NTNU – Trondheim
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Energy and Nutrient Recovery Potential from the Norwegian Food Supply System

Potensial for energi- og næringsstoffgjenvinning i det norske matproduksjonssystemet

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MASTER THESIS

for

Samantha Peverill
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Energy and Nutrient Recovery Potential from the Norwegian Food Supply System
Potensial for energi- og nærstoffgjenvinning i det Norske matproduksjonssystemet

Background and objective

This project will investigate the potential for improved resource management relating to the Norwegian food supply system, excluding aquaculture and fisheries. Phosphorous and energy mapping of biomass flows can highlight areas where energy potential and nutrient recovery can be simultaneously realized.

Also, the energy layer will be incorporated with a phosphorous layer to identify synergies between different critical materials. Defining a first version MFA model with consideration for separate layers (for example: dry matter, C, P, N, energy, economy) allows us to evaluate several indicators together for a more holistic systems perspective.

Phosphorous (P) is an essential nutrient for life and therefore vital for food production. P for use in agriculture is mined from rock phosphate, which is a finite resource. A deeper understanding of 'hot-spots' for reducing consumption and/or reusing secondary P can help to guide recycling efforts.

A recent report by Miljødirektoratet highlighted the fact that energy is prioritized when considering secondary biomass utilization. Any predictions of future system configurations must take this reality into account in order to be practical and realistic. This shows the importance and demand for renewable energy in the face of climate change and a changing understanding of the consequences of energy use.

In close collaboration with Helen Hamilton, energy and nutrient layers will be developed for use with the Norwegian phosphorous system model that is currently under development.

The project will begin with a literature review focusing on what is already known about the flows related to the food system in Norway, including the magnitude and origin of both food losses and food waste.

The following tasks are to be considered:

1. Literature review
2. System definition for the Norwegian food supply
3. Quantify the dry matter layer using existing data from the literature
    a. Adapting existing models to reflect the expansion of system boundaries
4. Expand the model to include an energy layer for the entire system
5. Expand the model to include a phosphorus layer for the same system
6. Interpret the results of this three-layer model for Norway; identify potentials for increasing the energy and phosphorus efficiency of the entire system and for creating synergies between the two goals

7. Develop scenarios for an increased energy and phosphorus efficiency in the Norwegian food supply chain
8. Interpret the results (strengths and weaknesses of the model, policy-relevant conclusions) and write the report

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Within 14 days of receiving the written text on the master thesis, the candidate shall submit a research plan for his project to the department.

When the thesis is evaluated, emphasis is put on processing of the results, and that they are presented in tabular and/or graphic form in a clear manner, and that they are analyzed carefully.

The thesis should be formulated as a research report with summary both in English and Norwegian, conclusion, literature references, table of contents etc. During the preparation of the text, the candidate should make an effort to produce a well-structured and easily readable report. In order to ease the evaluation of the thesis, it is important that the cross-references are correct. In the making of the report, strong emphasis should be placed on both a thorough discussion of the results and an orderly presentation.

The candidate is requested to initiate and keep close contact with his/her academic supervisor(s) throughout the working period. The candidate must follow the rules and regulations of NTNU as well as passive directions given by the Department of Energy and Process Engineering.

Risk assessment of the candidate's work shall be carried out according to the department's procedures. The risk assessment must be documented and included as part of the final report. Events related to the candidate's work adversely affecting the health, safety or security, must be documented and included as part of the final report. If the documentation on risk assessment represents a large number of pages, the full version is to be submitted electronically to the supervisor and an excerpt is included in the report.

Pursuant to "Regulations concerning the supplementary provisions to the technology study program/Master of Science" at NTNU §20, the Department reserves the permission to utilize all the results and data for teaching and research purposes as well as in future publications.

The final report is to be submitted digitally in DAIM. An executive summary of the thesis including title, student's name, supervisor's name, year, department name, and NTNU's logo and name, shall be submitted to the department as a separate pdf file. Based on an agreement with the supervisor, the final report and other material and documents may be given to the supervisor in digital format.

☐ Work to be done in lab (Water power lab, Fluids engineering lab, Thermal engineering lab)
☐ Field work

Department of Energy and Process Engineering, 14. January 2014

Olav Bolland

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Abstract

Agricultural and food supply systems are inefficient as evidenced by poor utilization of phosphorous (P), large losses of energy and sizeable and distributed losses of food (Wirsenius 2003; Cordell et al. 2011). Researchers have identified the need for a restructuring of the agricultural system, however, proposals for the optimal system are highly dependent on specialized interests, such as food security, nutrient efficiency or energy production (Wirsenius 2003; Schmid Neset et al. 2008; Jansa et al. 2010; Cordell et al. 2012). Regarding systemic changes, the disconnect between researchers addressing their compartmentalized issues could result in problem shifting. For example, a system optimized for energy production could accelerate nutrient depletion and/or increase nutrient pollution. In terms of evaluating solutions for secondary biomass utilization, the Norwegian Ministry of Environment has stated energy production as the priority (Miljødirektoratet 2013). Renewable energy sources are needed but the lack of concurrent consideration of issues like nutrient depletion is a strong concern. Norway has existing access to renewable energy in the form of hydropower, but lacks any domestic supply of P, which is a limited resource.

There has yet to be published a Material Flow Analysis (MFA) that incorporates multiple layers to evaluate the energy and nutrient perspectives in an agricultural system. This report used MFA to evaluate the Norwegian agricultural system in terms of dry matter, energy and phosphorous. The goal of this modeling was to identify synergies and overlaps between the ideal systems for P and energy optimization. This report aimed to improve the theoretical foundation upon which initiatives and policies are built, in order to ensure that the most advantageous leverage points are used for maximum efficiency. A baseline model was constructed with the three aforementioned layers. The agricultural system was modelled from domestic production through to post consumer waste collection. Following from this baseline, three scenarios were tested and the impacts on the P and energy system compared. Important indicators in the P layer proved to be fertilizer imported, the P incinerated, the P accumulation in soils. In the energy layer focus was placed on process energy use and energy production, as well as examining large sources of loss from the system.

The results indicate that Norway is not very food secure and is highly reliant on imports of phosphorous fertilizer for the food that is grown domestically. The Norwegian government must recognize the relative impacts that the agriculture and food system have on the energy and P cycles respectively. The system modeled in this report controls nearly 100% of the P cycling within the country along with aquaculture and fisheries, yet could provide a maximum of around 11% of the nation's electricity. In a country with access to hydropower, energy production should not be prioritized over phosphorous reduction, reuse and recovery.

Manure is not accepted by farmers as a source of P and is also a poor source of energy. Harvest residues, in contrast, appear to be a good source of both P and energy, without the same problems of transportation and spatial distribution. This novel and innovative multi-layered modeling successfully shed light on the inter-relations between phosphorous and energy in the Norwegian agricultural systems and contributed important preliminary results.

Acknowledgements

I would like to thank Roger Fage for supporting the idea of moving to a new continent in pursuit of knowledge and for helping to make it a reality. I am very grateful to my supervisors Daniel Beat Müller and Helen Hamilton for their great guidance and for keeping me on the right track. I cannot thank Rachel Spiegel and the rest of our classmates enough for keeping me on my feet when the going got tough. I am endlessly indebted to Vilde Fluge, my partner in play, for her endless patience, editing help and her skill of bringing out the best in people. Last but not least Jørgen Westrum Thorsen for challenging me and at the same time being a calm and reliable presence throughout these two years.

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1 Introduction and Background

Agricultural and food supply systems are inefficient as evidenced by poor utilization of phosphorous (P), large losses of energy and sizeable and distributed losses of food (Wirsenius 2003; Cordell et al. 2011). Researchers have identified the need for a restructuring, however, proposals for the optimal system are highly dependent on specialized interests, such as food security, nutrient efficiency or energy production (Wirsenius 2003; Schmid Neset et al. 2008; Jansa et al. 2010; Cordell et al. 2012). Regarding systemic changes, the disconnect between researchers addressing their compartmentalized issues could result in problem shifting. For example, a system optimized for energy production could accelerate nutrient depletion and/or increase nutrient pollution.

Norway's ban on landfilling organic waste came into effect in 2009, thereby calling attention to the magnitude of agricultural and food waste and necessitating new solutions for this flow (Section 9.4a of Waste Regulations, Norwegian Government 2009). For a perspective on the magnitude of food waste worldwide, approximately one third (1.3 billion tons per year) of the edible food produced for humans is lost or wasted and "the later a product is lost or wasted along the supply chain, the higher the environmental cost, as impacts arising for instance during processing, transport or cooking, will be added to the initial production impact" (FAO 2013).

In terms of evaluating solutions for secondary biomass utilization, the Norwegian Ministry of Environment has declared energy production as the priority (Miljødirektoratet 2013). This prioritization is driven by climate change concerns and the understanding that the energy sector is responsible for two-thirds of the world's greenhouse gas emissions (IEA 2013). Renewable energy sources are needed but the lack of concurrent consideration of issues like nutrient depletion is a strong concern. Norway has existing access to renewable energy in the form of hydropower, but lacks any domestic supply of phosphorous, which is a limited resource.

Phosphorous is an essential nutrient for life and therefore vital for food production. P in the form of mineral fertilizer used in agriculture is mined from rock phosphate, which is a finite resource flowing from extraction through consumption to waste, without contributing to desired growth or being captured in recycling loops. This P practice is unsustainable resulting in large losses. This resource often passes linearly through the anthropological system, ultimately leading to P accumulation in several environmental compartments, in turn causing problems such as the eutrophication of water bodies. In order to investigate more sustainable phosphorous use, it is essential to develop a deeper understanding of the stocks, sinks and major users of phosphorus by using systems analysis. This will allow us to identify 'hot-spots' for reducing consumption and/or reusing secondary P, such as that contained in manure, sewage sludge and harvest residues. Energy and phosphorous contents are closely linked in biomass and they can often be recovered in conjunction, generally through anaerobic digestion. With a broader scope than is possible in this report another important connection can be seen between P and energy which is the extensive energy requirements and pollution associated with the production of phosphorous fertilizers (Cordell et al. 2011).

Systems analysis in the form of Material Flow Analysis (MFA) has been applied to agriculture, with many researchers mapping phosphorous as shown by Cordell (2012), in a study of 18 recent Substance Flow Analysis studies related to phosphorus, and Wirsenius (2003) studied the energy perspective, as discussed later. The Food and Agriculture Organization of the United Nations (FAO) recently published a systems analysis of the global food supply chain with the report titled "Food Wastage Footprint: Impacts on Natural Resources" (FAO 2013). The authors calculated the carbon footprint, water footprint, land occupation/degradation impact and potential biodiversity impact of the food supply chain. More information on this report can be found in *Appendix #1.* In relation to the Norwegian context, Hamilton et al (in press) have constructed a phosphorous model of the whole economy, including agriculture.

However, there has yet to be published an MFA that incorporates multiple layers in order to evaluate the energy and nutrient perspectives in an agricultural system. In response to the concerns around the Norwegian situation, the aim of this thesis was to perform the first multilayered MFA for agriculture. This thesis used a layered approach and a common system definition to analyze multiple resources simultaneously. The aim was to evaluate options for secondary biomass utilization. Secondary biomass is generally a by-product or "waste" stream such as manure, slaughter waste or sewage sludge. The agricultural system was chosen to demonstrate the use of this integrated and layered analysis because it is among those anthropological systems that have the largest transformational influence on natural cycles, including nutrient and energy cycles.

1.1 Topic and Research Questions

The constructed model quantifies the flows, stocks, sources and losses in the Norwegian agricultural system in terms of mass, energy and phosphorous. The goal was to determine whether there are synergies and overlaps between the ideal systems for phosphorous and energy optimization. This report aimed to improve the theoretical foundation upon which initiatives and policies are built, in order to ensure that the most advantageous leverage points are used for maximum efficiency. The questions motivating this research include:

Q1- What are the magnitudes of flows in the agricultural system?
Q2- Where are key points of loss for energy and/or P and what are the magnitudes of these?
Q3- Where in the agricultural system could energy potential and nutrient recovery be simultaneously realized?
Q4- Where are potential leverage points in the system that could address multiple issues?
Q5- What should policy and initiatives prioritize?

Scenario Motivation

In MFA, after a baseline model has been created, scenarios can be used to test hypotheses and attempt to understand how changes made will affect the whole system. In order to answer research questions four and five, a number of scenarios were run on the baseline model of the Norwegian agricultural system.

The first scenario has two parts, one where waste from food markets and consumers was directed to biogas production, and another where production was reduced by the amount of avoidable food waste from the same processes. Scenario 1 was designed to show the difference between end-of-pipe solutions like diverting waste streams and preventative solutions like matching demand and supply more accurately.

In the second scenario, all recoverable waste streams were diverted to biogas production and it was assumed that the loss of secondary phosphorous was covered by primary sources. Scenario 2 is an extreme case to show how prioritizing energy recovery from secondary biomass (and ignoring nutrient recovery) could affect the import of P fertilizer and the losses in the system.

Following this introduction, Section 2 will outline the methods used to construct the first multi layer agricultural MFA model. The decisions that were made regarding data sources, process definition and product inclusion will be explained and justified. In this section flow equations for the dry matter and phosphorous layers can be found, along with information on stocks. In Section 3, the results of the baseline model will be stated and compared. This will be followed by important observations of scenario results. Section 4 provides the author's interpretations of the stated results along with critical information on uncertainties and data limitations. Section 5 looks to the future and suggests improvements to the constructed model, areas for data improvement, and also, policy recommendations for the Norwegian government. Final conclusions are stated in Section 6. References are listed next and followed by extensive Appendices in Sections 8.1 through 8.9.

2 Methods

This report used Material Flow Analysis (MFA) to evaluate the Norwegian agricultural system in terms of dry matter, energy and phosphorous. The author recognizes that there are many additional layers that could have been included in such an analysis, including water use, land use and carbon emissions. However, in Norway, water use is not an environmental issue that receives much attention, due to the abundance of fresh water and climate prone to precipitation. Also, local deforestation and the replacement of forest with agricultural production are not of great concern due to the lack of arable (and flat) land, as only 3% of Norway's land area is considered arable. Carbon is indirectly included through the inclusion of process energy use.

The agricultural system was investigated from domestic production through to post consumer waste collection. Since the focus was on nutrient and energy recovery, no distinction was made between edible and inedible waste and material other than that intended for human consumption was included (manure, harvest residues). A discussion of food waste definitions used in studies with different research questions is included in the Appendix.

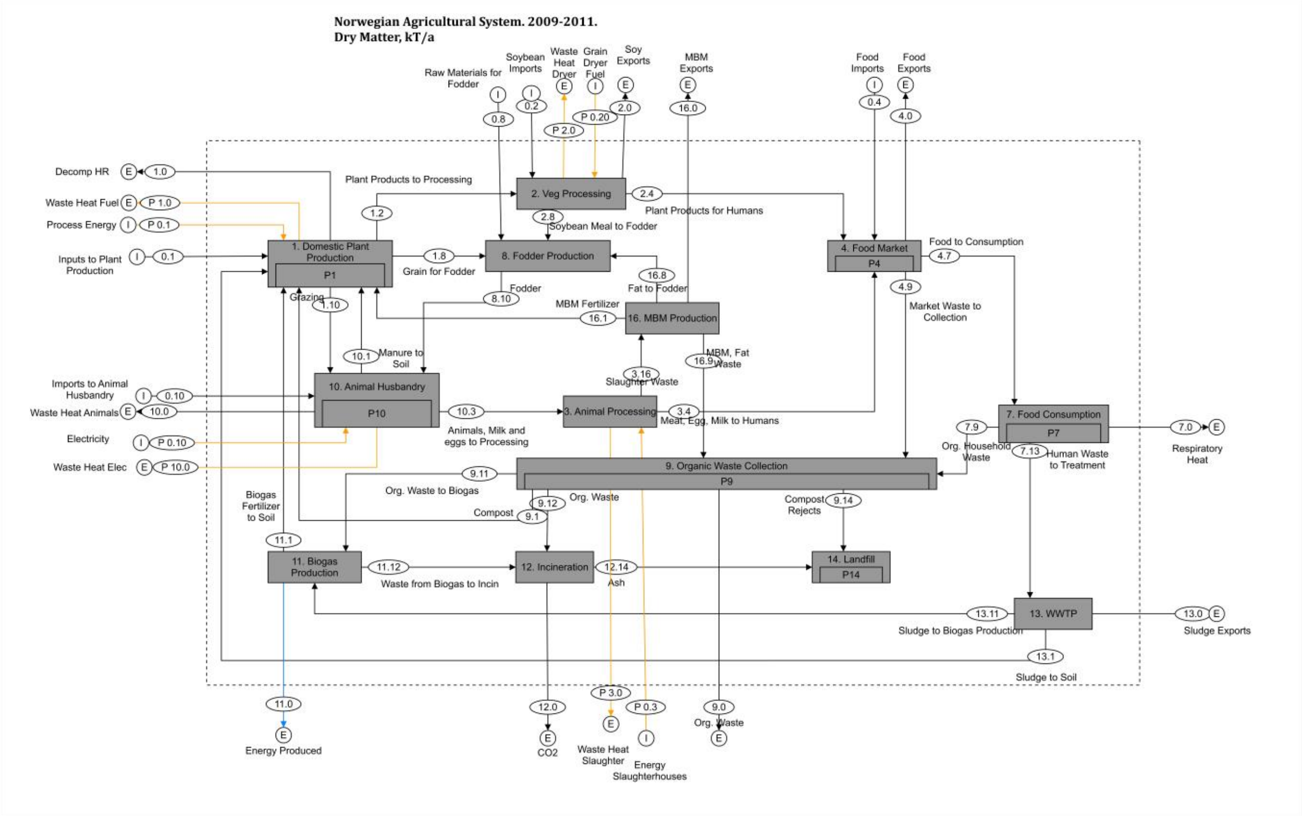

Figure 1. Common System Definition for the Norwegian Agricultural System

2.1 System Definition

In an attempt to encompass all definitions of food waste, this report endeavored to represent all of the major biomass flows that are part of the agricultural system. This work followed from a project report that quantified the mass and energy flows of the Norwegian agricultural sector (Peverill, 2013). The agricultural system is defined as the value chain, which begins at agricultural production and extends to the consumption or waste management of the biomass.

Fisheries and aquaculture fish production were left out of this analysis for several reasons. The aquaculture system in Norway is very large and complex. There are many researchers focusing on this in particular. Also, some important waste flows are very uncertain due to a lack of accurate reporting of discards and by-catch (FAO 2013). The consumption of both domestic and imported fish was included in the import flow into the Food Market process.

The system is shown above in Figure 1, with the black arrows indicating biomass flows and the orange arrows denoting process energy (only shown in the energy layer diagrams). The system boundary is indicated using dotted lines and imports and exports are those flows which traverse those lines. Flows are identified by two numbers, the process from which they originate and the process to which they flow. For example, the flow representing food flowing from the Food Market (Process 4) to Human Consumption (Process 7) is referred to as Flow 4.7. The Norwegian agricultural system is represented by 13 processes, which are connected with material flows. Dry matter flows were calculated to be used as the basis for all layers. Table 1 and Table 2 below list all the flows, equations and data sources used for the dry matter and phosphorous layers. Phosphorous flows do not distinguish between insoluble, soluble and plant available P. The energy flows were calculated by applying energy contents to the dry matter layer and represent simply the energy content of materials with no reference to the portion that could be extracted. The exceptions are process energy and energy production from biogas, which are both usable energy. The following is an introduction to each process in terms of what transformation takes place and the major flows in and out.

Domestic Plant Production (Process 1) represents the Norwegian farms and soil used for vegetable, fruit and grain production. Inclusion in the model was based on production volumes. The main vegetables included were potato, tomato, onion, carrot, cucumber, all cabbages and lettuces. The domestic fruits included were apples, strawberries and raspberries. The major four grains were included (Wheat, Rye, Barley and Oats) along with peas and oilseeds. This process receives mineral, animal and plant fertilizer and produces plant products for both animal and human consumption and also production waste and harvest residues. Imports and exports of seeds were not taken into consideration. Natural processes that create biomass or provide energy but cannot be quantified (Net Primary Production) are represented through the input flow to the Domestic Plant Production process.

The **Vegetable Processing process (Process 2)** receives all vegetable, grain and fruit from Norwegian production, aside from that which is wasted in the production stage and what is directed to fodder production. Direct sales from farms were not included in the model due to their minor volume (Regjeringen 2011). Vegetable Processing signifies the transformation of raw vegetables into their saleable products, whether that is raw vegetables packaged, or products such as pickles, jams and soups. Unfortunately, detailed information on Norwegian processing and processing waste was not found, so these products were assumed to continue on to Wholesale.

A major activity occurring in Vegetable processing relates to imported soybeans.
These soybeans are processed into soybean meal (80%), oil (19.5%) and lecithin (0.5%). The company Denofa is the primary receiver of soybean imports. They claim to receive around 420,000 tons of soybeans annually and produce 330,000 tons of meal, 85,000 tons of oil and 2500 tons of lecithin (Denofa 2014). Nearly 100% of the oil and lecithin are then re-exported (Flow 2.0). According to the Norwegian Agricultural Authority (SLF) only an average of 153,620 tons of domestically produced soybean meal is fed to Norwegian livestock (Flow 2.8). Therefore the rest of the soybean meal is assumed to be re-exported from this process. The soybean processing results in nearly 100% products or usable by-product because the soybean has no inedible parts. Denofa claims that it has miniscule amounts of waste, and no information was available to indicate otherwise.

Animal Processing (Process 3) represents all steps between receiving a live animal and producing saleable animal products. It also represents the grading of eggs and the processing of milk into products such as cheese, butter and ice cream. All slaughter waste in the model goes to Meat and Bone Meal Production, though in reality an unknown quantity is used for Biogas Production. Eggs flow through processing to wholesale with no assumed loss. The animal carcass information from SSB defines a carcass as "the body of an animal after being bled and having its insides, limbs, head, tail, udder etc removed. Also skinned, except for pigs" (SSB- Statistisk Sentralbyrå n.d.). Therefore assumptions were made regarding the weight of these additional animal parts, with the use of information from Wirsenius (2003).

The process named **Food Market (Process 4)** in some way represents the beginning of the involvement of four umbrella chains, though in truth they have some ownership interests in production as well. This part of the system was challenging to model due to a lack of consistent information. This may be due to data privacy in a very consolidated market. In Norway 100% of the food retail market is divided among four umbrella companies, listed below with their market shares as of 2009 (Stenmarck et al. 2011):

Norgesgruppen -40% market share
COOP- 24%
REMA 1000 – 20.3%
ICA – 15.7%

These chains control both the wholesale and retail activities in Norway. Also, most have interests in other areas. Norgesgruppen's owns several service and fast food chains (MIX, Deli de Luca and Fresh), has its own grocery company (ASKO) and is an owner of the largest Norwegian distributor of vegetables and fruits (BAMA) (Stenmarck et al. 2011). COOP owns several production companies, its own distribution company and has its own in-house brands. REMA 1000 also has its own labels, distribution and production companies and also owns Narvesen and 7- Eleven (Stenmarck et al. 2011). ICA Norge Ltd. owns its distribution network and also has ownership interests in two fruit and vegetable companies.

Therefore it was difficult to find and correlate data on the processing of vegetables, the distribution of food and the waste. Statistics tend to be unavailable when there are few and inter-related actors in the marketplace.

Information on food imports was collected from SSB and the analysis used an average of 2009-2011. The cutoff for inclusion was a magnitude of 1000 tons or more.
Imported fruits included are oranges, bananas and grapes. Products known to be used in processing, fodder or agriculture were subtracted from the aggregated statistics to avoid double counting.

In terms of waste flows, FAOStat Food Balance Sheets (FBS) give an estimation of Waste for each commodity. They define Waste as "wastage during the year at all stages between the level at which production is recorded and the household, i.e. storage and transportation"(FAOSTAT 2014). These values were considered to be wholesale waste. The FBS was also used to estimate food consumption by using the food supply quantities of different products.

Retail waste data comes from an analysis done with NorgesGruppen by Hanssen & Olsen (2008). They evaluated products wasted by the retail outlets over a period of weeks and then used NorgesGruppen's market share to scale the waste flows up to a national level. This report took the most disaggregated information and used the same method. Potential uncertainties stem from several assumptions and are discussed in the uncertainties section of this paper.

Retail and wholesale waste is combined into the Food Market Waste flow. Food Market waste is assumed to be collected by waste management companies, though in reality a small but growing proportion of edible waste is being recovered by food banks, Food Not Bombs groups and opportunistic individuals who practice "dumpster diving". There is not enough data to include this in the model, and it is likely to be negligible, but it is interesting to note that some waste is diverted prior to collection.

Food Consumption (Process 7) includes all food purchased and consumed by humans in Norway, whether from retail or in hotels and restaurants. Biomass from gardening or wood waste is excluded from household waste.

Fodder Production (Process 8) represents the domestic production of animal feed from both domestic and imported raw materials. The process has inputs of domestic and imported grains, fats from slaughter waste, soybean meal etc. Only animal feed to included animal groups was considered.

Wet Organic Waste Collection (Process 9) is an aggregated process representing nearly all domestic waste collection. Also included in this process is biological treatment such as composting. In the model, the waste is gathered here and then delved out to additional treatment options such as Biogas Production, Incineration or Landfill.

The **Animal Husbandry process (Process 10)** represents Norwegian farms raising cattle, pigs, sheep/lambs and chickens. Other animals raised for food, such as reindeer and goats, were left out due to insignificant production values. Fur animals were not considered to be part of the agricultural system, and also had small numbers compared

to the four animals chosen. Imported and exported live animals were excluded after having been deemed insignificant in the aforementioned project report (Peverill 2013). Grazing seasons were estimated from season specifics for Norway and the time that sheep and lambs spend grazing (and excreting) off of the farm was excluded as it was deemed insignificant to the research questions.
Animals were assumed to leave the farm alive to be slaughtered.

Biogas Production (Process 11) basically represents the conversion of food waste, slaughter waste and sludge into bioenergy and fertilizer. Information comes from Cambi, which is a company who built the waste to biogas plants in Norway.

Incineration (Process 12) is a popular choice for disposal of wastes in Norway and has doubled over the past ten years. 1.3 million tons of waste was incinerated in 2011 (SSB 2013). In the system, this process does not distinguish between incineration with and without energy recovery. It was not possible to disaggregate biomass from other incineration feedstocks; therefore energy production information was not usable. The flow of ash from the incineration process was not quantified due to a lack of data so the process has as net addition to stock (NAS) equal to the inputs.

WasteWater Treatment Plant (WWTP, Process 13)
Ola Stedje Hanserud collected the majority of the data used for the waste management flows in the compilation of the Norwegian P Model (Hanserud et al., in preparation). Uncertainties based on the incoming flow are discussed in the uncertainties section.
WWTP sludge going to landfill was left out, as it is only around 2.5% of the sludge amount.

Landfill (Process 14) is the last resort for some sorts of waste. As mentioned, it is no longer legal to landfill biodegradable wastes, though some exceptions are made for hazardous materials.

Meat and Bone Meal Production (MBM, Process 16) represents the transformation of slaughter waste into MBM. Slaughter waste is used for many different purposes depending on the quality and potential toxicity. In the model, MBM was used in agriculture, incinerated and used outside of the system. These values were found from Norsk Protein product data sheets and an average between different products at different production plants was used (Norsk Protein 2010). Then the production was assumed to represent the whole industry and was scaled up using an assumed market share for Norsk Protein of 85%.

2.2 Stocks

In MFA, stocks are used to show material or energy that does not flow directly through a process but instead remains there for a time, generally extending past the time scale of the analysis, three years in this case (2009-2011). The Landfill process is a good example, as material generally accumulates there with little to no outflow. Related to stocks is the variable of net addition to stock (NAS), which denotes how much material or energy remains in the process during the time period of the analysis.

The baseline system has no quantified stocks, though several processes have NAS and the system definition in Figure 1 includes a stock symbol in processes that could reasonably be assumed to have a stock. Domestic Plant Production, Animal Husbandry, Food Market, Food Consumption and Landfill have the option of stocks but not all have a quantified net addition or subtraction from stock in the current model. The NAS in Domestic Plant Production is relevant mainly to the Phosphorous accumulating in the soil. The amount of phosphorous that is accumulating in Norwegian soils is hypothesized by Hamilton et al (in press) to be the amount that is applied as sewage sludge and collected manure. When calculated via mass balance, the NAS in the base model was approximately the sum of the above two inputs. Therefore, this assumption was used to calculate the NAS in the base model and also the scenarios. The net addition to stock in Landfill is the summation of compost rejects (Flow 9.14) and Ash from Incineration (Flow 12.14). As previously mentioned, Flow 12.14 is not quantified, so NAS 14 is equal to Flow 9.14.

Table 1. Dry Matter Flow Equations and References

Flow Number	Flow Name	Flow Description	Flow Equation	References *
		Amount of dry matter (DM) contained in:		
0.1	Inputs to Plant Production	Products entering the system into Domestic Agriculture. Includes imported fertilizer and compost. Also includes natural processes which produce biomass.	Mass Balance	
0.2	Soybean Imports to Processing	Soybeans imported into Norway for processing into soybean meal	Soybeans Imported * Soybean DM%	1,3
0.4	Food Imports for Human Consumption	All food products imported into Norway	SUM of All [Imported foodstuff * DM%] - Fodder Imports	1,3,4
0.8	Imports to Fodder Production	All raw materials imported into Norway to be processed into animal fodder for poultry, lamb/sheep, cattle and pig	SUM of All [Imported fodder * DM%]	3,4,5
0.10	Imports to Animal Husbandry	All finished imports to animal husbandry. Includes hay, straw, fish waste and oilcakes for feed	SUM of All*DM%	1,3
1.2	Veg, Fruit and Grains to processing	Rye, barley, wheat and oats grown domestically for human consumption and major fruits and vegetables grown domestically	SUM of Grain Production For Humans*DM%) + SUM of [Veg or Fruit Production * DM%]	1, 4, 5
1.8	Grain to Fodder production	Rye, barley, wheat and oats grown domestically for animal consumption	SUM of All [Domestic Grains and Oilseeds to Fodder * DM%]	3,4,5
1.10	Animals Grazing on Pasture	Pasture and fodder crops grown domestically for animal consumption	SUM of All [Green Fodder and Hay * DM%]	1, 3,39
2.0	Soy Products Exported	Soybean meal, oil and lecithin not sold within Norway	Soybean Imported - Soybean Meal to Fodder	Balance
2.4	Veg and grain products to wholesale	Major fruits and vegetables grown domestically and grain to Humans. Only soybean processing is included.	SUM of [Grain to Food * DM%] + [Veg + Fruit Production * DM%]	1, 4,5

2.8	Vegetable Processing to fodder production	Soybean meal produced domestically from imported soybeans and fed to domestic livestock	Domestic Soybean Meal to Animals * DM% Soybean Meal	3,5
3.4	Animal products to wholesale	Milk, eggs and meat to the Food Market for human consumption	SUM of [Animals to processing * DM %]+ [Milk and Eggs * DM%]	1, 3
3.16	Slaughter waste to Meat and Bone Meal Production	All slaughter waste from the processing of animals. Milk and eggs are assumed to be unprocessed.	Mass Balance [Flow 10.3 - Flow 3.4]	Balance
4.0	Food Exports	All food products exported from Norway	SUM of all [Exported Foodstuff * DM%]	1,3,4
4.7	Products sold	All major food products consumed domestically	SUM of all [Food Supply per capita * capita * DM%]	4,16
4.9	Products rejected, damaged or unsold	All waste from wholesale and retail operations, including during transportation and storage.	SUM of all [Wasted Product at Retail * DM%] + [Wasted Product at Wholesale * DM%]	3,4,16,17
7.9	Consumption waste	All waste from consumption, including households, hotels, restaurants and other food service providers	SUM of [Average Organic Household Waste * Wet Organic Waste Portion *DM%] + [Organic Service Waste Average * DM%]	1, 20,21
7.13	Human waste to WWTP	Human wastes entering wastewater treatment facilities	[Discharge to Water from WWTP/(1-Treatment Efficiency)]* DM%	22
8.10	Fodder to Animals	All imported and domestic fodder fed to cattle, pig, lamb/sheep and poultry.	Domestic Fodder + Imported Fodder + Soybean Meal [0.8 + 1.8 + 2.8]	
9.0	Organic Waste Leaving the System	All waste exported from waste collection, including compost to landscaping and exported kitchen and household waste.	SUM of [Compost to Landscaping * DM%] + [Exported kitchen waste * DM%] + [Exported household waste * Organic fraction * DM%]	1, 3,24,25
9.1	Organic waste, composted, to agriculture	All composted waste that is used in domestic agriculture	Compost to ag*DM%	1
9.11	Organic waste to Biogas prod	All food waste used to produce biogas and fertilizer	SUM of [(All Food Waste to Cambi * DM% Uneaten Food)	2,3

9.12	Organic waste incinerated	All organic waste that is incinerated, with or without energy recovery	Mass Balance	Balance
9.14 / NAS 14	Organic waste landfilled	All organic waste that is landfilled, only that which is rejected from biological treatment (composting)	Compost Rejects * uneaten food DM%	3,37
10.1	Manure to Plant Production	Domestic animal manure applied to domestic fields for fertilization	(Manure per animal per year * Animal Population * 1-% grazing off farm))	1, 3, 30,3
10.3	Carcasses, milk, eggs to processing	Living animals, milk and eggs sent from farms to processing	(((Animal Carcasses/Carcass Portion)/Empty body portion) * DM %) + (Milk production * Milk density * DM %) + (Egg Production * DM%)	1, 3
11.1	Fertilzer to ag	Residual biofertilizer remaining from biogas production which is used as compost in domestic agriculture	SUM of all [Fertilizer from Biogas production * DM%]	2
11.12	Biogas-Remainder to Landfill	Residuals from biogas production not suitable for use	Mass balance from biogas production	Balance
12.0	CO2 from combustion	CO2 released during combustion		
12.14	Incin ashes to landfill	Unburnable products from incineration transported to landfill		
13.0	Sludge Leaving System	Sludge remaining from wastewater treatement that is used in greening and other uses outside of the system	Mass Balance	Balance
13.1	WW Sludge to Agriculture	Sludge remaining from wastewater treatement that is used in agriculture	Average DM Wastewater sludge to Agriculture	22
13.11	WW Sludge to Biogas Production	Sludge remaining from wastewater treatement that is used in biogas production	SUM of Plants Capacity	2
16.0	MBM Leaving System	Meat and bone meal used for pet feed, cement additives or other uses outside of the system	SUM of [Average MBM for Pet Feed + Avg MBM Exported + Avg MBM to Cement Ind * DM%]/Norsk Protein Market Share	27, 37

16.1	MBM to Agriculture	Meat and bone meal used for fertilizer in agriculture	[Average MBM to Agriculture * DM%]/Norsk Protein Market Share	27
16.8	Fat to Fodder Production	Residual fat from meat and bone meal production used in fodder production	[Average Animal Fat to Feed * DM%]/Norsk Protein Market Share	3, 27
16.9	MBM Incinerated	Meat and bone meal not fit for other uses is incinerated	[Average MBM incinerated * DM%]	3, 27

*** All energy contents were found from Wirsenius or Matevaretabellen and multiplied by the DM layer.**

1	(SSB- Statistisk Sentralbyrå 2013)
2	(Cambi n.d.)
3	(Wirsenius 2000)
4	(Norwegian Food Compostion Database 2013)
5	(SLF 2012, 2013b)
16	(FAOSTAT 2009)
17	(Hanssen & Olsen 2008)
20	(Møller, Hanne, Vold & Schakenda, Vibeke, Hanssen 2012)
21	(Niras 2004)
22	(Berge & Mellem 2012)
24	(Miljødirektoratet 2013a)
25	(Raadal et al. 2008)
27	(Animalia 2010; Animalia 2011; Animalia 2012)
30	(Nesheim, L., Dønnem, I. & Daugstad 2011)
31	(Karlengen et al. 2012)
37	(Norsk Protein 2010)
39	(Antikainen et al. 2005)
40	(University of Minnesota Extension 2014)

Table 2. Phosphorous Flows and Equations

Flow Number	Flow Name*	Flow Equation (DM)	References
0.1	Inputs to Plant Production	P fert imported + (Compost Imported * P%)	2, 40
0.2	Soybean Imports to Processing	Soybeans Imported * Soybean DM%	4
0.4	Food Imports for Human Consumption	SUM of All [Imported foodstuff * P%] - Fodder Imports	4,39,42, 50
0.8	Imports to Fodder Production	SUM of All [Imported fodder * P%]	4
0.10	Imports to Animal Husbandry	SUM of All*P%	4.43
1.2	Veg, Fruit and Grains to processing	SUM of Grain Production For Humans*P%) + SUM of [Veg or Fruit Production * P%]	4
1.8	Grain to Fodder production	SUM of All [Domestic Grains and Oilseeds to Fodder * P%]	4
1.10	Animals Grazing on Pasture	SUM of All [Green Fodder and Hay * P%]	4,39
2.0	Soy Products Exported	Soybean Imported - Soybean Meal to Fodder [Flow 0.2 - Flow 2.8]	
2.4	Veg and grain products to wholesale	SUM of [Grain to Food * P%] + [Veg + Fruit Production * P%]	4
2.8	Vegetable Processing to fodder production	Domestic Soybean Meal to Animals * P% Soybean Meal	4
3.4	Animal products to wholesale	SUM of [Animals to processing * P %]+ [Milk and Eggs * P%]	4
3.16	Slaughter waste to Meat and Bone Meal Production	[Flow 10.3 - Flow 3.4]	
4.0	Food Exports	SUM of all [Exported Foodstuff * P%]	4, 42, 44,45
4.7	Products sold	SUM of all [Food Supply per capita * capita * P%]	4
4.9	Products rejected, damaged or unsold	SUM of all [Wasted Product at Retail * P%] + [Wasted Product at Wholesale * P%]	4
7.9	Consumption waste	SUM of [Average Organic Household Waste * Wet Organic Waste Portion *P%] + [Organic Service Waste Average * P%]	20,21
7.13	Human waste to WWTP	[Average of (Discharge to Water from WWTP/(1-Treatment Efficiency)])	22,23
8.10	Fodder to Animals	Domestic Fodder + Imported Fodder + Soybean Meal [0.8 + 1.8 + 2.8]	
9.0	Organic Waste Leaving the System	SUM of [Compost to Landscaping * DM% * P% Org HH waste] +([Exported kitchen waste * DM%] + [Exported household waste * Organic fraction * DM%]) * P% Org Service waste	20, 21
9.1	Organic waste, composted, to agriculture	Compost to ag*DM% * P%	20
9.11	Organic waste to Biogas prod	SUM of (All Food Waste to Cambi * DM% Uneaten Food * P%)	20

9.12	Organic waste incinerated	Mass Balance	
9.14	Organic waste landfilled	Compost Rejects * DM% Uneaten Food * P% Org HH Waste	20
10.1	Manure to Plant Production	(Manure per animal per year * Animal Population) * (1-% grazing off farm))	31,48
10.3	Carcasses, milk, eggs to processing	(((Animal Carcasses/Carcass Portion)/Empty body portion) * DM %) + (Milk production * Milk density * DM %) + (Egg Production * DM%)	39,49
11.1	Fertilzer to ag	SUM of all [Fertilizer from Biogas production * DM%]	20
11.12	Biogas- Remainder to Landfill	Mass balance from biogas production	
12.0	CO2 from combustion		
12.14	Incin ashes to landfill		
13.0	Sludge Leaving System	Mass Balance	Balance
13.1	WW Sludge to Agriculture	Average DM Wastewater sludge to Agriculture	50
13.11	WW Sludge to Biogas Production	SUM of Plants Capacity	50
16.0	MBM Leaving System	SUM of [Average MBM for Pet Feed + Avg MBM Exported + Avg MBM to Cement Ind * DM%]/Norsk Protein Market Share	50
16.1	MBM to Agriculture	[Average MBM to Agriculture * DM%]/Norsk Protein Market Share	50
16.8	Fat to Fodder Production	[Average Animal Fat to Feed * DM%]/Norsk Protein Market Share	4
16.9	MBM Incinerated	[Average MBM incinerated * DM%]	50

***Flow Descriptions same as above**

2	(Cambi n.d.)
4	(Norwegian Food Compostion Database 2013)
20	(Møller, Hanne, Vold & Schakenda, Vibeke, Hanssen 2012)
21	(Niras 2004)
22	(Berge & Mellem 2012)
23	(Heinonen-Tanski & van Wijk-Sijbesma 2005)
31	(Karlengen et al. 2012)
39	(Antikainen et al. 2005)
40	(University of Minnesota Extension 2014)
42	(Christensen 2009)
48	(Zublena, et al. 1997)
49	(IFP 2006)
50	(Hamilton et al, in press)

2.3 Process Energy

Process energy is the operational energy needed to perform activities within a process. It was included for select processes to aid in comparing Scenarios 1.1 and 1.2 and further understand the savings potential of reducing production.
Process Energy equations are included in the following table (Table 3).

Table 3. Process Energy Equations and References

Flow #	Flow Name	Flow Description	Flow Equation	Ref.
E-0.1	Process Energy used in Plant Production	Includes the energy content of heating oil and gas used in greenhouses. Also, the generic gasoline and diesel used in agriculture.	Oil in greenhouse + Gas in greenhouse + Gasoline + Diesel	18, 54
E-0.2	Process Energy used in Grain Drying	Includes the energy content of fuel oil used in a grain dryer	Fuel oil used (L) * Heavy Fuel Oil LHV (MJ/L)	18, 52
E-0.3	Process Energy used in Animal Husbandry	Includes electric light and power used in agriculture.	Electricity (nok)/ Price of electricity (nok/kwh) * (MJ/kwh)	18, 53
E-0.10	Process Energy used in Animal Processing	Includes the energy contained in electricity and gas used in slaughterhouses	Tons of animal processed * gas+electricity used per ton * LHV of Natural gas (or MJ/kwh)	18, 55

18 (NILF 2011)
52 (Dukes 2013)
53 (Hafslund 2013)
54 (Murugesan et al. 2009)
55 (FAO 1991)

2.4 Scenario Methodology

The first scenario compared two options for using the residual food resources. In Scenario 1.1, food production and consumption were assumed to be constant but all current food wastes were directed to biogas production. This scenario was meant to simulate narrow thinking and end-of-pipe solutions. Scenario 1.1 directed all food waste from Organic Waste Collection to biogas production.

In Scenario 1.2, domestic food production was optimized to meet consumption needs precisely. In the model, this was achieved by removing avoidable food waste from the flows preceding its point of loss. Unavoidable food waste includes items such as banana peels and coffee grounds that are not commonly eaten. All waste from the food market was considered avoidable but only a portion of waste from human consumption can be prevented. Information from ForMat studies in Norway aided in this disaggregation (Schakenda 2011). The mix of goods was considered to be constant with the normal system and the reduction in production occurs domestically for demonstrative purposes. Changes in flow values can be seen in the following tables Table 9, Table 10 and Table 11, in the Appendix. Transfer coefficients are also located in the Appendix, in Table 18 with the process energy coefficients in Table 19.

Steps:

- Calculate avoidable food waste from Human Consumption
- Subtract avoidable food waste from Flow 4.7
- Flow 4.9 becomes zero
- Subtract former Food Market waste from Flows 2.4 and 3.4 based on their respective percentage of domestic supply
- Apply transfer coefficients to calculate other values.

Scenario 2 is an extreme example of optimizing for energy by diverting all residual resources to energy production. Residual resources are generally by-products or “waste” that still holds value such as nutrients and/or energy. In this scenario all harvest residues, production waste, collectible manure, sewage sludge and organic waste went to Biogas Production. Fertilizer was imported to cover phosphorous needs if necessary.

3 Results

3.1 Baseline Model

3.1.1 Dry Matter Results

Dry matter results are only included for the baseline scenario, to serve as a comprehensible introduction to the results. They will not be addressed in the scenario results. The scenario dry matter flow diagrams can be found in the Appendix, Figure 12, Figure 15 and Figure 16, with the affected flows marked in color and the unchanged flows remaining black. All flow tables from all scenarios are also attached in the Appendix with the same color system.

The flow diagram for the baseline can be seen in Figure 2 below. The width of the flows indicates their size and can be used to compare and quickly determine significance. The value of the flow is noted in kilotons (kT). The large (2,100 kT) import flow entering Domestic Plant Production is Net Primary Productivity, which will be addressed in Section 4.1.1. It is one of the largest flows in the system and serves to balance the Plant Production process on the dry matter and energy layers.

In the dry matter layer the largest flows revolve around feeding animals. This includes animals grazing, fodder to animals and grain for fodder with values of 2,400, 1,500 and 910 KT respectively. Animal husbandry has a mass balance inconsistency of 82%. In other words, inputs to Animal Husbandry exceed outputs by approximately 2,350,000 dry tons and this is not considered as an addition to stock. The Animal Husbandry process itself is 10% efficient in production of animals, eggs and milk. However, when Animal Processing is included, only 8% of the inputs emerge as marketable animal products for the domestic market.

The next largest flows relate to feeding humans directly, through Food Imports and the Food flowing to human consumption with values of 1,600 and 1,500 kT respectively. The Food Market process does not balance, with inputs exceeding outputs by 23%, or 448,000 dry tons. Domestic production accounts for only 26% of food inputs to the market. The largest mass balance inconsistency occurs in Food Consumption where the food entering the process exceeds outputs by 129% or 1.2 million dry tons. Uncertainties regarding the dry matter system are visualized in Figure 4 and discussed in Section 4.1.1.

Other mass balance inconsistencies exist in MBM Production and Incineration. Incineration does not balance (on any layer) due to the lack of quantified outputs or addition to stock. The overall efficiency of the dry matter system is 37%. Overall efficiency was calculated by taking useful food flows ie. Food to Consumption and Food Exports (Flow 4.7 + Flow 4.0) and dividing the sum by all inputs into the system, such as imports of food, fodder, etc. Losses from the system include waste flows to Incineration and outflows from the system, but are relatively small.

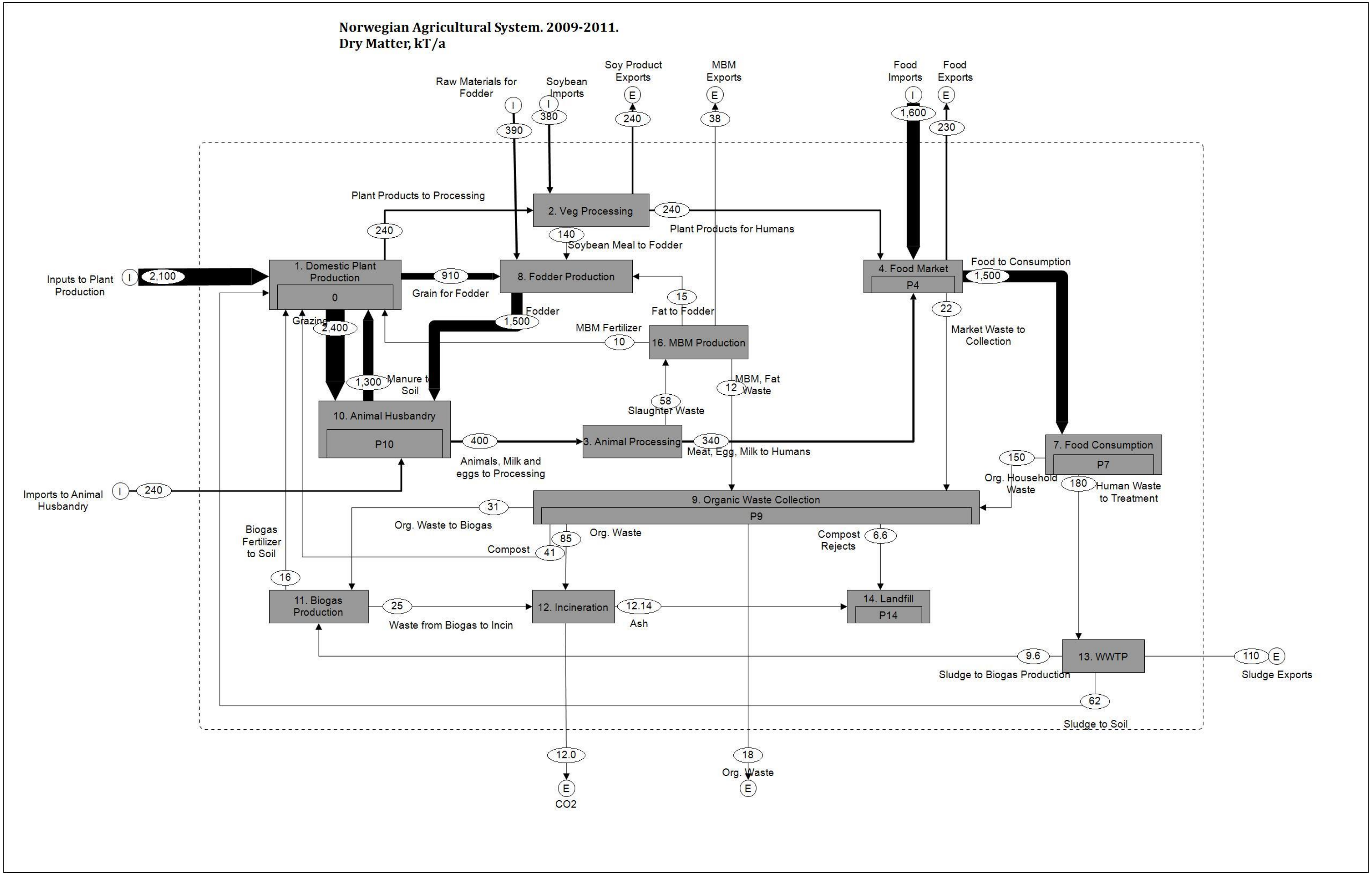

Figure 2. Sankey Diagram of Base Model Dry Matter Flows

3.1.2 Phosphorous Layer Results

The phosphorous flow diagram for the baseline can be seen in Figure 3 below. The Phosphorous layer is dominated by large flows around Animal Husbandry, relating to the consumption of fodder (7683 tons of P) and the outputs of manure and edible animal products with values of 13,306 and 4838 tons of P respectively. The imports of P fertilizer to Domestic Plant Production is a large input at 7987 tons of P and Food to Consumption is the second largest flow (after Manure to Soil) at 9,875 tons of P. In terms of phosphorous, Domestic Plant Production is 53% efficient, meaning that only half of the P entering the process is contained in usable outputs, in this case; pastures, grain, vegetables and fruits. There is a net addition to stock of 12,269 tons of P each year, which accumulates in the soil and a mass balance inconsistency of 6%, with outputs exceeding inputs. The inconsistency means that 1500 tons of P is unaccounted for as inputs to Plant Production. Animal husbandry in comparison is only 34% efficient, with the animals, eggs and milk containing around one third of the phosphorous of the inputs. When Animal Processing is included, efficiency drops even further to 15%. Animal Husbandry does not balance and the discrepancy is 25%, with outputs exceeding inputs by over 4,000 tons of P.

The Food Market does not balance, as in the DM layer, by a large margin. The imbalance is 31% with a deficit of over 3000 tons of P. In Human Consumption, the P discrepancy is 73% or 5,277 tons of P. The uncertainties in the phosphorous system are visualized by colored flows in Figure 5 below and discussed in Section 4.1.2. Incineration does not balance due to the lack of quantified outputs and MBM Production has a minute (1%) mass balance inconsistency.

The system in its entirety is 36% efficient in terms of the P contained in the food that actually reaches human consumption (and food exported) compared to all inputs to the system. The largest losses of phosphorous are the flows to Incineration, Organic waste from Collection and Waste from Biogas Production. In the baseline model, there is a loss of 2407 tons of P to Incineration and no current routes of recovery from that process. P contained in Compost Rejects placed in Landfill is also lost. Another important source of loss from the domestic system is waste streams that are exported, such as MBM, Organic Waste from Collection and Sludge from WWTP which together constitute another 3791 tons of phosphorous leaving the Norwegian nutrient cycle.

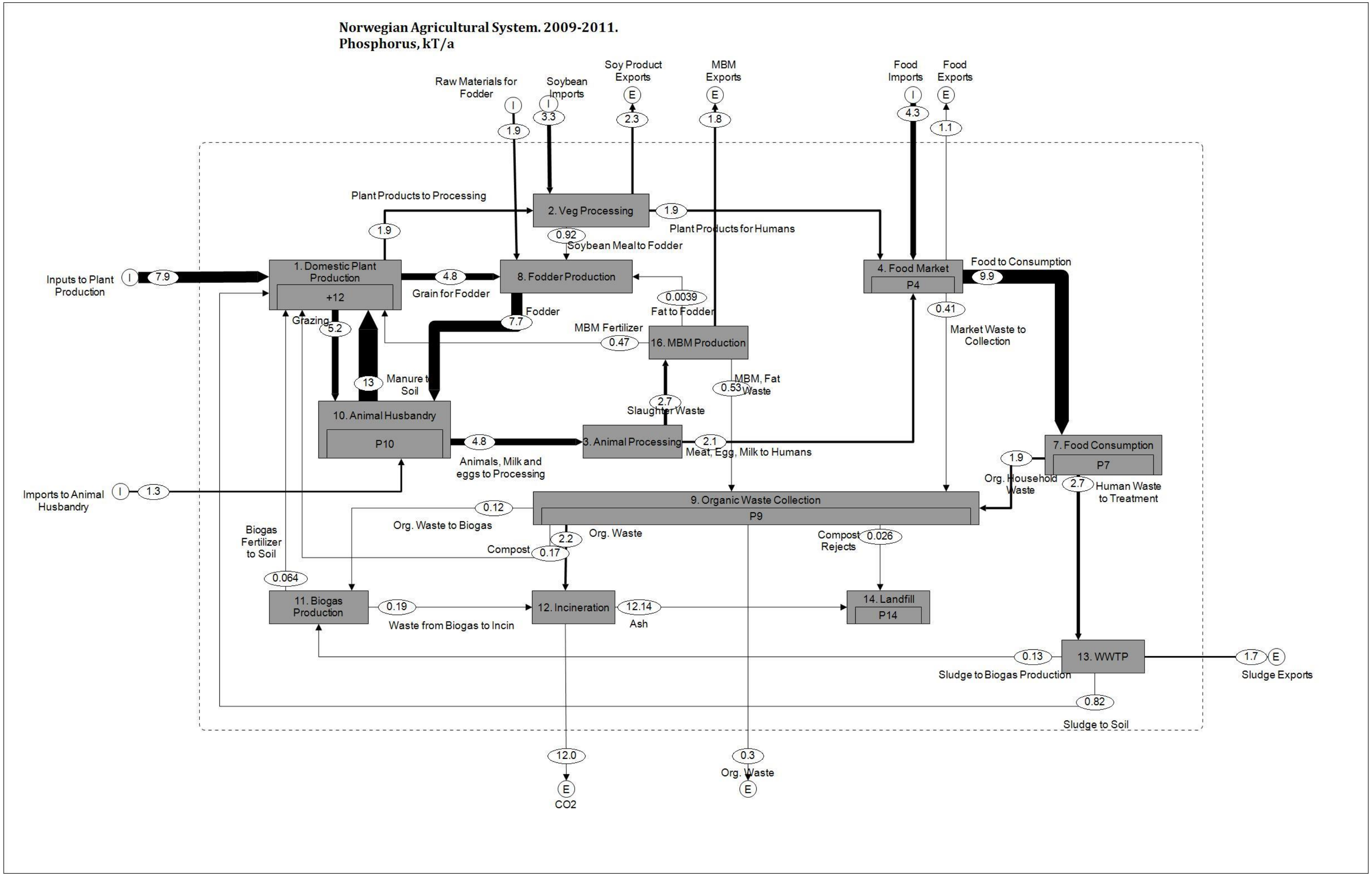

Figure 3. Sankey Diagram of Base Model P Flows

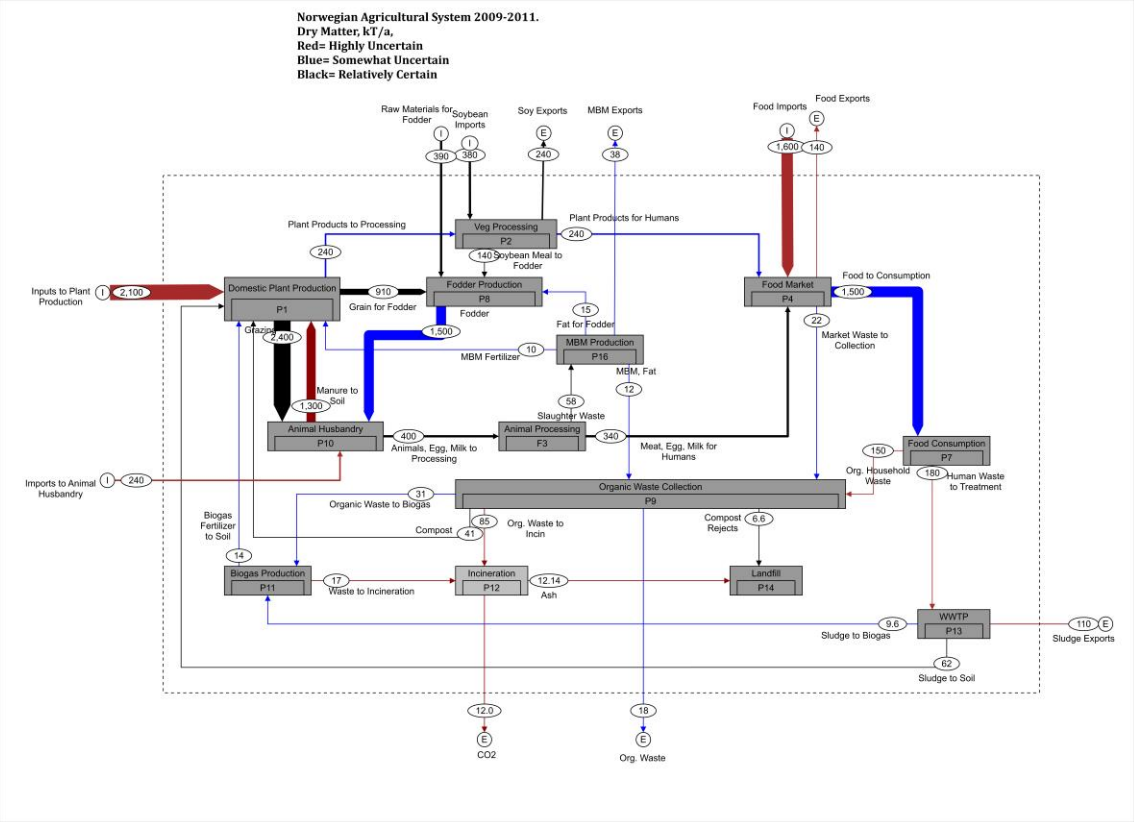

Figure 4. Dry Matter Uncertainty.

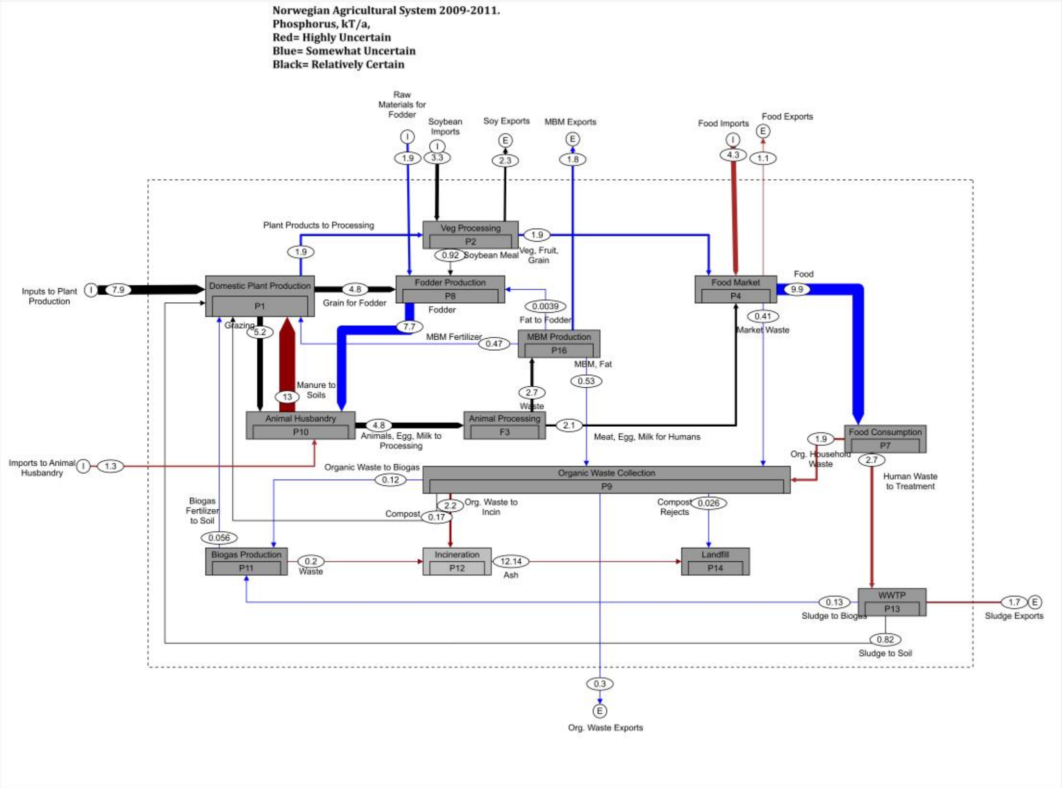

Figure 5. Phosphorous Uncertainty.

Energy Layer Results

The flows around Animal Husbandry are also dominant in the Energy layer. The relative magnitude of flows is evident in the energy flow diagram in Figure 6. Units in the figure are petajoules (PJ), which equals one quadrillion (10^{15}) joules. It is notable that a large portion (58%) of the energy intake of animals is emitted as heat, which cannot be collected or used. Energy analysis differs from phosphorous analysis in that energy is destined to dissipate, but preferably after it has performed useful work, in this case to maintain human bodies. Nearly all of the energy that reaches humans is lost as respiratory heat as well, but it has performed useful work and is therefore not considered a loss in the same way.

A very large flow (40 PJ) that is unique to the energy layer results from the decomposition of harvest residues that are left on the fields. Plant production is balanced and 57% efficient. The animals and products emerging from Animal Husbandry contain only 13% of the energy inputs and after processing, only 11%. The Animal Husbandry process is balanced by the outflow of respiratory heat, as is Food Consumption by humans.

The Food Market is 90% efficient in energy, though there is a 10% energy balance discrepancy, with inputs exceeding outputs and no quantified addition to stock. There is a similar discrepancy of 10% in MBM Production. The flow from Biogas Production to Incineration, as calculated by mass balance, results in a negative flow. Uncertainties regarding energy flows are visualized in Figure 7 and covered in the Discussion section. Overall efficiency of the system is 29% in terms of biomass energy and 27% if process energy is included. The largest losses of energy are Respiratory Heat loss from animals and humans and also the decomposition of Harvest Residues. Outflows of waste streams are quite small. Organic Waste from Collection to Incineration contains a significant amount of energy, though it is an order of magnitude smaller than the largest flows. Process energy is quantified for several processes and is immediately matched by a waste heat flow, with no energy becoming absorbed into the system. The largest process energy flow enters Plant Production and is a level of magnitude smaller than the biomass energy inputs.

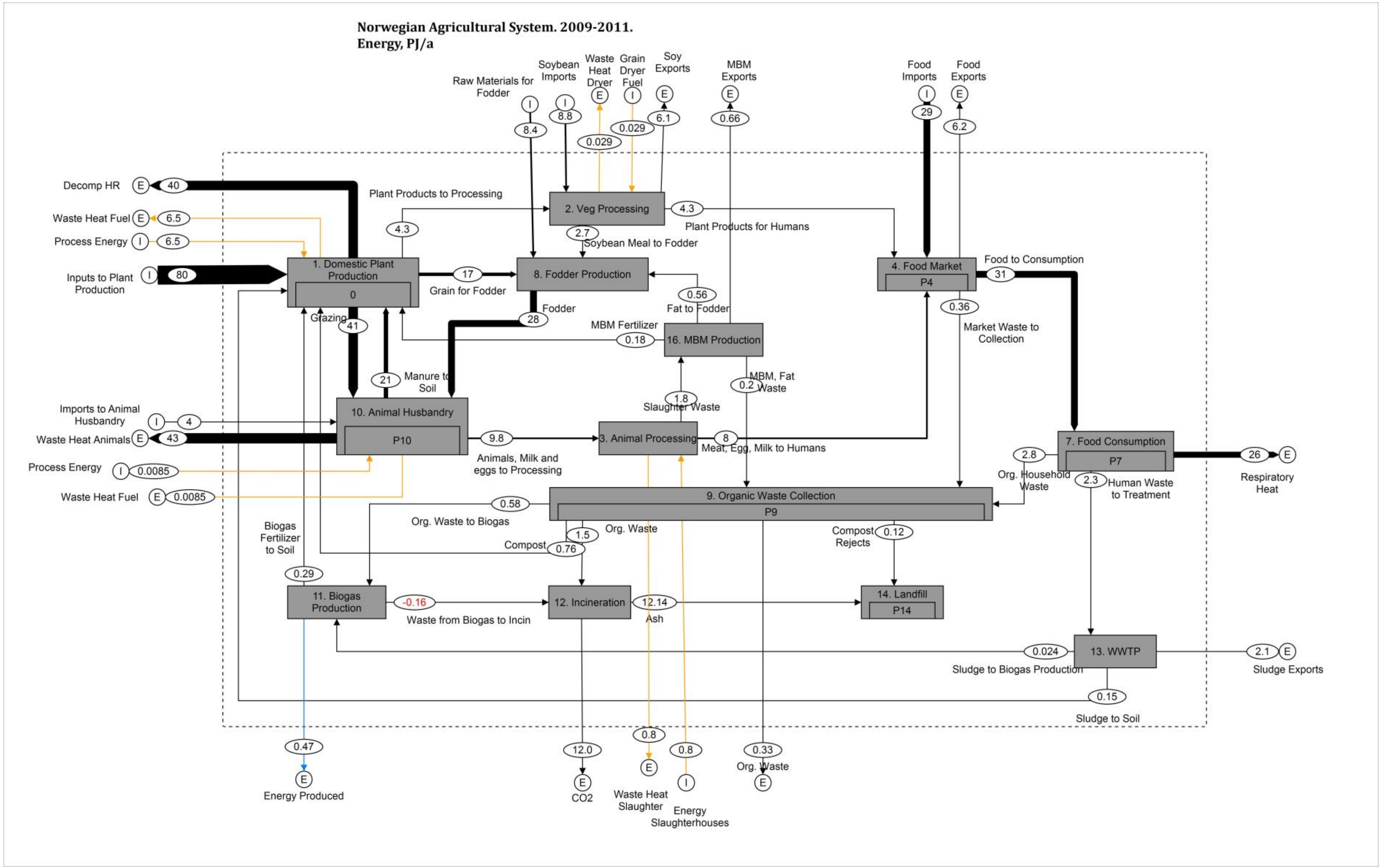

Figure 6. Sankey Diagram of Base Model Energy Flows

3.1.3 Comparison of Phosphorous and Energy Systems

The multi-layered MFA structure allows for a comparison of different levels through the use of a common system definition. The most important flows to compare are those waste flows that could be considered underutilized, for example manure, harvest residues, food waste and sewage sludge. Manure, WWTP sludge and MBM flows are relatively poor when it comes to energy content, but significant in terms of P. Harvest residues are not visible in the P layer, as they remain inside the process, but they represent a significant loss in the energy layer.

In the energy system, inputs to the Plant Production (NPP/solar energy) represent the largest flow by a considerable measure, nearly doubling the next largest flow. In contrast, the same flow in the P system (Inputs to Plant Production) is merely the third largest flow, after Manure to Soil and Food to Consumption, and followed closely by Fodder to Animals. In the P system, losses are of the same magnitude as the largest flows, whereas in the Energy system, they are at least one magnitude smaller.

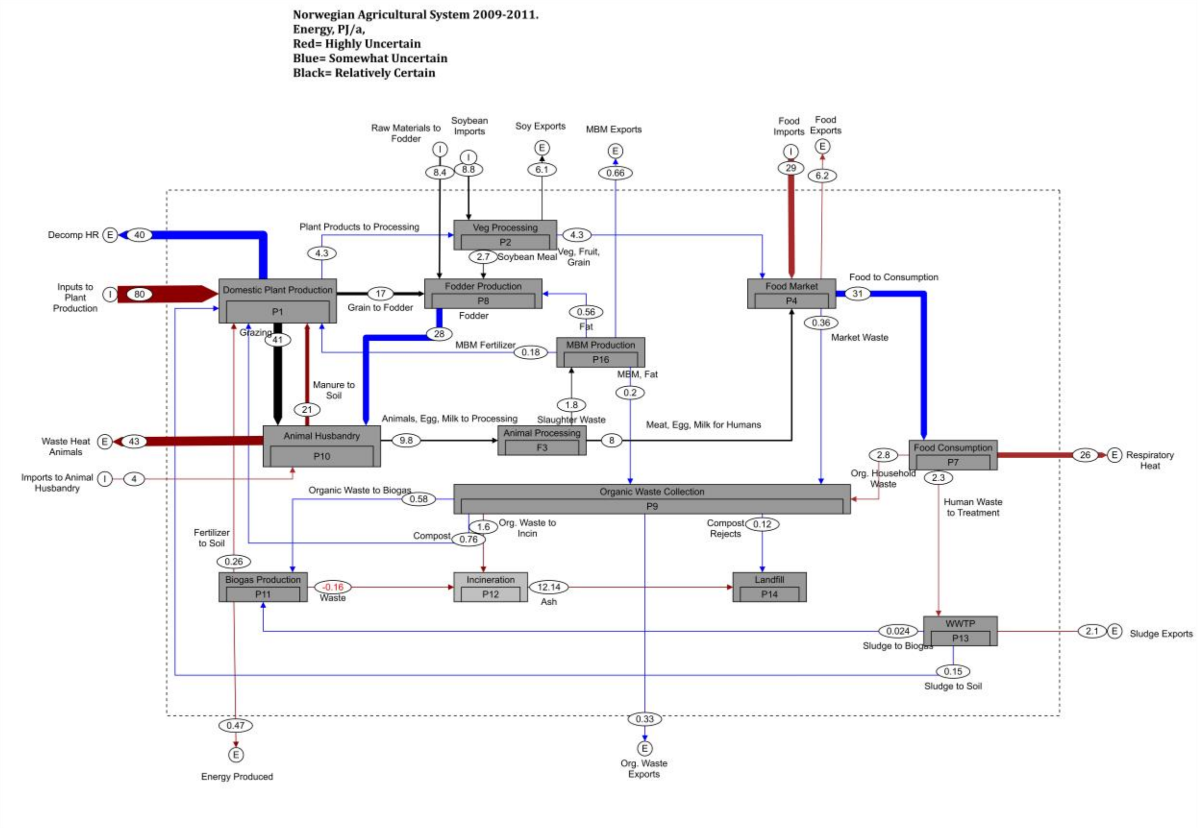

Figure 7. Energy Flows Uncertainty

3.2 Scenario 1.1. Redirection of Food Waste to Biogas Production

3.2.1 Phosphorous Layer Results 1.1

The DM and P flow diagrams for Scenario 1.1 can be found in Figure 12 and Figure 13, respectively with the changed flows highlighted through an adjustment of the flow color. Also, Table 9, Table 10 and Table 11 are attached in *Appendix 1* and list all flows for all scenarios. The changes instituted in this scenario primarily affected the flows surrounding Biogas Production. Compost production was removed but fertilizer from biogas production increased by 692 tons of P. There was no mass balance inconsistency in the Domestic Plant Production in the scenarios (compared to 1500 tons in the baseline model). P fertilizer imports increased by 974 tons of P but NAS remains constant. The efficiency of Plant Production dropped to 49%. Other inconsistencies and efficiencies remained constant with the baseline model. The previous loss of Organic Waste being exported from Waste Collection was eliminated in this scenario but Sludge Exports remained. The loss to Incineration was reduced by 173 tons of P.

3.2.2 Energy Layer Results 1.1

The energy flow diagram for this scenario is found in Figure 14 in the Appendix with changed flows marked in color. Although all outflows from Biogas Production increased by nearly fivefold, these flows remain small relative to the other flows. Due to the additional inputs, 2.13 PJ of additional energy was produced in the Biogas Production process. However, the discrepancy in Biogas Production increased fivefold as well, and there is a deficit of 0.89 PJ, resulting in a negative flow to Incineration. Process energy flows remained the same due to a constant level of production and a lack of quantified energy use in Biogas Production.

3.3 Scenario 1.2. Upstream Prevention of Food Waste

3.3.1 Phosphorous Layer Results 1.2

The dry matter flows diagram for Scenario 1.2 can be found in Figure 15 in *Appendix 2.* The phosphorous diagram is found below in Figure 8 with changes from the baseline marked in color. Nearly all flows were affected by the changes in this scenario, stemming from a 10% flow reduction from the Food Market to Food Consumption. This resulted in a 35% reduction in both of the domestic product flows (Flows 2.4 and 3.4). Plant production is balanced and only 48% efficient. Outputs decreased by 4216 tons of P and internal inputs reduced by 4851 tons of P. Imports of phosphorous fertilizer were reduced by 20% or 1,800 tons of P and NAS in Plant Production decreased by 4,037 tons of P.

Flows around Animal Husbandry decreased due to a smaller demand for products. Imports of Raw Materials for Fodder reduced by 675 tons of P, Fodder by 2,710 tons of P and Grazing by 1,826 tons P. The mass balance inconsistency in Animal Husbandry is also reduced. Overall efficiency of the P system increased from 36% to 42%. Losses remain with the flows to Incineration (1,103 tons P) but that is a decrease of 1,304 tons over the baseline scenario. Exports from Organic Waste Collection and MBM Production decreased as well.

3.3.2 Energy Layer Results 1.2

The energy flow diagram is shown below in Figure 9 with changes marked by color. The majority of flows were affected but the changes are smaller than in the P system. The driving change to the Consumption flow is 5% and the domestic production of plant and animal products is reduced by 16%. Biogas production remained the same, with 82% less organic waste going to incineration. The negative flow from Biogas Production was equal to the baseline model.

Overall efficiency of the system increased from 29% to 31%, though all other efficiencies remained constant from the baseline. All process energy flows were reduced, resulting in energy savings of 1.16 PJ as shown below in Table 4. Losses remain in Organic Waste to Incineration, Exported Sludge and Exported MBM.

Table 4. Process Energy Saved in Scenario 1.2

Process Energy Saved	kJ
0.1	1.03E+12
0.2	4.59E+09
0.3	1.26E+11
0.10	1.34E+09
Total Process Energy Saved	**1.16E+12**

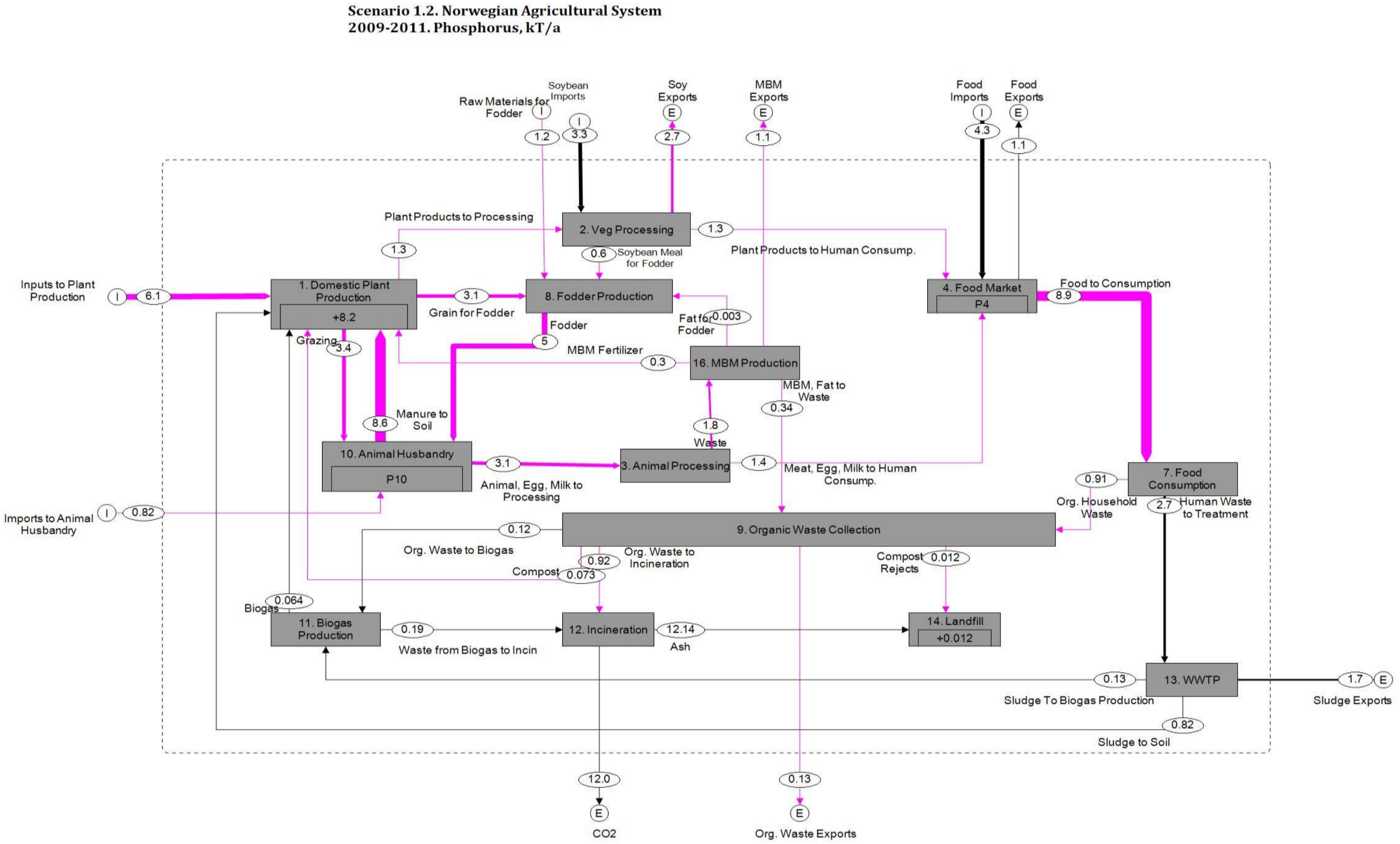

Figure 8. Scenario 1.2. Phosphorous Flows

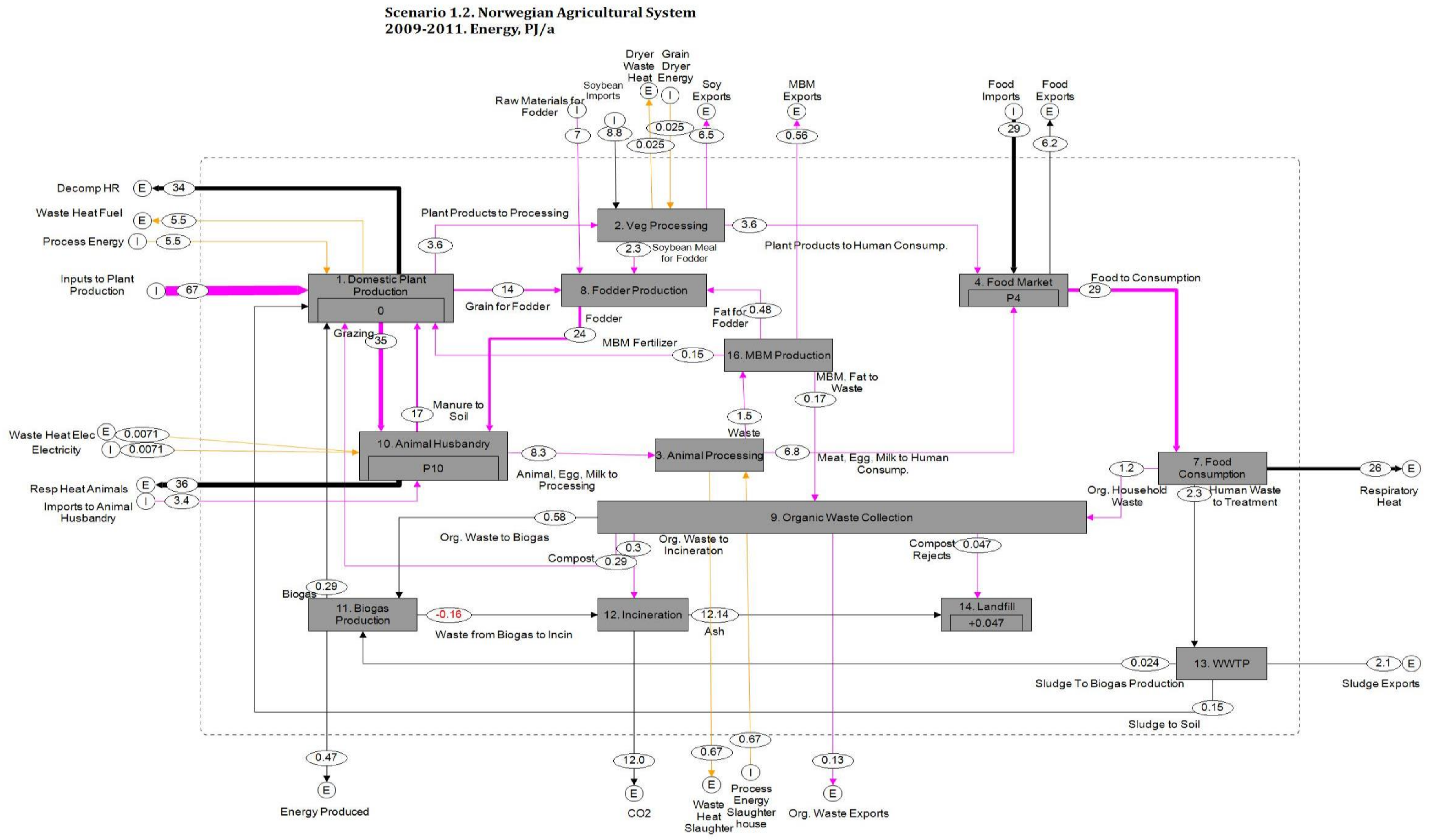

Figure 9. Scenario 1.2. Energy Flows.

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3.4 Scenario 2. Extreme Energy Prioritization

3.4.1 Phosphorous Layer Results 2

The flow diagram relating to these results is shown below in Figure 10 with changes marked in color. There are three unique flows into Biogas Production, from Plant Production, Animal Processing and Animal Husbandry. This scenario shows the value of harvest residues, which were hidden in the other scenarios. The Plant Production process was balanced against the loss of harvest residues by an increase in phosphorous fertilizer imports of 18%, or 1,444 tons of P. The NAS in soils dropped to zero and Plant Production efficiency increased to 72%. Animal husbandry remained unchanged from the baseline, though collected manure was redirected to Biogas Production. Overall efficiency of the system rose to 55%. There was one very large loss of Biogas Waste going to Incineration, which is 15,517 tons of P. It is by far the largest loss in any scenario.

3.4.2 Energy Layer Results 2

The flow diagram relating to these results is shown below in Figure 11 with changes marked in color. The most significant change was the increase in Biogas Production, an increase of 48.5 PJ over the baseline model. However, the energy balance discrepancy from Biogas Production is now 16 PJ. Process efficiencies remained constant with the base, with the exception of overall efficiency at 31%. Process energy did not change due to the constant production. Table 5 below gives a simple comparison of total flow values for select flows between the base and scenarios.

Table 5. Scenario Comparison

Scenario	**P Fertilizer Tons P**	**P to Incin Tons P**	**NAS P tons**	**Δ Energy Production PJ**	**Δ Process Energy PJ**
Base	7897	2407	12269	-	-
1.1	8871	2233	12269	2.13	-
1.2	6095	1103	8232	-	-1.16
2	9341	15705	0	48.5	-

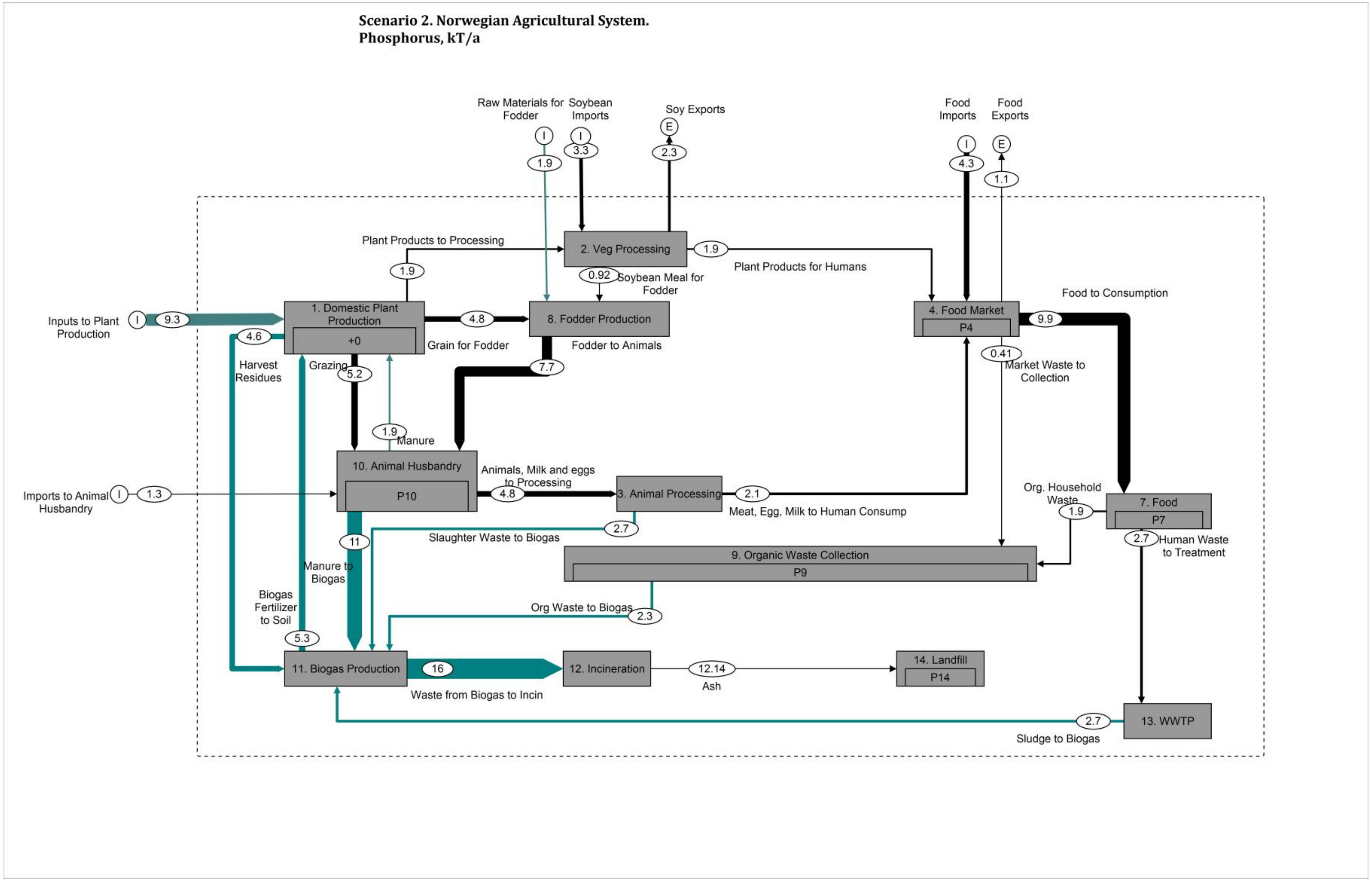

Figure 10. Scenario 2. Phosphorous Flows

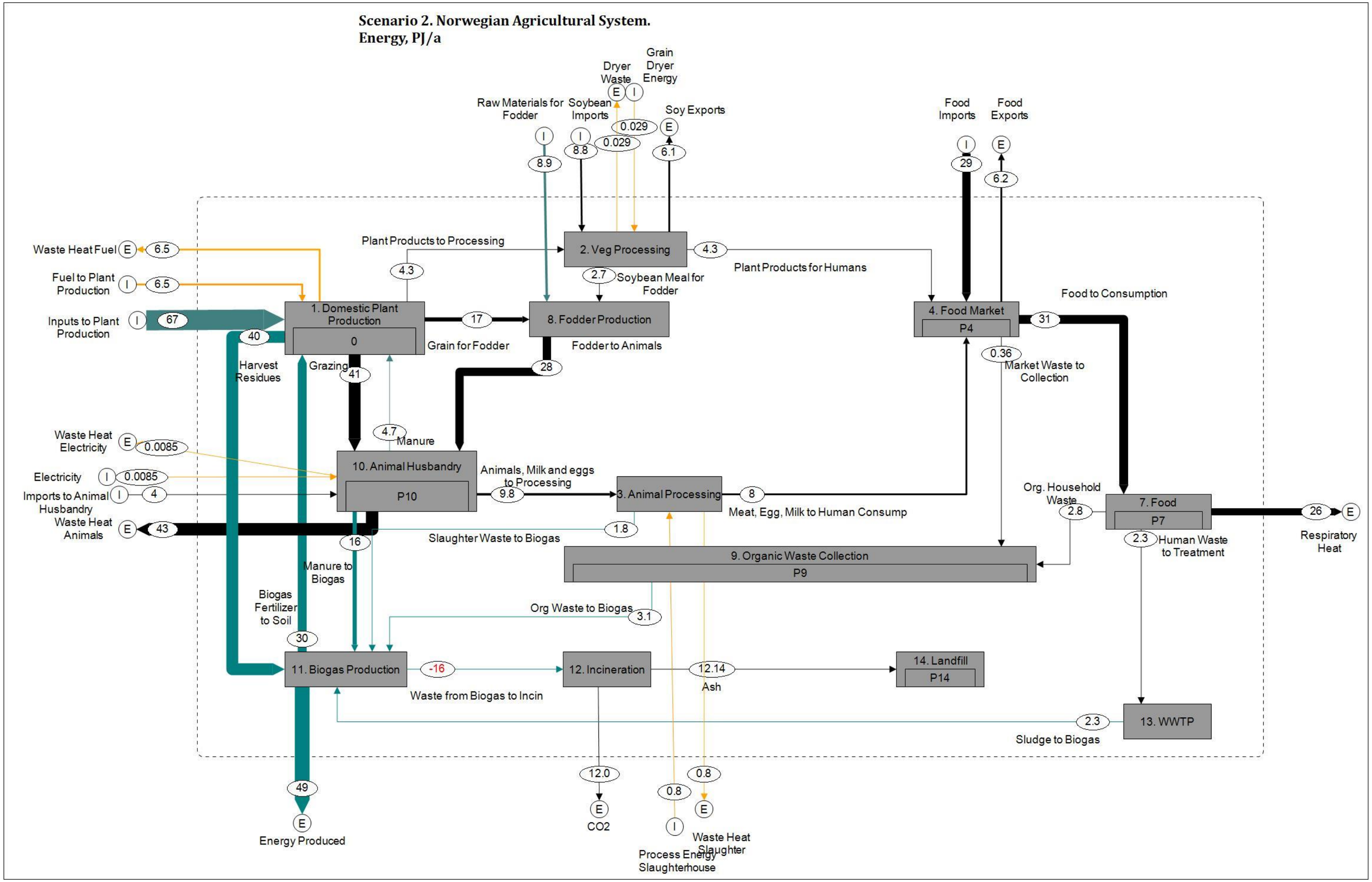

Figure 11. Scenario 2. Energy Flows.

4 Discussion

4.1 Base Model

The baseline model was created in order to answer the following research questions:

Q1 -What are the magnitudes of flows in the agricultural system?

Q2-Where are key points of loss for energy and/or P and what are the magnitudes of these?

Q3-Where in the agricultural system could energy potential and nutrient recovery be simultaneously realized?

The following section will discuss how well the baseline model can address these questions and also preliminary answers found in each layer.

A general consideration to be taken into account during analysis and comparison is that mass or energy balance inconsistencies affect listed efficiencies and are therefore listed as well. Imbalances occurring in the Food Market and Food Consumption processes on different layers make it difficult to regard the system as a whole and make reliable interpretations. In that manner the domestic production system is still somewhat separate from Food Consumption and the waste treatment system, making it difficult to analyze the flow of matter, energy or phosphorous through the whole system. Uncertainties were not quantified, rather all flows are rated Relatively Certain, Moderately Uncertain or Highly Uncertain in Table 7 below, based on the author's knowledge of parameter reliability. Uncertainties are also visualized in the Results section in Figure 4, Figure 5 and Figure 7 for DM, P and Energy respectively.

4.1.1 Base Model Dry Matter Layer

The very large in-flows into Domestic Plant Production in the DM and Energy layers are due to the natural phenomena generally referred to as Net Primary Production (NPP). NPP is the rate at which an ecosystem accumulates energy or biomass, for example the use of carbon dioxide in photosynthesis to sustain plant growth. This natural contribution exceeds the human applied inputs to plant production.

Inflows to Animal husbandry exceed outflows of meat, milk and eggs by over 80%. These flows are considered to be moderately certain and verifiable, so the reason for this discrepancy is unknown. The growth of animals that were not slaughtered during this time period could only contribute to the explanation if the amount of livestock were increasing; otherwise animals grown before the current models timespan should balance this. In addition, SSB information included some large imports to livestock feed that were not represented in the SLF data, so a direct import flow into Animal Husbandry was created. It is unclear whether this is representative of the situation in reality.

The imbalance in the Food Market, where inputs exceed outputs, may simply be Market Waste to Collection that is unaccounted for in other data, though this imbalance is not consistent through the layers. The amount of food wasted from the Food Market is considerably smaller than expected. Reliable sources for this flow were difficult to find, as retailers do not often advertise this information and SSB does not collect it. The data used relates to one study over a short time of NorgesGruppen (Hanssen & Olsen 2008). Significant assumptions were made to use this data on a national level. The first is the assumption that the retail outlets studied are representative of all NorgesGruppen outlets, and the other is that the other umbrella chains have similar waste patterns.

An alternative explanation for the discrepancy in the Food Market could relate to the uncertainty around using differing sources to determine Food to Consumption (FAO, 2009) and Food Imports (SSB, 2013). The values used for Food to Consumption were defined as the *food supply quantity*, after processing and not including fodder and seeds to agriculture. This may overestimate the amount of food that realistically flows from the Food Market to Human Consumption. Another source was evaluated for use, the SSB Table 10249 Quantities of food and beverages consumed per person per year, but it included only food consumed in the household and not in restaurants and other food service establishments, therefore severely underestimating food consumption.

Regarding the data on Norwegian production, imports and exports, some sources did not agree. Information was checked at SSB, SLF, FAOStat and the UN Commodity Trade Database. At times, sources differed considerably, but values that were similar between sources were most often used. Imports of food were taken from partially aggregated SSB import data (SSB- Statistisk Sentralbyrå 2013). The data was prepared by Hamilton et al (in press) for the construction of the Norwegian Phosphorous model. The uncertainty associated with this flow relates to some discrepancies in comparison to the FAO's Food Balance Sheet for Norway. The SSB data was maintained because it is closer to the source and therefore assumed to be more accurate. There is also uncertainty associated with assigning dry matter percentages to highly aggregate categories such as Vegetable Products or Meat Products.

In Human Consumption, dry matter inflows exceed outflows by around 130%. Also, P inflows exceeded P outflows by 73%. However, the flow representing human excrements is highly uncertain, so caution should be taken when interpreting this discrepancy, it could be due to limited data availability. The dry matter flow of Human Waste to Treatment (Flow 7.13) was derived from the P layer, so this will be discussed below in the phosphorous discussion.

4.1.2 Base Model Phosphorous Layer

The P layer can be compared with the work of Hamilton et al. (in press) as the authors have compiled a P model of the Norwegian system, including agriculture, fisheries and aquaculture. In terms of Domestic Plant Production, mineral fertilizer imports are comparable, and Hamilton et al. have a significant Organic Fertilizer flow in addition, 2,500 tons of P at time of writing, which is not matched in the current study. Referring to outputs from Plant Production, differences are insignificant aside from the current model indicating a smaller amount of grazing (2600 ton of P difference) and a larger amount of plant products to humans (1000 ton of P difference). The difference in human consumption of plant products may relate to some uncertainty in the data on domestic grain used in Norway. Statens Landbrukforvaltning (SLF) published three documents of relevance:

-Raw Materials used for Fodder, detailing use of domestic grain for animal consumption. (SLF 2010-2012)
-Grain to Food, indicating human consumption. (SLF 2013a)
-Total Grain Production in Norway. (SLF 2013b)

However, when summed, the disaggregated grain use significantly exceeds the published figures for overall production. SLF was contacted regarding this but did not reply, so the disaggregated numbers were used with the understanding that they may represent an overestimation. A different choice may explain the discrepancy between the current model and Hamilton et al.

The net addition to stock in Plant Production is comparable between the two studies and the current model lacking a flow indicating P runoff from soils can explain the slight discrepancy. The Hamilton et al model values this flow at 1200 tons of P and it should be included in further work on the current multi layered model. The phosphorous accumulation in Plant Production is an important result but must be interpreted with caution. The understanding of P stocks in soil is very limited and the current model does not distinguish between different types of P such as, soluble, insoluble and plant available. The plant availability of the P in different sources differs significantly and affects farmer decision-making regarding fertilizer (Hamilton et al, in press). For example, due to chemical precipitation, the phosphorous contained in sewage sludge is highly unavailable for absorption by plants. This is only part of the reason that P is accumulating in Norwegian soils. There is also a spatial dimension to manure availability and demand that leads to a deficit in some areas of the country, and a surplus in others (Hanserud et al, in preparation). The model put forth in this paper does not include the spatial resolution to discuss this, nor does it include practicalities such as transportation, which is an important factor when discussing manure use due to its high moisture content, and therefore weight. The assumptions used to calculate the net addition to stock in each scenario are based on few studies and the preliminary results of this model itself, and are therefore highly uncertain.

The mass balance inconsistency around the Food Market process was discussed in the dry matter layer above, where inputs exceeded outputs. In the P layer, however, the opposite is true and outputs exceed inputs. The Food Imports flow appears very low, though it is comparable with Hamilton et al, with the current model using 4300 tons P, and Hamilton et al. 4900 tons P. The discrepancy is over 3000 tons P so this difference does not explain it. Due to the fact that the discrepancy is incongruent with the dry matter layer, it is possible that either the dry matter percentages or the phosphorous contents used are erroneous. An unexpected variation exists between the two models in Food Exports flow, which is more than twice as large in the current model than in Hamilton et al. This could be a matter of system boundaries and differing choices regarding significance of certain products.

It was noted in the DM Results that domestic sources account for a mere 26% of food consumption in Norway, though it does not include domestic fish. Therefore Norway is highly dependent, not simply on imports of P fertilizer into Norway, but also on P fertilizer used in the countries that are growing the imported food. In the P layer the domestic supply percentage is around 41%, but that number is less informative because the majority of that P comes from imports in the first place. This high dependency on other regions is indicative of a nation with low food security.

The large mass balance inconsistency found in Food Consumption is also present in the Hamilton et al. model. This is not unexpected because the outflow of Human Waste was calculated in the same manner. The flow into WWTP (Flow 7.13) was calculated backwards from the outflow of the plants, using WWTP efficiency. The content of P in wastewater was known, along with the efficiency of wastewater treatment plants in removing phosphorous from waste (Berge & Mellem 2012). These variables were used to estimate the amount of P entering the wastewater treatment plants, that being Human Waste to Treatment. This value should be compared to averages on waste output per capita, though it proved difficult to find reliable sources for this information. Given the limited impact of this flow on the results, the Hanserud method above was retained.

There are different types of losses from the system, namely exports and incineration. P leaves the system entirely through exports of food, organic waste from collection, sludge and MBM. The P may go on to cycle through another system, but it has been removed from the Norwegian Agricultural System and is therefore considered a loss.
The more interesting loss is the nutrients that are contained in organic waste that is incinerated. Whether or not the heat destroys the P, it is mixed with many other elements and generally removed from the P cycle long term. The flows to Incineration are calculated by mass balance since the waste statistics do not disaggregate adequately to show organic material incinerated.

4.1.3 Base Model Energy Layer

The energy system can be roughly compared with Wirsenius (2003), who applied MFA to examine the biomass metabolism of the global food system. He completed a global flow analysis in terms of energy and evaluated various efficiencies. The report was very detailed related to products and by-products but aggregated on a regional level, dividing the world into only eight regions. The broad regional definition means that the results cannot be directly applied to the situation in Norway, due to the differing nature of agriculture and food systems in each country. Also, Wirsenius focused on energy and did not mention nutrients such as Phosphorous, which limits to use of his model as a tool to inform holistic agricultural policies but allows for simple efficiency comparisons.

Table 6. Energy System Comparison with Wirsenius

	Current Model	Wirsenius 2003*
Manure	0.28	0.37
Animal Waste heat	0.58	0.50
Food from Animals	0.11	0.09
Resp Heat from Humans	0.90	0.89
Feces/Urine	0.05	0.11
Uneaten Food	0.07	0.41

* Values for West Europe

Wirsenius did not include NPP is his model, he simply began with the Cropland and Permanent Grassland processes which receive no energy inputs. NPP is not useful as a leverage point to improve the energy system, but it is interesting to observe the magnitude of energy that is absorbed into biomass. Respiratory heat from Animal Husbandry is somewhat higher than in the Wirsenius study, which may indicate an underestimation in another output, such as manure. This is supported by the manure differences seen in Table 6. Animal waste heat is a biological fact and though that cannot be changed, it should serve as reasoning to encourage lower meat consumption for a more efficient system.

In regards to uneaten food, the current multi layer model severely underestimates the amount, at least in energy terms, as compared to Wirsenius's Western European values. This correlates with other studies of food waste (Gjerris & Gaiani 2013; Gustavsson et al 2011) however, data is not yet available on the magnitude or source of these waste flows in Norway. There are Norwegian initiatives pursuing this information, such as the CYCLE Project and ForMat (Cycle Project 2014; O. J. Hanssen & Møller 2013). More information on these research programs is attached in Appendices 6 and 7.

The Wirsenius model does not extend beyond Food Intake so there can be no comparison of Waste and Waste to Energy processes. In the current model, there is negative flow resulting from energy balance calculations in the Biogas Production process. The energy produced (Flow 11.0) is considered to be in the correct range based on production information from Cambi stating a producton of 103-105m^3 of biogas per wet ton of input and fertilizer comprising 40-46% of input (Sargalski 2008). The energy balance deficit may relate to an overestimation of the energy content applied to Biogas Fertilizer to Soil (Flow 11.1). The value used was 18.5 kJ/g DM and was the gross energy higher heating value for uneaten food (Wirsenius 2003), as the energy content of this fertilizer was not available.

In general, the energy flows through the system as expected, with a small proportion reaching consumption and large losses in Animal Husbandry. The energy layer is incomplete without data on energy production through incineration of biological waste, but that information was not available. The flows into the Incineration process are measured in potential energy, so it is not possible to assume energy production without knowledge and data on incinerator efficiency.

4.1.4 Comparison Between Phosphorous and Energy Layers

In the P layer the aim is to minimize the inputs into Plant Production because it represents a dependence on both a non-renewable resource and the countries that produce it. However in the energy layer, the same flow (Flow 0.1) represents the magnitude of energy that plants absorb and therefore make available for use by humans.

Mass balance inconsistencies that do not match between layers are also interesting to investigate further, such as the Food Market, Animal Husbandry and MBM Production. In the Food Market, inputs exceeded outputs by 23% in DM and 10% in energy, but outputs exceeded inputs by 31% in the P layer. Animal Husbandry dry matter inputs exceed outputs by 82%, the process balances on the energy layer and outflows exceed inflows by 25% in terms of P. Similar differences can be seen in MBM Production. These variances could indicate problems with the dry matter, energy or phosphorous contents applied to the base data.

Table 7. Table of Uncertainties

1- Relatively Certain **2- Moderately Uncertain** **3- Highly Uncertain**

	Dry Matter		**P**		**Energy**	
	Rating	Reason	Rating	Reason	Rating	Reason
0.1	3	Mass Balance	**1**	**Direct Data from fertilizer company**	3	Energy Balance
0.2	1	Direct Data from company. Matches with FBS.	1	Good data on P content	1	Good data on Energy Content
0.4	3	Fish import significantly lower than FBS.	3	Based on DM numbers	3	Based on DM numbers
0.8	1	Good level of aggregation.	**2**	**Missing some P contents.**	1	Based on DM numbers
0.10	3	Assumptions from Import Data	3	Based on DM numbers	3	Based on DM numbers
1.0					2	Some data out of date
1.2	2	Only one source, some discrepancy between documents	2	Based on DM numbers, Good P contents	2	Based on DM numbers
1.8	1	Good level of aggregation.	1	Good data on P content	1	Good data on Energy content
1.10	1	SSB data	1	Good data on P content	1	Good data on Energy Content
2.0	1		1	Good data on P content	1	Good data on Energy Content
2.4	2	No information available on processing, flow should be lower.	2	Good data on P content, but based on DM numbers	2	Good data on Energy Content, but based on DM
2.8	1	Good level of aggregation.	1	Good data on P content	1	Good data on Energy Content
3.4	1	Reliable statistics	1	Good data on P content	1	Good data on Energy Content
3.16	1	Simple assumptions, good base data	1	Good data on P content	1	Good data on Energy Content
4.0	3	Large potential for error	3	Based on DM numbers	3	Based on DM Numbers
4.7	2		2	Based on DM numbers, Good P contents	2	Good data on Energy Content, but based on DM
4.9	2	Variety of Sources, uncertain related to whether there is overlap	2	Based on DM numbers, Good P contents	2	Good data on Energy Content, but based on DM
7.0	Only in Energy				1	Consistent with other studies
7.9	3	Complex, many sources and assumptions	3	Based on DM numbers	3	Based on DM Numbers

7.13	3	Two ways to calculate, very different results.	3	Based on DM numbers	3	Based on DM Numbers
8.10	2	Only one source, some discrepancy between documents	2	Based on DM numbers	2	Based on DM numbers
9.0	2	Variety of Sources, uncertain related to whether there is overlap	2	Based on DM numbers	2	Based on DM numbers
9.1	1	Simple assumptions, good base data	1	Based on DM numbers	**2**	**Used HHV for uneaten food**
9.11	2	Data not up-to-date	2	Based on DM numbers	2	Based on DM numbers
9.12	3	Mass Balance	3	Mass balance	3	Energy Balance
9.14	1	Good base data	2	Uncertain P content	2	Uncertain Energy Content
10.0	Only in Energy				2	Energy Balance
10.1	3	Some data out of date, uncertain assumptions	3	Based on DM numbers	3	Based on DM numbers
10.3	1	Simple assumptions, good base data	1	Good data on P content	1	Good data on Energy Content
11.0	Only in Energy				3	Some data out of date, difficult to find company data
11.1	2	Some data out of date, difficult to find company data	2	Based on DM numbers	**3**	**Used HHV for uneaten food**
11.12	3	Mass Balance	3	Mass balance	3	Energy Balance, negative flow
12.0	Not Quantified					
12.14						
13.0	3	Mass Balance	3	Mass balance	3	Energy Balance
13.1	1	Good level of aggregation.	1	Good data on P content	2	Uncertain Energy Content of Sludge
13.11	2	Some data out of date, difficult to find company data	2	Good data on P content, but based on DM numbers	2	Uncertain Energy Content of Sludge
16.0	2	Simple assumptions, good base data, but doesn't balance	2	Good data on P content, but based on DM numbers	2	Good data on Energy Content, but based on DM
16.1						
16.8						
16.9						

4.2 Scenario Discussion

The scenarios were designed to answer research questions four and five below.

> Q4- Where are potential leverage points in the system that could address multiple issues?
>
> Q5- What should policy and initiatives prioritize?

This section will discuss the extent to which the scenarios answered these questions and the preliminary answers that have been found. It will discuss the effects that changes in different flows had on the important parts of the system highlighted in the Results and discussed above, such as the largest flows, imports of P fertilizer, energy production, efficiencies and losses.

The amount of imported P fertilizer is one of the most important indicators of improvement or degradation of the system in terms of P. However, it is difficult to compare the flow between a scenario and the baseline, due to the large mass balance inconsistency in the baseline model. Comparison between the scenarios is possible because Plant Production is assumed to balance in all.

Table 8 below lists the changes in select flows between the different scenarios and also makes a first attempt at creating metrics with which to compare them. A positive number in the changes section indicates that the flow has increased, a negative number indicates a decrease. In general we would like the P numbers to decrease, energy production to increase and process energy to decrease. The metrics will be explained and discussed in each of the following sections.

4.2.1 Scenario 1.1 Redirection of Food Waste to Biogas Production

The end-of-pipe approach of diverting food waste to biogas production had minor effects on a systemic level, impacting primarily the waste treatment system and energy production. The changes in inputs and mass balance caused an increase in the amount of P fertilizer that must be imported by 274 tons of P. This can be seen in Table 8 below. The first row tells us that in Scenario 1.1, the fertilizer imports increased by 974 tons of P but flows to incineration decreased by 173 tons. In addition, 2.13 PJ of additional energy was produced over the baseline. The two metrics say that for every additional PJ produced, 457 tons of P of further fertilizer was needed and 81 tons of P *less* went to incineration. Without information on process energy inputs into biogas plants it is not possible to make conclusions about the net energy gain. There was an improvement in terms of losses to Incineration because material that was once incinerated now flowed to Biogas Production where energy was transformed and at least a portion of the phosphorous was retained in the Biogas Fertilizer that was applied to soils.

4.2.2 Scenario 1.2 - Upstream Prevention of Food Waste

The idea with this scenario was to compare it to Scenario 1.1 in order to observe the differences between end-of-pipe and proactive solutions. Food to Consumption (Flow 4.7) was directly reduced by 10% and the elimination of Market Waste resulted in a further reduction of inputs needed to the Food Market (Flows 2.4 and 3.4). In the P layer the reduction magnified backwards from 10% to 35%, meaning that the above changes caused a 35% reduction in production (in terms of P) from both Plant Production and Animal Husbandry. This is turn led to a large reduction of P imports (by 1800 tons of P). Losses to incineration decreased by 1,304 to 1,103. In the energy layer, the same changes represented only 5% and 16% reductions. It appears to be characteristic of the energy layer that changes have less impact.

Scenario 1.2 metrics from Table 8 are slightly different since they relate to saving energy rather than producing it. The first metric tells us that saving 1 PJ of energy accompanied a savings of 1553 tons of P in the form of imported fertilizer. Also, per PJ saved 1124 tons of P *less* went to incineration. This shows that Scenario 1.2 gave an improvement in all areas. The expectation was that energy saved from reducing food production and distribution would exceed the energy produced by diverting food waste. According to Quested et al. (2011), food waste prevention reduces greenhouse gas emissions by around eight times more than diverting the same food waste from landfill to anaerobic digestion. However, according to the results, 1.16 PJ of energy were saved, which is approximately half as large as the additional energy production in Scenario 1.1 from simply redirecting the waste to biogas production. This does not indicate that a proactive approach is more effective than end-of-pipe when speaking of energy. In contrast to Quested et al.'s claim, waste is not being diverted from landfill, simply from incineration, so Scenario 1.2 cannot benefit from reduced methane from landfills, which likely represents most of the savings referred to by Quested et al. In reference to the gap between expectations and results, the current multi layer model does not account for all process energy, such as transportation and storage, so that may make up some of the difference, or process energy could be underestimated.

4.2.3 Scenario 2 – Extreme Energy Prioritization

Scenario 2 introduces the potential of harvest residues, which appear to be a better source of energy than manure and easier to transport due to reduced moisture content. They are also a good source of phosphorous containing much more than all sewage sludge from WWTP and almost as much as all domestic Grain to Fodder. It is likely that harvest residues are also better distributed spatially around the country, as opposed to manure.

This extreme re-routing of secondary biomass serves to eliminate the P accumulation in Plant Production but leads to an 18% increase in P fertilizer imports. Though significant, this is less severe problem shifting than predicted and is due to the fact that all P coming into the process is now taken up and used rather than accumulating in soil. The metrics for Scenario 2 indicate that for every PJ of extra energy produced, only 29 tons of P extra fertilizer was needed but 274 additional tons of P was incinerated
Additional energy production is significant at 48.5 PJ over baseline though the MBI is now 16 PJ. That is 13,472 GWh additional potential energy or equivalent to 11.3% of all Norwegian electricity consumption in 2012 (SSB 2013). This is a very important result because it shows the extent to which the Norwegian agricultural system can affect the energy system in Norway. In the extreme circumstance when all possible biomass streams are directed to energy production, at most 11.3% of Norway's electricity needs can be met. This quantity also does not include the conversion efficiency of biogas to electricity or the energy requirements of transportation and biogas production plants, which will further lower the net addition to production.

In contrast, agriculture is responsible for almost 100% of the phosphorous cycling in Norway, along with aquaculture and fisheries, and we would need to sacrifice a considerable amount of P to incineration in order to enact this scenario. Scenario 2 had the largest loss of phosphorous to incineration at 15,705 tons of P, which is nearly double the amount of P in fertilizer that is imported currently. The P content used for the flow from Biogas Production to Incineration may be unrealistically high, depending on the actual content. If it is composed of inorganic components this will lower the P and energy contents.

The trade-off between P as a pollution source and P as a resource depletion problem needs to be evaluated. The P accumulating in the soils could eventually leach out and lead to pollution problems in nearby water sources. The extent to which this is a problem in Norway is beyond the scope of this paper. Increased phosphorous fertilizer importation causes increased reliance on a limited resource and the countries that control supply. In addition, there are considerable pollution problems associated with the production of fertilizer, along with extensive energy requirements. The weighting of these factors is dependent on the values, scope and focus of the decision maker(s) but they are important things to be aware of during this analysis.

Table 8. Scenario Comparison Metrics

					Comparison Metrics	
Scenario	**Δ P Fertilizer Imports Tons P**	**Δ P to Incin Tons P**	**Δ Energy Production PJ**	**Δ Process Energy PJ**	**Δ P Fertilizer Imports/ Δ Energy**	**Δ P to Incin/ Δ Energy**
1.1	+974	-173	+2.13	-	457 tons P imported/add. PJ produced	-81 tons P/PJ produced
1.2	-1801	-1304	-	-1.16	1553 tons P saved/PJ saved	1124 tons P less/PJ saved
2	+1444	+13298	+48.5	-	29 tons P imported/add. PJ produced	274 tons P incinerated /add. PJ produced

In summary, Scenario 1.1 improves energy production and incineration losses, but results in an increase of fertilizer needs. Scenario 1.2 shows improvement in all areas. Scenario 2 has two negative results relating to P, but imports considerably less fertilizer per PJ compared to Scenario 1.1. Comparison is still dependent on a policy makers values and goal, but this sheds light on the important variables.

5 Future Challenges and Recommendations

Extensive data must be accumulated via research and possibly in conjunction with government regulated reporting in order to improve the baseline model to the level where reliable interpretations can be made. Data improvement is needed regarding the amount of energy obtained from incinerating organic waste and the process energy used in incinerators and biogas production plants. This information would allow for the improvement of the energy layer in order to more reliably make comparisons between scenarios. It would also be valuable to approximate transportation requirements for manure, harvest residues and sewage sludge. More research is needed on the current situation with, and the potential of, harvest residues. It is important to know the fate of current residues and amounts that are left on fields, burnt or used for animal bedding.

This model would benefit from a subsystem that models the soil dynamics and the uptake of P from different sources. An integration of information regarding the availability of P from secondary sources such as manure, biogas fertilizer and harvest residues would aid in understanding which resources are contributing to plant growth and which to NAS. This understanding could help to minimize the import of P fertilizer as much as possible to match the actual needs of plants. The model would also benefit from further layering to include other nutrients that are important for agriculture, such as nitrogen and potassium.

Data improvement is needed on the amount, composition and origin of food wastes as is being pursued by the ForMat and Cycle Projects as elaborated in Appendix 7. Food Waste at the Norwegian Level (O. J. Hanssen & Møller 2013; Cycle Project 2014). The Fra Avfall til Ressurs (From Waste to Resource) waste strategy report from the Norwegian Environmental Ministry (Miljøverndepartementet 2013) recognized the supply chain impacts of poor food utilization and even mentioned the importance of phosphorous. However it failed to set real targets, stating only that the Government will work to limit the amount of food wasted. A report from Østfoldforskning put forth a methodology for companies to map food loss in the food processing industry so the research community is providing the framework to improve reporting in this area and simply needs government support (Møller et al., 2012). If the government required companies to report their waste statistics, this would improve the availability of information and if publicly available, also possibly lead to consumer pressure to reduce these wastes.

Food waste from retailers and consumers represents a small loss at the systemic level and attention must be diverted upstream to recognize its relative significance. It is not plausible to expect a complete elimination of food waste in the Norwegian agricultural system. Regulations need to be enacted that reflect the waste food hierarchy shown in Figure 20 in the Appendix. This hierarchy was adapted from the general waste hierarchy and shows the options for dealing with food waste in order of preference, or impact. Ideally the waste can be reduced, or redistributed to people or livestock, as represented by the upper tiers. The first three tiers move towards preventing the waste occurring, and the bottom two are deemed “waste management” and include compost and bioenergy and disposal. In Norway, however, there are no government initiatives that address the “waste in advance” portion of the food waste pyramid.

For the material that cannot be dealt with within the top three tiers of the waste hierarchy, biogas is preferable over incineration or landfilling. Using agricultural and food waste also avoids the land use and food price issues that face other biofuel feedstocks such as corn.

In terms of the large losses surrounding Animal Husbandry, steps should be taken to encourage reduced consumption of meat and animal products. The Norwegian population could be educated on the value of other protein sources or helped to understand their actual daily protein requirements. This is a very difficult issue to address politically because it is a matter of personal choice and habits.

6 Conclusion

Norway is not very food secure and is highly reliant on imports of phosphorous fertilizer for the food that is grown domestically. The Norwegian government must recognize the relative impacts that the agriculture and food system have on the energy and phosphorous cycles respectively. The system modeled in this report controls nearly 100% of the P cycling within the country along with aquaculture and fisheries, yet could provide a maximum of around 11% of the nation's electricity. In a country with access to hydropower, energy production should not be prioritized over phosphorous reduction, reuse and recovery. Exceptions to this include sewage sludge and manure spreading which are simply leading to P accumulation in soils. This report has recommended the addition of soil dynamics to the baseline model. However, with the current understanding of P availability and concern about P leaching into waterways, this study concludes that the flow of sewage sludge would be better utilized for energy rather than spread on the fields. Manure is not currently a good source of P or energy. From a P perspective this conclusion follows from the farmer's disregarding the P content due to doubts around plant availability and it's subsequent accumulation in soils. Furthermore, manure is low in energy content and difficult to transport to biogas production plants. Small, decentralized biogas production near to agricultural land could be a solution in the future.

Harvest residues, in contrast, appear to be a good source of both P and energy, without the same problems of transportation and spatial distribution. There may be other competitive factors based on how much harvest residue is used as animal bedding or otherwise, but they are an interesting resource to investigate from both a P and an energy perspective. In conclusion, this novel and innovative multi-layered modeling successfully shed light on the inter-relations between phosphorous and energy in the Norwegian agricultural systems and contributed important preliminary results.

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8 Appendices

8.1 Appendix 1. All Flow Tables, All Scenarios

Table 9. Dry Matter Flows, all Scenarios

Dry Matter in tons				
Flows	0- Normal	1.1- Use all existing food waste	1.2- Reduce Production by Waste Amount	2- Divert all waste to Biogas
0.1	2.08E+06	2.06E+06	1.68E+06	4.03E+06
0.2	3.75E+05	3.75E+05	3.75E+05	3.75E+05
0.4	1.63E+06	1.63E+06	1.63E+06	1.63E+06
0.8	3.90E+05	3.90E+05	3.16E+05	4.05E+05
0.10	2.44E+05	2.44E+05	1.97E+05	2.44E+05
1.2	2.38E+05	2.38E+05	1.93E+05	2.38E+05
1.8	9.10E+05	9.10E+05	7.37E+05	9.10E+05
1.10	2.35E+06	2.35E+06	1.91E+06	2.35E+06
2.0	2.38E+05	2.38E+05	2.64E+05	2.38E+05
2.4	2.38E+05	2.38E+05	1.93E+05	2.38E+05
2.8	1.37E+05	1.37E+05	1.11E+05	1.37E+05
3.4	3.44E+05	3.44E+05	2.78E+05	3.44E+05
3.16	5.82E+04	5.82E+04	4.72E+04	0.00E+00
4.0	2.33E+05	2.33E+05	2.33E+05	2.33E+05
4.7	1.51E+06	1.51E+06	1.42E+06	1.51E+06
4.9	2.15E+04	2.15E+04	0.00E+00	2.15E+04
7.9	1.49E+05	1.49E+05	5.96E+04	1.49E+05
7.13	1.78E+05	1.78E+05	1.78E+05	1.78E+05
8.10	1.45E+06	1.45E+06	1.18E+06	1.45E+06
9.0	1.77E+04	0.00E+00	6.74E+03	0
9.1	4.13E+04	0.00E+00	1.57E+04	0
9.11	3.12E+04	1.82E+05	3.12E+04	1.70E+05
9.12	8.49E+04	0.00E+00	1.29E+04	0
9.14	6.60E+03	0.00E+00	2.51E+03	0
10.1	1.30E+06	1.30E+06	1.05E+06	2.93E+05
10.3	4.02E+05	4.02E+05	3.25E+05	4.02E+05
11.1	1.59E+04	7.46E+04	1.59E+04	1.39E+06
11.12	2.49E+04	1.17E+05	2.49E+04	2.17E+06
12.0				
12.14				
13.0	1.07E+05	1.07E+05	1.07E+05	0
13.1	6.22E+04	6.22E+04	6.22E+04	0
13.11	9.60E+03	9.60E+03	9.60E+03	1.78E+05
16.0	3.77E+04	3.77E+04	3.05E+04	0
16.1	1.00E+04	1.00E+04	8.11E+03	0
16.8	1.51E+04	1.51E+04	1.22E+04	0

16.9	1.17E+04	1.17E+04	9.47E+03	0
Flows only in Scenario 2				
1.11				2.21E+06
3.11				5.82E+04
10.11				1.00E+06

Table 10. Energy Flows, All Scenarios

Energy in kilojoules (kJ)

Flows	0- Normal	1.1- Use all existing food waste	1.2- Reduce Production by Waste Amount	2- Divert all waste to Biogas
0.1	7.98E+13	7.92E+13	6.75E+13	6.73E+13
0.2	8.77E+12	8.77E+12	8.77E+12	8.77E+12
0.4	2.92E+13	2.92E+13	2.92E+13	2.92E+13
0.8	8.36E+12	8.36E+12	7.04E+12	8.93E+12
0.10	4.04E+12	4.04E+12	3.40E+12	4.04E+12
1.0	3.98E+13	3.98E+13	3.35E+13	0.00E+00
1.2	4.26E+12	4.26E+12	3.58E+12	4.26E+12
1.8	1.67E+13	1.67E+13	1.41E+13	1.67E+13
1.10	4.12E+13	4.12E+13	3.47E+13	4.12E+13
2.0	6.08E+12	6.08E+12	6.51E+12	6.08E+12
2.4	4.26E+12	4.26E+12	3.58E+12	4.26E+12
2.8	2.69E+12	2.69E+12	2.27E+12	2.69E+12
3.4	8.04E+12	8.04E+12	6.77E+12	8.04E+12
3.16	1.76E+12	1.76E+12	1.48E+12	0.00E+00
4.0	6.18E+12	6.18E+12	6.18E+12	6.18E+12
4.7	3.10E+13	3.10E+13	2.94E+13	3.10E+13
4.9	3.65E+11	3.65E+11	0	3.65E+11
7.0	2.59E+13	2.59E+13	2.59E+13	2.59E+13
7.9	2.75E+12	2.75E+12	1.17E+12	2.75E+12
7.13	2.32E+12	2.32E+12	2.32E+12	2.32E+12
8.10	2.83E+13	2.83E+13	2.38E+13	2.83E+13
9.0	3.28E+11	0.00E+00	1.33E+11	0.00E+00
9.1	7.64E+11	0.00E+00	3.09E+11	0.00E+00
9.11	5.77E+11	3.32E+12	5.77E+11	3.11E+12
9.12	1.53E+12	0.00E+00	2.75E+11	0.00E+00
9.14	1.22E+11	0.00E+00	4.94E+10	0.00E+00
10.0	4.30E+13	4.30E+13	3.62E+13	4.30E+13
10.1	2.07E+13	2.07E+13	1.74E+13	4.69E+12
10.3	9.81E+12	9.81E+12	8.26E+12	9.81E+12
11.0	4.67E+11	2.60E+12	4.67E+11	4.90E+13
11.1	2.94E+11	1.64E+12	2.94E+11	3.00E+13
11.12	-1.60E+11	-8.91E+11	-1.60E+11	-1.60E+13

12.0				
12.14				
13.0	2.14E+12	2.14E+12	2.14E+12	0.00E+00
13.1	1.53E+11	1.53E+11	1.53E+11	0.00E+00
13.11	2.36E+10	2.36E+10	2.36E+10	2.32E+12
16.0	6.59E+11	6.59E+11	5.55E+11	0.00E+00
16.1	1.75E+11	1.75E+11	1.48E+11	0.00E+00
16.8	5.64E+11	5.64E+11	4.75E+11	0.00E+00
16.9	2.05E+11	2.05E+11	1.72E+11	0.00E+00
Flows only in Scenario 2				
1.11				3.98E+13
3.11				1.76E+12
10.11				1.60E+13
Process Energy Flows				
0.1	6.53E+12	6.53E+12	5.50E+12	6.53E+12
0.2	2.90E+10	2.90E+10	2.45E+10	2.90E+10
0.3	7.98E+11	7.98E+11	6.72E+11	7.98E+11
0.10	8.47E+09	8.47E+09	7.13E+09	8.47E+09

Table 11. Phosphorous Flows, all Scenarios

Phosphorous in tons				
Flows	0- Normal	1.1- Use all existing food waste	1.2- Reduce Production by Waste Amount	2- Divert all waste to Biogas
0.1	7897	8871	6095	9341
NAS 1	12269	12269	8232	0
0.2	3254	3254	3254	3254
0.4	4343	4343	4343	4343
0.8	1913	1913	1238	1917
0.10	1265	1265	819	1265
1.2	1931	1931	1250	1931
1.8	4845	4845	3136	4845
1.10	5177	5177	3351	5177
2.0	2333	2333	2658	2333
2.4	1931	1931	1250	1931
2.8	922	922	597	922
3.4	2103	2103	1361	2103
3.16	2735	2735	1770	0
4.0	1144	1144	1144	1144
4.7	9875	9875	8867	9875
4.9	415	415	0	415
7.9	1921	1921	913	1921
7.13	2677	2677	2677	2677

8.10	7683	7683	4974	7683
9.0	297	0	130	0
9.1	165	0	72	0
9.11	125	2862	125	2336
9.12	2219	0	915	0
9.14	26	0	12	0
10.1	13306	13306	8613	1857.98
10.3	4838	4838	3132	4838
11.1	64	755	64	5313
11.12	188	2233	188	15705
12.0				
12.14				
13.0	1728	1728	1728	0
13.1	821	821	821	0
13.11	127	127	127	2677
16.0	1765	1765	1143	0
16.1	470	470	304	0
16.8	4	4	3	0
16.9	526	526	341	0
Flows only in Scenario 2				
1.11				4558
3.11				2735
10.11				11448

8.2 Appendix 2. Flow Diagrams

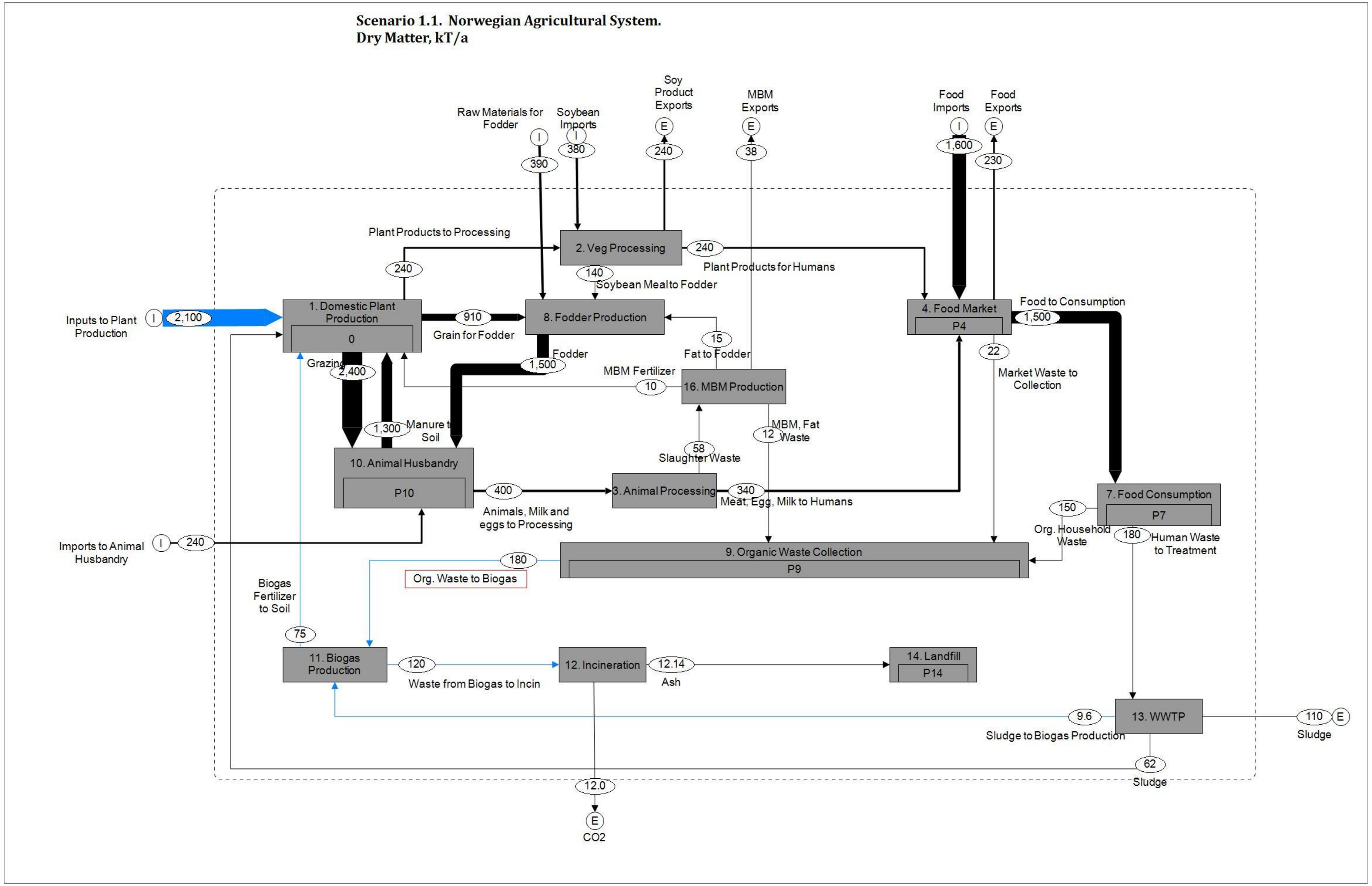


Figure 12. Scenario 1.1. Dry Matter Flows.

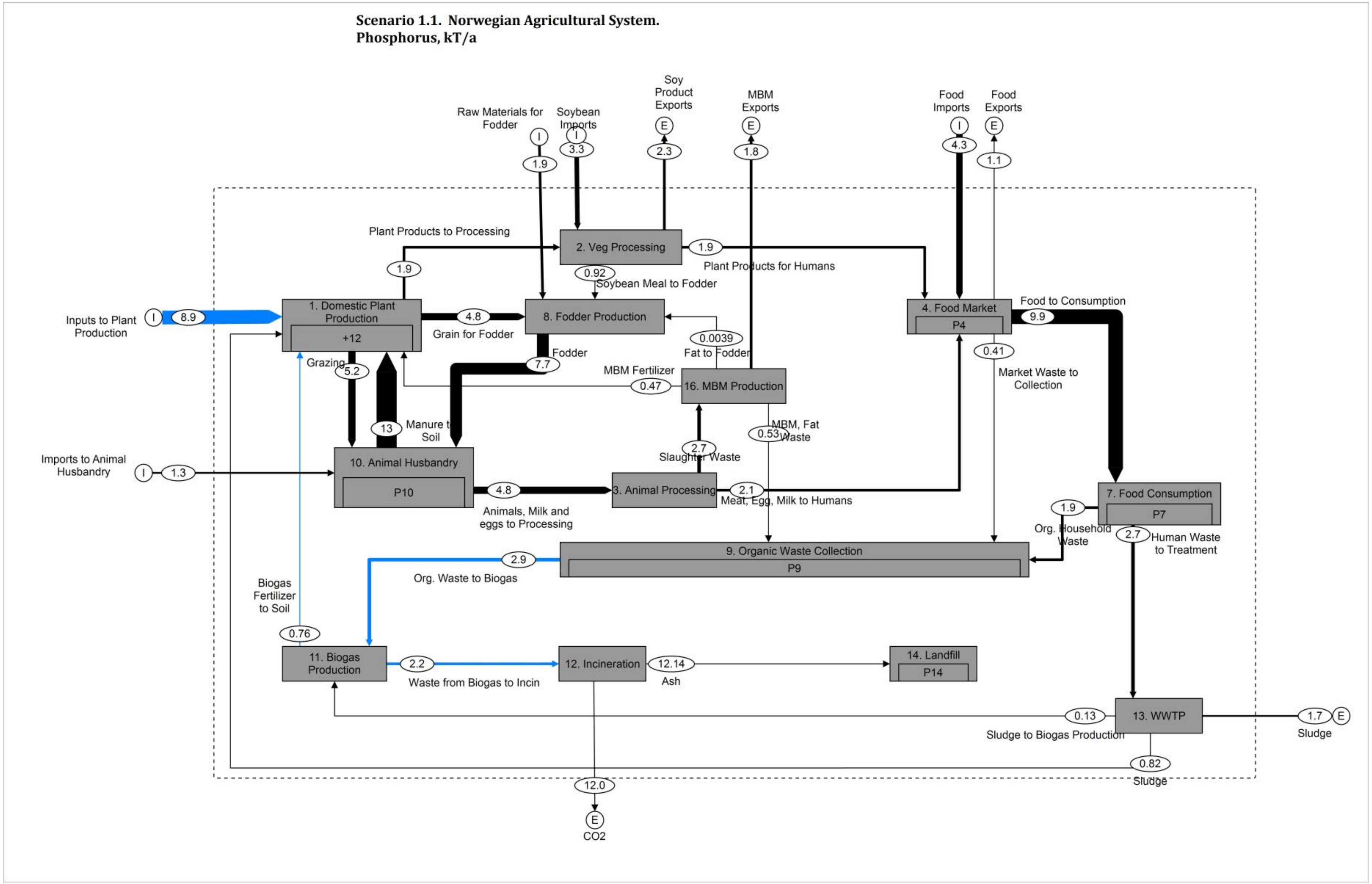


Figure 13. Scenario 1.1. Phosphorous Flows.

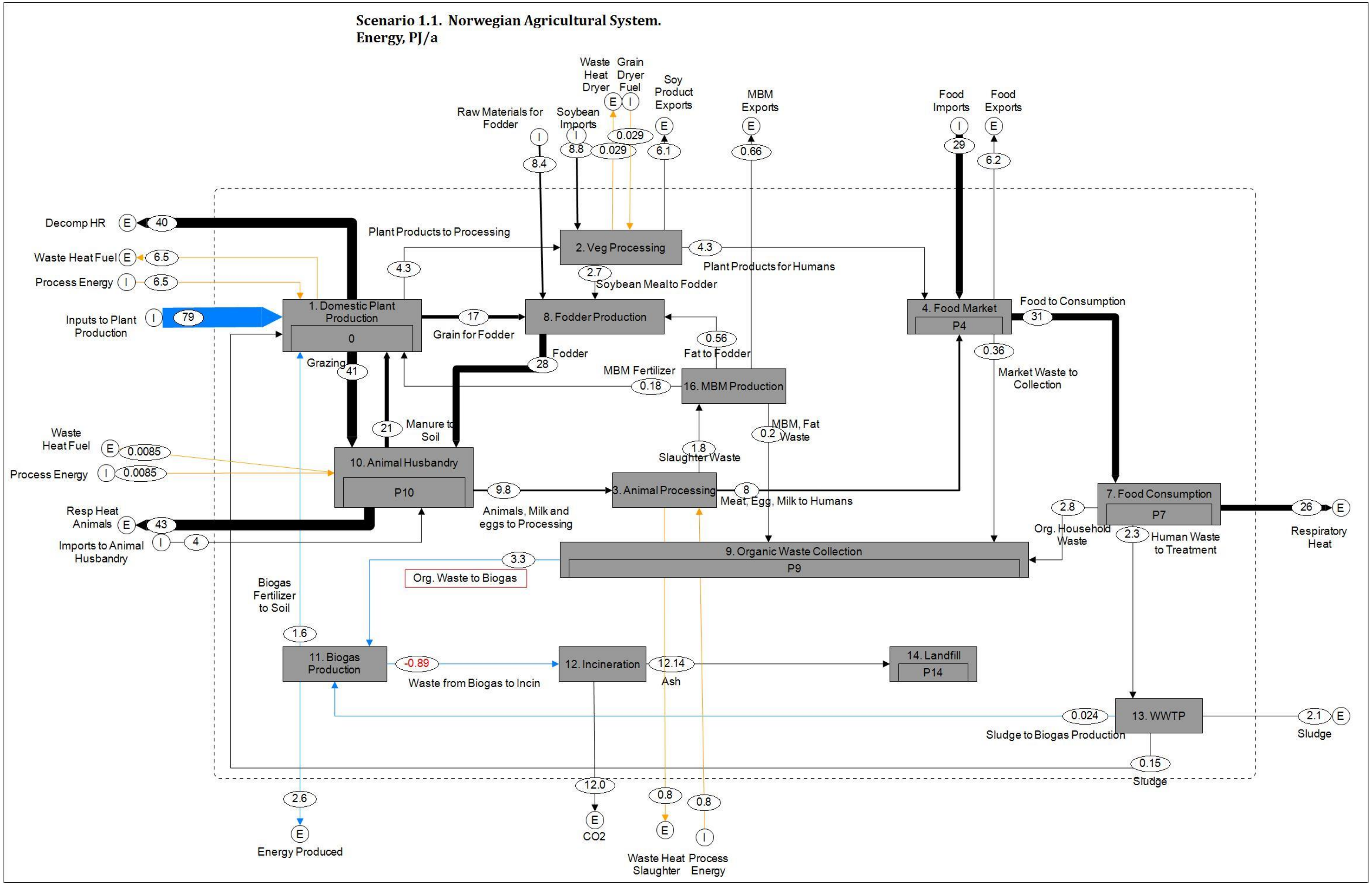


Figure 14. Scenario 1.1. Energy Flows

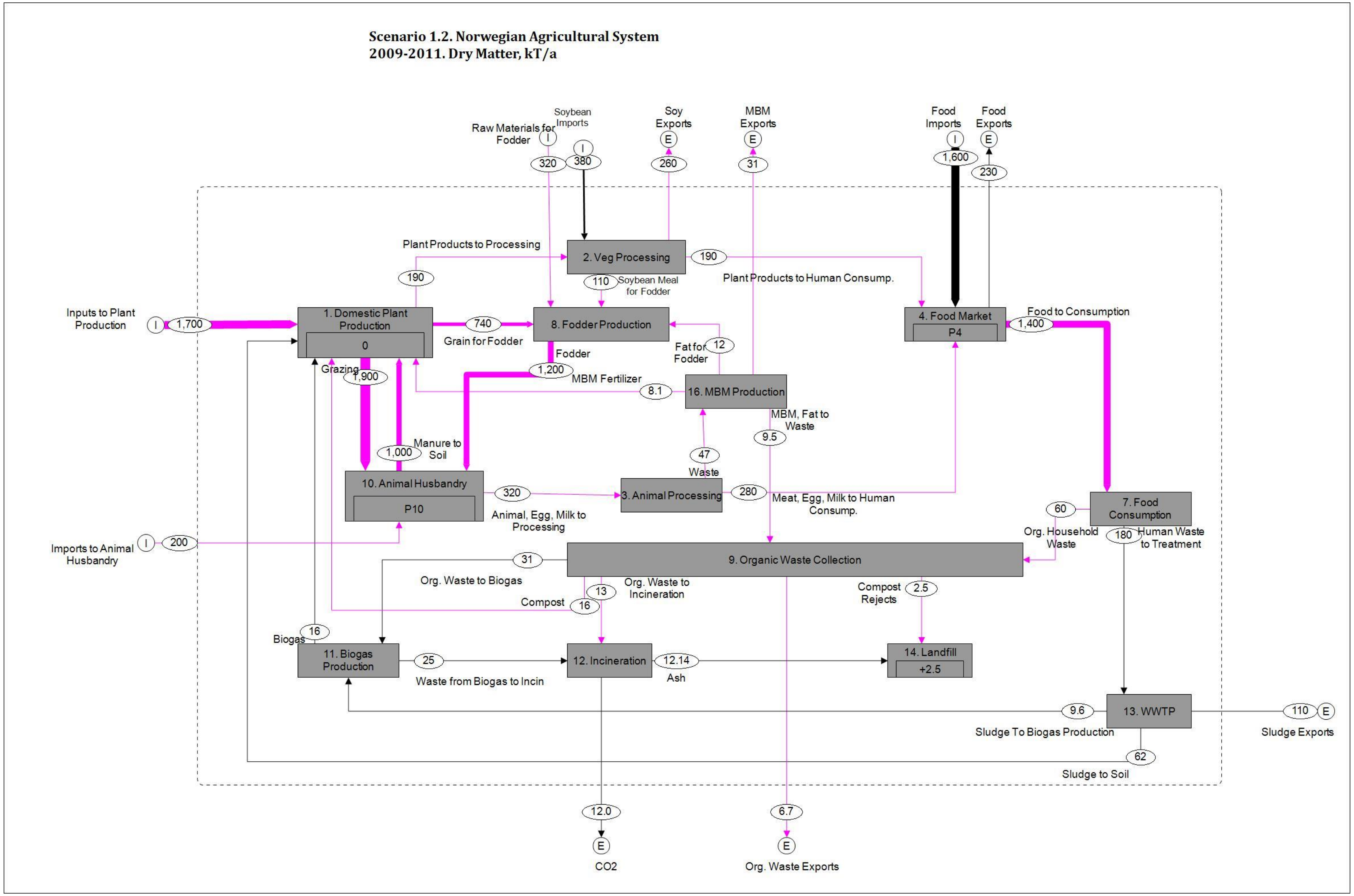


Figure 15. Scenario 1.2. Dry Matter Flows.

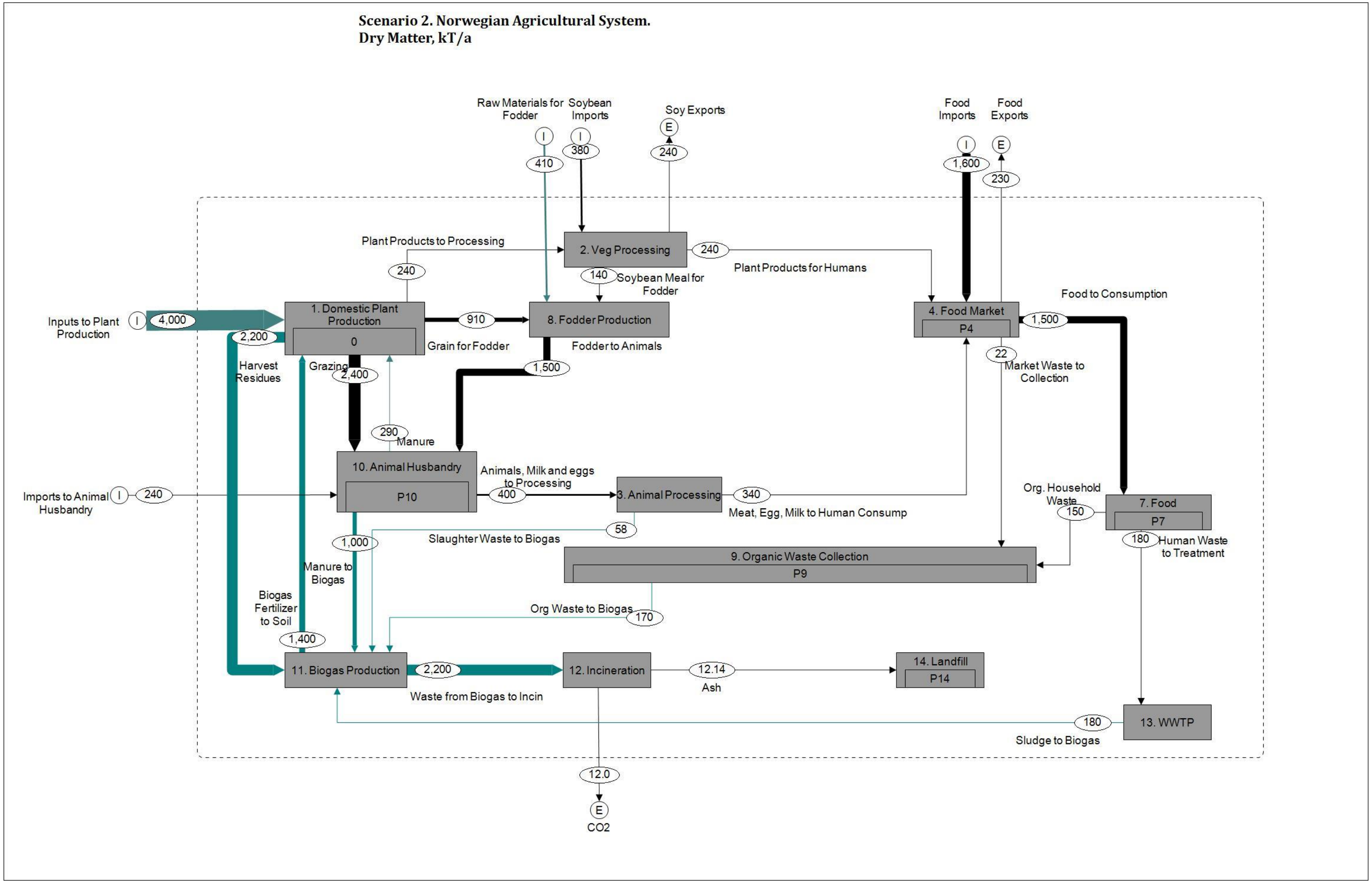


Figure 16. Scenario 2. Dry Matter Flows

8.3 Appendix 3. Mass Balance Inconsistencies- Baseline Model

Table 12. Dry Matter Layer Mass Balance Inconsistencies

	Dry Matter Discrepancies				
Process	**In (kT)**	**Out (kT)**	**Discrepancy (kT)**	**Percentage Difference**	**Possible Cause**
4	2220	1770	448	23%	
7	1510	337	1180	129%	NAS. Human growth. Data limitations.
10	4050	1700	2350	82%	NAS-Animal growth. Data limitations.
12	123	0	123		No data on outputs
16	58	74.5	-16.3	25%	

Table 13. Phosphorous Layer Mass Balance Inconsistencies

Process	In (1000 tons)	Out (1000 tons)	NAS	Discrepancy (1000 tons P)	Percentage Difference	Possible Cause
1	22.7	11.9	12.26	-1.5	-6%	Soil Accumulation
4	8.4	11.4		-3	31%	
7	9.9	4.6		5.3	73%	
10	14.1	18.1		-4	25%	Incorrect P contents
12	2.4	0	0	2.4		No data on outputs
16	2.74	2.76		-.02	1%	

Table 14. Energy Layer Mass Balance Inconsistencies

Energy					
Process	**In**	**Out**	**Discrepancy (kj)**	**Percentage difference**	**Possible Cause**
4	4.15E+13	3.75E13	4 E12	10%	Energy Contents, Data Quality
12	1.37E+12	0	1.37E12		No data on Outputs
16	1.76E+12	1.60E+12	1.61E+11	10%	

8.4 Appendix 4. Efficiencies- All Scenarios

Table 15. Dry Matter Efficiencies

DM Scenarios	Baseline	1.1	1.2	2
4	79%	79%	79%	79%
10	10%	10%	10%	10%
Overall	37%	37%	39%	26%

Table 16. Biomass Energy Efficiencies

Energy	0	1.1	1.2	2
4	90%	90%	90%	90%
10	13%	13%	13%	13%
Overall	29%	29%	31%	31%

Table 17. Phosphorous Efficiencies

P	0	1.1	1.2	2
1	53%	51%	48%	72%
4	132%	132%	144%	132%
10	34%	34%	34%	34%
Overall	36%	36%	42%	55%

8.5 Appendix 5. Transfer Coefficients

Table 18. Transfer Coefficients

Flows	Dry Matter		Phosphorous		Energy	
0.1	Mass Balance		Mass Balance		Energy Balance	
0.2	Given		Given		Given/constant	
0.4	108%	of 4.7	44%	of 4.7	94%	of 4.7
0.8	27%	of 8.10	25%	of 8.10	30%	of 8.10
0.10	61%	of 10.3	26%	of 10.3	41%	of 10.3
1.0	Only in Energy		Only in Energy		Given	
1.2	Equal to	2.4	Equal to	2.4	Equal to	2.4
1.8	63%	of 8.10	63%	of 8.10	59%	of 8.10
1.10	586%	of 10.3	107%	of 10.3	420%	of 10.3
2.0		0.2-2.8		0.2-2.8		0.2-2.8
2.4	16%	of 4.7	20%	of 4.7	14%	of 4.7
2.8	9%	of 8.10	12%	of 8.10	10%	of 8.10
3.4	23%	of 4.7	21%	of 4.7	26%	of 4.7
3.16		10.3 - 3.4		10.3 - 3.4		10.3-3.4
4.0	Given		Given		Given	
4.7	Given		Given		Given	
4.9	1%	of All inputs to 4	5%	of All inputs to 4	1%	All inputs to 4
7.0	Only in Energy		Only in Energy		84%	of 4.7
7.9	10%	of 4.7	19%	of 4.7	9%	of 4.7
7.13	12%	of 4.7	27%	of 4.7	7%	of 4.7
8.10	361%	of 10.3	159%	of 10.3	289%	of 10.3
9.0	10%	of All inputs to 9	10%	of All inputs to 9	10%	of all inputs to 9
9.1	23%	of All inputs to 9	6%	of All inputs to 9	23%	of all inputs to 9
9.11	Given by Capacity		Given by Capacity		Given by capacity	
9.12	Mass Balance		Mass Balance		Energy Balance	
9.14	16%	of 9.1	16%	of 9.1	16%	of 9.1
10.0	Only in Energy		Only in Energy		58%	of all inputs to 10
10.1	322%	of 10.3	275%	of 10.3	211%	of 10.3
10.3	117%	of 3.4	230%	of 3.4	122%	of 3.4
11.0	Only in Energy		Only in Energy		78%	of all inputs to 11
11.1	39%	of All inputs to 11	25%	of All inputs to 11	49%	of all inputs to 11
11.12	Mass Balance		Mass Balance		Energy Balance	
13.0	Mass Balance		Mass Balance		Energy Balance	
13.1	35%	of 7.13	31%	of 7.13	7%	of 7.13
13.11	Given by Capacity		Given by Capacity		Given By Capacity	
16.0	65%	of 3.16	65%	of 3.16	37%	of 3.16
16.1	17%	of 3.16	17%	of 3.16	10%	of 3.16
16.8	26%	of 3.16	0%	of 3.16	32%	of 3.16
16.9	20%	of 3.16	19%	of 3.16	12%	of 3.16

Table 19. Process Energy Transfer Coefficients

Process Energy Flows		
0.1	11%	of all outputs from 1
0.2	0.42%	of (2.4 + 2.8)
0.3	10%	of 3.4
0.10	0.1%	of 10.3

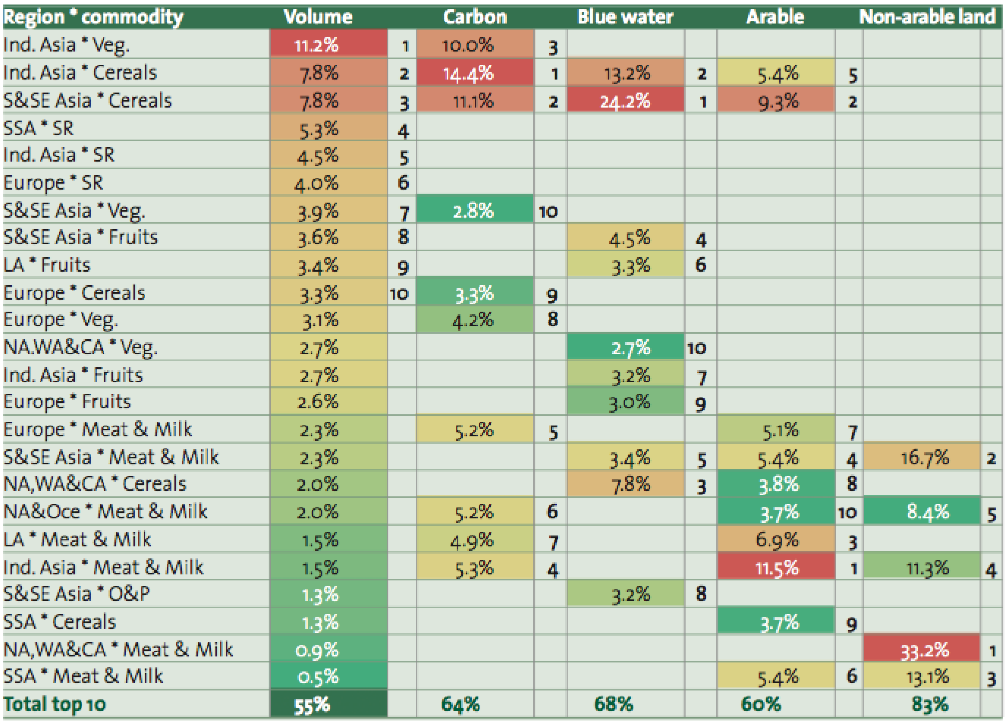
8.6 Appendix 6. Past and Current Initiatives

There are many reasons the food system is an important topic for systems perspective-based research and immediate action. There is a momentum behind the topic on all levels (international, European, Norwegian) with diverse actors demanding that we address our unsustainable food system. Though there are differing perspectives on why food waste is a problem, there are very few researchers taking a holistic approach to the system. Motivations range from practical discussions of waste management, lost economic value and environmental impacts to philosophical discourses about our ethics and moral obligations to take care of food due to the starvation experienced by many people today.

This residual resource is generated from households, grocery stores, food processing and the service industries. According to the FAO (2013), consumer food waste in developed countries, at 222 million tons, is nearly as much as the total net food production in sub-Saharan Africa, at 230 million tons.

They made “Region*commodity pairs” to try and identify hotspots for research, policy and action. Select results are shown in Figure 17. The figure shows the top 10 pairs for each of the categories: Volume, Carbon, Blue water and Arable Land. It also shows the top 5 region*commodity pairs for Non-arable land. For example, Industrial Asia’s wastage of Cereals represents nearly 8% of total food waste in volume. 14% of carbon from total food waste, 13% of blue water used to grow wasted food and 5% of arable land used to grow wasted food.

Figure 17. Top Region*Commodity Pairs (FAO 2013)



Region * commodity	Volume		Carbon		Blue water		Arable		Non-arable land	
Ind. Asia * Veg.	11.2%	1	10.0%	3						
Ind. Asia * Cereals	7.8%	2	14.4%	1	13.2%	2	5.4%	5		
S&SE Asia * Cereals	7.8%	3	11.1%	2	24.2%	1	9.3%	2		
SSA * SR	5.3%	4								
Ind. Asia * SR	4.5%	5								
Europe * SR	4.0%	6								
S&SE Asia * Veg.	3.9%	7	2.8%	10						
S&SE Asia * Fruits	3.6%	8			4.5%	4				
LA * Fruits	3.4%	9			3.3%	6				
Europe * Cereals	3.3%	10	3.3%	9						
Europe * Veg.	3.1%		4.2%	8						
NA.WA&CA * Veg.	2.7%				2.7%	10				
Ind. Asia * Fruits	2.7%				3.2%	7				
Europe * Fruits	2.6%				3.0%	9				
Europe * Meat & Milk	2.3%		5.2%	5			5.1%	7		
S&SE Asia * Meat & Milk	2.3%				3.4%	5	5.4%	4	16.7%	2
NA,WA&CA * Cereals	2.0%				7.8%	3	3.8%	8		
NA&Oce * Meat & Milk	2.0%		5.2%	6			3.7%	10	8.4%	5
LA * Meat & Milk	1.5%		4.9%	7			6.9%	3		
Ind. Asia * Meat & Milk	1.5%		5.3%	4			11.5%	1	11.3%	4
S&SE Asia * O&P	1.3%				3.2%	8				
SSA * Cereals	1.3%						3.7%	9		
NA,WA&CA * Meat & Milk	0.9%								33.2%	1
SSA * Meat & Milk	0.5%						5.4%	6	13.1%	3
Total top 10	**55%**		**64%**		**68%**		**60%**		**83%**	

The global volume of food wastage was around 1.6 Gtonnes of “primary product equivalents”, while the edible waste was 1.3 Gtonnes. For a sense of scale, total agricultural production was approximately 6 Gtonnes (FAO 2013).

Results from the study indicated that the responsibility for overall food wastage volume was divided fairly evenly between upstream (production, handling and storage) at 54% and downstream, including processing, distribution and consumption, at 46% of total volume (FAO 2013). Agricultural production alone represented 33%. Of course the downstream values vary hugely between regions, generally based on income levels.

In terms of carbon footprint, food wastage ranked as the number three emitter in the world, after the US and China, with 3.3 Gtonnes of CO_{2eq} (not including impacts from land use change). Almost 30% of the world's agricultural land area went to wasted food production, which used nearly 1.4 billion hectares of land (FA0 2013).

There are many hotspots where improvements can be realized and the fact that Europe shows up several times in the above list shows that European production is not excluded from this. Even though most of the impact of food production on biodiversity occurred in tropical and sub-tropical regions (FAO 2013), this is still relevant in Norway if foods imported from those places were subsequently wasted.

Despite the thorough research from the FAO, and their use of the novel approach of including multiple indicators in a systems analysis, P and energy were not included and the countries were aggregated in a way that does not aid in understanding national systems.

European Level

On the European level, there is a large project called FUSIONS (Food Use for Social Innovation by Optimizing Waste Prevention Strategies), which began in August 2012 and will run until July 2016. It is funded by the European Commission's framework programme 7 (FOOD). The European Commission has stated targets of reducing food waste by 50% by 2020, and also reducing the resource inputs to the food supply chain by 20% in the same period. The FUSIONS initiatives will approach the issue with the question, "How can social innovation help reduce food waste?" They hope to harmonize definitions and methods for mapping food waste in Europe and to develop the basis for a common "Food Waste policy "for the EU-27. (ForMat, 2013)

There are 21 project partners from 13 countries, including universities, consumer organizations and businesses. These coordinated efforts will attempt to describe lessons learned from previous and ongoing projects in both Europe and North America and lay the foundation for a joint methodology.

FUSIONS advertised their list of partners and also a list of "members" (who support the project but are less engaged). Østfoldforskning is the only Norwegian partner but has a central role, and ForMat and REMA 1000 are the only Norwegian members. Norway is not represented in the initiatives section. Sweden, in contrast, has four partners, 18 members and five initiatives (EU FUSIONS 2014).

Table 20 gives a brief overview of the different initiatives on food waste on different levels and with differing scopes and focus. More detail is found in the text and in the references given.

Table 20 Overview of Food Waste Initiatives Globally, in Europe and in Norway

Name	Type and Regional Scope	Focus (Stages)	Goal	Partners	Definition Used	Time Span
ForMat	Norwegian Study		-25% Norwegian food waste by 2015.	Østfoldforskning Nofima	Food loss' was defined as "Food that is not suitable for sale at the full price' Distinguish edible and potentially edible and exclude inedible.	Ongoing
Cycle	Nordic Initiative	Whole FSC		Many	Not specified	Four years. Began March 2013
FAO Food Losses and Waste	Global Report	Whole FSC	Information Gathering		*Only consider what was intended for human consumption* *food losses* early in the FSC *food waste* at the retail and final consumption stages.	Report complete, now working on the Food Wastage Footprint
FAO Food Wastage Footprint	Global Report	Whole FSC	Information gathering		Food wastage refers to any food lost by deterioration or waste. Thus, the term "wastage" encompasses both food loss and food waste (as defined above).	Phase I complete.
FUSIONS	EU-27 Initiative	Whole FSC	-50% in food waste -20% in FSC resource inputs By 2020	21 from 13 countries. Involves all Nordic countries except Iceland See Figure #	Not specified	August 2012- July 2016
Prevention of Food Waste	Norwegian Industry Initiative			Nofima, Østfoldforskning and SIFO		Complete. July 2010-June 30 2013

8.7 Appendix 7. Food Waste at the Norwegian Level

Several research institutions and programs have investigated the food waste situation in Norway. Nofima is a food research institution in Norway, which works with industry and has a focus on naturally increasing the shelf life of high value products like beef and lamb. Nofima had a Food Waste Prevention project in Norway with a focus on high volume and value food waste with short or variable shelf life (Nofima - Prevention of food waste Project n.d.). It was funded by the Research Council of Norway and ran from July 2010 to June 2013. They collaborated on this project with Østfoldforskning and SIFO (Statens Institutt for forbruksforskning). Nofima is also a participant in the ForMat project, which was tightly linked to the Food Waste Prevention project.

The ForMat project thus far was an industry endeavor with the goal of a 25% reduction in food waste in Norway by 2015 (ForMat 2013). It appeared that the project was concluded but discussion with a Østfolkforskning researcher indicated that it continues. It involves NHO (Confederation of Norwegian Enterprise) and retail and the food industries, but the professional responsibility is held by Østfoldforskning. The project has three sub-projects,

- Survey of food waste every year
- Communication and dissemination
- Network projects related to specific value chains or issues of food waste (O. J. (Østfoldforskning) Hanssen & Møller 2013)

The ForMat project has produced three reports discussing the results of surveys of food waste in Norway from manufacturers, wholesalers, grocery stores and consumers.
They found that the five main drivers of increased food waste in Norway (Hanssen n.d.) are as follows:

- Population increase
- Younger generations waste more (60+ years waste 10% of fresh food, 26-39 waste 27%)
- Waste amounts per person are larger in small households and more people are living alone
- Less meals are eaten at home
- Increased product variety is available

In their customer polling, the most frequent reason for disposing of a product was that it was "out of date", meaning that many consumers do not understand 'best before' markings are simply a warning to be more aware of product freshness after a certain amount of time. In 2012, ForMat established a "matsentral" in the Oslo area to redistribute food to those in need. ForMat aided with funding and the Salvation Army, Blue Cross and Church City Mission established Matsentralen SA in September 2013. It was estimated that this initiative would help 3000 clients daily and prevent up to 1000 tons of food waste per year (ForMat..).

Also in Norway, there is a very promising recent initiative that involves many diverse partners with the goal of improving resource utilization in the Norwegian food chain. It's called the CYCLE Project and it will run for four years, having started in March 2013, with a budget of 500 million kroner (majority funded by the Norwegian Research Council)(Cycle 2013). They are taking an interdisciplinary and holistic approach, recognizing the interconnectedness of the FSC and the potential for problem shifting. In terms of product groups they focus on fish, chicken and vegetables. There are five different research areas, or work packages, most including a strong technology focus:

- Automated quality differentiation & sorting of co-streams and waste
- Resource-efficient bioprocessing technologies for food industry
- Bio-processing of waste for feed, fertilizer & energy
- Food safety & logistics
- Socio-economy – market & consumer (Cycle Project 2014)

There are many partners, including Sintef, NTNU, the BAMA group, Nofima, SIFO, Bioforsk, VTT and others (See Figure 18 Cycle Project Partnersfor a more detailed list). The project involves not only Norwegian institutions and considerations but also research partners from Finland and Denmark.

Figure 18 Cycle Project Partners

Clearly the third work package is most relevant to this report with the goal expressed as follows: “Convert waste not appropriate for utilization as human food to feed, feed ingredients or fertilizer, possibly in combination with energy production.” (EU FUSIONS 2014)

The sheer magnitude of these wastes and impacts shows the importance of pursuing research and taking action on food waste. There are some obstacles when undertaking research in this area, and an important one relates to how you define your terms. A discussion of definitions in the literature follows.

8.8 Appendix 8. Definitional Discussion

All parties do not agree on what the terms “food waste” or “food loss” are describing. According to Gjerris & Gaiani (2013), most studies on food waste are nearly impossible to compare due to differing definitions and methodology. From the literature reviewed for this report it was clear that the authors were not always explicit about the definition that they are using. The FAO Report on Global Food Losses and Waste (Gustavsson et al., 2011) was very clear and elaborates on the terms used. As seen in the title, the authors differentiated between food “losses” and “waste”. In both accounts they were only considering products directed to human consumption, automatically excluding animal feed and product portions that are not edible (bones etc). The definitions were taken from another author, Parfitt et al 2010. According to Parfitt and the FAO, *food losses* are those that happen early in the FSC such as those during production, post-harvest and processing and *food waste* happens at or near the end of the FSC, at the retail and final consumption stages.

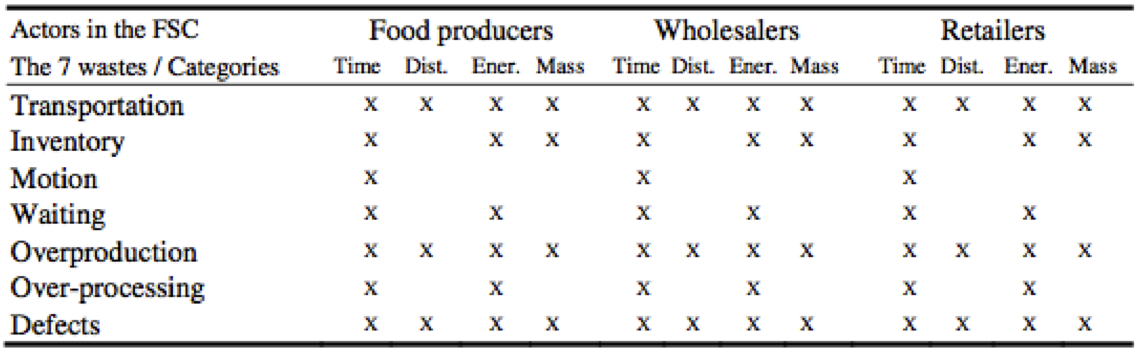
The way food waste is defined has many important implications, including comparability between studies, but also with ethical issues (Gjerris & Gaiani 2013). In their investigation into household food waste in Nordic countries, Gjerris and Gaiani only looked at the waste thrown from private households, thereby excluding the FSC wastes accompanying that end user disposal. Some extremists go so far as to include overconsumption of food, and consumption of animal proteins as food waste (Gjerris & Gaiani, 2013). Also, the terms ‘avoidable’, ‘partially avoidable’, and ‘unavoidable’ have been used by some studies and organizations (Stenmarck et al. 2011).
Stenmarck defines avoidable food waste as food that was edible at some point prior to disposal (for example leftovers) partially avoidable food waste is waste generated because of different consumer habits (e.g. bread crusts, apple skins); and unavoidable food waste is inedible but cannot be separated prior to preparation and consumption (e.g. eggshell, coffee grounds). The FAO definition is useful because it automatically excludes this last category of unavoidable food waste, though that may prove difficult during data collection in practice.

Another interesting perspective comes from researchers at the Department of Production and Quality Engineering at the Norwegian University of Science and Technology (NTNU). Chabada et al. (2013) have applied the seven wastes approach from Lean Production theory to see what light it sheds onto a Norwegian fresh food supply chain. Lean theory defines waste as any activity that adds costs or consumes time without adding value to the customer (Womack and Jones, 2005).
The seven types of waste are:

- Transportation
- Inventory
- Motion
- Waiting
- Overproduction
- Over-processing
- Defects

(Chabada et al. 2013)

The conference paper describing their efforts towards a framework for waste identification (Chabada et al. 2013) also related these seven types to four categories of waste: time, distance, energy and mass. From an environmental perspective we are most interested in the energy and mass. The results are presented in Figure 19 where for Food producers, Wholesalers and Retailers, the seven waste types are listed in relation to the four categories of waste. It shows that Transportation, Overproduction and Defects cause all types of waste, at all nodes examined.



Actors in the FSC	Food producers				Wholesalers				Retailers			
The 7 wastes / Categories	Time	Dist.	Ener.	Mass	Time	Dist.	Ener.	Mass	Time	Dist.	Ener.	Mass
Transportation	x	x	x	x	x	x	x	x	x	x	x	x
Inventory	x		x	x	x		x	x	x		x	x
Motion	x				x				x			
Waiting	x		x		x		x		x		x	
Overproduction	x	x	x	x	x	x	x	x	x	x	x	x
Over-processing	x		x		x		x		x		x	
Defects	x	x	x	x	x	x	x	x	x	x	x	x

Figure 19 Classification of wastes in fresh food supply chains. Chabada et al. 2013

8.9 Appendix 9. Waste Food Hierarchy

Food Waste Pyramid for London designed by Tristram Stuart in collaboration with the Feeding the 5000 steering group, the Mayor's Waste Strategy team, the London Food Board, Peoples for London, Friends of the Earth, WRAP, FareShare & FoodCycle

Figure 20 Waste Food Hierarchy by Tristram Stuart