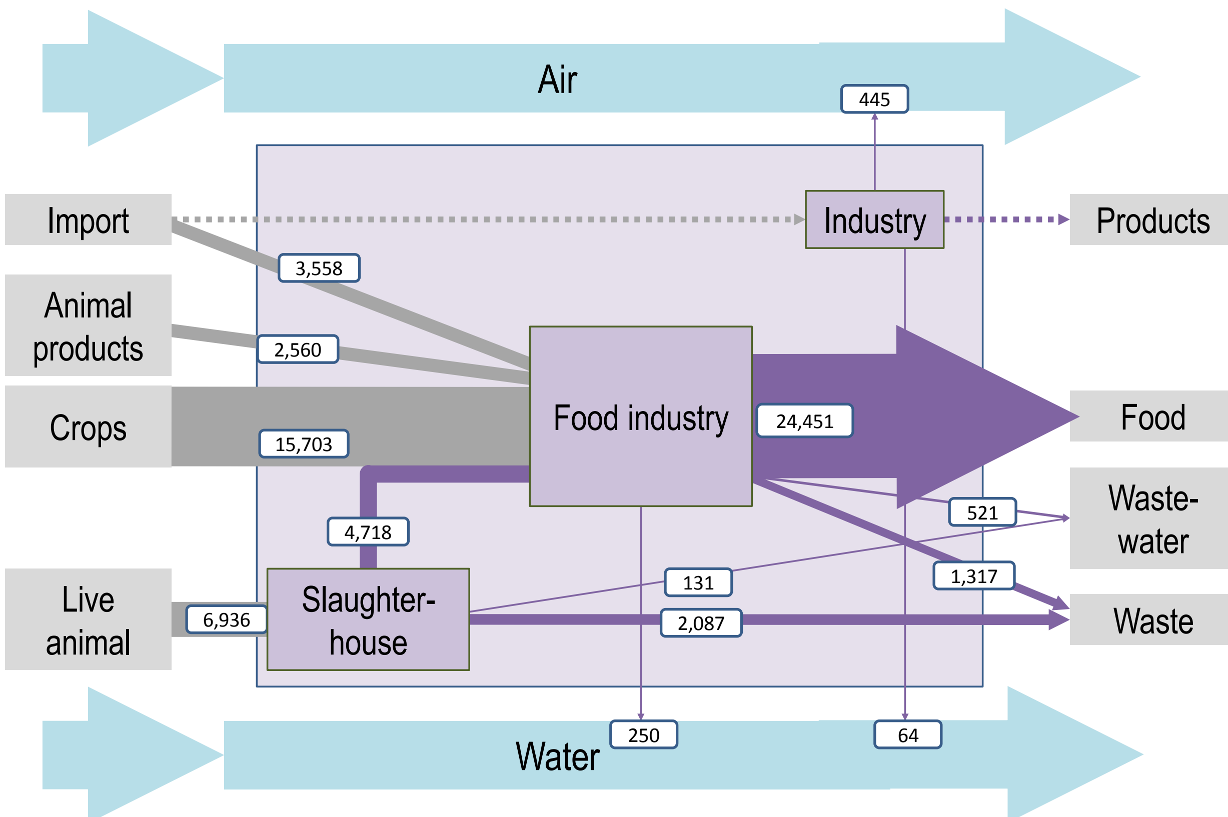


Figure 24. Quantified flow chart for Food industry/Industry. The arrows are scaled with respect to size. Unit is in tonnes of N_r. Dotted lines are unknown data.

4.8.4 Households, service and retail – the quantified flow chart

In Figure 21, the flow chart for Household/service/retail is presented. This figure is different from the one in chapter 3 Methods and materials. The reason for this was that data for household and restaurants etc. wasn't separable. The wastewater is from what Scanian inhabitants eat plus food waste flushed down the drain. The waste is both from household and restaurants and similar activities. Total waste and wastewater from Household Restaurants etc. is 9,235 tonnes. The waste and wastewater are disposed in technical systems. Small scale heating is also a part of technical systems. The inflow to the left is obtained through backwards calculation based on outflows.

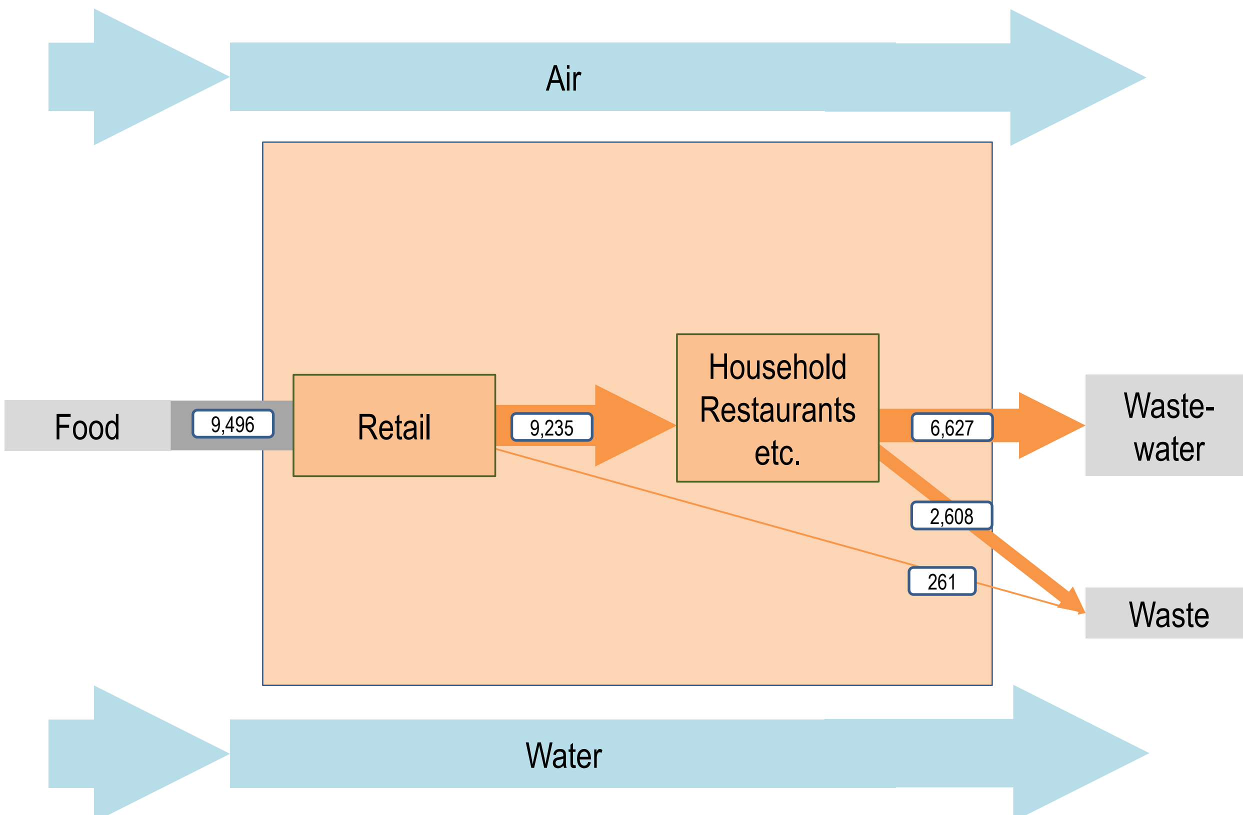


Figure 25. Quantified flow chart for Household/Retail/Service. The arrows are scaled with respect to size. Unit is in tonnes of N_r.

4.8.5 Technical systems – the quantified flow chart

The quantified flow chart (Figure 26) shows larger inflow than output. The waste and wastewater are both from Food industry, Slaughterhouse and Household etc. The NH_3 emission from biological treatment and urea for incineration plants are unknown, which is illustrated with dotted lines. Fuel is total fuel (8,902 tonnes) minus food waste to incineration (1,333 tonnes).

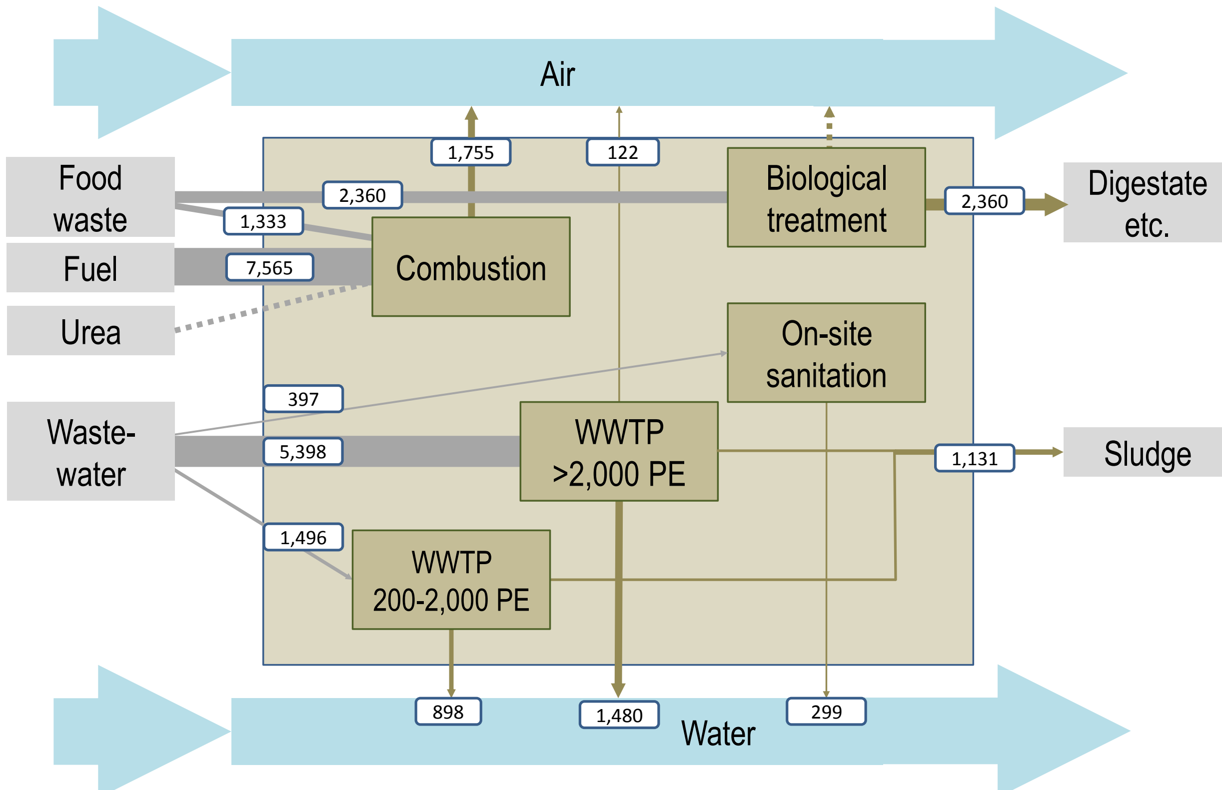


Figure 26. Quantified flow chart for Technical systems. Unit is in tonnes of N_r. The arrows are scaled with respect to size. Dotted lines are unknown flows.

4.8.6 Transport – two quantified flow charts

The emissions to air from transport consist of NO_x NH_3 and N_2O (Figure 27). About 41% of the emissions are from international transport, which Scanians have no control over. International transportation is from shipping in Scanian waters and aviation in Scanian airspace. The Scanian emissions involve transportation by car etc. and working machinery (Figure 28).

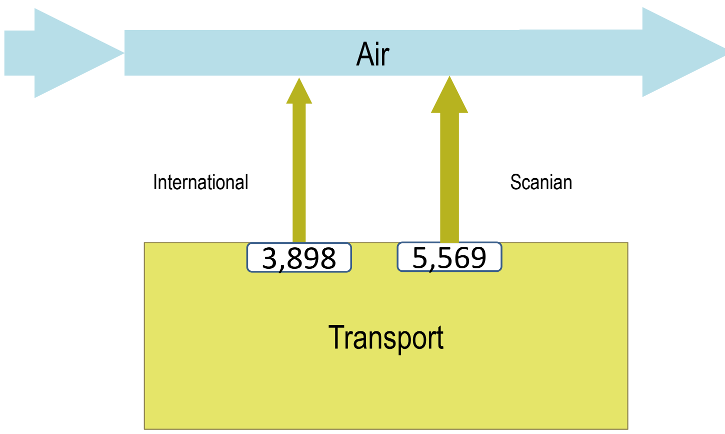


Figure 27. The emissions from transport including international transport. The arrows are scaled with respect to size. Unit is in tonnes of N_r.

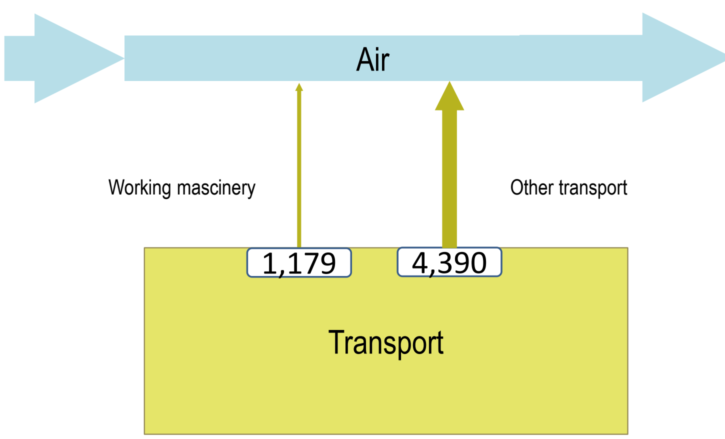


Figure 28. The emissions from transport excluding international transport. The arrows are scaled with respect to size. Unit is in tonnes of N_r.

4.8.7 Water – two quantified flow charts.

The total N_r load to sea is 11,929 tonnes (Figure 29).

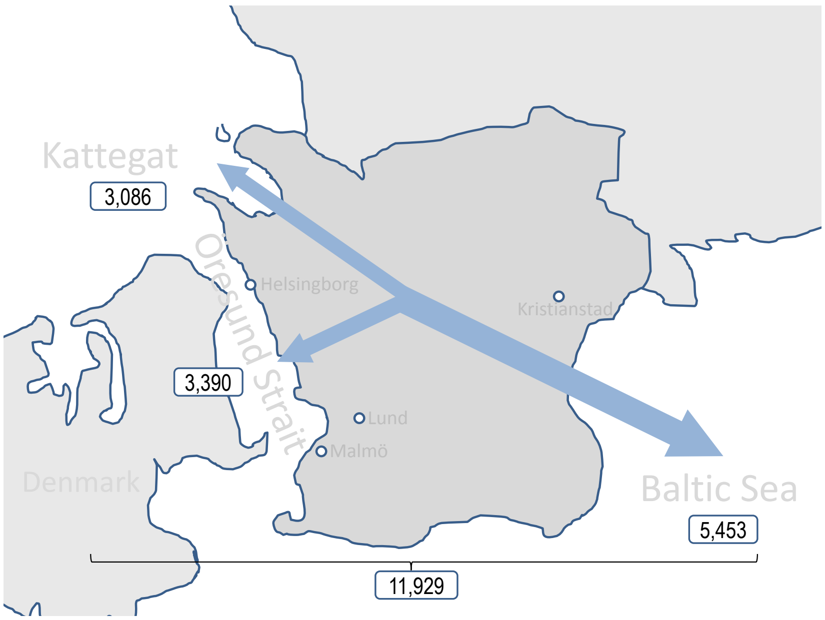


Figure 29. The leakage into the sea (Miljömål, n.d.). The arrows are scaled with respect to size. Unit is in tonnes of N_r.

Figure 30 shows the summation of leakage, emission and deposition to water from Air and the sectors in society.

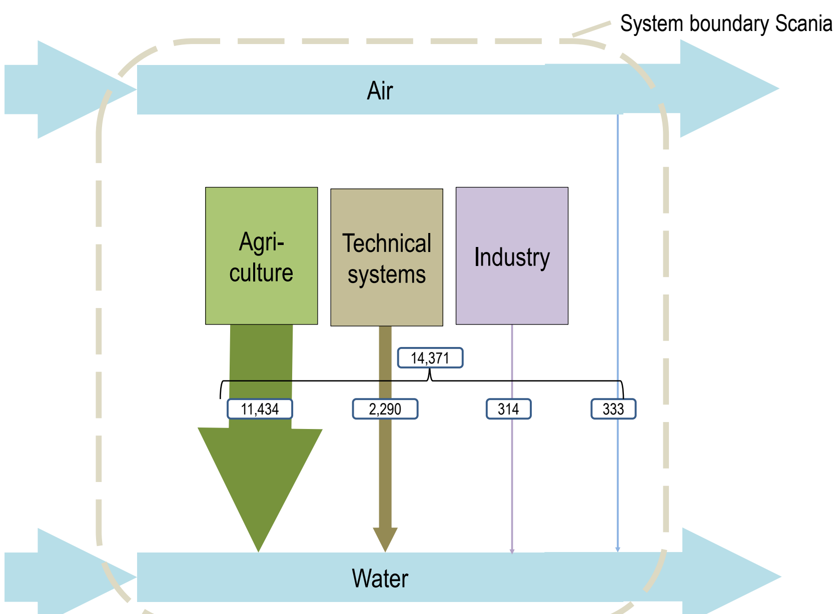


Figure 30. The leakage, emissions and deposition to water from Air and the sectors in society. The arrows are scaled with respect to size. Unit is in tonnes of N_r.

The difference between the values in both of these calculations:

- 11,929 tonnes (Figure 29) and
- 14,371 tonnes (Figure 30)

is 2,442 tonnes.

4.8.8 Nitrogen flows in Scania – the flows

The quantified flows in sections 4.1-4.7 should fit within the flow chart for Scania (Figure 6); this is summated in Table 55.

The middle column is the quantified nitrogen flow. In the left column is the origin of the flow, e.g. deposition stems from the subsystem Air. Manure stems from the livestock box within the sector Agriculture/Forestry/Fishery. The right column is called Destination, which refers to where the flow ends up, e.g. milk enters food industry and the harvest has three destinations; livestock (fodder), stock (seed) and food industry (raw material). Combustion includes leakage from wastewater and waste sites and landfills (19 tonnes to water) and also emission to air from waste and WWTPs (122 tonnes).

Table 55. Final values for all N_r flows, middle column. The table shows which box within the sectors the flow stems (origin) from and also where the flow is transported or ends up (destination).

Origin [$tonne$]	**Flow** [$tonne$]	**Destination** [$tonne$]
Air	Deposition (11,302)	Agricultural land (5,060)
		Forestland (4,070)
		Built-up areas (1,030)
		Natural land (755)
		Water (333)
WWTP	WWTP sludge (1,131)	Agricultural land (572)
		Forestland (41)
		Other land (518)
Import	Mineral fertilizer (32,673)	Agricultural land (32,673)
Livestock	Manure (25,624)	Agricultural land (24,377)
		Combustion (1,247)
Stock	Seed (598)	Agricultural land (598)
Air	N fixation (5,121)	Agricultural land (5,121)
Agricultural land	Harvest (48,637)	Stock - seed (598)
		Livestock (32,336)
		Food industry (15,703)
Agricultural land	Crop residue (1,346)	Combustion (1,346)
Livestock	Milk (2,024)	Food industry (2,024)
Livestock	Egg (429)	Food industry (333)
		Household (96)

Origin [$tonne$]	Flow [$tonne$]	Destination [$tonne$]
Livestock	Dead animal (387)	Destruction (387)
Livestock (4,547)	Live animal (6,936)	Slaughterhouse (6,936)
Import (2,389)		
Agricultural land (32,336)	Fodder (35,964)	Livestock (35,964)
Import (3,628)		
Forestland	Wood (476)	Combustion (65)
		Other use[EEE] (411)
Fishery	Fish (370)	Food industry (203)
		Export (167)
Industry (68)	Wastewater (6,624)	Water (333)
Food industry (771)		WWTP >2,000 PE (5,398)
Slaughterhouse (131)		
Combustion (22)		WWTP 200-2,000 PE (1,496)
Household (6,632)		On-site sanitation (397)
Livestock (9%)[FFF]	Produced food (24,451)	Export (23,032)
Agricultural land (59%)		
Fishery (1%)		Retail (1,419)
Slaughterhouse (18%)		
Import (13%)		
Food industry (1,317+771)	Food waste	Food industry – fodder (1,918)
		Biological treatment (2,360)
Slaughterhouse (2,218)		Combustion (1,697)
		WWTP (652)
Household etc. (2,574)		Water (250)
Food industry (1,424)	Food in retail (9,462)	Household etc. (8,132)
		Restaurants and hotels etc. (1,103)
Import (8,072)		Combustion (261)
Agricultural land (1,346)	Fuel (8,902)	Combustion (8,902)
Forestland (65)		
Livestock (1,247)		
Food waste (1,299)		
Food industry (398)		
Imported fuel (4,547)		

EEE Could be used in peppermills and as timber.
FFF Since this flow does not include the food waste occurring in food industry the inflows are presented in percentage.

Origin [*tonne*]	**Flow** [*tonne*]	**Destination** [*tonne*]
Biological treatment (2,360)	Digestate etc. (2,360)	NH3 (?) Agricultural land (898) Other use (1,462?)
Transport (9,467) Agricultural land (8,000) Combustion (1,897) Industry (445)	Emissions to Air (19,809)	Air (19,809)
Air (333) Agricultural land (10,824) Forestland (610) Industry (64) Food industry (250) Combustion (19) On-site sanitation (299) WWTP 200-2,000 PE (898) WWTP >2,000 PE (1,480)	Leakage/discharges (14,761)	Water (14,761)

4.9 Nitrogen flows in Scania – the flow chart

In this section all the flows from section 4.1-4.8 are put together in a flowchart for Scania. Figure 31 explains the ID for the flows that will be used further on. The ID number will be used in the flow chart instead of typing the calculated value (Figure 32), in the following Table 56 the inflows and outflows and the calculated values are displayed.

A. Agriculture/Forestry/Fishery
B. Food industry/Industry
C. Household/Retail/Service
D. Technical systems
E. Transport
F. Air
G. Water

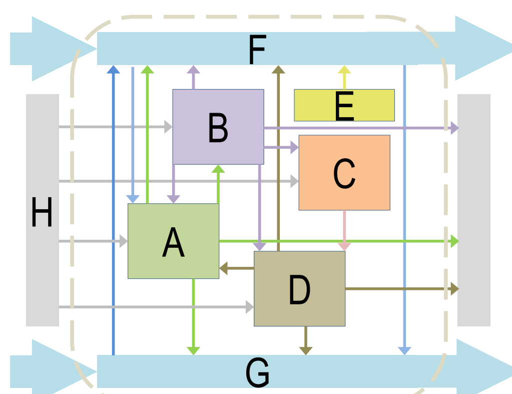


Figure 31. The ID letters for the different subsystems and sectors within society. The arrows are scaled with respect to size and also have the colour of the sector they stem from.

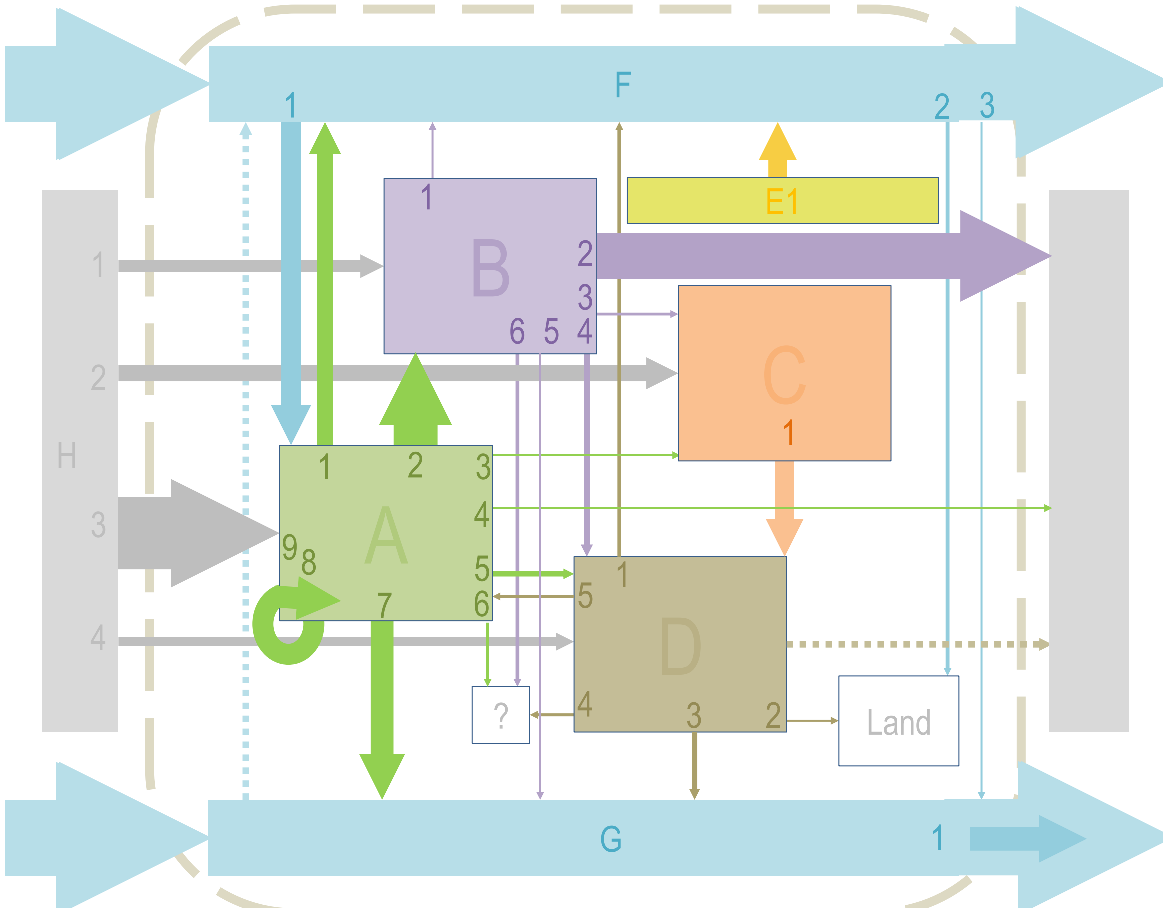


Figure 32. The quantified nitrogen flows for Scania. The arrows are scaled with respect to size. Dotted lines are unknown data. Twirling arrow, which is not scaled, represents the internal flow. Explanation coding is found below ID in Figure 31.

The grey arrows are imported foodstuff, animals or fertilizers. The land box appearing in right corner in Figure 32 contains deposition from air to other land use than agriculture and forestry, i.e. built-up land. It also contains sludge from WWTP used for e.g. landfill or construction. The box with a question mark is including stock, sludge and a surplus from biological treatment. A8 and A9 are internal flows between agricultural land and livestock. The inflows to the box with question mark and land box are the unknown flows; possible stocks and retention equal 7,105 tonnes. Below follows an explanation on the flows in Table 56.

The quantified flows from Figure 32 are presented in Table 56 - the outflows out of the sectors and the air and waste.

Table 56. All of the nitrogen flows in the same colour as the sector or subsystem they stem from.

ID		N_r [tonne]	Sum [tonne]
A1	N20	1,650	8,000
	NH3	6,350	
A2	Crops	15,703	22,810
	Milk	2,024	
	Egg	333	
	Live animals	4,547	
	Fish	203	
A3	Egg		96
A4	Fish		167
A5	Crop residue	1,346	2,658
	Horse manure	1,247	
	Grot	65	
A6	Animals for destruction	387	1,396
	Wood	411	
	Seed	598	
A7	Agricultural land	10,824	11,434
	Forestland	610	
A8	Fodder	32,366	
A9	Manure	24,377	
B1	Emissions to air		445
B2	Exported food		23,032
B3	Food to retail		1,419
B4	Biological treatment	2,360	4,709
	Combustion	1,697	
	Wastewater	652	
B5	Emissions to water		250
B6	Fodder	1,890	B6
C1	Wastewater	6,627	9,496
	Waste from household	2,608	
	Waste from retail	261	
D1	Combustion		1,897
D2	Sludge		518
D3	Combustion	19	2,696
	On-site sanitatio	299	
	WWTP 200-2,000 PE	898	
	WWTP >2,000 PE	1,480	
D4	Surplus from biological treament		1,462
D5	Soil amandment	898	1,511
	WWTP slugde	613	
E1	Emissions to air		9,467
F1	Forestland deposition	4,070	14,251
	Agricultural deposition	5,060	
	Fixation	5,121	
F2	Deposition (other land)		1,839
F3	Deposition (water)		333
G1	Leakage to the sea		11,945
H1	Live animal	2,389	5,947
	Other food	3,558	
H2	Food		8,043
H3	Fodder	3,628	36,301
	Mineral fertilizer	32,673	
H4	Fuel		4,547

4.10 Data uncertainties – the evaluation

Here the data will be evaluated and categorized according *relatively certain*, *relatively uncertain* and *uncertain* according to Sörenby (2010) (Figure 33). (For more information, go to section *6) Make the results understandable, reproducible and transparent by illustration and interpretation*, page 23)

RELATIVELY CERTAIN	RELATIVELY UNCERTAIN	UNCERTAIN

Figure 33. The different categories for evaluation and colour coding according to Sörenby (2010)

All flows used similar method for calculation nitrogen content, i.e. the food database (National Food Agency, 2015b) and conversion factors 5.3-7.71 for different feedstuff (National Food Agency, 2015a). Furthermore, all flows were interpreted by the same person (the author), and therefore this will not be a part of the evaluation.

In Agricultural sector an average for the three agricultural production areas was used in many cases, sometimes as a rough estimate and sometimes because it was the only available source of data. In general the method of using the three agricultural production areas showed quite reasonable results, i.e. the calculated value was similar to other calculations for the Scanian agriculture. For this reason whenever the three agricultural production areas are used in calculations it is evaluated as yellow.

In the flow chart it is also hard to separate assumptions made for the calculation and assumptions made for destination and origin of the flow. This makes the evaluation more complicated. An example is the harvest, where the total harvest from the field is reliable data from Statistics Sweden. But without assumptions about destination of the flow it is impossible to position the harvest in the flow chart.

Reported data for Scania from *"Utsläpp i siffror"* (Swedish EPA, n.d.) is used for N_r in wastewater to WWTP and wastewater discharged into water. In some cases the source is also used to quantify emissions to air. This should be a reliable source of data, although Linderholm & Mattson (2013) point out that some parts of the database are inaccurate. Since the data is for Scania, it is categorized as relatively certain. In Table 57, the flows B1, B4, B5 and D3 contain data from this source and all of them are categorized as green.

If the flow contains different flows with different colours, e.g. A2 contains crops, milk, egg, live animals and fish with different data qualities. The flow will be coloured with respect to the largest flow. An example is A5, which has two yellow flows and one red. The sum of the two yellow flows is greater than the red and therefore A5 will be categorized as yellow.

The categorization from the evaluation of data uncertainty is given in Table 57.

Table 57. The categorization according to *relatively certain*, *relatively uncertain* and *uncertain*.

ID	Flow	Evaluation
A1	N_2O	The statistics from RUS (n.d. a) has an evaluation method where the data got graded between 1-3[GGG] depending on quality, this data gained 2 out of 3 (see footnote). But when comparing to other data or calculation methods used here it is relatively certain.
	NH_3	Two methods; RUS (n.d. a) and an average of the three agricultural production areas gave similar results.
A2	Crops	The total harvest from Scanian acres should be categorized green, since data was avaliabe for Scania. But this calculated values is based on a number of assumtions for fodder and animal production.
	Milk	The milk production and number of milk cow data was for Scania, calculated value shold be reliable.
	Egg	Scaled from statistics for Sweden, using number of hens in egg production in Scania and Sweden.
	Live animals	Two different methods showed similar results. Both methods are based on rough assumptions.
	Fish	The statistics for tonnes of fish was for Scania. Although assumptions for destination are relatively uncertain.
A3	Egg	Scaled from statistics for Sweden, using number of hens in egg production in Scania and Sweden.
A4	Fish	The statistics for tonnes of fish was for Scania. Although assumptions for destination are relatively uncertain.
A5	Crop residue	Based on an average for the three agricultural production areas. No other data found.
	Horse manure	No data was found, assumption made through conversation with farmer and an employee at a horse riding school.
	Grot	Data found for Scania. Assumption about whether it is used inside of Scania (destination) makes in uncertain.
A6	Animals for destruction	Scaled from Swedish statistics. Using percentage for the different livestock; poultry, cattle and swine.
	Wood	Statistical data for Scania.
	Seed	Based on an average for the three agricultural production areas. No other data found.
A7	Agricultural land	Based on an average for the three agricultural production areas. No other data found.
	Forestland	Swedish values for leakage 1-2 kg/ha where the value 1.5 was assumed by the author. This value is just a rough estimate.
A8	Fodder	Two calculation showed similar results. But the calculations comprices rough assumptions.
A9	Manure	The calculation based on number of livestock gave similar results as the average for the three agricultural production areas.
B1	Emissions to air	Reported data for Scania from “utsläpp I siffror”.

[GGG] 1 = good quality, 2 = some uncertainties, 3 = uncertain results (RUS, n.d. c)

ID	Flow	Evaluation
B2	Exported food	Based on a number of assumptions.
B3	Food to retail	Based on a number of assumptions.
B4	Biological treatment	About half of the calculated value is based on statistics for collected food waste in Scania. The other half from slaughtehouses and food industry are assumed using values from Jensen et al. (2011).
	Combustion	All waste in Scania is delt with within Scania. This is probably not the case since each municipality decide how to manage their waste disposal. There is probably municipalities outside of Scania receiving Scanian waste and vice versa. The calculated value is based on counting backwards which also is unreliable.
	Wastewater	Reported data for Scania from "utsläpp I siffror".
B5	Emissions to water	Reported data for Scania from "utsläpp I siffror".
B6	Fodder	From calculated food waste from slaughterhouses and food industry. Assumed part that is used as fodder is assumed using values from Jensen et al. (2011). Many assumptions and calculation to obtain calculated value.
C1	Wastewater	The toliet waste is based on food intake and food flushed down the drain. Since the calculated value was similar to the one found in litterature, it appeared reasonable. The value from litteratur was slightly lower, but since protein consuption has increased so should the nitrogen content in the toilet.
	Waste from household	Based on Swedish average household waste per person together with Scanian population.
	Waste from retail	Swedish waste factors used together with statistical data for Scania.
D1	Combustion	The statistics from RUS (n.d. a) has an evaluation method where the data got graded between 1-3 depending on quality. The average grade of the data used here was 2/3. But when comparing to other data or calculation methods used here it is relativeli certain.
D2	Sludge	Statistical data for Scania.
D3	Combustion	Reported data for Scania from "utsläpp I siffror".
	On-site sanitation	If the method and data from (Stockholm County Board, 2013) is correctly interpreted by the author tha calculated value should be reliable. But since the data themselves are uncertain the flow is marked as yellow.
	WWTP 200-2,000 PE	Backwards counting toghether with assumed N_r removal efficiency.
	WWTP >2,000 PE	Reported data for WWTP in Scania.
D4	Surplus from biological treament	No substrate data for actual biogas production or biological treatment was found. Half of the collected food waste was obtained from reported data. The rest was assumed using food waste in food industry and slaughter house.
D5	Soil amandment	Based on an average for the three agricultural production areas. No other data found.
	WWTP slugde	Statistical data for Scania.

ID	Flow	Evaluation
E1	Emissions to air	The statistics from RUS (n.d. a) has an evaluation method where the data got graded between 1-3 depending on quality[HHH]. The average grade of the data used here was 1/3.
F1	Forestland deposition	Based on an average for the three agricultural production areas.
	Agricultural deposition	Based on an average for the three agricultural production areas.
	Fixation	Expert judgement
F2	Deposition	Based on an average for the three agricultural production areas.
F3	Deposition	Based on an average for the three agricultural production areas.
G1	Leakage to the sea	SLU together with SMHI are assumed to give reliable statistics for Scania.
H1	Live animal	Two calculation showed similar results for the Scanian part of slughtered animals. But the calculations comprices rough assumptions.
	Other food	Backwards counting
H2	Food	From thea assumption that 15 % of the food in Sweden has Scanian origin. Backwards calculation from food consumption.
H3	Fodder	Scaled from Swedish data.
	Mineral fertilizer	Statistical data for Scania.
H4	Fuel	Roughly calculated with the same nitrogen content and heting value for all fuels.

[HHH] 1 = good quality, 2 = some uncertainties, 3 = uncertain results (RUS, n.d. c)

5 Possible changes of urban nitrogen flow

This chapter is devoted to possible changes of urban nitrogen flow and contains a short literature review of the connection between diet and nitrogen in and effects of urine separation. For the two research questions different scenarios was constructed. The goal in this chapter is to describe potential and not established effects of change. Figure 34 shows the flow chart the urban nitrogen flow highlighted in red.

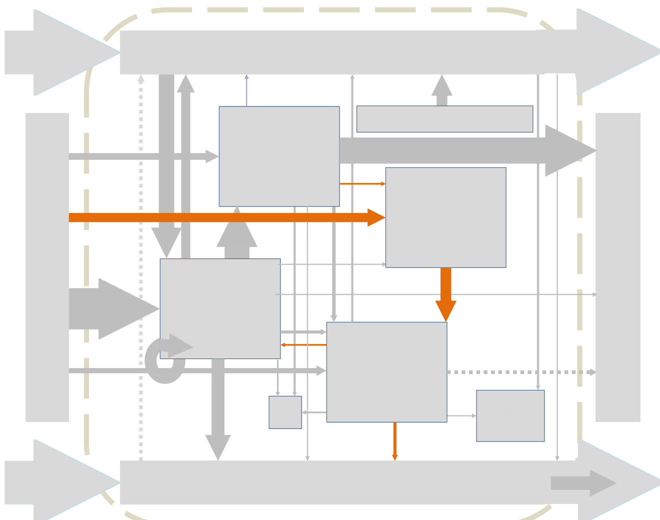


Figure 34. The urban nitrogen flow highlighted.

In order to make results and calculations in this chapter comparable with results and discussions for chapter 4 the same protein purchase per person and day will be used, i.e. 112 grams.

5.1 Urine separation

According to Swedish EPA (1995) about 88% of the nitrogen leaving your body is in the urine (Figure 35).

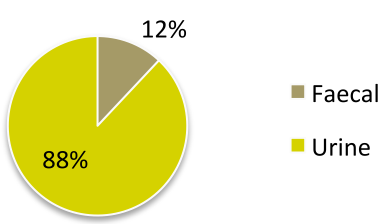


Figure 35. Most of the nitrogen leaving the human body is dissolved in urine.

For 1,288,908 people living in Scania 31st of December 2014, (Statistics Sweden, n.d.), the total calculated value of nitrogen in urine is 5,339 tonnes and 728 tonnes in faeces. The corresponding value for 2010 and the 1,243,329 people who lived there is, in urine 5,150 tonnes and in faeces 702 tonnes. This calculated value of nitrogen is compared to other nitrogen containing flows in Scania (Figure 36).

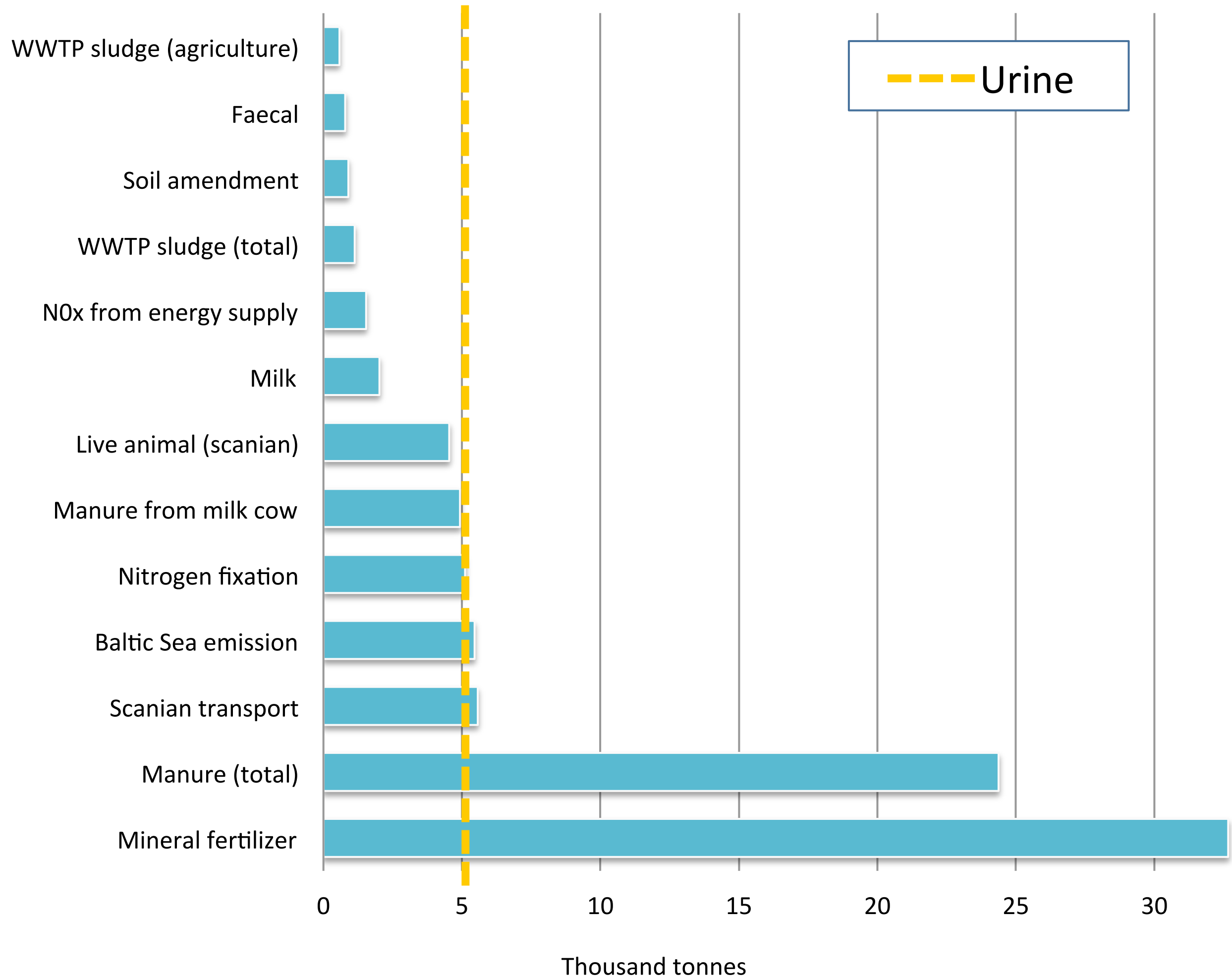


Figure 36. The N_r in urine (5,150 tonnes) compared to other nitrogen flows in Scania. The calculated amount of nitrogen in urine is similar to the nitrogen in live animal (Scanian), manure from milk cow and the leakage of nitrogen into the Baltic Sea.

The N_r in urine is 9 times as much as in the total amount in sludge spread on agricultural land and almost 5 times as much as in the total sludge production. The N_r in urine corresponds to 16% of the used chemical fertilizer in Scania.

The urine is a relatively large flow compared to other Scanian flows. There is thus a potential to recycle large amounts of nitrogen through urine separation. If this potential can be realized will not be discussed here, instead is a discussion of the potential impacts will follow.

5.1.1 Possible effects introducing urine separating system in Scania

Spångberg et al. (2014) compares the environmental impact from three scenarios utilizing the toilet waste in different ways. The first scenario explores the possibility of source-separating blackwater[III] and using it as fertilizer – the blackwater scenario. In the second scenario – the urine scenario – source-separated urine is used as fertilizer while the faecal water is treated in advanced

[III] Blackwater contains faeces, urine and flush water from toilets.

WWTP. The last scenario uses chemical fertilizer and advanced WWTP to remove N_r and P from the blackwater – the NP scenario. The three scenarios were designed such that all had the same emissions with water from the WWTP. The sludge produced in the WWTP was assumed not to be reused in agriculture. The WWTP in the different scenarios did not use autotrophic nitrogen removal (Spångberg et al., 2014).

Since the blackwater scenario isn't in the area of interest in this study only the results from the NP and Urine scenarios will be compared (Table 58).

Table 58. The results from comparison of urine scenario and NP scenario from Spångberg et al. (2014).

Impact on	NP scenario vs. urine scenario	Urine scenario potential saving (times better/worse)
Energy use	The results revealed that the urine scenario used less primary energy and than the NP scenario. The processes at the WWTP made the NP scenario 3 times as energy consuming as the urine scenario. About 78% of the energy in the NP scenario was devoted to N_r and P removal at WWTP	60-80%
Global warming potential (GWP)	The NP scenario had almost two times as much GWP (16 kg CO_2-eq/FU[JJJ]) compared to urine scenario (9.5 kg CO_2-eq/FU) mostly because of the treatment in the WWTP, which produced 48% of the GWP in the NP scenario. The spreading of fertilizer had a great part of the emissions in both of the scenarios, although it was larger in the urine scenario. More than half of the GWP in the urine scenario came from spreading, the corresponding value for NP was 30%.	40%
Eutrophication	The NP scenario using chemical fertilizer had a lower impact on potential eutrophication and acidification. The emissions were mainly gaseos from spreading and storage of the urine. The impact in PO_4^{3-}-eq/FU was 19 times as large in the urine scenario compare to the NP scenario.	-19
Acidification	The acidification potential in the urine scenario was due to the ammonia emissions from storage and spreading, while the acidification potential in the NP scenario came from production of chemical fertilizer and treatment in WWTP. The emissions in g PO_4^{3-}-eq/FU was 5 times as large in the urine scenario.	-5

The study by Spångberg et al. (2014) was designed to have the same emissions from WWTP to fulfil the commitments of the Baltic Sea Action Plan[KKK]. Without these requirements the primary energy use and GWP would be more similar for all scenarios but on the other hand the eutrophication impact from water emission from WWTP would differ.

Spångberg et al. (2014) in a sensitivity analysis for the energy use in WWTP used the nitration-anammox process for N_r removal. This lowered the energy use and eliminated the organic carbon source, which reduced the primary energy use with 17% for the urine scenario and 45% for NP scenario.

[JJJ] Kg CO_2-eqvivalents per functional unit

[KKK] The Baltic Sea Action Plan is the action plan for the Baltic Sea. It was signed by the coastal states in 2007 and has impact on action programs to reduce nitrogen load from agriculture, WWTP, forestry and industry. (HELCOM, 2015)

Spångberg et al. (2014) concluded that two main processes affect the results; NH_3 emissions from storage and spreading of urine plus better N_r and P removal processes at WWTP in both scenarios. The urine scenario showed less impact within all categories, except energy use, compared to the blackwater scenario. This was mainly a result of a smaller volume being stored, shorter storage time and larger energy use at WWTP. The results also points out that urine fertilizer is an exceptionally clean fertilizer with low cadmium content compared to blackwater and chemical fertilizer.

5.1.2 Scenario – urine separation

If urine separation toilets were to be installed the nitrogen flow would change. In Figure 37 there are two schematic diagrams of the nitrogen flow in society. The first scenario is where a small amount of the nitrogen returns to agriculture via WWTP sludge. The grey arrow to the left represents the chemical fertilizer.

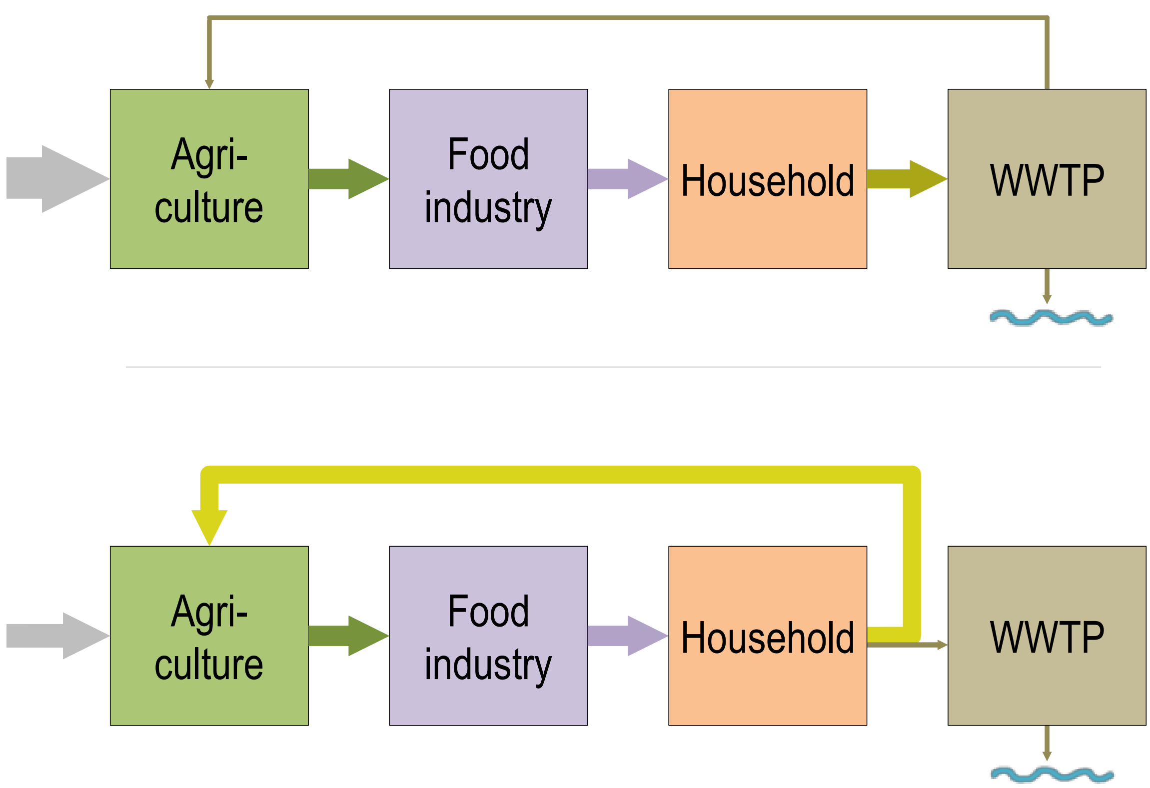


Figure 37. The WWTP sludge is returned to agriculture on top. At the bottom the urine separation could seize more of the nitrogen and return it to the agriculture

If all the urine in Scania would be collected via the installation of urine separating toilets it could have the following potential positive effects:

- Decreased N_r load to WWTP (-5,150 tonnes)
- Increased reuse of urban nitrogen in agriculture compared to WWTP sludge (+900%)
- Decreased need of mineral fertilizer (-16%)
- Decreased energy use in WWTP (60-80% less energy than NP scenario)
- Decreased GWP from treatment at WWTP (40% less energy than NP scenario)

Negative effects:

- Increased ammonia emissions from storage and spreading of urine (19 times as much compared to NP scenario)
- Increased acidification potential (5 times as much compared to NP scenario)

Neutral effects:

- The emissions from WWTP will not change since WWTPs will follow the restrictions set by the regional environmental authorities.

5.2 Dietary change

Tumlin & Mattsson (n.d.) performed a study on five large WWTPs in Sweden over the years 1992-2012. They discovered that the nitrogen load has gradually increased from 12-13 g per person and day to 14 g per person and day. Studies of household wastewater point toward that the increase came from the households and not the industries. The increase could be connected to the changed food preferences.

According to Danius and Burström (2001) essentially all consumed quantity of N_r ends up in urine and faeces and is transported to wastewater management. A small amount will leave the body in the forms of nails, skin and sweat (Skredsvik-Raudberget, 1998). The nitrogen content in protein is about 16% of the weight (Danius et al., 2002; Swedish Food Agency, 2015), which makes the amount of nitrogen in the toilet waste directly linked to the protein content in the food consumed.

In Figure 38 it is noticeable that the protein purchased has increased over the years 1960-2013. Year 1980 the average Swede purchased 87 g of protein á day. The same value for the year 2010 was 112 grams.

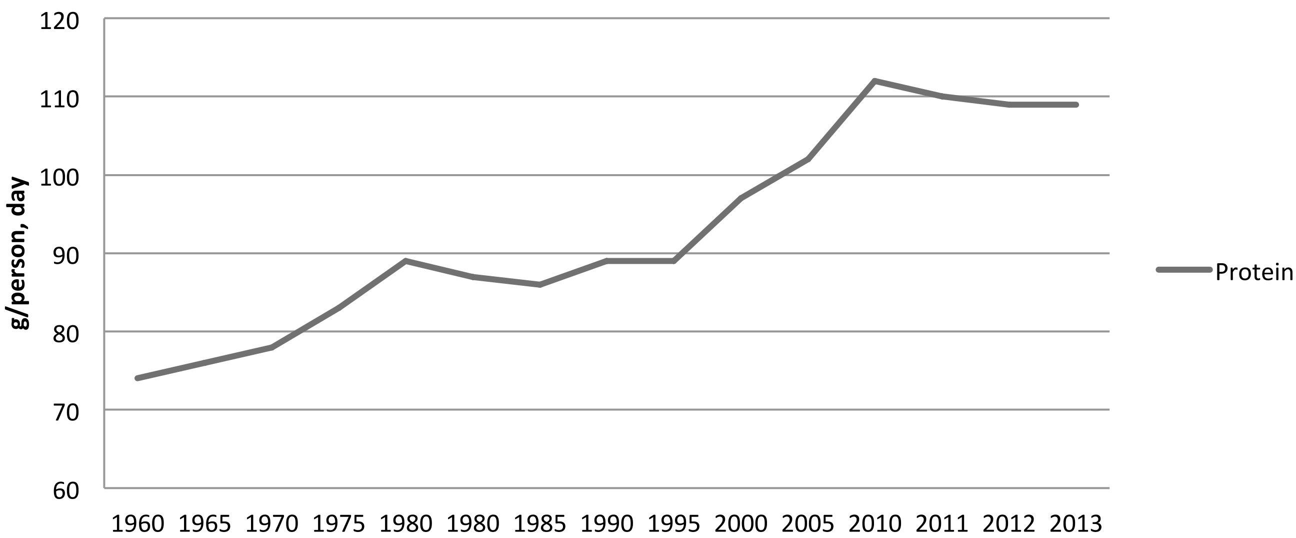
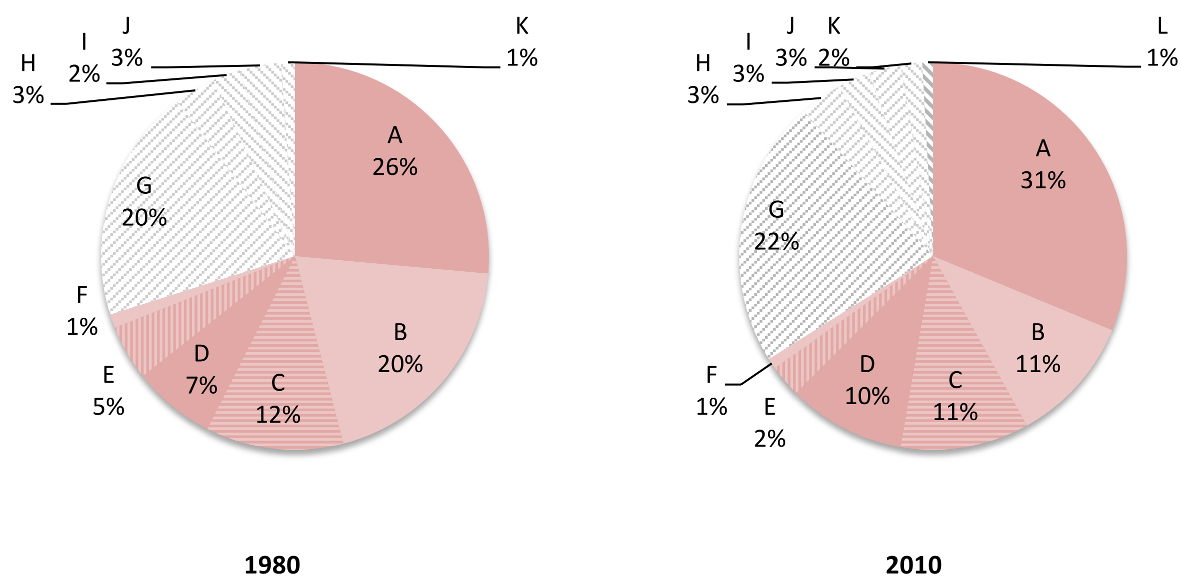


Figure 38. Purchased amount of protein over the years 1960-2013. This includes total delivery of food from producers to household and large scale catering services. It also includes the consumption of the producer such as farmer's consumption of her own products (milk, egg and potatoes etc.). Food waste from household and large scale catering services generated after delivery is included. (Swedish Board of Agriculture, 2014a)

Figure 39 shows origin of the protein in the diets year 1980 and 2010.



A	Meat and meat products	G	Bread and cereal products
B	Milk	H	Other foods
C	Cheese	I	Vegetables
D	Fish and crustaceans etc.	J	Potatoes and potato products
E	Eggs	K	Fruit and berries
F	Cream and milk powder	L	Beverages with alcohol

Figure 39. The purchased protein supply in Sweden 1980 and 2010 (Swedish Board of Agriculture, 2014a). A-F is protein from meat and animal products, coloured in pink. G-K is vegetarian protein with grey colour to the left in both pie charts.

Figure 39 shows that the meat purchase is a bigger part of the total protein purchase year 2010 compared to year 1980. The protein purchase from meat increased from 23 to 35 grams/person and day, which is 4.4 kg more meat purchased per person and year. If this protein was meat with 20% protein content, 4.4 kg corresponds to 22 kg of increased red meat purchase per person and year. The Swedish Board of Agriculture (2013b) has found that the purchase of meat has increased with 36% (to 87 kg per person) over the years 1980-2011. The meat and meat products are the largest sources of protein in the Swedish diet.

Danius, et al. (2002) made an LCA comparison for reduced meat purchase in the municipality of Västerås. They concluded that a reduced amount of meat consumed led to less N_r emission from WWTP. If the inhabitant consumed 50% less meat the emissions from the WWTP would decrease by 10%. In the study no substitute was assumed on the plate instead of the piece of meat, which was tolerable nutritionally but possibly not in practice because of the desire to eat. With lessened meat purchase follows effects outside of the Västerås region, which to a large extent depends on the environmental impact from animal production, which was not located in Västerås, for example animal fodder imported from USA and South America.

Another comparison between a vegetarian and an omnivore, using diet templates for vegetarian and omnivorian diets, gave the result that the N_r load from a vegetarian (5,2 kg/year) was 88% of the N_r load from the omnivore (5,9 kg/year) (Steineck et al., 2000, s. 64).

Van Grinsven et al. (2014) examine nitrogen efficiency in the food system and the effects of cutting Europe's meat and dairy intake. They concluded that one way to increased nitrogen efficiency would be policies for reduction of chemical fertilizer leading to improved housing, storage and application of manure and ammonia. One other option would be higher prices for nitrogen intensive food or nudging consumers to eat food with less nitrogen pollution, i.e. less meat and dairy.

5.2.1 Scenario – dietary change

Adults and children above 2 years should eat 10-20 energy percentage (E%) of protein. (Nordic Nutrition Recommendations, 2012). Nordic Nutrition Recommendation (2012) give reference values for energy intake based on sedentary lifestyle and active lifestyle. Here an average between the two lifestyles is used and in Table 59 a mean value[LLL] for two different age classes is given. The author calculated their need for kcal for one day using the MD Mifflin method[MMM]. If you weigh 60 kg and is 163 cm tall and don't move all day (e.g. master thesis work) you would have to eat 1,583 kcal to keep the same body weight.

[LLL] Data is separated into female and male values.
[MMM]MD Mifflin method available at: http://matkalkyl.se/berakna-energibehov-kcal.php

Table 59. How much protein you should eat per day based on calorie intake (Nordic Nutrition Recommendations, 2012). 1 g protein is 4 calories.

Type of person	Calorie need *[Kcal/day]*	Protein 10 E% *[g/person, day]*	Protein 15 E% *[g/person, day]*	Protein 20 E% *[g/person, day]*
Author	1,583	39.6	59.4	79.2
31-60 years	2,365	59.1	88.7	118.2
18-30 years	2,520	63.0	94.5	126.0
Hard training	5,000	125.0	187.5	250.0

Average value for the two age classes and 10 E% from protein, i.e. minimized protein intake, give the calculated value 61.1[NNN] g per person and day. An average person ate 80.6 g of protein the year 2010 (National Food Agency, 2012). The purchased amount was 112 g. The gap between could be referred to as food waste, i.e. 28%[OOO] is food waste. Protein purchase 1980 was 87 g per person and day. If assuming same amount of food waste as in 1980 an interesting similarity occurs between the average value for 10 E% of protein and how people ate in the 1980's (Figure 40). The similarity could also be a result of an overestimation of food waste in 1980.

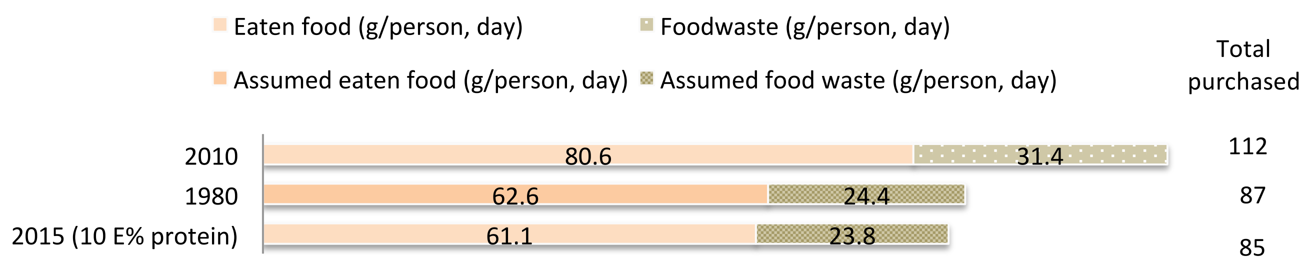


Figure 40. Could it be that we should eat like in the 80's? The left side of each bar is the ingested food protein. The right side of the bar is the food waste protein. The total sum to the right is the purchased amount of food protein.

There is a potential to decrease the influent load to the WWTP through less protein intake. If this potential can be realized will not be discussed here, instead is a discussion of the potential impacts will follow. Here follows an example with different scenarios for such a protein intake change in Scania. Assumptions and conditions:

- Raw pork[PPP] has a protein content of 19.19 g per 100 g (National Food Agency, 2015b)
- Meat has the conversion factor 6.25
- The carcass weight of a swine is 90 kg
- 31% of protein intake was meat and meat products the year 2010

[NNN] $\frac{59.1+63}{2} = 61.1\ g$

[OOO] $1 - \frac{80.6}{112} = 28\%$

[PPP] Raw pork – translated from Swedish: "fläsk kött rå"

In the scenarios pork is used as an example to be able to relate the nitrogen content to food and animals. The nitrogen content is however the same regardless of in what form the protein intake occurs, i.e. the author could have chosen carrots instead of pork as an example; although to use pork in the scenarios provide a better basis to discuss nitrogen pollution in society, not just in the wastewater treatment.

There are four scenarios developed (Table 60):

1. The same protein intake as year 2010 is called the *2010 100% pork* scenario. The 2010 100% pork scenario represents the N_r load from Scanian population 2010 but with higher N_r pollution from the animal production, i.e. all protein intake is from pork.
2. The red meat intake as 2010 is called the *2010 RMI* scenario represent the N_r load from red meat in 2010, i.e. only 31% of the total N_r in the diet comes from meat. Other protein intake is excluded from this scenario.
3. Ingesting minimal protein intake is called the *MPI* scenario. The MPI scenario shows the decreased N_r load from minimal protein intake. This shows how much less N_r load the new diet would give, i.e. 19.5 g less á day.
4. For increased red met intake the *IMI 10%* scenario was developed. The IMI 10% scenario shows what happens if the protein consumption continues to rise.

These scenarios are used to compare different N_r load into WWTP and for discussion up-stream for N_r management.

Table 60. The diet scenarios.

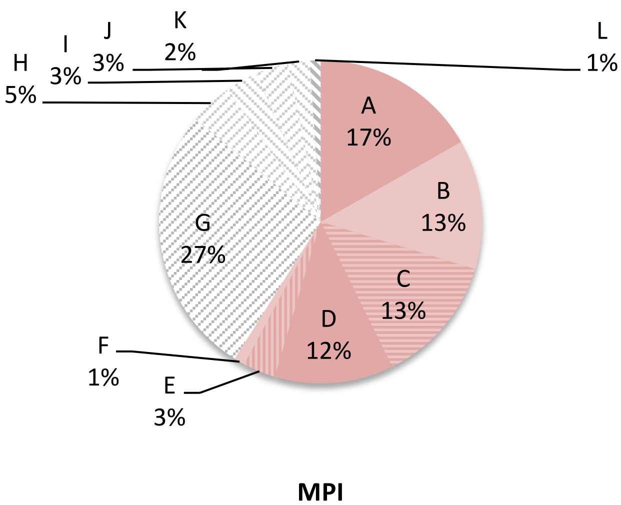
Scenario	
2010 100% pork	Unchanged protein intake: 80.6 g The protein ingestion is 100% pork.
2010 RMI	Red meat intake as 2010 (RMI 2010). The N_r load from 2010's red meat ingestion: 31% of 80.6 equals 25 g
MPI	Minimal protein intake (MPI). Decreased protein intake, 10 E% and an average for the two age classes 18-30 and 31-60 from Table 59 : 19.5 g The lessened protein ingestion consists of pork.
IMI 10%	Increased meat intake with 10% (IMI 10%). Increased red meat ingestion with 10% gives this extra protein intake: 10% of 80.6 equals 8.1 g

With those facts the results is as follows in Table 61. In Scania 1,325,450 swine were slaughtered in 2010.

Table 61. Calculation for minimized protein intake when the origin of the protein is pork.

	Per person *[kg]*	Per person *[Swine]*	Per person *[kg/year]* 7 N Nitrogen 14.01	Scania *[tonnes]*	Scania *[Swine]*	Scania *[tonnes]* 7 N Nitrogen 14.01
2010 100% pork	153	1.7	4.7	190,607	2,117,856	5,852
2010 RMI	48	0.5	1.5	59,088	656,535	1,814
MPI	-37	-0.4	-1.1	-46,115	-512,385	-1,416
Increase 10 %	+9	+0.1	+0.5	+11,580	+128,668	+585

Cutting 19.5 g of red meat per person and day, i.e. the *MPI* scenario changes the origin of the protein in the food (Figure 39). The vegetarian protein (G-L) forms a substantial part of the nitrogen intake (40%) if 19.5 g of red meat is cut from the diet (Figure 41).



A	Meat and meat products
B	Milk
C	Cheese
D	Fish and crustaceans etc.
E	Eggs
F	Cream and milk powder
G	Bread and cereal products
H	Other foods
I	Vegetables
J	Potatoes and potato products
K	Fruit and berries
L	Beverages with alcohol

Figure 41. New distribution of protein intake if only cutting red meat consumption.

If the population in Scania consumed according to MPI scenario it could have the following potential positive effects:

- Less N_r load into WWTP (-1,416 tonnes)
- Less N_r pollution from animal production (-512,000 swine)
- The same effects in WWTP as in urine scenario by Spångberg et al. (2014), i.e. less energy needed for N_r removal. Here in a smaller scale compared to urine separation.

No change in emissions to water, since WWTP will follow restrictions set by the regional environmental authorities.

5.3 Reduced energy use in WWTP

In wastewater, the organic matter and nitrogen compounds must be removed inter alia to maintain water quality in the environment and to avoid toxic algal blooms (Kartal et al., 2010). Today the WWTP are often energy-inefficient and the BOD removal and nitrification processes consume 70-80% of the energy use at the WWTP (Siegrist et al., 2008). The energy-consuming processes are mainly to create an oxygen-rich environment for bacterial nitrification and for organic carbon, which is added for removing nitrates though bacterial denitrification (Kartal et al., 2010). The use of autotrophic nitrogen removal, the use of anammox, could reduce electrical energy use by 40-50%, due to reduced aeration energy and the utilizing of biogas production and the process hardly does not involve any external carbon source, which otherwise most often is methanol (Siegrist et al., 2008).

When comparing the different scenarios above, the energy use in WWTP becomes a less relevant factor when looking at potential improvement. For future investments, the use of anammox could be a more effective way of improving the nitrogen management compared to installing urine-separating toilets or trying to influence people to change their habits? To answer this question a deeper understanding of the impacts of and potentials for all the scenarios has to be achieved.

6 Discussion

This thesis was meant to investigate and quantify the flow of N_r in Scania and additionally be a basis for comparison between urban nitrogen flow and other flows of nitrogen in Scania. First the N_r flows in Scania will be discussed, in other words the result of the SFA. After that the results from chapter 5 is discussed where possible changes of the urban nitrogen flow will be summarized with a continued discussion. Finally the method of SFA will be discussed.

6.1 Nitrogen flow in Scania

Total in- and outflows for Scania are illustrated in Figure 42. The largest flow in Scania is the one containing imported mineral fertilizer into agriculture (Figure 32). The nitrogen fixation, that is to say cultivation of legumes, is about half of the inflow from air to agricultural land. On top of this, the animal production is adding N_r to agricultural land via manure and the use of fodder, which is mainly an internal agricultural flow. Combustion of fossil fuels and burning of biomass, including transportation, is emitting another 11,000 tonnes of N_r, in the form of NO_x, to air. Large flows of food and feedstuff are imported, refined in food industry, sold in retail and exported or turned into food waste. The urban nitrogen flow represents a relatively large flow, 6,627 tonnes of toilet waste and together with food waste the urban nitrogen flow is 9,235 tonnes. The urban nitrogen flow continues from household and restaurants to technical systems, turning the N_r into digestate, soil amendment, WWTP sludge, N_2 and N_r in effluent flow.

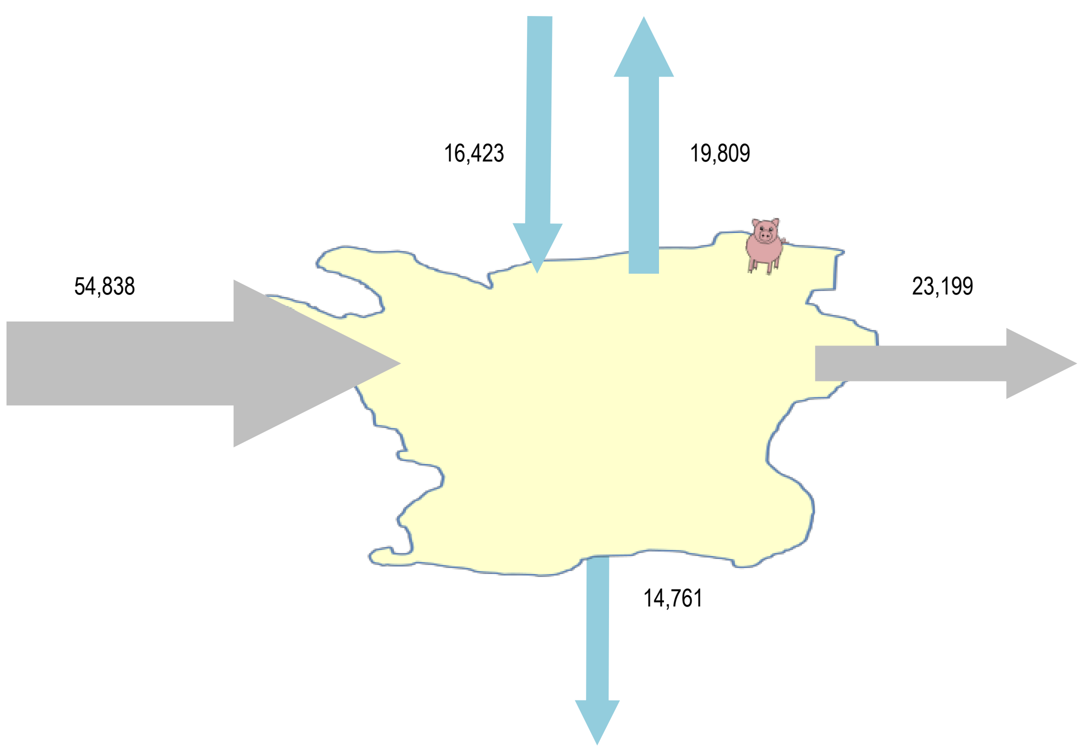


Figure 42. The N_r flows crossing the system boundary for Scania.

Figure 42 is unbalanced, which caused by the definition of substance. Choosing N_r as substance makes it irrelevant to mass balance in boxes that have processes shifting N_r to N_2 or vice versa. For example the processes within transport and combustion turn N_2 in air to N_r and the processes at WWTPs turn N_r into N_2.

6.1.1 Interference on natural nitrogen cycle and the threats

Combustion of fossil fuels and burning of biomass, animal production, cultivation of legumes and the use of mineral fertilizers have altogether led to an intensification of N_r within the region (Figure 43).

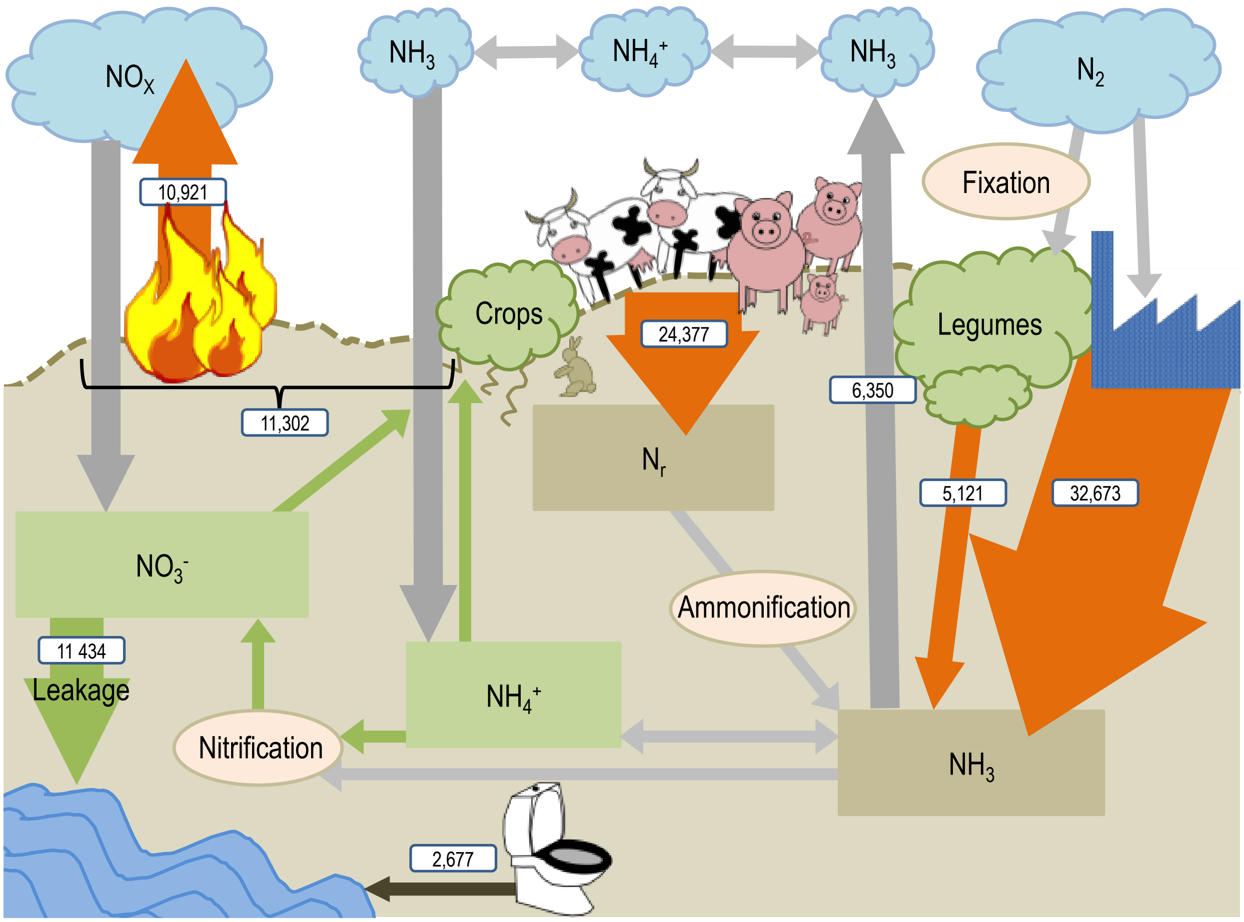


Figure 43. Scania's contribution to the intensification of Nr and interference with the natural nitrogen cycle. The deposition is divided into 50% from NO_x and 50% from NH_3. The NH_3 emission as well as the NO_3^- leakage is from agricultural activities. The toilet represents leakage into water from wastewater treatment.

All above-mentioned activities in Figure 43 is leading to Scania emitting N_r into the three surrounding seas and the ambient air. Scania has an effect on the five threats from disturbing the natural nitrogen cycle (Table 62).

Table 62. The five threats from disturbance of the nitrogen cycle (from Table 3) combined with the quantified flows of N_r in different forms.

Threat to	N_r compound	Effects
Water quality	N_r	14,800 tonnes of N_r leaking to water, mainly from agriculture followed by wastewater treatment
Air quality	NH_3	7,000 tonnes mainly from agriculture
	NO_X	11,000 tonnes mainly from transport but also from combustion
Greenhouse balance	N_2O	1,900 tonnes mainly from agriculture but also from Technical systems
	NO_x	11,000 tonnes mainly from transport but also from combustion
	N_r	11,300 tonnes of deposition over Scania
Ecosystem and biodiversity	N_r	11,300 tonnes of deposition and 14,800 tonnes of N_r leaking to water
Soil quality	N_r	11,300 tonnes of deposition and 14,800 tonnes of N_r leaking to water Mineral fertilizer, manure, nitrogen fixation are large inputs affecting soil quality

These results show that Scania is a net contributor of N_r to air, soil and water. Scania contributes to eutrophication, formation of particulate matter, tropospheric ozone, smog, acidification, global warming, ozone depletion and threatening of species. Scania not only affects its own land and inhabitants but also surrounding seas though water leakage and emission to surrounding air. The planetary boundaries for disturbance of the nitrogen cycle have already been exceeded for humanity to operate safely, and Scania is a contributing to and not reducing this negative impact.

6.1.2 The subsystems

The sectors accounting for the largest emissions to air are by far transport and agriculture (Figure 22). Transport is the main contributor to NO_x emissions and agriculture is responsible for most of the N_2O and NH_3 emissions (Figure 19). These emissions all have different environmental effects. Technical systems notably contribute to NO_x emissions and N_2O emission while emissions from food industry/industry can be considered negligible in the context of the other sectors. The deposition in Scania adds 5,000 tonnes freely available N_r as plant nutrient to agricultural land, 4,000 tonnes on forestland and in total 11,000 tonnes of N_r within the Scanian system boundary (Figure 21). Deposition is mostly in the form of nitrate or ammonium from NO_x and NH_3 emissions respectively. These emissions are 16,000 tonnes from Scanian activities. Despite the large amount of deposition originating from outside of Scania, the region is emitting more than it receives. When excluding nitrogen fixation (5,121 tonnes) the total net emissions to air are 8,507[QQQ] tonnes.

In agriculture/forestry/fishery the largest N_r flow is found; mineral fertilizer spread on agricultural land (Figure 23). The internal flows of fodder and manure are also a substantial part of all the flows within Scania. The calculations for fodder used quite old data from Danius & Burström (2001). A perhaps better and more up-to-date data source for fodder could be

[QQQ] Total N_r emissions to air equal 19,809 tonnes (Figure 22) and total deposition equals 11,302 tonnes (Figure 21) gives the calculation: 19,809-11,302=8,507.

Databoken[RRR] (Eng. The data book) from Agriwise[SSS]. The leakage to water from agriculture is 73% of the total leakage of N_r. The NH_3 and N_2O emissions in Scania stems to about 90% from agriculture. This segment uses and consumes by far the largest amount of N_r and is also the sector where losses and emissions to water are the highest in absolute amounts. 30% of the N_r input on agricultural land either leaks to water or is emitted to air as N_r.

The food industry/industry contains large flows (Figure 24). The sector has relatively low emissions to air and water compared to the flow of food and food waste. This sector has a larger impact, when looking at N_r pollution further back in the food production chain, i.e. animal production and cultivation of crops, i.e. if the emissions from agriculture in Scania are included. If looking up-stream in food production chain the emissions or effects on air and water are large and will also occur outside the Scanian boundaries, i.e. in other regions or countries.

About 30% of the purchased food ends up in the wastewater and the rest in the waste fractions, either with separately collected food waste or together with all household waste (Figure 25). The waste from Retail is small in comparison, which could be a result of larger incentive for business to minimize waste. Since all emissions from waste and wastewater management is allocated to technical systems and the only inflow is food it might seem like the most irrelevant sector. But in this study it's the most relevant box. The flows in this sector is the direct result of how people live their lives, what habits they have, what food and technical solutions they have access to, which is a result of restrictions set by regional authorities and the government. The N_r pollution occurs both upstream from food production and downstream from waste and wastewater.

It is obvious that the conservation of matter principle has not been applied for the technical systems (Figure 26). The total inflow is about 7,300 tonnes from which 16% ends up in the sludge, 2% is emitted to air as NH_3 and N_2O, and 37% of the N_r content in wastewater is discharged into water. The large WWTPs (>2,000 PE) contribute to 10% of the total emissions to water in Scania. The remaining amount of N_r has seemingly disappeared, about 3,400 tonnes. Most of this N_r is probably, through energy consuming processes, transformed into N_2. Another quite large inflow is the fuel entering combustion in both incineration plants and small scale heating. The outflow of N_r from combustion is 1,755 tonnes of mainly NO_x. The N_r in fuel entering the incineration plants turns into N_2 and NO_x is formed during all combustion processes from the N_2 in the ambient air.

The transport within the system boundary of Scania is the largest contributor to NO_x emissions. About 40% of these emissions are from international transport within Scanian airspace and waters (Figure 27). The Scanians have no control over these international transports. Since this study is intended to show all flows without regard to who the polluter is, these emissions are included in the flow chart. These tonnes of mainly NO_x could be part of the deposition on land, but it has not been possible to calculate this.

The activities within society that account for the largest emission to water are by far agricultural, followed by WWTPs and forestry (Figure 30). Deposition to lakes, wastewater from food industries and leakage from one-site sanitation are about the same (2% each of the total inflow to water). All of these emissions are assumed to leave the system boundary without retention. For

[RRR] Databoken is available at: http://www.agriwise.org/databoken2/index.html
Username and password are required to access data.
[SSS] Agriwise is a cooperation between SLU, Landshypotek, LRF consult and Swedbank (Agriwise, n.d.)

WWTP located at the coast this is a fair assumption, but leakage from agriculture, forestland, on-site sanitation and emissions far upstream might not exit Scania but could be stored in, and lost from plants and soil depending on and affected by soil type, soil treatment, crops grown, rain, irrigation and harvesting. The value for N_r to water from SMHI and SLU (Figure 29) was about 2,400 tonnes lower than the value used (14,371 tonnes compared to 11,929 tonnes). The lower value was perhaps closer to reality, since SMHI and SLU are assumed to have a more delicate and reliable method than a master thesis like this ever can produce due to its timeframe and authors lack of methodological experience. This either means that the calculated value (summation from all sectors and deposition) is too high or that this difference could equal the retention in soil and plant uptake.

6.2 Urban nitrogen flow

Figure 36 shows the size of the urban nitrogen flow (or the urine flow) in comparison to other flows in Scania. The urine is a relatively large flow compared to other Scanian flows. Today only the sludge is returned to agricultural land from the wastewater system and its N_r content is only about 11% of that in urine (Table 17 and Figure 36). The most common fertilizer in Scania is mineral fertilizer. It is relevant to change the current nitrogen management for several reasons. Two main approaches; up-stream and downstream, of the nitrogen management occurring today seem contra productive (Figure 44).

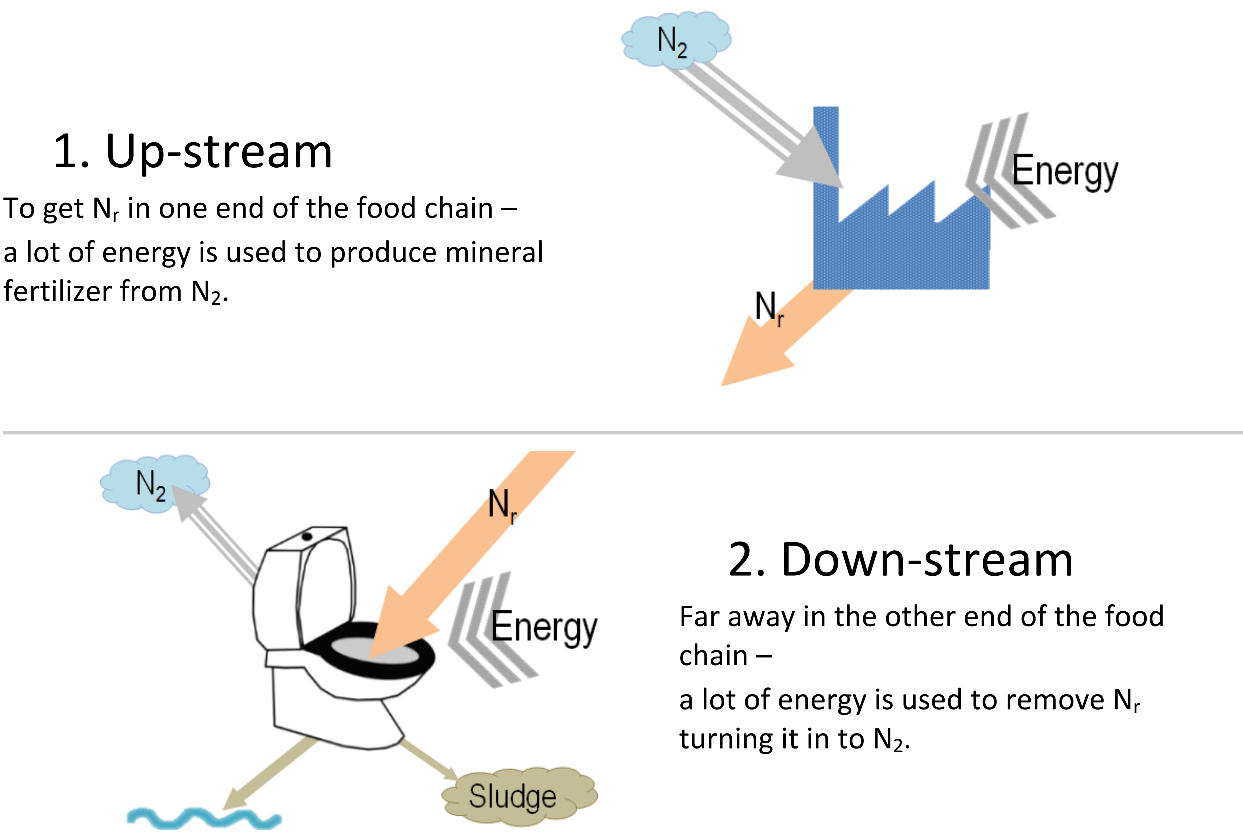


Figure 44. The two approaches in different ends, up- and down-stream, of the food chain using energy to convert nitrogen between different forms.

These two approaches in Figure 45 together may seem contra productive since both of them use a lot of energy to convert nitrogen between different forms and resources is needed in both ends of the nitrogen management. One method of improving the nitrogen management could be to reduce energy consumption in N_r removal at WWTP, i.e. improve point two. Another way is eating less protein, most desirable reducing the animal protein. This change in diet could lead to decreased need for mineral fertilizer from reduced animal production, plus decreased need for N_r removal from decreased N_r load to WWTP, i.e. small improvement of both point 1 and 2. Another way of closing the loop is the installation of urine separating toilets, i.e. large improvement of both point 1 and 2, i.e. both up- and down-stream activities.

Source separation of the toilet waste could potentially have many positive consequences, such as reduced need for mineral fertilizer and reduced energy use followed by reduced climate impact. But the system also increases eutrophication and acidification potential when urine is reused on agricultural land. In this report the potential is assumed to be 100% of the total urine. In reality the amount of collected urine is less, about 70-80% due e.g. some people's unwillingness to sit down while urinating. It is also not reasonable to assume that the toilets in Scania would be replaced.

Dietary change would impact the N_r load to WWTP. It could seem like a comfortable approach to decrease influent load to WWTP compared to installing new technique. However, installation of urine separating toilets and dietary change both involve interference with human life and habits. What upsets a human being more; to eat 19.5 grams of protein less a day or to learn how to use a new toilet?

Scanian N_r flow differs from other regions and national flows mainly due to the large share of agriculture and food industry. In Stockholm with larger population size and less agriculture and food industry the urban nitrogen flow is bound to be even larger in comparison with Scania. In regions with less agriculture and food industry the urban nitrogen flow becomes even more relevant to use and take advantage of or lower the N_r load into WWTPs.

6.3 Method discussion

There are few regional studies of nutrient flows and especially for nitrogen there are few examples found. The regional SFA provided a new type of information and put various sectors and emissions in relation to each other. It also provided important and useful data for regional and perhaps even municipal planning. It also put the discussion of investments and measures to reduce emissions and improve the management of natural resources, in a perspective between sectors.

Disadvantages of the SFA method are that it is time consuming, not easily repeatable, uncertain and based on many assumptions and more or less reliable data. If another SFA for Scania would be performed for another year it would probably differ from the results in this study, and it would not be obvious why this was. Was it due to different assumptions, more or less access to data or real changes in the nitrogen flows?

Figure 45 presents the flow chart and the data evaluation together. The different colours of the subsystems are grey in order to highlight the result of the data evaluation. When looking at the uncertainty of data (Figure 45) it becomes obvious that the data collection wasn't a walk in the park. Out of the 30 arrows only 10 are green and 33% of the total calculated value in tonnes are marked as green (Figure 46).

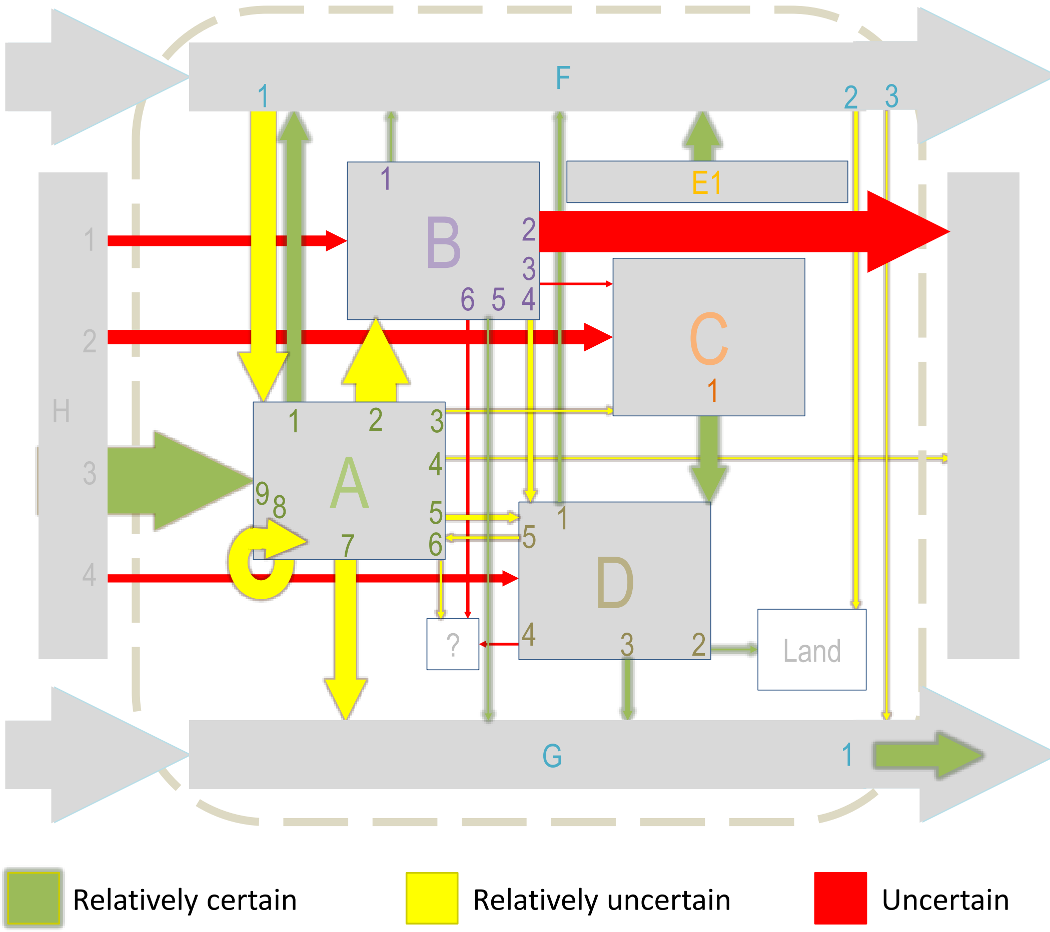


Figure 45. The data uncertainties.

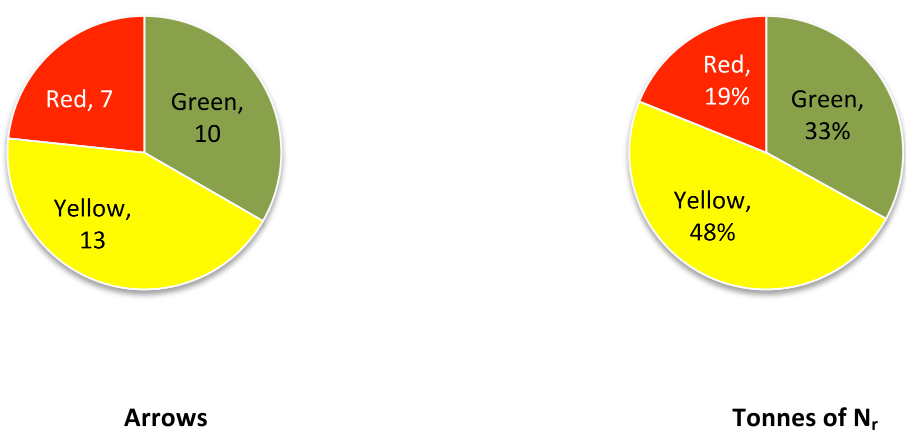


Figure 46. The right pie chart shows distribution of the number of arrows. The right pie chart shows distribution of the total amount of calculated tonnes, i.e. 19% of the tonnes in the flow chart for Scania (Figure 32) are marked as red.

The major eyesore in Figure 45 is the fact that one of the largest flows is marked as red, i.e. based on very unreliable calculations, that is the flow of exported produced food. The N_r flow within the food industry is uncertain with very limited data sources. Statistics Sweden provides reliable data for many other flows such as mineral fertilizer. The colour green on arrows, that is high reliability, most often stem from that someone is "forced" to collect the data, i.e. report the data to the government or a municipality. For other flows data was difficult to find.

To govern the flows of nutrients in society, we have to have knowledge on how and where the flows are and how big they are, to be able to have an effective management of nutrients. For example, we need this information to be able to make assessments of where it is most cost effective to govern flows. One interesting discussion is where within society we should invest to make the nutrient flows more sustainable. Is it:

- up-stream, such as what people eat or how they fertilize, or is it
- down-stream with end-of-pipe solutions, such as improved processes at WWTPs, or could it be that it is
- most favourable to govern flows both up- and down-stream?

In the next 10 or 20 years big investments in the technical systems – wastewater treatment, heating plants, waste management – will be decided upon and at the same time changes in transportation, agricultural practices and possibly also changes in the diets will be discussed. Information and knowledge about the nitrogen flows will therefore be very useful to municipal and regional planning in Scania in order to make relevant decisions for future investments.

7 Conclusions

The agriculture contains the largest N_r flows, with large inflows in mineral fertilizer, deposition and N_r fixation. About 30% of input to agricultural land is lost to air and water. The crops are both used as fodder and in food production. The animal production produces a large amount of manure, which is spread on agricultural land. Scania has a large food production, where animal products, slaughtered animals, imported material and crops are raw material. A large portion of the produced food is exported. The flows of nitrogen in Scania probably differ from the flows in other Swedish regions. The urban nitrogen flow is a relatively large flow and also contributes to water discharges and energy consuming processes. Transport gives rise to a big part of the air emissions. The emissions from Scania to the surrounding sea and ambient air are bigger than what is deposited on or fixated in Scanian ground .The leakage and emissions of N_r affect most of the environmental problems that we know and that are of priority in Sweden.

The urban nitrogen management could today be referred to as inadequate or even unsustainable. Only a very small part of the N_r consumed as food is recycled and used as fertilizer on agricultural land. Much of the N_r is lost to air and water, air or as N_2 through energy consuming processes at WWTP. There is a great potential for improvement of how the flows of nitrogen are managed in the Scanian context. One suggested improvement is urine separation, which could have positive effects but also increase eutrophication and acidification potential. Other possible improvements of nitrogen management are diet change to reduce the N_r load on WWTPs and the use of anammox to reduce energy use at WWTPs. To weigh those options against each other and propose future strategies and actions further examination is required.

This SFA provides new information and put the sectors in society in relation to each other. This could be important input for municipal and regional planning, especially for when decisions are made for future investments that affect nitrogen flows. Despite the usefulness of obtaining knowledge, it is very difficult to find reliable data, which almost only occurs when someone is forced to report the data.

7.1 Further work

Beyond the scope of this study is a discussion on how to change the flows in Figure 32. Some arrows are a result of the large food production in Scania and might be a necessary evil in order to have domestic food production. Questions to discuss; What are the capabilities or potential improvements for successful nitrogen management in the different sectors and subsystems? How could the flows change in order to have a more successful nitrogen management? Which flows are necessary in order to have the food production in Scania and Sweden? To answer these questions and to determine where the measures are most cost-effective or what solutions are reasonable and sustainable, further investigation is needed.

In order to use the SFA for monitoring over time, a more developed method is required to get more accuracy in the calculated values. First and foremost an improved knowledge about materials and environmental accounting is essential, i.e. it has to be easier to collect data in order to have more green arrows in Figure 45. For some sectors of society accessible data already exists, judging from Figure 45, i.e. parts of agriculture, water and air emissions. To facilitate quantification of regional flows, factors or key indicators like the ones in Table 35 and Table 44, should be developed. The factors could i.e. be rough estimates for generated waste or wastewater for the different sectors in society.

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Appendix A – Nitrogen content for KN-codes

	Description of chapter	Conversion factor[1]	Protein content[2]	N_r content[3]
1	LEVANDE DJUR			
2	KÖTT OCH ÄTBARA SLAKTBIPRODUKTER			0,029
3	FISK SAMT KRÄFTDJUR, BLÖTDJUR OCH ANDRA RYGGRADSLÖSA VATTENDJUR	6,25	20%	0,032
4	MEJERIPRODUKTER; FÅGELÄGG; NATURLIG HONUNG; ÄTBARA PRODUKTER AV ANIMALISKT URSPRUNG, INTE NÄMNDA ELLER INBEGRIPNA NÅGON ANNANSTANS	6,25	18%	0,029
5	PRODUKTER AV ANIMALISKT URSPRUNG, INTE NÄMNDA ELLER INBEGRIPNA NÅGON ANNANSTANS	6,25	20%	0,031
6	LEVANDE TRÄD OCH ANDRA LEVANDE VÄXTER; LÖKAR, RÖTTER O.D.; SNITTBLOMMOR OCH SNITTGRÖNT			0,029
7	GRÖNSAKER SAMT VISSA ÄTBARA RÖTTER OCH STAM- ELLER ROTKNÖLAR			0,029
8	ÄTBAR FRUKT SAMT ÄTBARA BÄR OCH NÖTTER; SKAL AV CITRUSFRUKTER ELLER MELONER	6,25	1%	0,001
9	KAFFE, TE, MATTE OCH KRYDDOR	6,25	5%	0,008
10	SPANNMÅL	6,25	1%	0,002
11	PRODUKTER FRÅN KVARNINDUSTRIN; MALT; STÄRKELSE; INULIN; VETEGLUTEN	6,25	11%	0,017
12	OLJEVÄXTFRÖN OCH OLJEHALTIGA FRUKTER; DIVERSE ANDRA FRÖN OCH FRUKTER; VÄXTER FÖR INDUSTRIELLT ELLER MEDICINSKT BRUK; HALM OCH FODERVÄXTER	6,25	5%	0,008
13	SCHELLACK O.D.; NATURLIGA GUMMIARTER OCH HARTSER SAMT ANDRA VÄXTSAFTER OCH VÄXTEXTRAKTER	6,25	5%	0,008
14	VEGETABILISKA FLÄTNINGSMATERIAL; VEGETABILISKA PRODUKTER, INTE NÄMNDA ELLER INBEGRIPNA NÅGON ANNANSTANS	6,25	5%	0,008
15	ANIMALISKA OCH VEGETABILISKA FETTER OCH OLJOR SAMT SPALTNINGSPRODUKTER AV SÅDANA FETTER OCH OLJOR; BEREDDA ÄTBARA FETTER; ANIMALISKA OCH VEGETABILISKA VAXER	6,25	0%	0,000
16	BEREDNINGAR AV KÖTT, FISK, KRÄFTDJUR, BLÖTDJUR ELLER ANDRA RYGGRADSLÖSA VATTENDJUR	6,25	5%	0,008
17	SOCKER OCH SOCKERKONFEKTYRER	6,25	5%	0,008
18	KAKAO OCH KAKAOBEREDNINGAR	6,25	5%	0,008
19	BEREDNINGAR AV SPANNMÅL, MJÖL, STÄRKELSE ELLER MJÖLK; BAKVERK	6,25	5%	0,008
20	BEREDNINGAR AV GRÖNSAKER, FRUKT, BÄR, NÖTTER ELLER ANDRA VÄXTDELAR	5,70	8%	0,015
21	DIVERSE ÄTBARA BEREDNINGAR	6,25	1%	0,001
22	DRYCKER, SPRIT OCH ÄTTIKA	6,25	5%	0,008
23	ÅTERSTODER OCH AVFALL FRÅN LIVSMEDELSINDUSTRIN; BEREDDA FODERMEDEL	6,25	5%	0,008

[1] Conversion factor from National Food Agency. (2015a, February 16). *Protein.* Retrieved April 15, 2015, from www.livsmedelsverket.se: http://www.livsmedelsverket.se/livsmedel-och-innehall/naringsamne/protein/
[2] Protein content interpreted by the author together with protein content for food from National Food Agency. (2015, February 22). *Food database (Swedish: Livsmedelsdatabasen).* Retrieved April 16, 2015, from www.livsmedelsverket.se: http://www.livsmedelsverket.se/livsmedelsdatabasen
[3] The quote of protein content and conversion factor.

Sveriges Lantbruksuniversitet
Institutionen för energi och teknik
Box 7032
750 07 UPPSALA
www.slu.se/energiochteknik

Swedish University of Agricultural Sciences
Department of Energy and Technology
P. O. Box 7032
SE-750 07 UPPSALA
SWEDEN
http://www.slu.se/en/departments/energy-technology/