NTNU – Trondheim
Norwegian University of
Science and Technology

Interactive data visualization of the Norwegian phosphorus cycle, coupling phosphorus with dry matter and energy in a multi-layered material flow analysis model

Richard Olav Rud

Master in Industrial Ecology
Submission date: June 2015
Supervisor: Daniel Beat Mueller, EPT
Co-supervisor: Helen A. Hamilton, EPT
Gang Liu, EPT

Norwegian University of Science and Technology
Department of Energy and Process Engineering

NTNU
Norwegian University
of Science and Technology

Department of Energy
and Process Engineering

EPT-M-2015-73

MASTER THESIS

for

Richard Olav Rud

Spring 2015

Interactive data visualization of the Norwegian phosphorus cycle, coupling phosphorus with dry matter and energy in a multi-layered material flow analysis model

Interaktiv datavisualisering basert på den norske fosfor balansen, sammenkobling av fosfor, tørrstoff og energi i en flerlags materialstrømsanalyse-modell

Background and objective

Phosphorus (P) is a critical nutrient for food production, and the current linear use of P is unsustainable. P is a non-renewable material, and therefore sustainable management of the material is essential. Beyond being a critical nutrient, P is coupled with energy and dry matter. As a result, the management of P affects other material cycles and energy, and therefore a holistic understanding is crucial in order to manage P in a sustainable manner.

In order to gain understanding of the interconnected nature between P, energy and other materials, these must be included in the analysis in order to get a systems-wide understanding. Including energy and dry matter with P in a multi-layered material flow analysis (MFA) increases the complexity. Increased complexity could make it challenging for decision makers to gain understanding of the problem domain, and especially, detect problem shifting. This emphasizes the importance of visualizing the research, and is the motivation for conducting this study.

Based on the Norwegian P system (Hamilton et al., 2014), and more specifically the Norwegian agriculture and waste sector (Hamilton 2015), a interactive data visualization is to be created as an application allowing the user to interactively explore complex flow scenarios, giving a multidimensional overview, coupling P, dry matter and energy. This study should result in an application that helps providing easier insight to the research results, trying to close the knowledge gap between scientists and decision/policy makers.

This project is a continuation of the project work conducted in the fall of 2014 (Rud, 2014), and further development of this application should focus on improving the interactive Sankey model as well as finding complementary visualization techniques. All main drivers of the Norwegian P, dry matter and energy cycle should be addressed with the purpose of creating understanding of the interconnected nature of the Norwegian P model. This project should further on look at food waste related issues (Hamilton, 2015), comparing recycling food waste as biofuel or fertilizer production versus food waste prevention, letting the user explore alternative scenarios. The food waste related scenarios should especially be addressed from an energy and P resource perspective.

The following tasks are to be considered:

1. Literature study

- **a.** Research the Norwegian phosphorus cycle (Hamilton et al., 2014) with emphasis on the agriculture and waste sector (Hamilton, 2015) in order to get a systems-wide understanding of the Norwegian phosphorus cycle including energy and dry matter.
- **b.** Explore the data used for modeling the Norwegian agriculture and waste system (Hamilton, 2015) in order to identify key challenges and interventions related to the agriculture and waste sector, for the P, energy and dry matter layer.
- **c.** Investigate both scenarios included in Hamilton's (2015) research, including food waste prevention and food waste recycling, based on the agriculture and waste sector (Hamilton 2015).
- **d.** Summarize the findings and draw conclusions based on the literature, which is to be used as the basis for the creation of the interactive data visualization.

2. Requirements for the interactive data visualization

- **a.** The application should emphasize on *visually* showing:
  - **i.** The interconnected nature of the phosphorus, energy and dry layer in Norway for the agriculture and waste sector
  - **ii.** Major inputs and losses in the agriculture and waste sector related to food waste, with an emphasis on the amount of avoidable food waste.
  - **iii.** A representation of both the food waste prevention and food waste recycling scenarios, and how these scenarios affect all of the three layers (P, dry matter and energy layer).
- **b.** Visualization techniques to be used:
  - **i.** The multilayered MFA system should be presented as a Sankey diagram using the already existing prototype (Rud, 2015) as the starting point for further development and scenario creation.
  - **ii.** Additional visualization techniques should be investigated and included where it is expected to provide additional insight into the system.
  - **iii.** All visualization techniques used in the visualization model must be documented and justified, in relation to why these methods could help to improve readability of Hamilton's research.

3. Application design

- **a.** Determine a storage structure for all of the three data layers (P, dry matter, and energy).
- **b.** Create the design layout, including:
  - **i.** Desired input and output results of the application.
  - **ii.** Visualization techniques to be used for the multilayered system.

iii. The use of interactive features.
iv. Annotation.
v. Color.
vi. Placing and organizing the visual elements in a user-friendly layout.

4. Application development

a. Develop the application by creating an interactive data visualization based on the application requirements and design process, using web technologies including, HTML, CSS, SVG, JavaScript and Data Driven Documents (D3).

5. User testing

a. Perform user testing on the constructed application.
b. User testing should be documented.

6. Application revision

a. If possible, revise the application based on the findings from the user testing.

7. Evaluation

a. Evaluate the end result related to the tool's ability to convey the research results.

8. Write a thesis report

-- " --

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
Department Head

Daniel B. Müller
Academic Supervisor

Research Advisor: Helen A. Hamilton and Gang Liu

Interactive data visualization of the Norwegian phosphorus cycle, coupling phosphorus with dry matter and energy in a multi-layered material flow analysis model

Richard Olav Rud

Master Thesis

Department of Energy and Process Engineering

Norwegian University of Science and Technology

Trondheim, June 2015

Supervisor 1: Professor Daniel Beat Mueller

Supervisor 2: PhD Candidate Helen Ann Hamilton

Preface

This document is a Master Thesis in Industrial Ecology conducted at the Norwegian University of Science and Technology (NTNU) under the Department of Energy and Process Engineering.

The objective of this thesis was to use interactive data visualization techniques for communicating the results from a multi-layered MFA study related to food waste in Norway.

Supplementing this document is the interactive version of the visualization techniques referred to as the visual narrative and the Norwegian food waste dashboard. These could be accessed through the following links:

The visual narrative: http://folk.ntnu.no/richaror/storyline/
The Norwegian food waste dashboard: http://folk.ntnu.no/richaror/dashboard/

**As for now, Internet Explorer users might experience compatibility issues with the JavaScript framework (D3) used for this project. It is therefore highly advisable to use another browser when looking at the final project online.*

The visual narrative is a introductory application that dose not require any prerequisites. It is thought of as an introduction to the exploratory dashboard. On the other hand, the exploratory dashboard is intended for more advanced users.

Hopefully this project could contribute as supplementary material for the ongoing food waste research conducted by Helen A. Hamilton, Samantha M. Peverill, Daniel B. Müller and Helge Brattebø.

Trondheim, 2015-06-09

Richard Olav Rud

Acknowledgments

First I want to thank my two supervisors that have made this project possible, PhD Candidate Helen Ann Hamilton and Professor Daniel Beat Müller. Thank you for the all the help, creative input and inspiration given during this project.

Secondly, I am grateful for all the work done by the open source community, making great programming libraries, tools and technologies available for free. Keep up the good work!

Richard Olav Rud

Abstract

The utilization of data visualization to explore complex systems is arguably an indispensable method for increasing understanding of a specific problem domain. It is argued that visualization techniques for presenting material flow analysis results should be further developed. This thesis explores the effectiveness of combining material flow analysis with data visualization techniques to communicate the impacts of targeted policies for managing food waste for the Norwegian food production, consumption and waste system. By employing data from ongoing research that examines the use of dry matter, phosphorus and energy in a Norwegian context, the aim of this study was to develop a web application that uses a combination of visualization techniques to communicate the multifaceted issues related to food waste. A selection of different visualization techniques were applied and evaluated in relation to their ability to communicate the research utilized in this thesis. A combination of both commonly used visualization techniques from material flow analysis with more novel visualization techniques, were applied showing promising results. In the end, a user test was conducted to assess the learnability and usability of the application. The results of the user test indicates that there is a potential to develop a tool for effective resource management of biomass, including phosphorous and energy, by communicating material flow analysis results more efficiently using modern data visualization methods.

Sammendrag

Bruken av datavisualisering for å utforske komplekse systemer er uten tvil en uunnværlig metode for å øke forståelsen av et spesifikt problemområdet. Det argumenteres for at visualiseringsteknikker for å presentere resultater fra materialstrømanalyse bør videreutvikles. Denne oppgaven utforsker effekten av å kombinere materialstrømanalyse med datavisualiseringsteknikker for å kommunisere konsekvensene av målrettet politikk for håndtering av matavfall fra det norske matproduksjons- og konsumpsjonssystemet. Ved å benytte data fra pågående forskning som undersøker bruken av biomasse, fosfor og energi i en norsk sammenheng, er hensikten med dette prosjektet å utvikle en web-applikasjon som bruker en kombinasjon av visualiseringsteknikker for å kommunisere de flerdimensjonale utfordringene knyttet til matavfall. Et utvalg av ulike visualiseringsteknikker ble benyttet og evaluert i forhold til deres evne til å kommunisere forskningen som benyttes i denne oppgaven. En kombinasjon mellom tradisjonelle visualiseringsteknikker, ofte benyttet i forbindelse med materialstrømsanalyse, og mer eksperimentelle visualiseringsteknikker, ble tatt i bruk. Disse ga oppløftende resultater. Til slutt ble en brukertest gjennomført for å vurdere læringsutbytte og brukervennligheten til applikasjonen. Resultatene fra brukertesten indikerer at det finnes et potensiale for å utvikle et verktøy for effektiv ressursforvaltning av biomasse, inkludert fosfor og energi, ved å kommunisere materialstrømsanalyseresultater mer effektivt ved hjelp av moderne datavisualiseringsmetoder.

Contents

Preface i
Acknowledgment ii
Abstract iii

List of Figures **viii**

List of Tables **xi**

1 Introduction **2**
1.1 Background 2
1.2 Research gap 4
1.3 Objectives 5
1.4 Structure of the Report 6

2 Related work **7**
2.1 Resource assessments of food waste systems 7
2.2 Visualization techniques: Material flow analysis and multidimensional data . 9

3 Method **13**
3.1 Data 13
3.2 System development and implementation 14
3.3 MFA 15
3.4 User testing 15

4 Results **19**
4.1 The narrative visualization 19

4.2 The Norwegian food waste dashboard 35
4.2.1 General structure 35
4.2.2 The phosphorus and energy flow diagram 39
4.2.3 Scenario comparison 45
4.2.4 Problem shifting 49
4.2.5 The Norwegian food production and consumption system quantified . 52
4.2.6 Avoidable food waste 54
4.2.7 Recycling versus prevention 57
4.3 User testing 58

5 Discussion **60**
5.1 The visual narrative 60
5.2 The Norwegian food waste dashboard 61
5.2.1 Comparing scenarios 61
5.2.2 Approach 62
5.2.3 Limitations 64
5.3 Development process 65
5.4 User testing 66
5.5 How does this project improve the communication of the research conducted by Hamilton et al. (2015b)? 67
5.6 What are the main benefits and shortcomings of the tools ability to convey the research? 67

Bibliography **69**

A Code for generating the energy and phosphorus layer **75**
A.1 Generating the phosphorus layer 75
A.2 Generating the energy layer 83

B The complete source code **91**
B.1 Overview file structure 91
B.2 Link to all of the code on GitHub 92

B.2.1 Code: The Norwegian food waste dashboard 92
B.2.2 URL: The Norwegian food waste dashboard 92
B.2.3 Code: The narrative visualization 92
B.2.4 URL: The narrative visualization 92
B.3 References for programming libraries 93
B.3.1 MAMP 93
B.3.2 Globe plugin 93
B.3.3 TopoJSON 93
B.3.4 D3: Data-driven documents 93
B.3.5 Parallel coordinates library 93
B.3.6 ColorBrewer 93
B.3.7 Advanced legend 93
B.3.8 C3 93
B.3.9 intro.js 94
B.3.10 d3-funnel-charts 94
B.3.11 fullPage.js 94

C Results: User testing **95**

List of Figures

4.1 Navigation bar 20
4.2 Issues addressed in the Visual Narrative application 20
4.3 The amount of food waste in the developed world 21
4.4 Interactive legend 21
4.5 The amount of wet organic waste in Norway 22
4.6 Highlighting a legend item 22
4.7 Quantifying food waste in Norway 23
4.8 Linking the original data sources 24
4.9 Title, text content and annotation 24
4.10 Comparing only two categories of process energy 25
4.11 Agriculture sector emissions 25
4.12 "Hidden" information 26
4.13 A limited resource (Top 10 phosphate rock reserves in the world) 27
4.14 Phosphorus use in Norway 28
4.15 Strategies for food waste in the European Union 29
4.16 Comparison of governmental spending 29
4.17 Potential for increased energy production 30
4.18 Animated transition 31
4.19 Wet organic waste as an energy source 32
4.20 Showing a selection of possible tradeoffs between the baseline and different food waste scenarios 32
4.21 Highlighting the pathway of the baseline scenario 33

4.22 Brushing and rearranging the scale for the parallel coordinates plot 33
4.23 Presenting the user with a direct link to the Norwegian food waste dashboard 34
4.24 Illustrating the dataflow for the Norwegian food waste dashboard 35
4.25 Menu 36
4.26 Step-by-step walkthrough of the application 36
4.27 Acknowledgments 37
4.28 Collapsible boxes, example 1 37
4.29 Collapsible boxes, example 2 38
4.30 Phosphorus Sankey diagram, baseline scenario 40
4.31 Energy Sankey diagram, baseline scenario 40
4.32 Flow diagram legend (phosphorus) 41
4.33 Gridlines 41
4.34 Button for switching between scenarios in the phosphorus layer 41
4.35 Button for switching between scenarios in the energy layer 41
4.36 Hovering over flows 42
4.37 Dynamic titles 42
4.38 Phosphorus: Scenario 1: Recycling food waste 43
4.39 Phosphorus: Scenario 2: Preventing food waste 43
4.40 Energy: Scenario 1: Recycling food waste 44
4.41 Energy: Scenario 2: Preventing food waste 44
4.42 Introduction Text with complementary link 44
4.43 Comparing scenarios as multiple clusters of bar charts 46
4.44 Interactive legend for scenario comparison (unselecting scenarios) 47
4.45 Interactive legend for scenario comparison (Hovering over a specific scenario) 47
4.46 "Waste to biogas" from the "Scenario comparison" diagram 48
4.47 Showing problem shifting through a parallel coordinates plot 50
4.48 Hovering over the table gives the user a highlighted view of the selected pathway 50
4.49 Brushing function for the parallel coordinates plot 50
4.50 Rescaling the axis 51
4.51 The Norwegian food production and consumption system quantified 53

4.52 Comparing domestic production with avoidable food waste 53
4.53 Popup table, “Comparing production with consumption and losses” 53
4.54 Stacked bar chart for showing the avoidable food waste measured as dry matter content 55
4.55 Highlight effect for the stacked bar chart 55
4.56 Unselecting the default food groups 56
4.57 Popup table, avoidable food waste 56
4.58 “Recycling versus prevention” diagram 58
4.59 Questions from the user testing 59

C.1 Results from the users perceived usability of the tools 95
C.2 Results from the tasks 96

List of Tables

B.1 Files included in the Norwegian food waste dashboard 91
B.2 Files included in the visual narrative 92

Chapter 1

Introduction

1.1 Background

Food waste is estimated to currently amount to one third of all produced food, having a tremendous effect on the world's ecosystem (Wirsenius, 2003), effecting water use, land use, loss of biodiversity and the carbon footprint (FAO, 2013). Therefore, in order to reduce food related environmental impacts, it is important to reduce unnecessary food production. Expected growth in food production due to population growth in the coming years (Kytzia et al., 2004) reinforces environmental concerns (Foley et al., 2013) and amplifies the need for effective resource management.

Research has been conducted in Norway finding that Norway approaches food waste with recycling strategies, using food waste as a source for bioenergy (Hamilton, Peverill, Müller & Brattebø, 2015b). Bioenergy production, increases the phosphorus demand, since biomass inputs depends on phosphorus (Hamilton et al., 2015a). Therefore, energy and phosphorus are closely linked, indicating that both resources should be addressed when trying to optimize the food production and consumption system in Norway (Hamilton et al., 2015b).

Phosphorus is an essential nutrient for food production (Cordell, Drangert & White, 2009), and it is estimated that the current use of the substance will lead to depletion (Schmid Neset, Bader, Scheidegger & Lohm, 2008). Beyond being a critical nutrient, phosphorus is also considered a pollutant, if accumulated in the wrong environmental compartments (Yuan, Shi, Wu, Zhang & Bi, 2011). Furthermore, phosphorus-resources are only abundant in a few countries, and Norway is one of many countries heavily dependent on the import of phosphates (USGS, 2015).

Closely linked with phosphorus, is energy. Producing food is energy intensive, and it is estimated that approximately 5 MJ of energy is required to produce an output of 1 MJ of energy embedded in food for human consumption. The result is a negative energy balance and an inefficient system (Kytzia et al., 2004). Using predominantly fossil fuels, this negative energy balance has a large impact on greenhouse gas emissions (Cordell et al., 2009).

The current strategy for reducing food waste laid out by The European Union Committee (House of Lords, 2014) is based on the food waste hierarchy, where in descending order, prevention is seen as the most favorable option followed by preparation for reuse, recycling, other recovery methods and disposal as the least favored option. According to Hamilton at al. (2015b) such a predetermined attitude might inhibit the search for a systems-wide understanding. Instead, performing a holistic analysis of the food production and consumption system looking into multiple resources, current policies can be evaluated and future scenarios can be investigated, leading the way towards better understanding of food waste issues for decision makers (Hendriks et al., 2010; Hamilton et al., 2015b).

Understanding the negative impact of increasing food waste, the Norwegian government has acknowledged that food waste is a major issue, and that reduction of food waste is high on the political agenda (Brekk, 2010). However, according to Hamilton et al. (2015b), it is not clear whether food waste prevention is the prevailing strategy. As opposed to what the government claims, it appears that strategies focus on recycling solutions for creating energy, rewarding the production of bioenergy from organic waste. This is reflected in the state budget as well as the new intersectoral biogas strategy (Regjeringen, 2015; Hamilton et al., 2015b; Klima- og Miljødepartementet, 2014), which highlights biogas as one of the top measures for climate mitigation in Norway (Klima- og Miljødepartementet, 2014).

It has previously been attempted to quantify the amount of avoidable food waste in Norway (Hanssen & Schakenda, 2011; Hanssen & Møller, 2013). However, a systems-wide assessment of the mass, energy and critical material flows for the Norwegian food production, consumption and waste system, has never been carried out (Hamilton et al., 2015b). Hamilton et al. (2015b) has researched the Norwegian food waste system, quantifying biomass (dry matter content), energy and phosphorus, including imports, exports, domestic supply, losses and sinks. In addition, this study also included scenario analysis, comparing food waste prevention with food waste recycling.

A systems-wide assessment of the Norwegian food waste system can be used to evaluate current material flows and stocks, using material flow analysis (MFA) as a tool for decision makers to evaluate current policy to see if it complies with goals for sustainable management. As a result, current improvements and future preparations related to future flows and stocks could be made, while at the same time lowering the risk of problem shifting between different environmental compartments (Hendriks, 2010; Brunner, 2012).

Having gained increased attention as a tool for decision making (Bringezu & Moriguchi, 2002), visualization of MFA results might amplify the method as an effective tool for resource management. As stated by Brunner (2012), MFA results could only reach its full potential if the results are visualized in an engaging way.

1.2 Research gap

Based on the assessment of the Norwegian food production and consumption system focusing on avoidable food waste (Hamilton et al., 2015b), the overall goal of this project is to provide knowledge in the crossroads of data visualization and MFA.

Traditionally, Sankey diagrams have been used for visualizing MFA results (Brunner, 2012). For one-dimensional data, this technique has proven successful if we are to judge it by its frequent application in the field of industrial ecology (Schmidt, 2008a). On the contrary, dealing with multidimensional data as referred to in this paper as multi-layered MFA, traditional Sankey diagrams are limited (Rud, 2014).

A great deal of research has been done regarding the use of data visualization for scientific application (Fox & Hendler, 2013), and this rapidly evolving field contains a range of approaches. Many prior works have investigated possible visualization techniques for multi-dimensional and multivariate data (Kosara, Bendix & Hauser, 2005; Inselberg, 1985; Santos & Brodlie, 2004; Spears, 1999). Previous effort has been made to investigate and develop a visualization technique for multi-layered MFA models (Rud, 2014), where the central idea was to simultaneously display multiple MFA layers using transparent Sankey diagrams. This idea proved to be insufficient for larger datasets and layers that have different scales, providing the user with a cluttered layout, adding confusion instead of understanding (Rud, 2014). On this basis, there is still lacking a suitable framework for visualizing multi-layered MFA models (Rud, 2014).

The belief that a single visualization technique could be developed (Rud, 2014) is in this project abandoned. Therefore, combining visualization techniques to tackle problems of complex and interconnected nature, translating large volumes of data into valuable insight, is needed (Lima, 2011). Thus, with increasing availability and affordable visualization technologies for the web (Fox & Hendler, 2013), this study hopes to further develop existing visualization techniques alongside the traditional Sankey diagram layout of MFA, using web-technologies. Using the communicative power of interactive data visualization, including animation, interaction and storytelling, to convey MFA research, this project aims at trying to create a foundation for understanding the multifaceted impacts of increasing food waste. Especially, in the context of the research conducted by Hamilton et al. (2015a; 2015b), it is crucial that problem shifting is adequately communicated so that decision making is based on a holistic understanding of the problem domain in order to minimize trade-offs. This includes, showing transitions between scenarios, and how different scenarios affect specific environmental compartments, as well as the trade-offs occurring between the scenarios. With the data from the study conducted by Hamilton et al. (2015b), the goal of this project is to develop both an explanatory and exploratory tool solving the aforementioned challenges.

1.3 Objectives

The main contribution of this work is threefold. First, a review of the literature for both food waste and multidimensional visualization techniques is to be conducted. Secondly, developing an explanatory visual narrative for giving the user insight into the problem domain in conjunction with an exploratory dashboard solution for interacting with the data behind the Norwegian food waste system (Hamilton et al. 2015b). Thirdly, the resulting tool should be user tested in order to confirm the learnability and usability of the tool.

More specifically, the following tasks are to be considered:

1. A review of literature related to food production and food waste, focusing on phosphorus, energy and biomass (dry matter), both in a global and Norwegian context.

2. An exploration and identification of key challenges and interventions related to food waste for the Norwegian food production, consumption and waste system, using the data from Hamilton et al. (2015b), including an investigation of the food waste prevention and food waste recycling scenarios.

3. A review of literature related to possible complementary visualization techniques supporting the already established use of Sankey diagrams in MFA, specifically focusing on multidimensional data visualization.

4. Document the visualization techniques used, and argue why they improve the communication of the research conducted by Hamilton et al. (2015b).

5. Develop a web-based data visualization tool for exploratory and explanatory investigation of the Norwegian food production, consumption and waste system.

6. Evaluating the tool by conducting a user test.

7. Evaluate the end result, related to the tool's ability to convey the research of Hamilton et al. (2015b).

1.4 Structure of the Report

The remainder of this thesis has the following structure. In Chapter 2 related work is reviewed. In Chapter 3 the methods used in this project is presented. Chapter 4 presents the results. The results are then discussed in Chapter 5, alongside conclusions and recommendations for future work.

Chapter 2

Related work

This project investigates related work, including resource assessments of food waste systems and visualization techniques in conjunction with material flow analysis and multidimensional data. The relevant literature is reviewed below.

2.1 Resource assessments of food waste systems

Assessing food production and consumption systems have been gaining increased attention in the field of industrial ecology (Wirsenius, 2003).

Wirsenius (2003) modeled the biomass metabolism of the global food system, uncovering food production as one of the most influential activities on the anthroposphere, altering material and energy cycles. Assessing the biomass flows for the global food system, Wirsenius (2003) discovered that the major drivers of the biomass system, was meat production, mainly due to the lower feed conversion efficiency, this was also supported by the research conducted by Refsgaard, Bergsdal, Pettersen & Berglann (2011). Simultaneously, animal husbandry is also a major driver of phosphorus (Hamilton et al., 2015a).

Risku-Norjaa & Mäenpääb (2006) assessed the food system in Finland. The main findings suggest that changing consumption patterns have a greater effect in reducing environmental impacts than changing production patterns. Despite this, a change in diet from mixed to mainly plant based, is expected to have a negative effect on the economy, due to the same concern advertised by Wirsenius (2003), that meat production is more intensive than plant production and thus positively stimulates the economy by an increased throughput of materials. Beyond this, the study (Risku-Norjaa & Mäenpääb 2006) emphazise livestock husbandry as the main contributor to acid emissions, and that soil cultivation leads to major outputs of GHG emissions. Furthermore, the study (Risku-Norjaa and Mäenpääb 2006) does not take into consideration deposition of nutrients into waterbodies or biodiversity issues.

Studies related to food production and consumption systems often only look at a single resource in isolation (Hamilton et al., 2015a; Cooper & Marquet, 2013; Ott & Rechberger, 2012; Schmid et al., 2008). According to Hamilton et al. (2015a) this is unfortunate due to the interconnected nature of many resources, including phosphorus and energy (Hamilton et al.2015). As an example, increasing bioenergy production could indirectly lead to an increase in phosphorus accumulating in agricultural soil due to increased upstream demands for biomass. Derived from this notion, Hamilton et al. (2015a) arguments that there is a need for a systems-wide understanding, to avoid problem shifting. As suggest by Hamilton et al. (2015a), future models of the food production, consumption and waste system must provide a holistic view in order to understand the interconnected nature of multiple resources, and thus to avoid displacing of problems (2015b).

The importance of studying system as an interconnected whole, were also addressed by Kytzia et al. (2004), assessing the material, energy and monetary flows in an economically extended MFA. Looking at the relationship between monetary exchanges and resource consumption is arguably important in order to understand the driving forces behind environmental issues.

In a Norwegian context, several studies have been conducted on avoidable food waste. Most up to date is the research conducted by Ostfold Research (Hanssen & Schakenda, 2011; Hanssen & Møller, 2013). Ostfold Research conducted a series of studies focusing on avoidable food waste in the whole value chain from food processing, wholesale, retail and human consumption. These studies confirms that there is a huge potential in reducing food waste and quantifies the amount of avoidable food waste being discarded, distributed among the various food groups.

An assessment of biomass (dry matter content), energy and phosphorus in a multi-resource MFA for the Norwegian food production, consumption and waste system, was first conducted by Hamilton at al. (2015b). The study investigates the impact of targeted policies related to food waste prevention and food waste recycling, and is crucial in providing a systems-wide understanding of the Norwegian food production, consumption and waste system. The data used in the study provides a quantification of the mass, energy and critical flows of the Norwegian food production, consumption and waste system, creating a foundation for effective resource management. Taking a multidimensional approach includes investigating possible tradeoffs between different environmental compartments. At the core of the research (Hamilton et al., 2015b), the dry matter content of the system was calculated in order to derive the content of the highly coupled resources, energy and phosphorus.

Coupling phosphorus and energy makes it possible to detect problem shifting. Especially noteworthy is the comparison between food waste recycling and food waste prevention. Recycling avoidable food waste to biogas seems to only have a marginal energy return if the process energy requirements upstream are accounted for. Moreover, increasing food waste increases the total imports of phosphates as well as accumulation of phosphorus in agricultural soil. Therefore, the study (Hamilton et al., 2014) indicates that governmental priorities should focus on preventing food waste in the firs place. In addition, the relative importance of biogas as a substitute for energy, and phosphorus as a critical material for food production, seems evident. Despite this, it seems that policy makers neglects this relationship (Hamilton et al., 2015b).

2.2 Visualization techniques: Material flow analysis and multidimensional data

The Sankey diagram has been a well renowned visualization technique. From Minard's drawing in 1861 of Napoleon's march into Russia (Tufte, 1983), to the application of Sankey diagrams in the field of industrial ecology (Schmidt, 2008a; Schmidt, 2008b), this visualization technique has proven to be a favorable way for scientists to quantify flows in a systems perspective.

The visualization of Sankey diagrams has not traditionally focused on displaying high-dimensional data. Therefore, it is challenging to apply this visualization technique for multi-layered MFA models. As is the case for the research conducted by Hamilton et al. (2015b), presenting dry matter, energy and phosphorus data simultaneously. The most relevant research appears to be previous work that investigates visualization of networks, multidimensional and multivariate data, in addition to animation and interaction techniques.

Translating multidimensional data into comprehensible information is considered by Santos & Brodlie (2004) as one of the major challenges in the field of data visualization. Supported by Spears (1999), is the idea that principles of general visualization techniques could be used for inspiration in order to create customized visualizations to accommodate specific needs.

Spears (1999) highlight the use of color, glyphs and parallel coordinates as the most prominent techniques for visualizing multidimensional data. First, color is valuable for adding an extra dimension to almost all types of visualizations, both different colors, and the use of saturations (Spears, 1999). Additional research conducted by Harrower & Brewer (2003) investigates effective color schemes, and at the same time provides a tool for selecting color schemes. Harrower & Brewer (2003) created color schemes with the purpose of styling maps. Even so, the "ColorBrewer" tool has been become a widely used tool for working with color schemes and color saturations, and it is implemented as a part of the D3 data visualization framework for accessing different color scales (Bostock, Ogievetsky & Heer, 2011), which is especially useful when separating different dimensions. Glyphs, on the other hand, apply small shapes that vary depending on the dimension they represent (Spears, 1999; Kirk, 2012). Additionally we have parallel coordinates, originating from the work conducted by Inselberg (1985). The parallel coordinates technique is based on having multiple axes sequentially, where each of the axes represents a separate dimension (Spears, 1999). As highlighted by Kirk (2012), this technique is especially good for looking at correlations and consistencies that exists in a dataset. For multilayered MFA, parallel coordinates could be relevant when trying to visualize problem shifting and tradeoffs between different dimensions. Kosara, Bendix & Hauser (2005) proposed a parallel coordinates technique, similar to what is the case of Sankey diagrams, using weighted edges between the different dimensions instead of the traditional lines (Inselberg, 1985). This work (Kosara, Bendix & Hauser, 2005) is based on the axis layout for parallel coordinates and the technique of weighted flows as well as weighted nodes, hence letting the values of a dataset determine the size of the flows and nodes.

Research conducted by Heer & Robertson (2007) on animated transitions, suggests that animation is beneficial for engaging the user and increasing understanding when transitioning between datasets. Further on, an emerging branch of data visualization research is storytelling with data. Segel & Heer (2010) refer to this as narrative visualization, bringing together storytelling techniques and interactive data visualization. A study conducted by Segel & Heer (2010) investigated a set of narrative visualizations in order to identify techniques for storytelling with data. Their main findings suggests that combining a narrative structure with visualization techniques, using animation and interaction, is good for enhancing reader engagement with data. Simultaneously, their findings suggest that the use of interaction and animation must avoid being exaggerated. Moreover, Segel & Heer (2010) mention the relatively scarce use of interactivity when working with flow charts, something highly relevant for MFA.

Despite huge advancements in the field of data visualization, there is limited research focusing on visualization techniques for MFA. Most prominent is Schmidt's (2008a; 2008b) work on investigating the use of Sankey diagrams in energy and material flow management. Schmidt (2008a) provides a historical overview of the application and methodological framework alongside a review of the current application of Sankey diagrams in industrial ecology (Schmidt, 2008b). The main strength highlighted by Schmidt (2008b) is the effect of Sankey diagrams to drive the users attention to the most crucial parts of a system, while still portraying the interconnected complexity. Furthermore, aggregated levels of display could be tailored to increase or decrease the complexity of the systems (Schmidt, 2008b). This also complies with what Shneiderman (1996) suggests, providing an overview first, then zoom and filter before giving details on demand. The opposite could also be the case, going from detail to overview, as proposed by van den Elzen & van Wijk (2014). Both cases support both top-down and bottom-up analysis of systems, increasing or decreasing complexity (Schmidt, 2008b), and are highly relevant when dealing with multidimensional systems.

Furthermore, a number of projects have investigated the use of Sankey diagrams for visualizing energy flows. Work conducted on the energy flows for the city of Weimar (Reihmann, Hanfler & Froelich, 2005), suggests that a tool for supporting decision making such as Sankey diagrams must include multiple views, catering to both expert and novice users. Further on, the study highlights the importance of interaction, so to facilitate exploration in order to fulfill different requirements. Deng, Li & Shao (2014) stresses the need for automated process for the creation of Sankey diagrams when visualizing energy systems, due to the complexity of these systems.

Despite a lack of research on visualization techniques for MFA, the freeware STAN was developed for working with material flow analysis. STAN is a software with the ability to graphically model material and substance cycles, manage data, perform calculations and graphically present results (Cencic & Rechberger, 2008). Despite this, STAN is not optimized for communication purposes, lacking the ability to interactively visualize scenarios as well as view multiple layers simultaneously. STAN only allows exporting MFA results as static imagery, making it hard to reuse elements for communication purposes in other media (Rud, 2014).

Using the aforementioned techniques as a basis, this project provides a combination of explanatory and exploratory visualization techniques for communicating the research of Hamilton et al. (2015b). At the same time, this project aims at creating a basis for future work with regards to visualizing multi-layered MFA systems.

Chapter 3

Method

3.1 Data

The data behind this project is mainly derived from the work conducted by Hamilton et al. (2015b). Hamilton et al. (2015b) utilized historical figures based on averaged data from national statistics, reports and scientific articles for the period 2009-2011, for calculating the flows and stocks of phosphorus, energy and biomass (dry matter content). The data was altered in multiple iterations, including aggregation of the data, which improved the readability of the results, as well as making the data easier to work with in terms of creating a user-friendly visualization. Further on, the data has three dimensions, including phosphorus, energy and dry matter. The dry matter content was used as the basis for deriving the phosphorus and energy layer. For both phoshporus and energy, two scenarios were created, including "Scenario 1: Recycling food waste" and "Scenario 2: Food waste prevention". The project conducted by Hamilton et al. (2015b) is ongoing at the moment of writing this thesis, and therefore certain numbers might be subject to change.

The data for both of the Sankey diagrams (labeled flow diagrams for the Norwegian food waste dashboard) uses data derived from Hamilton et al. (2015b) in its entirety. The other diagrams included in the Norwegian food waste dashboard applies some data from of the dataset provide by Hamilton et al. (2015b) alongside supplementary data, all assembled to substantiate specific contexts based on an overall investigation of the problem domain.

The data was mainly provided in Microsoft Excel files As a result, the files were manually converted to more programmatically manageable JavaScript Object Notation (JSON) and Comma-separated Value (CSV) files.

Furthermore, complementary data was derived from Norway Statistics, including historical figures on wet organic waste (Miljødirektoratet, 2015) and GHG emissions broken down for different sectors (SSB, 2015). The mineral fertilizer statistics were collected from historical reports created by The Norwegian Food Safety Authority (2013a; 2013b; 2013c; 2014; 2015). Further on, the future estimates for biogas potential in Norway were based on the report from the Ministry of Climate and Environment (Klima- og Miljødepartementet, 2014). For estimating budget priorities an investigation of the state budget was conducted (Regjeringen, 2014a). The amount of food waste on a global scale uses data from the Food and Agriculture Organization of the United Nations (FAO, 2013) and the avoidable food waste amounts for the visual narrative was taken using the report from Ostfold Research (2011).

3.2 System development and implementation

No specific systems development methodology was adopted in its entirety, arising from the fact that only a single developer was involved in the development of the application. However, principles of agile software development methodologies based on the agile manifesto (Fowler & Highsmith, 2001) were used as a referencing framework. First, focusing on individuals and interaction over process and tools. Secondly, providing a functioning application over comprehensive documentation. Thirdly, collaboration with the researchers involved over a prefixed requirements specification. Lastly, responding to change over following a strict plan. Overall the development of the tool used an iterative approach.

The application is implemented using web technologies, including HTML, CSS, SVG and JavaScript. At the core of the data visualization, the D3 visualization framework was implemented for easy manipulation of data and rendering into shapes as SVG's allowing the application to be displayed in a web browser, automating the data handling processes (Bostock, Ogievetsky & Heer, 2011). Other D3 based libraries have also been applied, including C3.js, a D3 based charting library for creating simple visuals, including bar charts and line charts. For parallel coordinates the parcoords.js library was used. As mentioned in the previous section, JSON and CSV files were used for storing the data, alongside directly storage of data in JavaScript files when using the C3.js programming library.

Additional technologies and frameworks include fullpage.js as a JavaScript framework for scrolling between elements in the storyline visualization. Twitter Bootstrap a HTML, CSS and JavaScript framework for layout and interactive components. JQuery, a JavaScript based framework for dynamic web content, as well as intro.js, a JavaScript framework for giving instructions to the user.

For version control and code management, Git and Github were used. The development was further conducted using MAMP, a virtual server for working locally with code development. The final project was deployed using the NTNU server.

3.3 MFA

This project did not involve conducting a Material Flow Analysis (MFA). However, MFA methodology was used at the core of this project for presenting the flows and stocks of the Norwegian food production, consumption and waste system, following the principles of MFA. MFA has methodological variations, including substance flow analysis (SFA) for analyzing individual substances (Brunner, 2012) as well as bulk-MFA, assessing the total material flows within a system (Kytzia et al., 2004). In this project the term MFA will be used for the sake of clarity and encompass energy, phosphorus and dry matter.

3.4 User testing

A user study was conducted to evaluate the usability of the application, as well as the effectiveness of the data visualization techniques in terms of communicating results. This includes an overall evaluation of both the storyline and dashboard visualization. The user test combined both qualitative tasks for the user to solve and quantitative questions for ranking the overall usability of the application. Five users were recruited based on Nielsen's (Nielsen & Landauer, 1993; Nielsen, 2000) recommendation. Two of the users were female and three were male. The age of participants where in the range between 21 – 26 years old, the average

age was 24.4. Most of the users were familiar with the concept of data visualization, but none had any prior knowledge in MFA. It is worth mentioning that Norwegian regulation limits the type of information that could be stored about a specific user (Personopplysningsloven, 2000). Thus, information that could identify a person requires concession from The Norwegian Data Protection Authority (Eika, 2011). As follows, the results from the user testing were stored in such a way to avoid results being attributed to the individual user. Consequently, this project avoided linking the results with names, age, location and other identifying data.

The main objective of the user study was to document the learnability and usability of the application through a questionnaire. A number of tasks were given to evaluate the communicative power of the application, and a number of questions were given to uncover the usability. The questionnaire was divided in two parts, one with specific tasks to be solved during the test, and one part with questions about general usability. The tasks where created specifically to solve for issues related to food waste, while the usability questions used a slightly modified version of the System Usability Scale (SUS) by Brooke (1996), which in a study by Tullis & Stetson (2004 as cited in Stone, Jarrett, Woodroffe & Minocha, 2005), were evaluated to give the most reliable result. The System Usability Scale uses a 5-point Likert scale (1 = strongly disagree, 5 = strongly agree).

The user test was set up such a way that the recruited users were given the URLs of the project ("http://folk.ntnu.no/richaror/storyline/" and "http://folk.ntnu.no/richaror/dashboard/") for conducting the tests remotely, before filling out a questionnaire.

The users were asked to solve the following tasks:

- T1: Do you think there any environmental benefits associated with recycling food waste, if this is the case, what do you think these are?
- T2: What do you think are the environmental benefits associated with food waste prevention?
- T3: Do you think are the conflicting issues related preventing food waste in the first place versus recycling food waste to biogas policies.

- T4: Do you think are any major trade-offs between choosing a policy focusing on recycling food waste versus a policy focusing on preventing food waste, if so, what do you think are the major trade-offs?
- T5: If you were to decide, what do you see as the best scenario with regards to policy making (focus on food waste recycling or food waste prevention)?
- T6: What types of food do we in Norway throw away the most?
- T7: Which step in the value chain do you think has the greatest potential for reducing food waste?
- T8: Which process/processes (Plant Production, Animal Husbandry, Food Processing, Human Consumption, Waste Management and/or Biogas Production) do you think has the most impact on the overall phosphorus system?
- T9: Which process/processes (Plant Production, Animal Husbandry, Food Processing, Human Consumption, Waste Management and/or Biogas Production) do you think has the most impact on the overall energy system?

The users were asked to answer the following questions (Based on SUS):

- Q1: I think that I would like to use a system like this more frequently to learn about a specific topic
- Q2: I found the system unnecessarily complex
- Q3: I thought the system was easy to use
- Q4: I think that I would need the support of a technical person to be able to use this system in a proper way
- Q5: I found the various functions in this system were well integrated
- Q6: I thought there was too much inconsistency in this system
- Q7: I would imagine that most people would learn to use this system very quickly
- Q8: I found the system very hard to use
- Q9: I felt very confident using the system
- Q10: I needed to learn a lot of things before I could get going with this system

Chapter 4

Results

This chapter presents the developed web application, including the visualization techniques and technologies used for the narrative visualization and the Norwegian food waste dashboard. The last part of this chapter presents the results of the user test.

4.1 The narrative visualization

The narrative visualization gives the user an overall introduction to issues related to food waste. The technique applied to the visual narrative can be categorized as an interactive slideshow (Segel & Heer, 2010). The interactive slideshow combines storytelling with interactive graphs, structured as a narrative, addressing multiple issues related to food waste. The technologies used, includes the fullPage.js JavaScript plugin with D3 and C3 for interactive visualization components, including Colorbrewer by Harrower & Brewer (2003) for determining the use of color and color saturations.

A total of 26 slides were provided, giving the user a step-by-step walkthrough of food waste related issues. The general structure of the slideshow is downwards scrolling using the mouse, keyboard or touch events (drag behavior on media devices like smartphones and tablets) with a clickable navigation bar for directly navigating between slides (as bullet points) on the right side as seen in figure 4.1.

Figure 4.1: Navigation bar

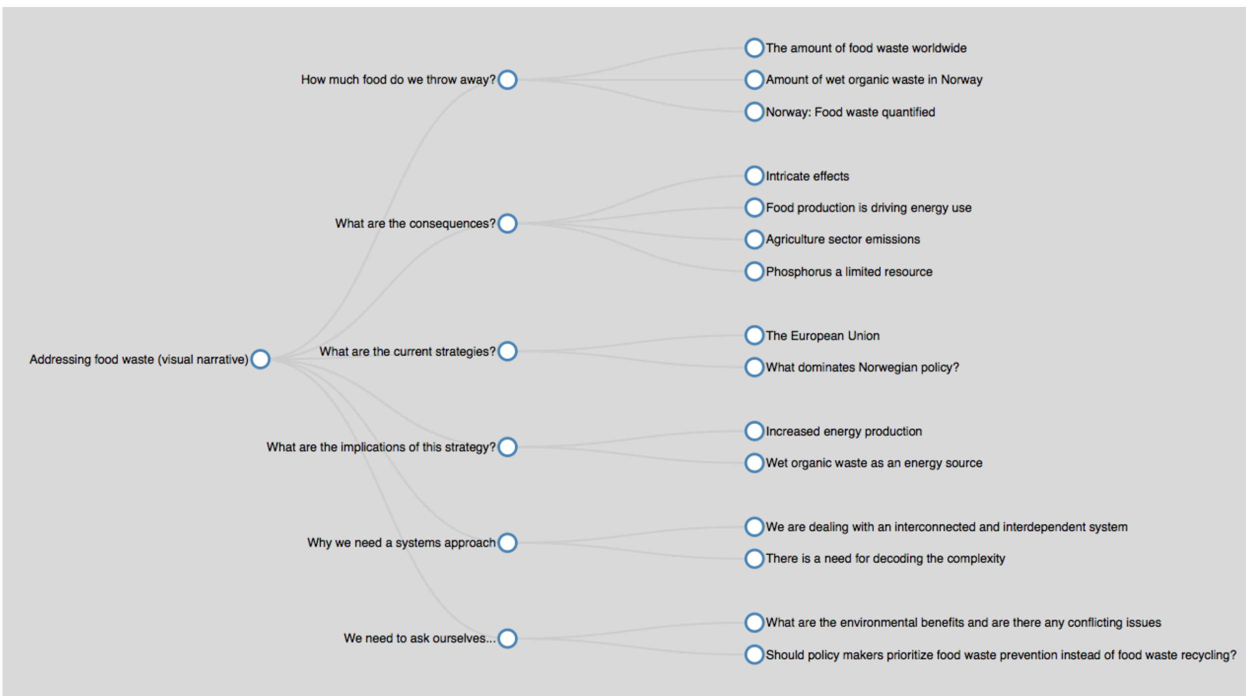


Figure 4.2: Issues addressed in the Visual Narrative application

The key issues related to the research conducted by Hamilton et al. (2015) are present in the visual narrative. The main issues addressed are listed in figure 4.2. Figure 4.2 displays the hierarchical structure of the visual narrative, with topics and subtopics presented.

“How much food do we throw away?” is the first topic addressed. The first graphic, as seen in figure 4.3, depicts the amount of food wasted in the developed world. Making use of the interactive legend, categories could be selected by the user, as seen in Figure 4.4, by

Figure 4.3: The amount of food waste in the developed world

Figure 4.4: Interactive legend

hovering over the legend item or clicking it to temporarily remove the category. The x and y-axis of the diagram scales accordingly. The interactive functionality is a recurring element for all of the bar charts used in the visual narrative.

The next “slide” presents the growth of wet organic waste in Norway from 1995-2011, as depicted in figure 4.5. As with all of the other bar charts, the categories in the legend can be highlighted by hovering over one of the legend items, as illustrated in figure 4.6.

Quantifying avoidable food waste, the slide presented in figure 4.7, utilizes data from Ostfold Research (Hanssen & Schakenda, 2011) to show how much avoidable food waste is discarded throughout the value chain distributed among the various food groups. Moving from a global (as illustrated in figure 4.3) towards a Norwegian context.

After having given information to the user about food waste quantities, both global and national, the slideshow moves on discussing the consequences of increasing food waste. It is worth noting, as a common denominator, that all of the data used for the individual diagrams includes references to the original data source (data sources, journal references,

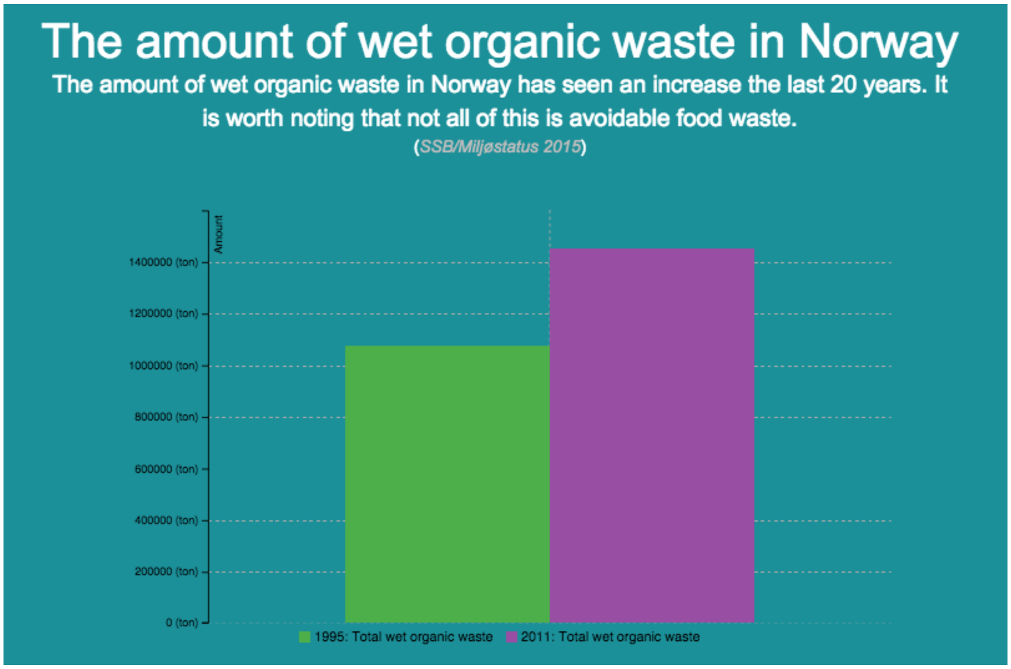


Figure 4.5: The amount of wet organic waste in Norway

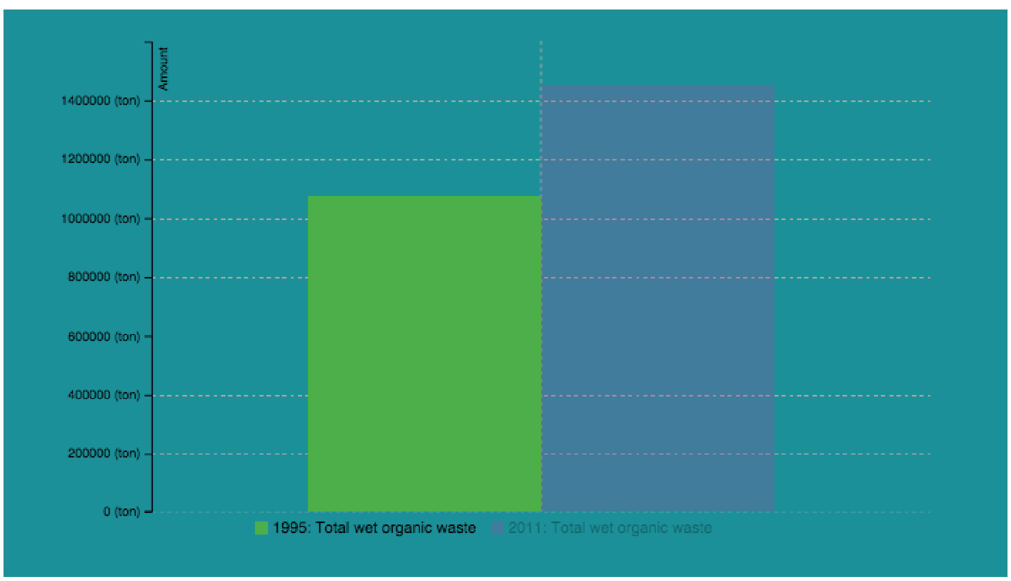


Figure 4.6: Highlighting a legend item

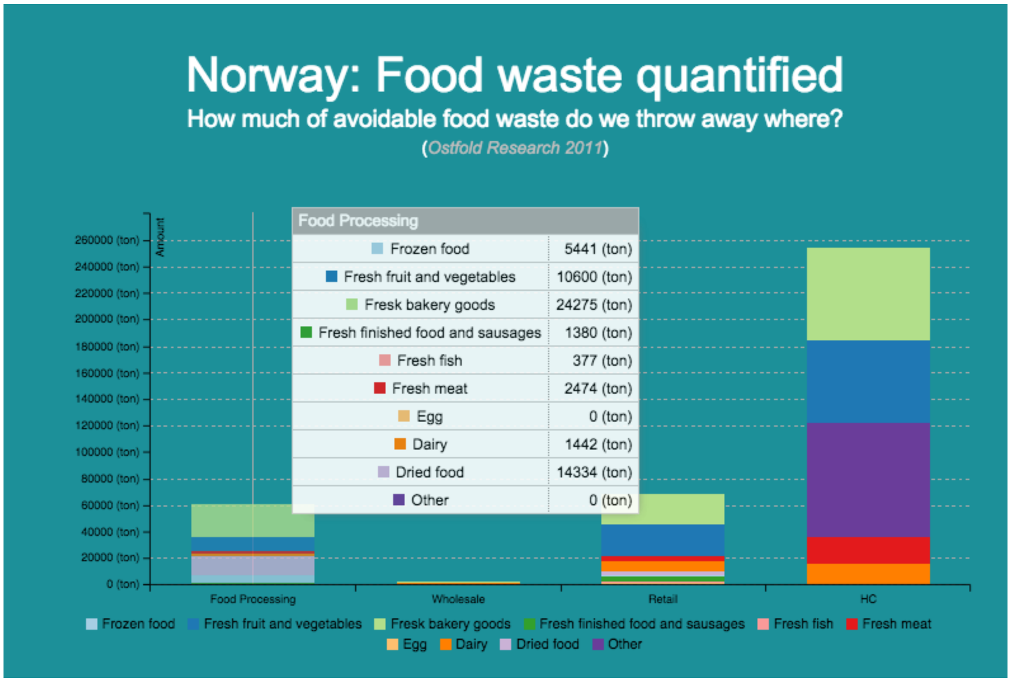


Figure 4.7: Quantifying food waste in Norway

article references and so on). These are added directly as hyperlinks wherever the original link is available online, as illustrated in figure 4.8, showing the intricate effects of increasing food waste. Each graph has a title followed by text content, complementing the graph (see figure 4.9). Annotation follows the x and y-axis as seen in figure 4.9, quantifying the process energy use related to the Norwegian food production and consumption system. Moreover, detailed information is given in a table when hovering over a certain element in the diagram, as depicted in figure 4.7. The bars in figure 4.9 were aligned horizontally, due to the large difference in gigajoules of energy between the different categories. Moreover, it is possible to remove categories, and for example only display the use of process energy for fertilizer production and biogas production, to get a better overview as seen in figure 4.10.

The next diagram in the visual narrative applies a pie chart with hovering capabilities to display agriculture emissions distributed among Norwegian sectors, as depicted in figure 4.11. Implementing the aforementioned pie chart tries to contextualize the agricultural sector with the overall greenhouse gas emissions in Norway. However, it is worth mentioning that food production also indirectly increases emissions in other sectors, something that is not obvious looking at the diagram.

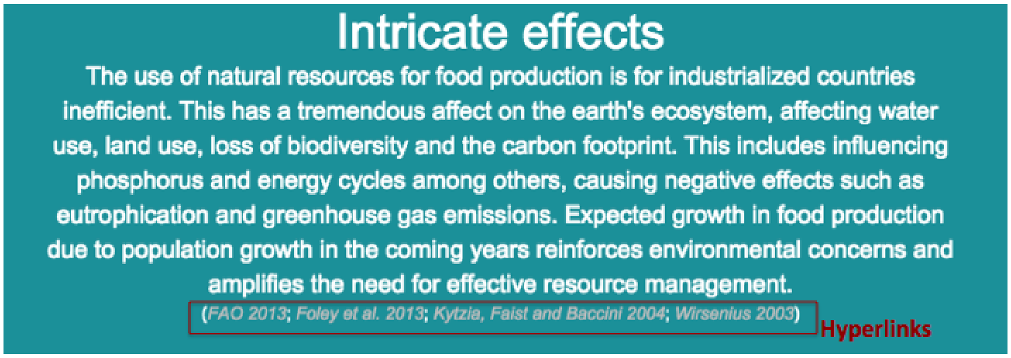


Figure 4.8: Linking the original data sources

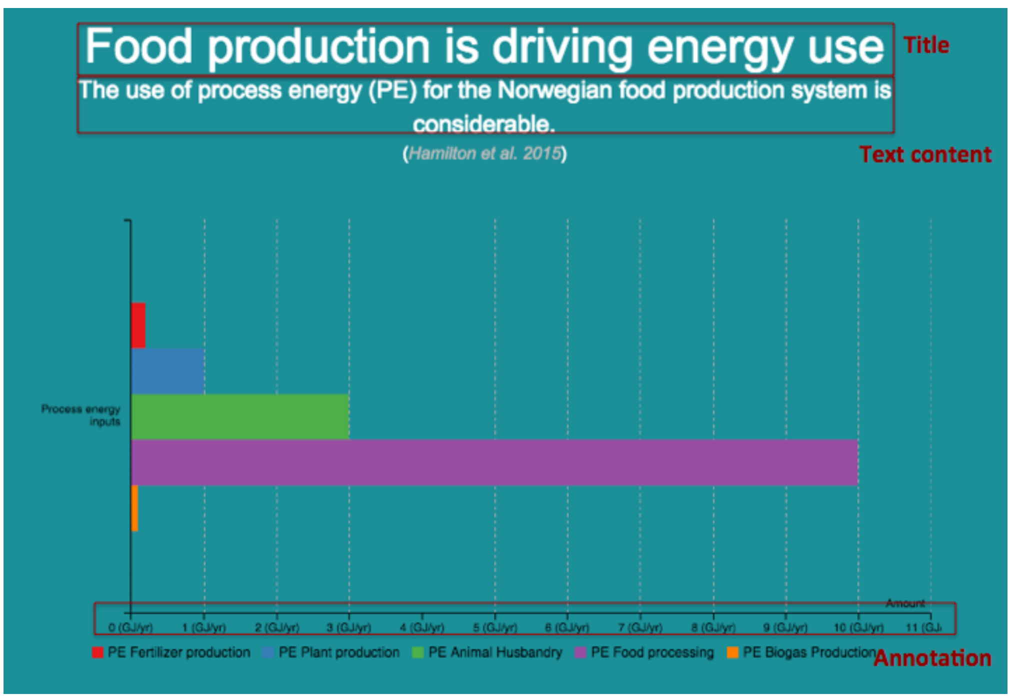


Figure 4.9: Title, text content and annotation

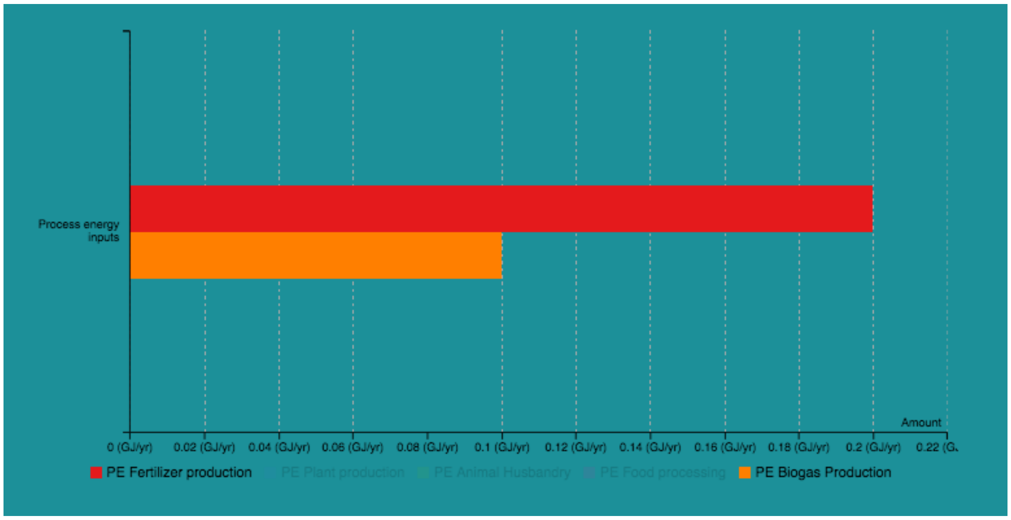


Figure 4.10: Comparing only two categories of process energy

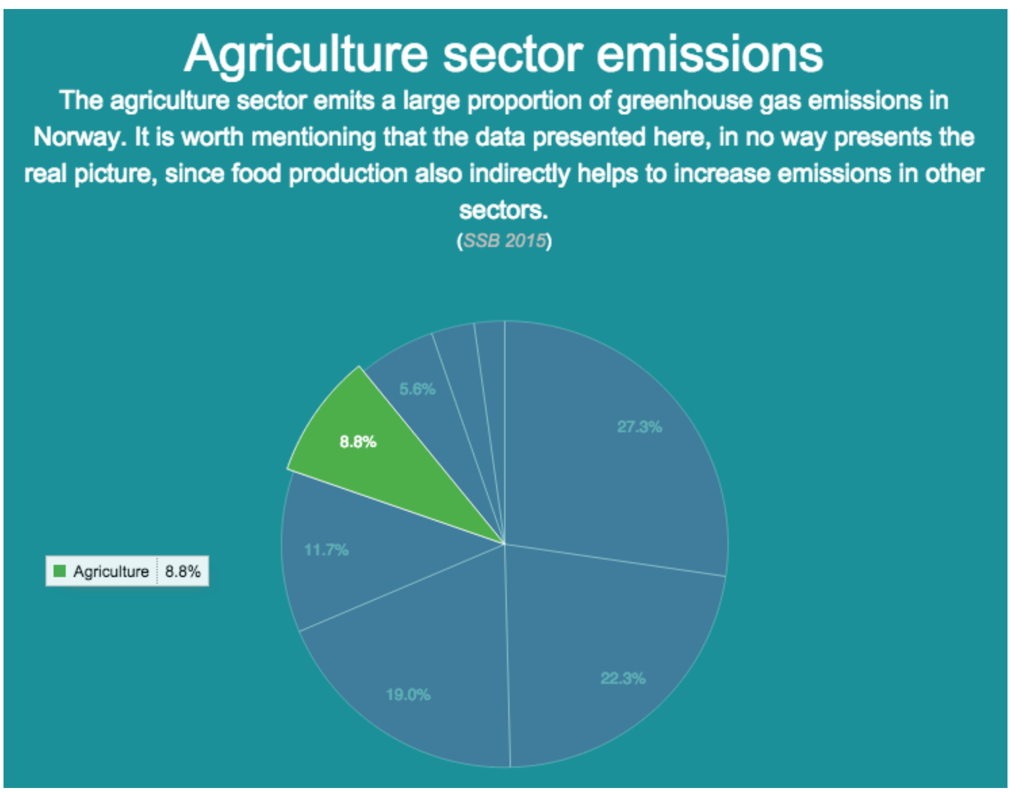


Figure 4.11: Agriculture sector emissions

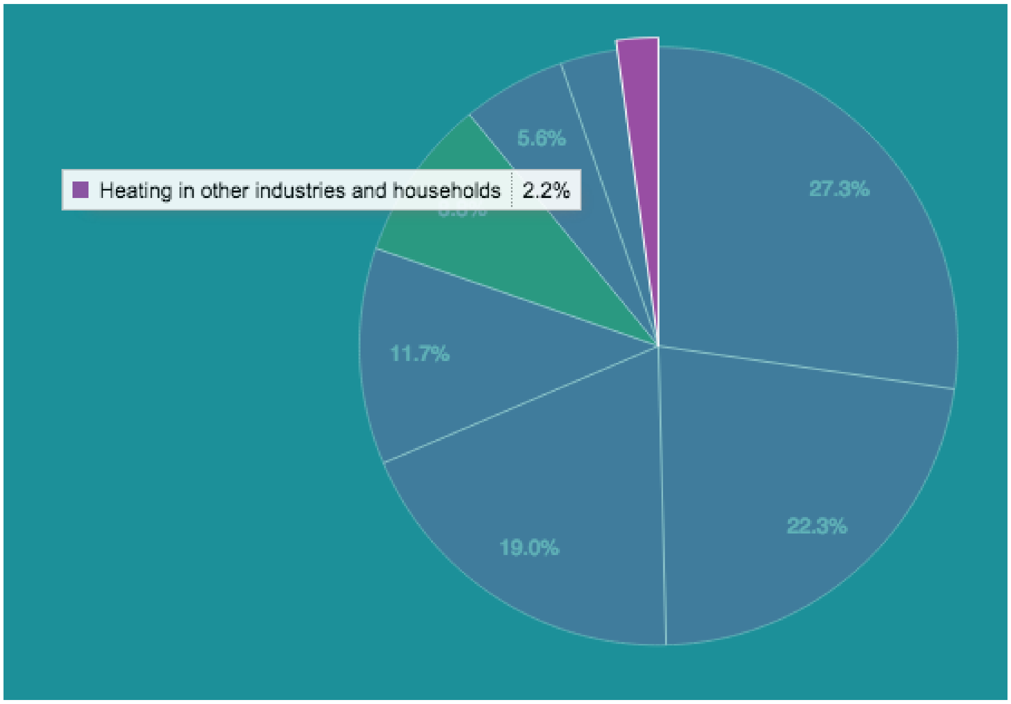


Figure 4.12: “Hidden” information

Further on, two categories are missing labels, due to low values, respectively Energy supply (3,1%) and Heating in other industries and households (2,2%). By hovering over the aforementioned categories or using touch events on smartphones or tablets, the information becomes available, as seen in figure 4.12.

The next visual element presented in the visual narrative is an animated globe, listing the top ten phosphate reserves in the world. The animated globe uses a plugin (TopoJSON) created for D3, manipulating a dataset containing all of the world’s countries, modified for this project, only viewing selected countries as seen in figure 4.13. The countries include Western Sahara and Morocco, China, Algeria, Syria, South Africa, Jordan, Russia, United States, Australia and Peru in descending order based on phosphate resources. The diagram tries to convey that phosphorus also is a geopolitical issue, providing information to why it is important to manage this scarce substance in a sustainable way.

The next visual element presents a graph depicting the use of phosphorus in Norway over the last few years, as seen in figure 4.14, indicating the likelihood of a steady demand for phosphorus in the future.

After presenting the effects of increasing food waste, the visual narrative presents the

Figure 4.13: A limited resource (Top 10 phosphate rock reserves in the world)

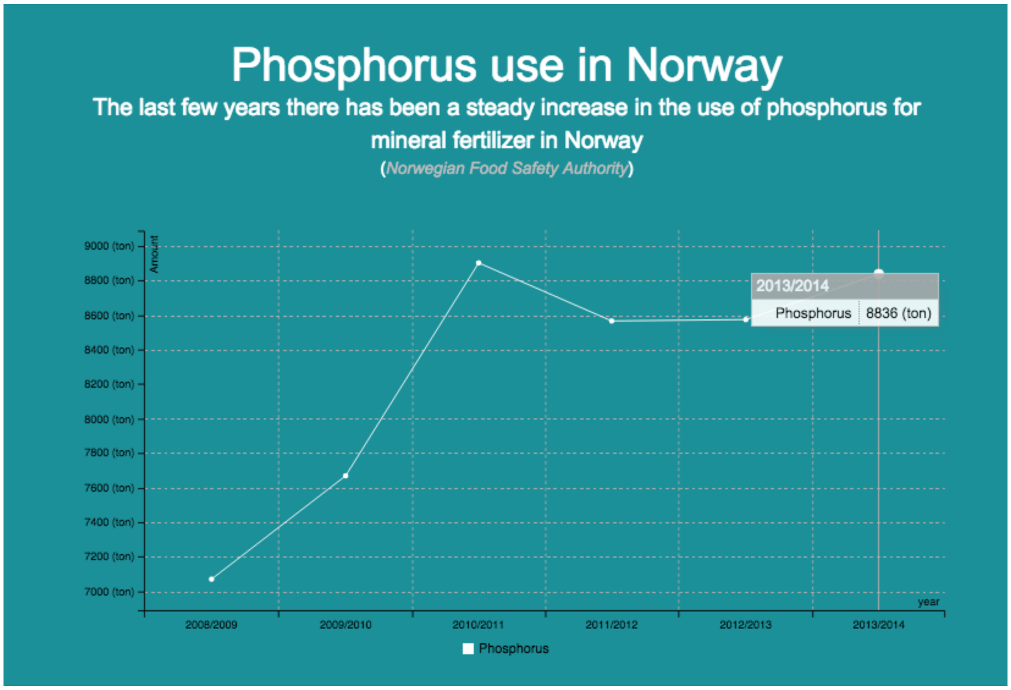


Figure 4.14: Phosphorus use in Norway

current strategies for managing the increasing amount of food waste. First, the hierarchy principles favored by the European Union (House of Lords, 2014) is presented in figure 4.15. Secondly, Governmental spending related to food waste prevention strategies and biogas strategies are compared, as depicted in figure 4.16.

The next part of the interactive slideshow presents the implications of the strategies previously portrayed. First, the potential for biogas is presented as a circle diagram, as illustrated in figure 4.17. Figure 4.18 illustrates the animated transition that occurs when the user hover over the circle diagram.

Moving on, the next slide displays a diagram showing the increased use of wet organic waste as a resource for energy comparing the year 1995 with 2011, as seen in figure 4.19.

Towards the end, the visual narrative argues why we need a systems approach. As illustrated in figure 4.20, a parallel coordinates plot (Inselberg, 1985) is presented, showing a selection of relevant indicators, illustrating tradeoffs between different food waste scenarios.

A table supports the parallel coordinates plot, which could be hovered in order to highlight the pathway of a specific scenario, as seen in figure 4.21. The parallel coordinates plot also makes it possible to select and deselect values on the y-axis using a brushing method or

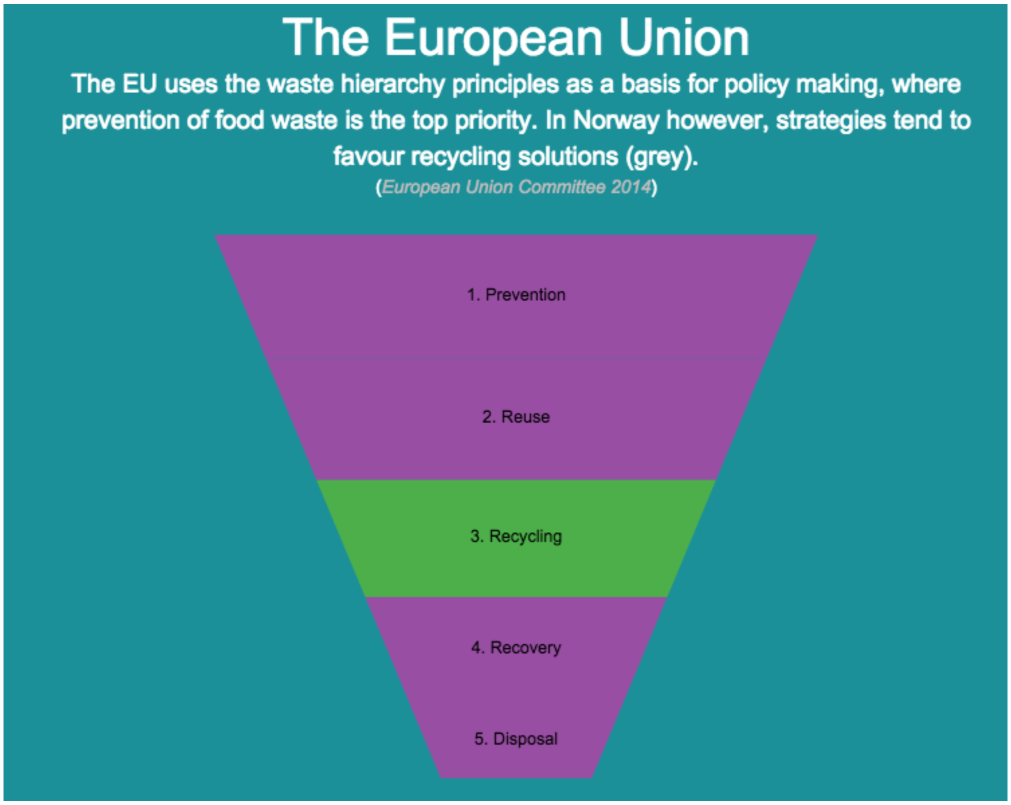


Figure 4.15: Strategies for food waste in the European Union

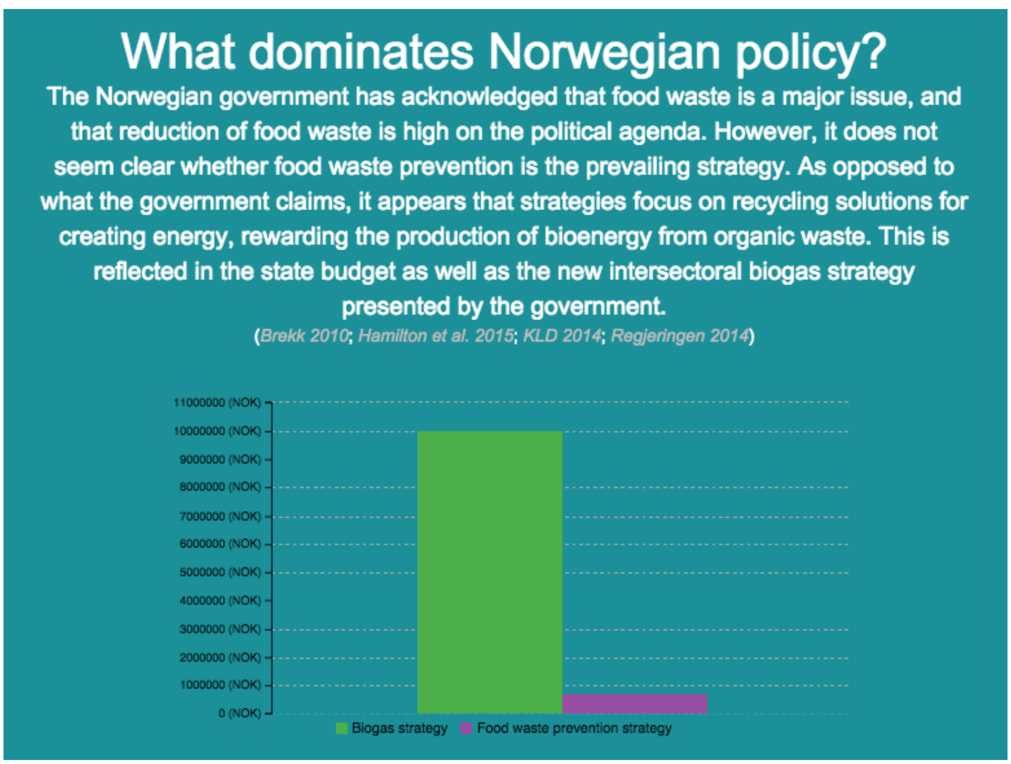


Figure 4.16: Comparison of governmental spending

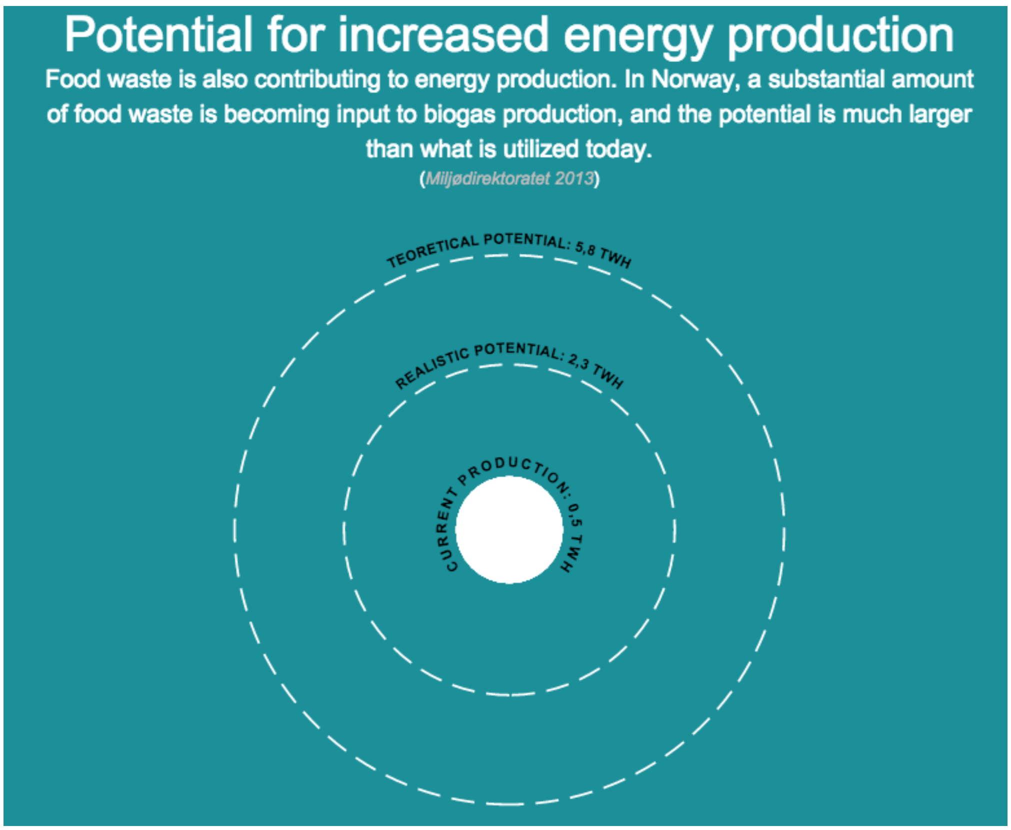


Figure 4.17: Potential for increased energy production

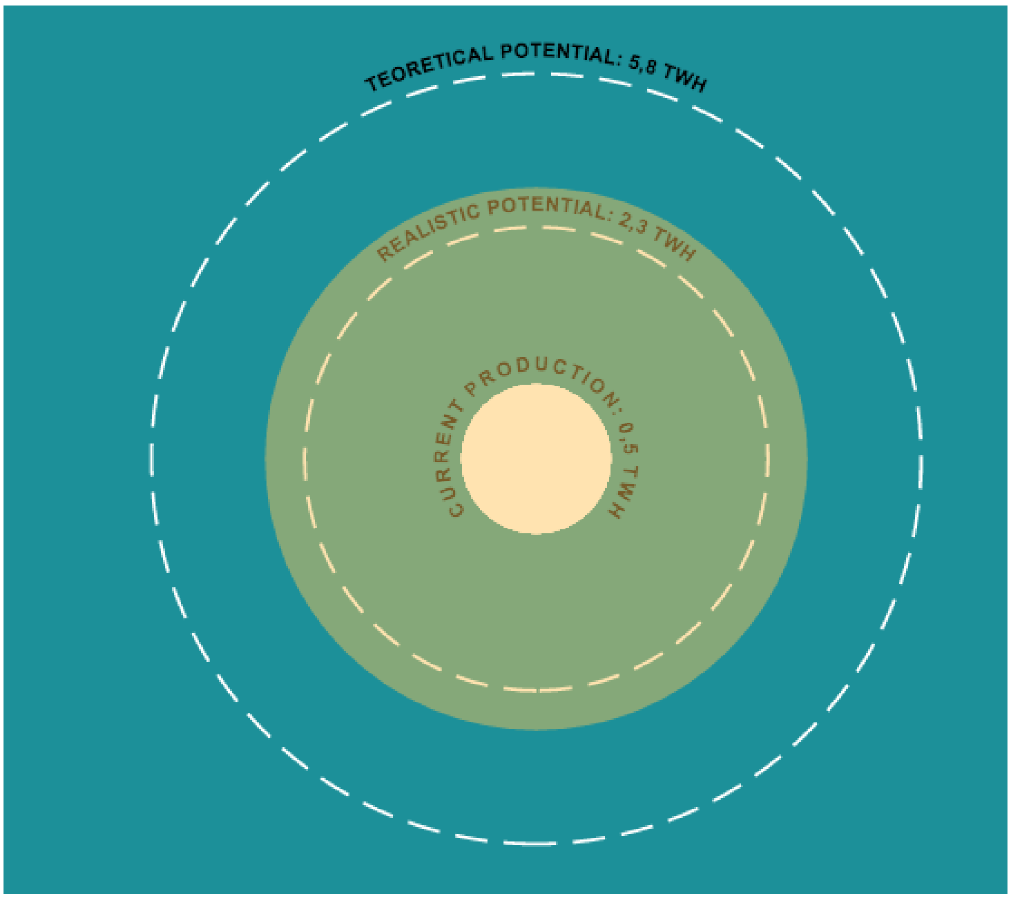


Figure 4.18: Animated transition

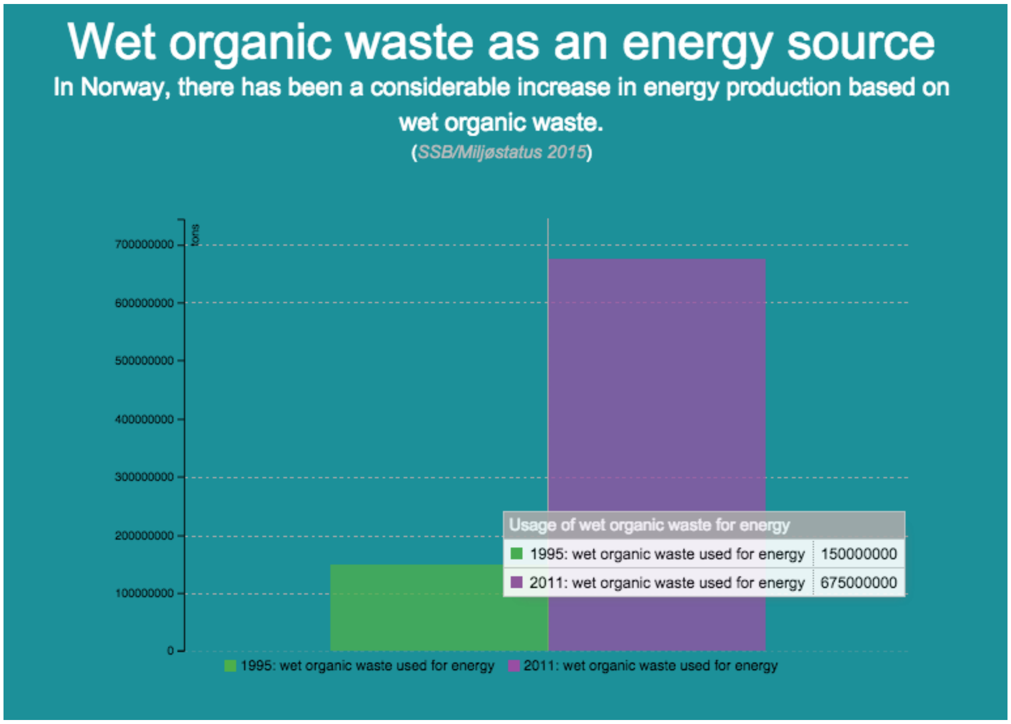
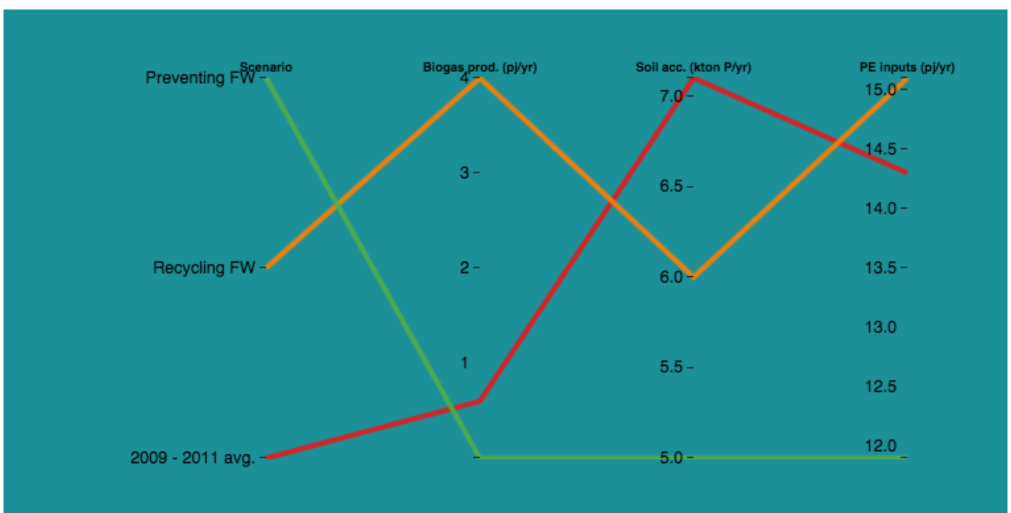
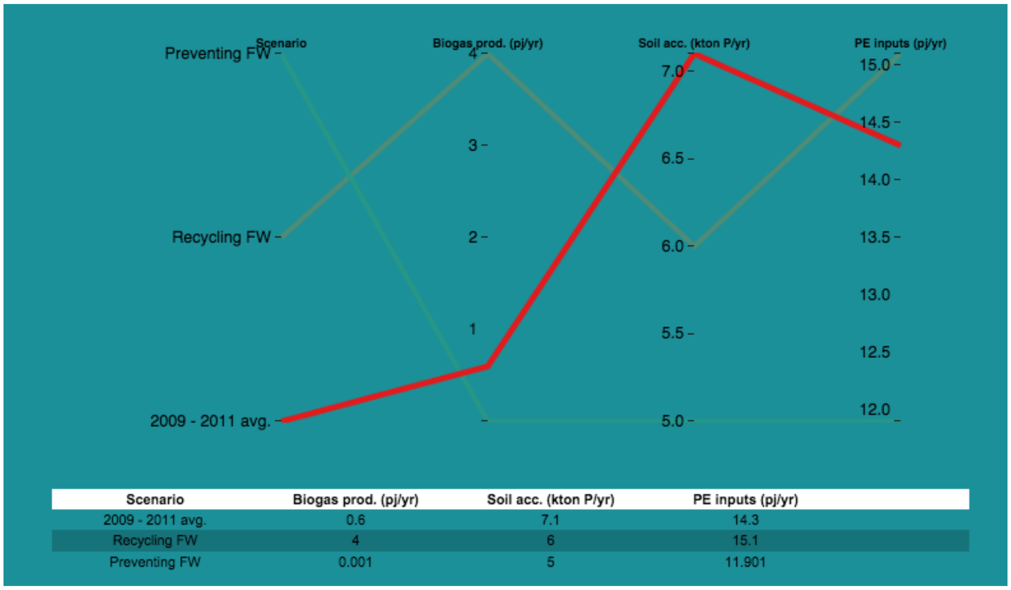


Figure 4.19: Wet organic waste as an energy source



Scenario	Biogas prod. (pj/yr)	Soil acc. (kton P/yr)	PE inputs (pj/yr)
2009 - 2011 avg.	0.6	7.1	14.3
Recycling FW	4	6	15.1
Preventing FW	0.001	5	11.901

Figure 4.20: Showing a selection of possible tradeoffs between the baseline and different food waste scenarios



Scenario	Biogas prod. (pj/yr)	Soil acc. (kton P/yr)	PE inputs (pj/yr)
2009 - 2011 avg.	0.6	7.1	14.3
Recycling FW	4	6	15.1
Preventing FW	0.001	5	11.901

Figure 4.21: Highlighting the pathway of the baseline scenario

rearrange the scale, as illustrated in figure 4.22. It is worth mentioning that the brushing functionality only seems to function for a selection of browsers, including Firefox, Chrome and Opera.

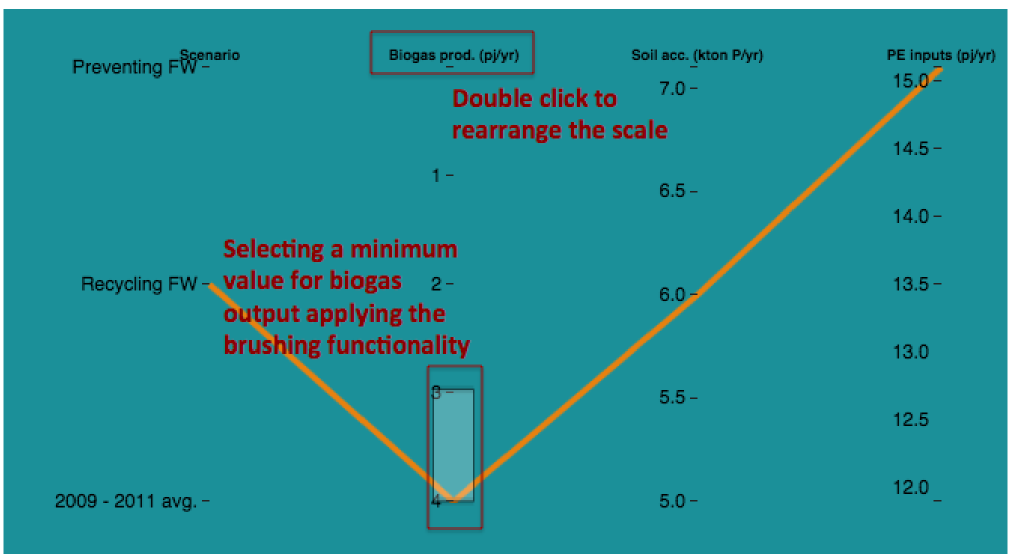


Figure 4.22: Brushing and rearranging the scale for the parallel coordinates plot

At last, a series of questions are presented to the user. These questions are intended as a starting point for further exploration using the Norwegian food waste dashboard, which will be presented in the next section of this chapter. As seen in figure 4.23, a button at the end

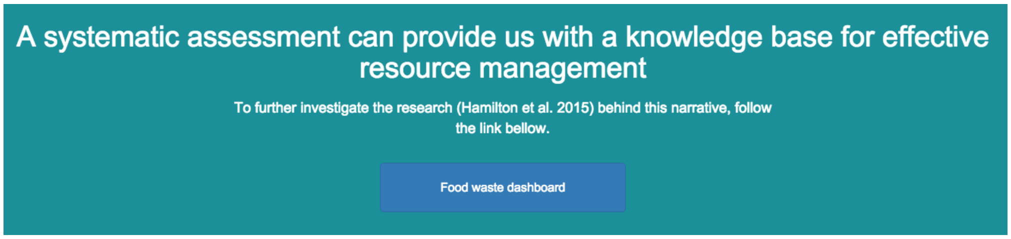


Figure 4.23: Presenting the user with a direct link to the Norwegian food waste dashboard

of the visual narrative sends the user to the Norwegian food waste dashboard.

4.2 The Norwegian food waste dashboard

The Norwegian food waste dashboard is a standalone web application using the JavaScript based framework D3, together with web-frameworks, including Twitter Bootstrap for general layout and JQuery for interaction. For a step-by-step walkthrough of the Norwegian food waste dashboard, a JavaScript library called intro.js was implemented. In addition to this, D3-based libraries, including C3, d3-funnel-charts, parcoords.js were used to develop and implement charts in the web application. The general dataflow of the Norwegian food waste dashboard is illustrated in figure 4.24.

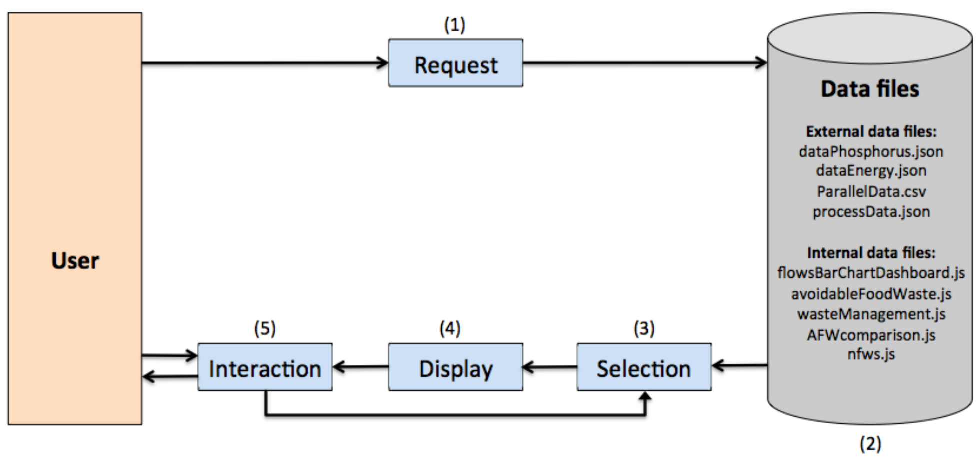


Figure 4.24: Illustrating the dataflow for the Norwegian food waste dashboard

4.2.1 General structure

The general layout of the dashboard includes a menu, as seen in figure 4.25. This includes a “Show me how” button providing the user with a step-by-step guide of how to use the application, as illustrated in figure 4.26. The next menu button, “Background information”, provides a link to the visual narrative presented in the first section of this chapter. The “Acknowledgments” button sends the user to a listing of the main tools and data sources were all of the tools are linked to their resource page, as illustrated in figure 4.27. As seen in figure 4.25, the next menu button “What is Material Flow Analysis” links to the MFA Wikipedia page, providing an introduction to the MFA methodology. The last menu button

Figure 4.25: Menu

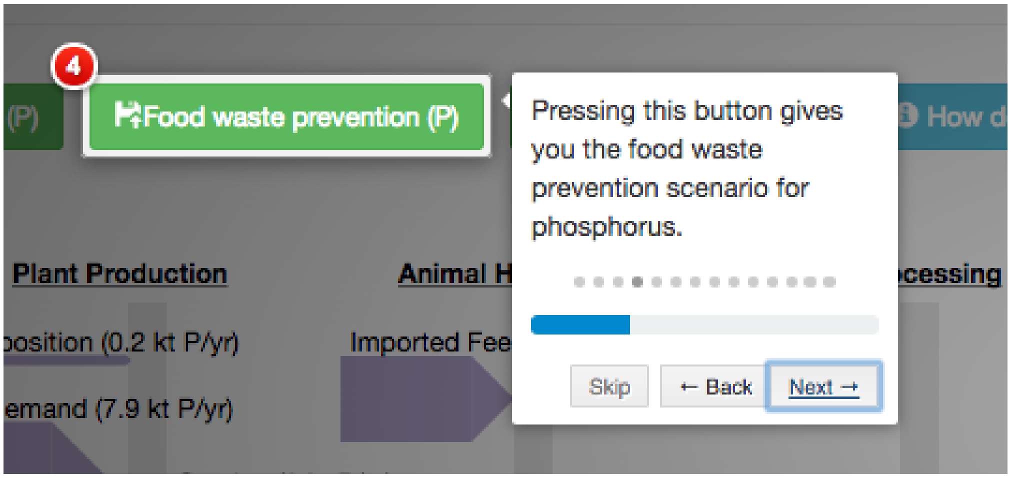


Figure 4.26: Step-by-step walkthrough of the application

"NTNU's Industrial Ecology Programme", links the user to the industrial ecology study programme at NTNU. In addition the general layout consists of clickable collapsible boxes, for making it easy for the user to combine different diagrams of choice, as illustrated in figure 4.28 and 4.29. Both the phosphorus and energy flow diagram is provided as default, as depicted in figure 4.30 and 4.31.

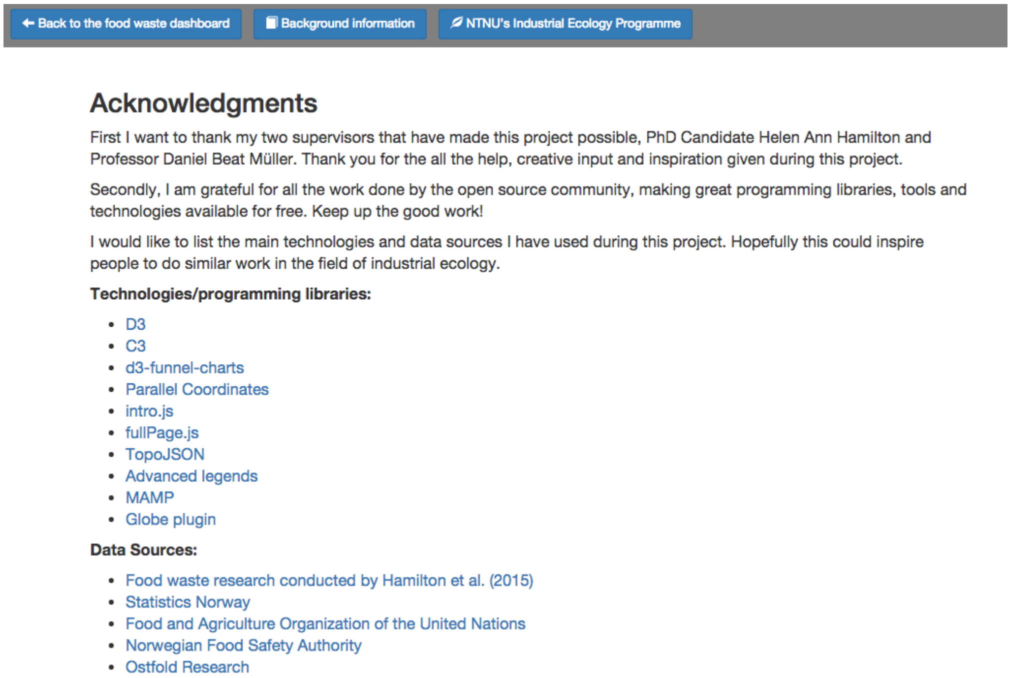


Figure 4.27: Acknowledgments

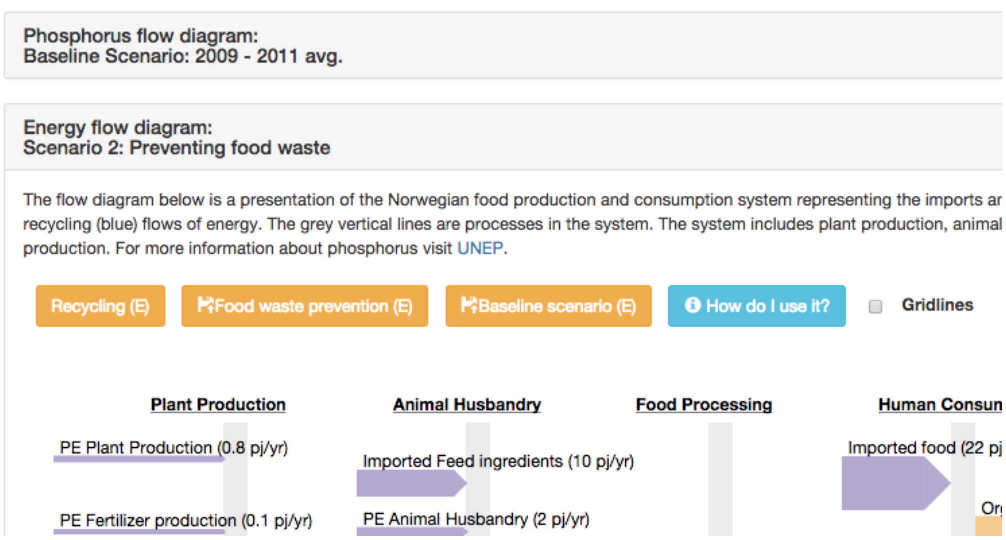


Figure 4.28: Collapsible boxes, example 1

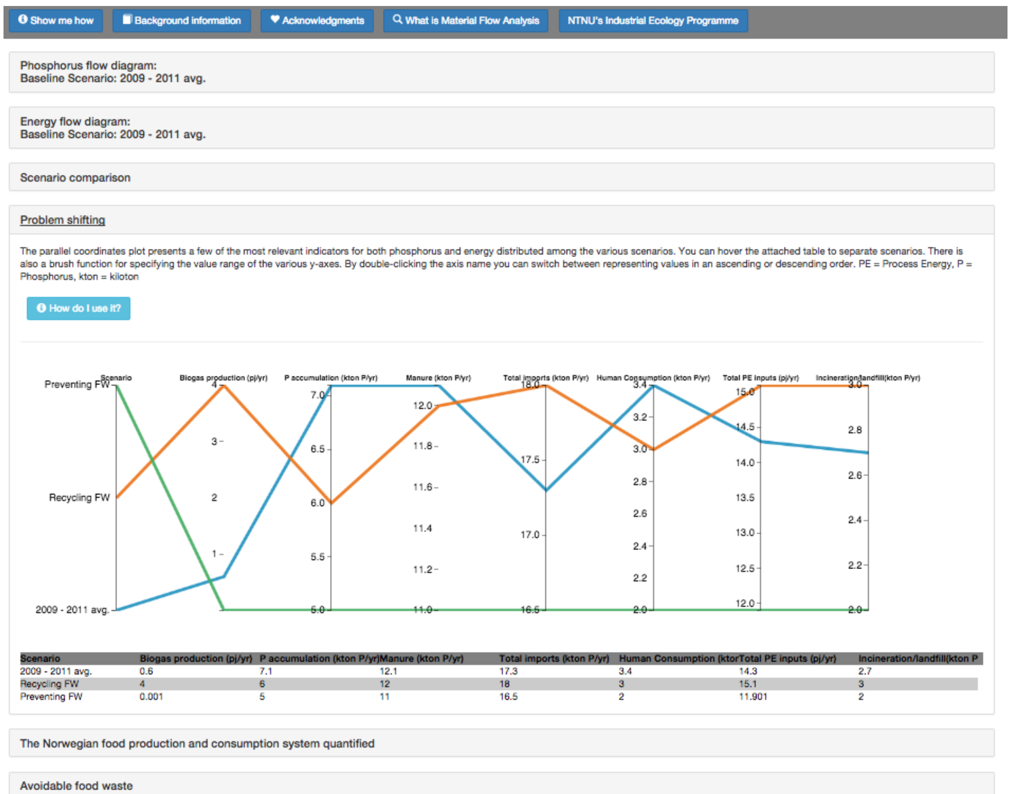


Figure 4.29: Collapsible boxes, example 2

4.2.2 The phosphorus and energy flow diagram

Technical

The phosphorus flow diagram as seen in figure 4.30, and the energy flow diagram as seen in figure 4.31, are both following the same structure, based on Sankey diagram notation and MFA methodology. The Sankey diagrams are created using the D3 framework, but the Sankey diagrams are not generated using the Sankey plugin in D3 (Rud, 2014). Instead, customized code were developed (Appendix A). The code in its entirety is provided as an attachment to this thesis and could also be accessed online (Appendix B). The code automatically generates Sankey diagrams based on the MFA data provided by Hamilton et al. (2015b) for visualizing flows using Sankey diagram notation where the thickness represents the magnitude of the flow, hence the amount of phosphorus and energy for each layer, as seen in figure 4.30 and 4.31. Since all of the flows are generated as basic line elements, the use of different colors and arrows were used to separate between imports, exports, losses, domestic supply and domestic recycling flows, as seen in figure 4.30 and 4.31. The colors are supported by a legend, as illustrated in figure 4.32. In addition, horizontal gridlines were applied as depicted in figure 4.33. The gridline function is off by default, and is accessed using the checkbox, as shown in figure 4.33. The gridlines were applied in order to support the animated transition between the different scenarios, making the changes more visible. Gridlines could be applied for both the phosphorus and energy layer. Furthermore, both of the Sankey diagrams are scaled, meaning that a minimum pixel value is given to ensure visibility of the smallest flows. As a result, the ranges of input values are distributed among an interval.

For switching between scenarios, buttons were provided as seen in figure 4.34 and 4.35, providing animated transitions between the scenarios for each layer. It is also possible to hover over the flows for detailed information as seen in figure 4.36, even though the same information is provide explicitly in the diagram itself. It is also possible for the user to see which scenario is being applied, as the title of the collapsible box is dynamic, as illustrated in figure 4.37. In addition, both Sankey diagrams have a “How do I use it?” button (see figure 4.34 and 4.35), giving information about how to use the specific diagram. The “How do I use it?” button is a recurring theme for all of the diagrams used in the Norwegian

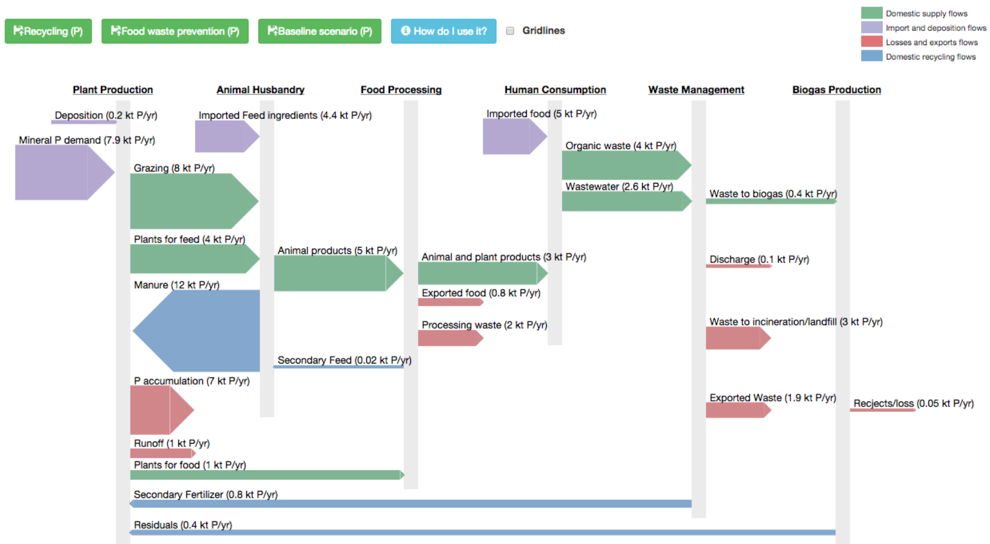


Figure 4.30: Phosphorus Sankey diagram, baseline scenario

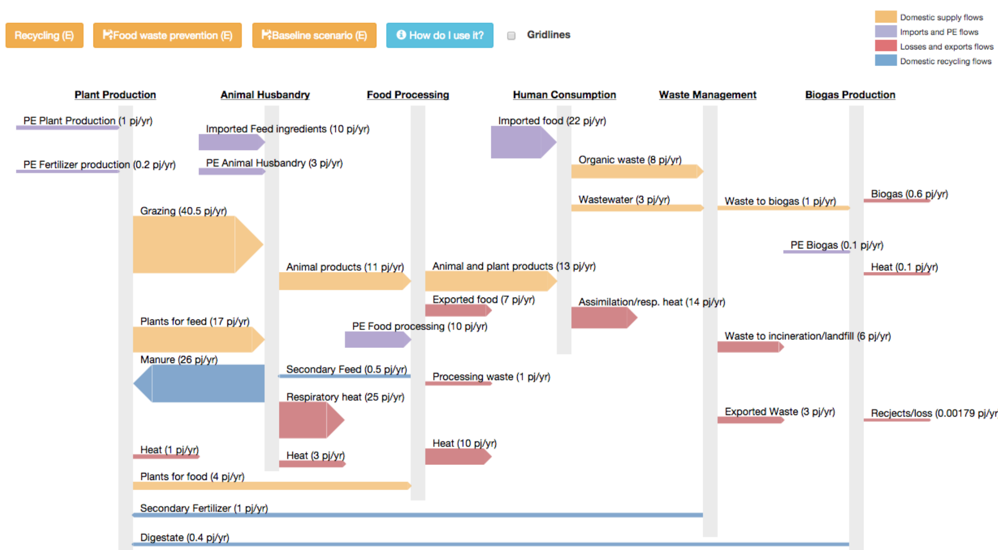


Figure 4.31: Energy Sankey diagram, baseline scenario

food waste dashoard. Each of the Sankey diagrams are also given an introduction text with complementary information as a link, see figure 4.42.

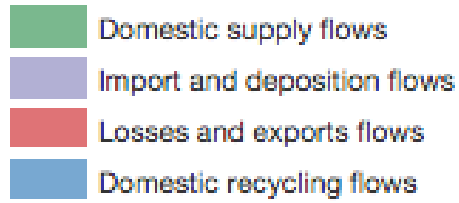


Figure 4.32: Flow diagram legend (phosphorus)

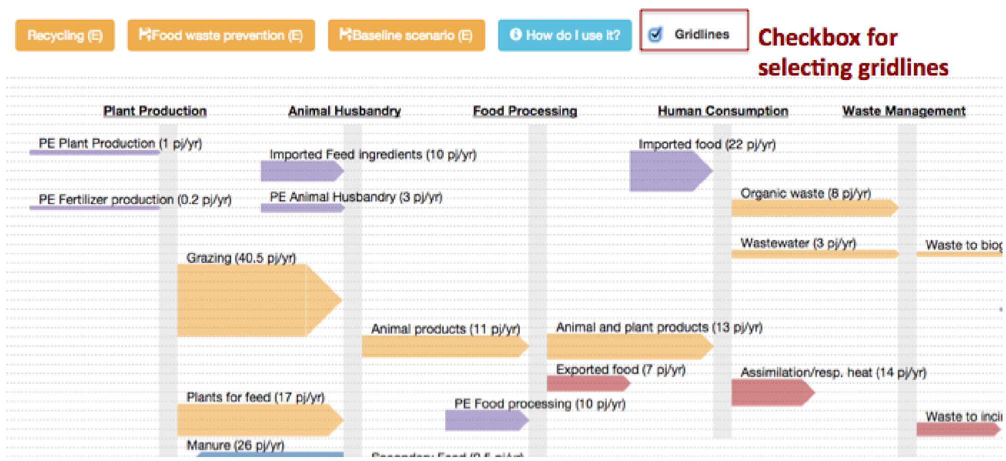


Figure 4.33: Gridlines

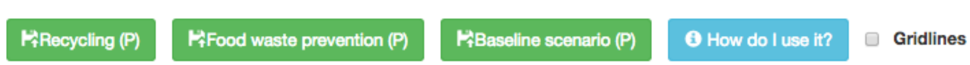


Figure 4.34: Button for switching between scenarios in the phosphorus layer

Figure 4.35: Button for switching between scenarios in the energy layer

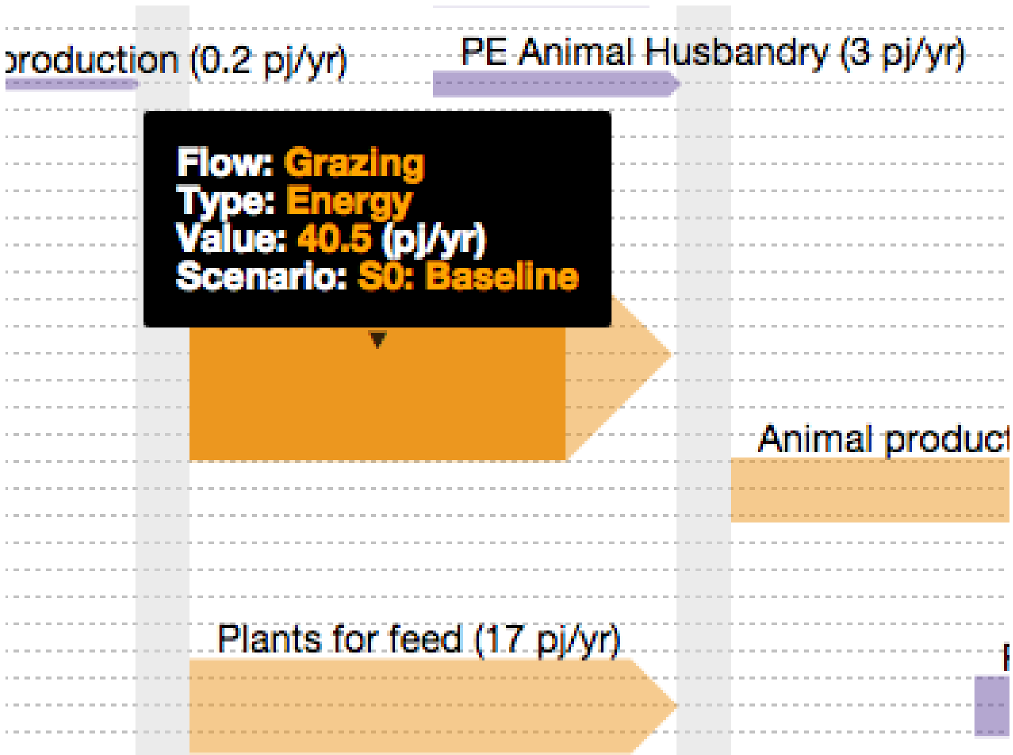


Figure 4.36: Hovering over flows

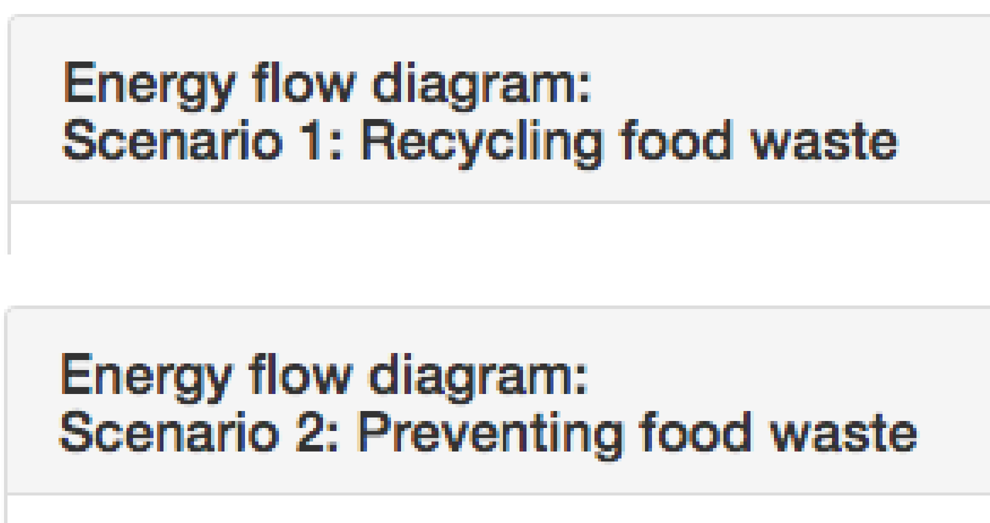


Figure 4.37: Dynamic titles

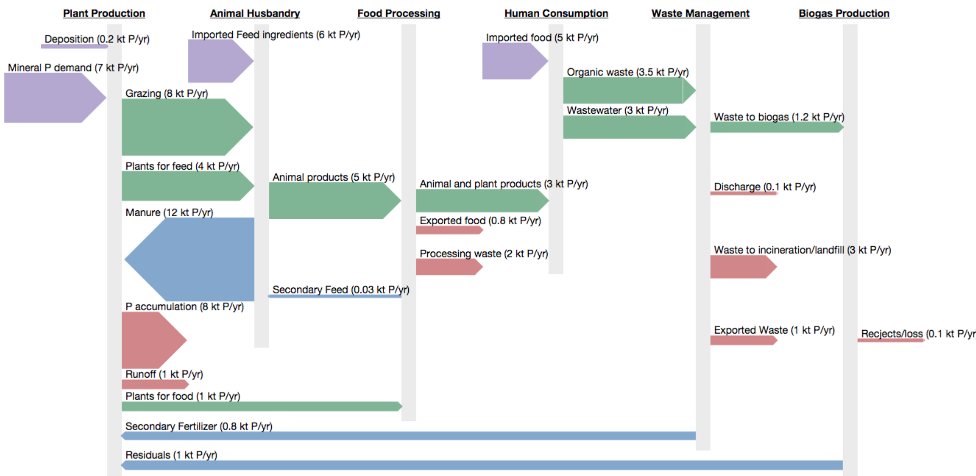


Figure 4.38: Phosphorus: Scenario 1: Recycling food waste

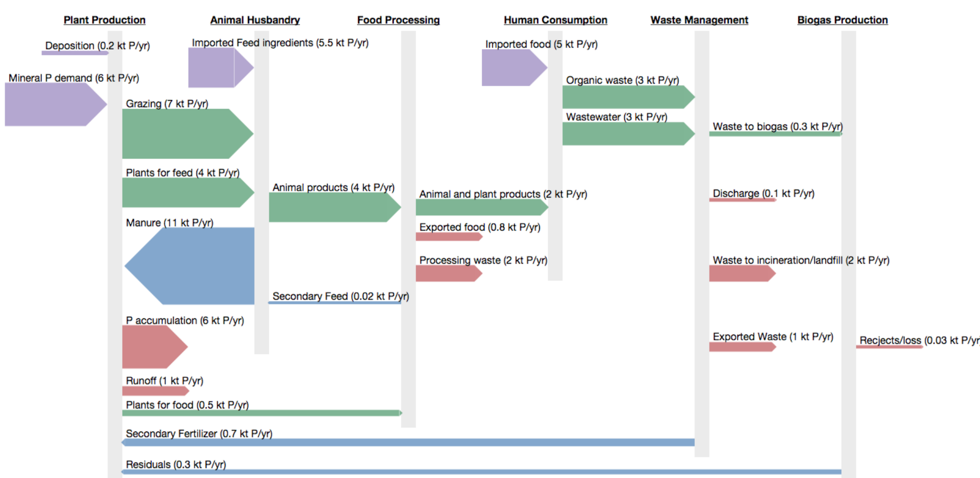


Figure 4.39: Phosphorus: Scenario 2: Preventing food waste

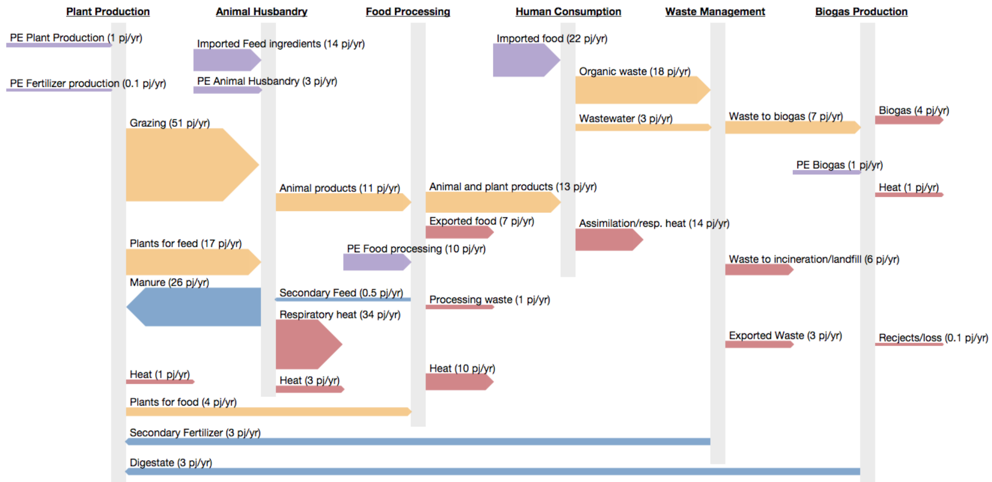


Figure 4.40: Energy: Scenario 1: Recycling food waste

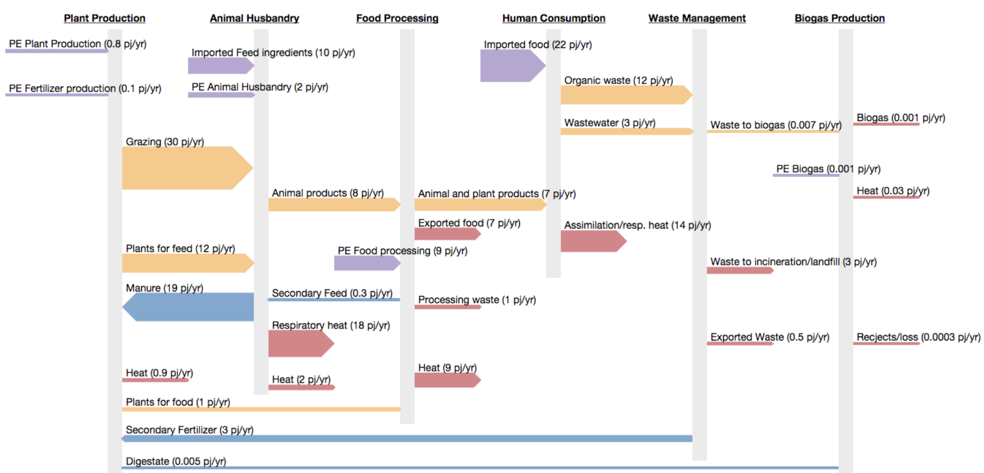


Figure 4.41: Energy: Scenario 2: Preventing food waste

Phosphorus flow diagram:
Baseline Scenario: 2009 - 2011 avg.

The flow diagram below is a presentation of the Norwegian food production and consumption system representing the imports and deposition (purple), losses and exports (red), domestic supply (green) and recycling (blue) flows of phosphorus (P). The grey vertical lines are processes in the system. The system includes plant production, animal husbandry, food processing, human consumption, waste management and biogas production. For more information about phosphorus visit UNEP.

Figure 4.42: Introduction Text with complementary link

In relation to the food waste research

As is visually depicted in the dashboard, “Animal Husbandry” is a major driver of both energy and phosphorus for all of the three scenarios. In the context of communicating research results, the energy layer shows increasing energy returns when producing biogas from food waste, and that these were marginal due to upstream demand for process energy as a result of increasing food production, as seen in figure 4.40. Furthermore, biogas output varies tremendously between the three scenarios, especially comparing the food waste recycling scenario with the food waste prevention and baseline scenario, as seen when comparing figure 4.31, 4.40 and 4.41. At the same time, increasing biogas production leads to increases in the phosphorus layer, including total import of phosphorus (“Mineral P demand”, ”Imported Feed ingredients” and “Imported food”), phosphorus accumulation in agricultural soil and phosphorus in manure applied to plant production, as seen in figure 4.38. Visually, there are only marginal changes for most of the flows when looking at the animated transitions for the phosphorus layer. This is due to the scaling.

In terms of overall system implications, the food waste prevention scenario (see figure 4.39) is less phosphorus import dependent. Between the different scenarios, the animated transitions helps showing that animal husbandry is largely driving the demand for phosphorus. At the same time, animal husbandry accounts for a large amount of phosphorus flowing back to plant production as manure. The largest imports of the systems are mineral phosphate demand for application on soil together with imported feed ingredients. This is largely due to downstream demands of phosphorus for animal husbandry production (see figure 4.30, 4.38 and 4.39).

4.2.3 Scenario comparison

Technical

The “Scenario comparison” diagrams as seen in figure 4.43, uses the same data as the phosphorus and energy flow diagram, where the data is stored in the same file as the code for generating the diagrams. The diagrams uses an interactive bar chart layout based on D3.js and C3.js, distributing all of the flows vertically combining the three scenarios as clusters,

Figure 4.43: Comparing scenarios as multiple clusters of bar charts

separated by color saturations. Green color saturations for phosphorus and yellow color saturations for energy.

The visualization technique allows the user to compare different flows distributed among the three scenarios at the same time. Allowing the user to quickly see how the different scenarios affect a certain flow, the visualization technique addresses the difficulties of a multi-layered MFA and shares many similarities with what often is referred to as small multiples (Tufte, 1983). Enabling the possibility to view large quantities of data simultaneously, the two diagrams makes it more accessible to compare scenarios then the Sankey diagram. Moreover, this visualization technique makes it possible for the user to select or unselect scenarios as desired, showing one or multiple scenario at a time, using the interactive legend, as exemplified in figure 4.44 and 4.45.

Figure 4.44: Interactive legend for scenario comparison (unselecting scenarios)

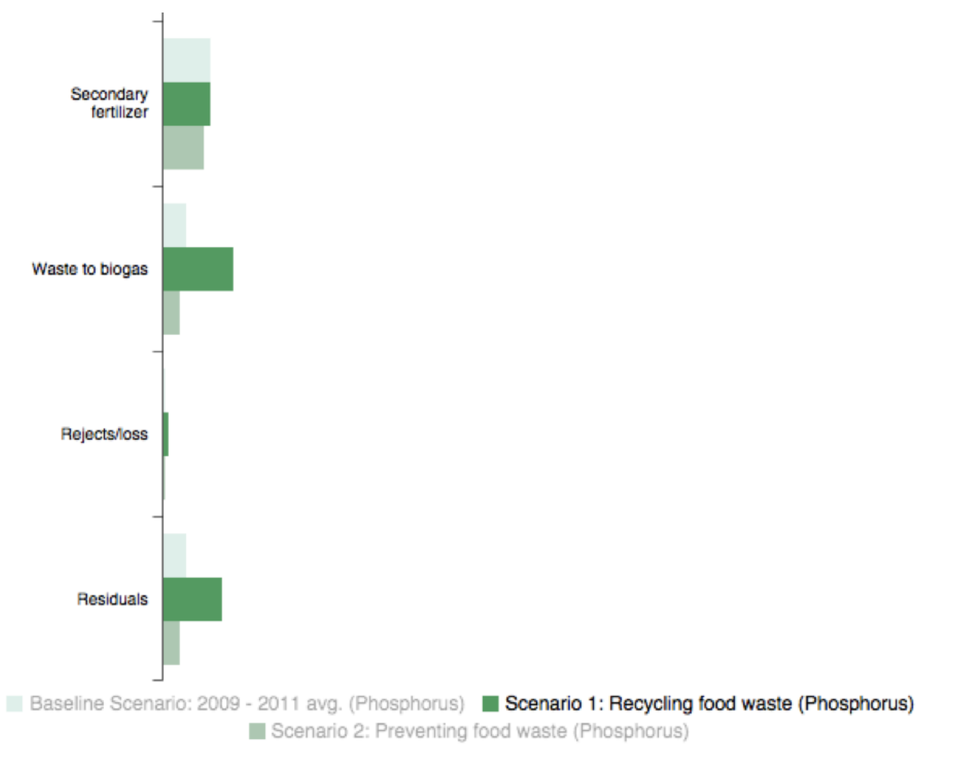


Figure 4.45: Interactive legend for scenario comparison (Hovering over a specific scenario)

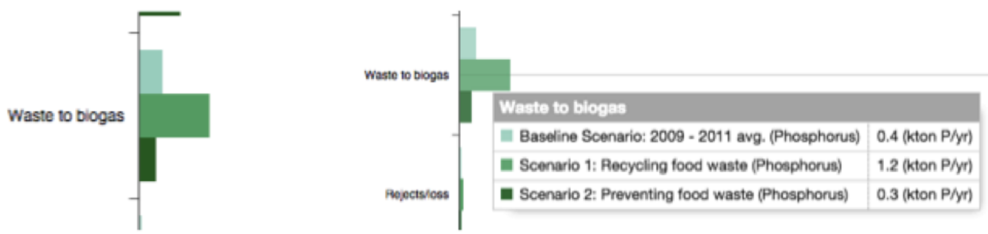


Figure 4.46: “Waste to biogas” from the “Scenario comparison” diagram

In relation to the food waste research

For conveying the research of Hamilton et al. (2015b), this diagram presents similar information as displayed in the Sankey diagrams. However, this visualization technique adds to the understanding of the scenarios. In addition, the “Scenario comparison” diagram makes it easier to see the differences between scenarios, as is the case with for example the "Waste to biogas" flow (see figure 4.46).

4.2.4 Problem shifting

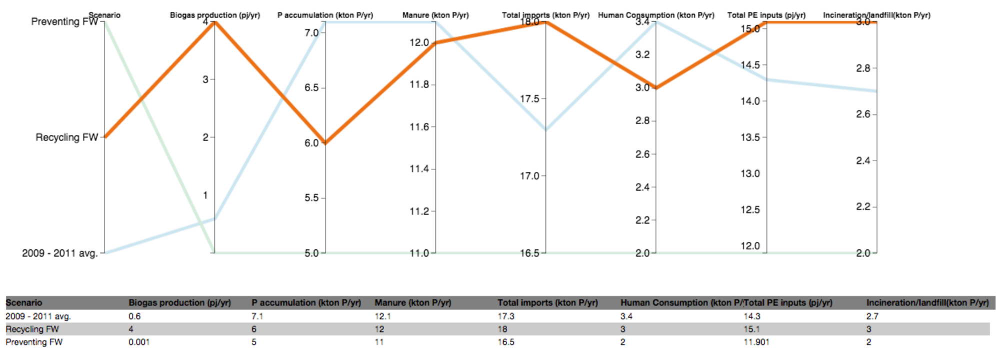
Technical

The “Problem shifting” diagram in figure 4.47 uses a parallel coordinates plot to presents a selection of the most influential indicators (both individual and aggregated flows) for both phosphorus and energy, distributed among the various scenarios. The diagram is created using parcoords.js a D3-based JavaScript library. The “Problem shifting” diagram uses the same approach as the parallel coordinates plot presented in the visual narrative, the only difference is that this diagram present more data.

The layout allows you to hover the attached table to separate scenarios, as illustrated in figure 4.48. In addition to this there is a brush function for specifying the value range of the various y-axes, as seen in figure 4.49. Also, by double-clicking the axis name you can switch between representing values in an ascending or descending order (currently only working in the following browsers, Opera, Chrome and Safari), as seen in figure 4.50. For distinguishing between the different scenarios, pathways through the plot are represented with different colors.

Scenario	Biogas production (pj/yr)	P accumulation (kton P/yr)	Manure (kton P/yr)	Total imports (kton P/yr)	Human Consumption (kton P/	Total PE inputs (pj/yr)	Incineration/landfill(kton P/yr)
2009 - 2011 avg.	0.6	7.1	12.1	17.3	3.4	14.3	2.7
Recycling FW	4	6	12	18	3	15.1	3
Preventing FW	0.001	5	11	16.5	2	11.901	2

Figure 4.47: Showing problem shifting through a parallel coordinates plot



Scenario	Biogas production (pj/yr)	P accumulation (kton P/yr)	Manure (kton P/yr)	Total imports (kton P/yr)	Human Consumption (kton P/	Total PE inputs (pj/yr)	Incineration/landfill(kton P/yr)
2009 - 2011 avg.	0.6	7.1	12.1	17.3	3.4	14.3	2.7
Recycling FW	4	6	12	18	3	15.1	3
Preventing FW	0.001	5	11	16.5	2	11.901	2

Figure 4.48: Hovering over the table gives the user a highlighted view of the selected pathway

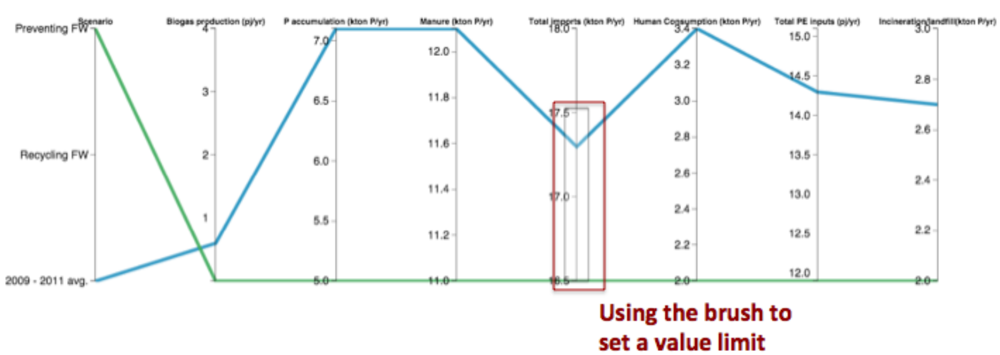


Figure 4.49: Brushing function for the parallel coordinates plot

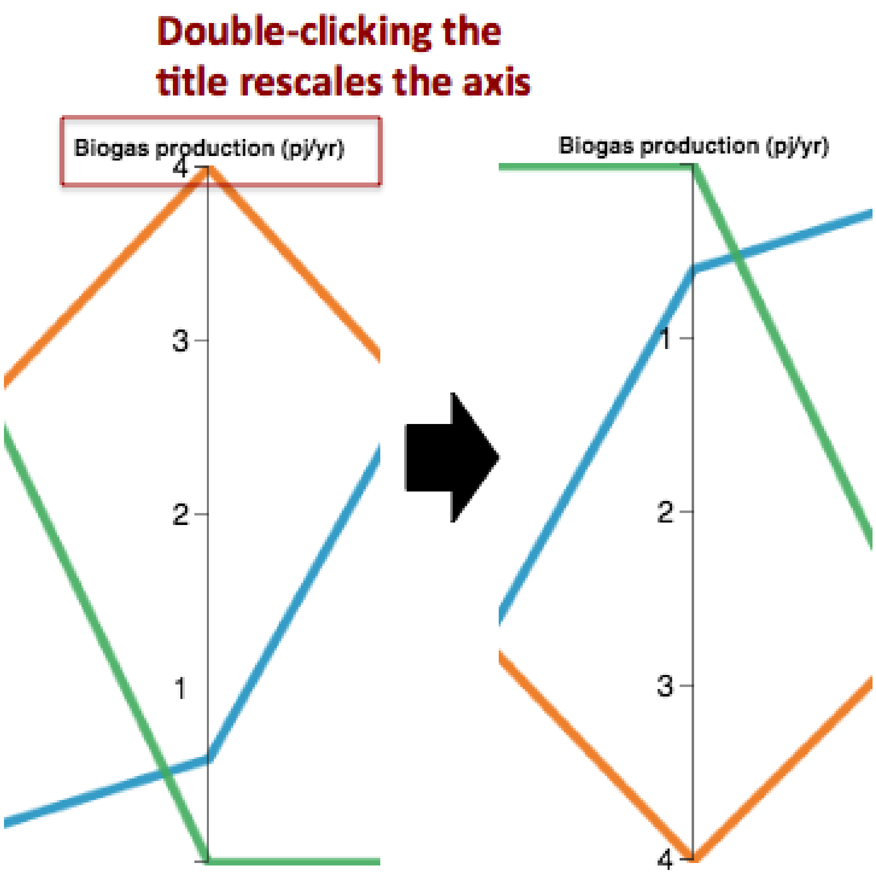


Figure 4.50: Rescaling the axis

In relation to the food waste research

In relation to food waste research, the parallel coordinates plot enables the user to compare multiple layers and different variables at the same time, depicting the tradeoffs in the system. The main purpose of the plot is to communicate the problem shifting that occurs when choosing a specific scenario. The parallel coordinates technique supports the conclusions provided by Hamilton et al. (2015b), which consequently assumes that the recycling for biogas scenario has significant tradeoffs related to central phosphorus indicators, including soil accumulation and total imports. At the same time, the parallel coordinates plot presents the process energy inputs required upstream ("Total PE inputs") for the recycling food waste scenario, showing that biogas ("Biogas production") only gives marginal returns in terms of net energy output if we compare the pathway for the prevention scenario with the recycling scenario.

4.2.5 The Norwegian food production and consumption system quantified

Technical

For quantifying the Norwegian food production and consumption system in terms of dry matter, a quick overview was developed using the base scenario for dry matter (Hamilton et al., 2015b). The diagram as seen in figure 4.51, is a combination between a stacked bar chart (Kirk, 2012) and a single layered tree map (Shneiderman, 1992) using the D3-based JavaScript library C3. The diagram also makes it possible for the user to select and compare different categories, as seen in figure 4.52.

The imports, domestic production and mass balance inconsistencies were compared with human consumption, exports and avoidable food waste. Color saturations where applied to distinguish between production and import (purple saturations) and total consumption and losses (orange saturations). In addition, hovering over the diagram also provides a popup table, depicting the quantities of the selected categories (see figure 4.53). Moreover, the x and y-axis rescale when selecting or unselecting categories.

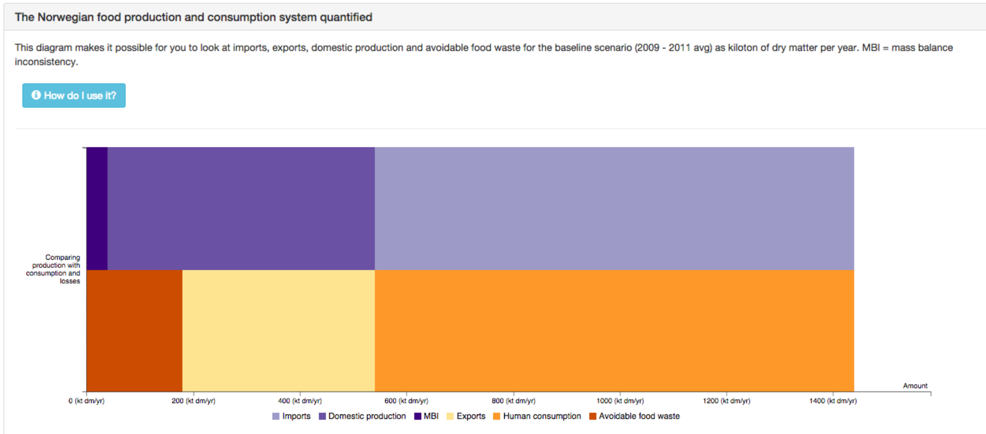


Figure 4.51: The Norwegian food production and consumption system quantified

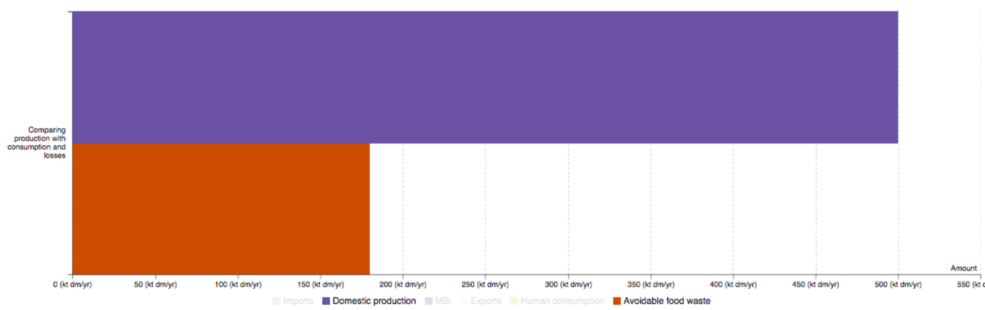


Figure 4.52: Comparing domestic production with avoidable food waste

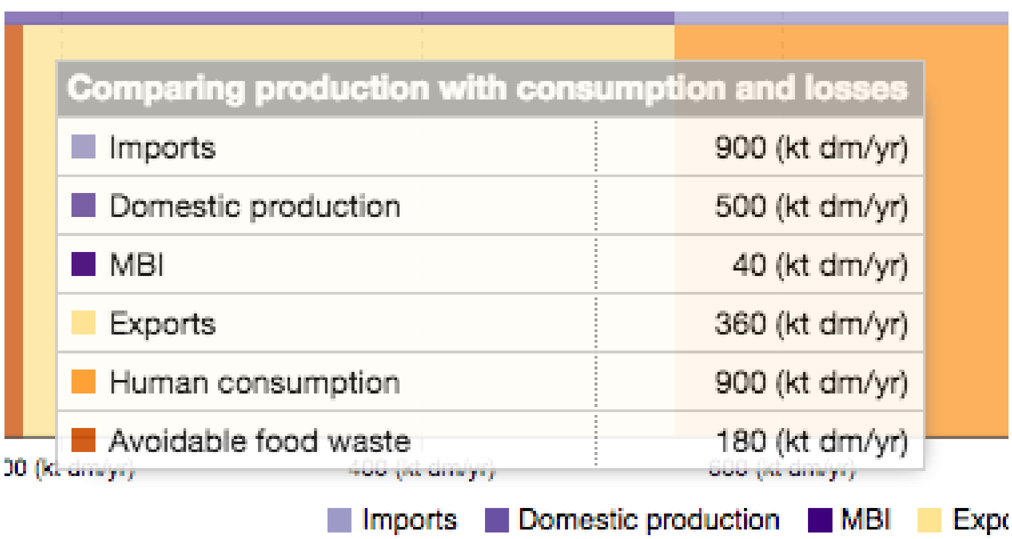


Figure 4.53: Popup table, “Comparing production with consumption and losses”

In relation to the food waste research

The main idea was to communicate the quantities of dry matter on a larger scale, putting the avoidable food waste in context with the overall production and consumption of food products. As an example, in the case of preventing food waste, imports could be reduced increasing food security, or, land used for agriculture could be used for other purposes. This is also related to Norwegian politics, where food security is a political target (NOU 2013:10).

4.2.6 Avoidable food waste

Technical

Figure 4.54 illustrates a stacked bar chart illustrating the amount of avoidable food waste in Norway. The chart uses C3, the D3-based JavaScript library. The data is based on a study conducted by Ostfold Research (Hanssen & Schakenda, 2011) adapted by Hamilton et al. (2015b) for dry matter purposes. The same chart is applied in the visual narrative (see figure 4.7).

The visual presentation of avoidable food waste is distributed throughout the value chain in a logical sequence from left to right, while food groups are separated by different colors for each individual step in the value chain. The chart supports interactive manipulation by hovering the different categories in the legend for highlighting a specific food group, as seen in figure 4.55, or selecting/unselecting food groups by clicking the interactive legend, as illustrated in figure 4.56. By hovering over each individual stacked bar, a table is presented, quantifying the amount of dry matter calculated for each food group distributed among the steps in the value chain, as seen in figure 4.57.

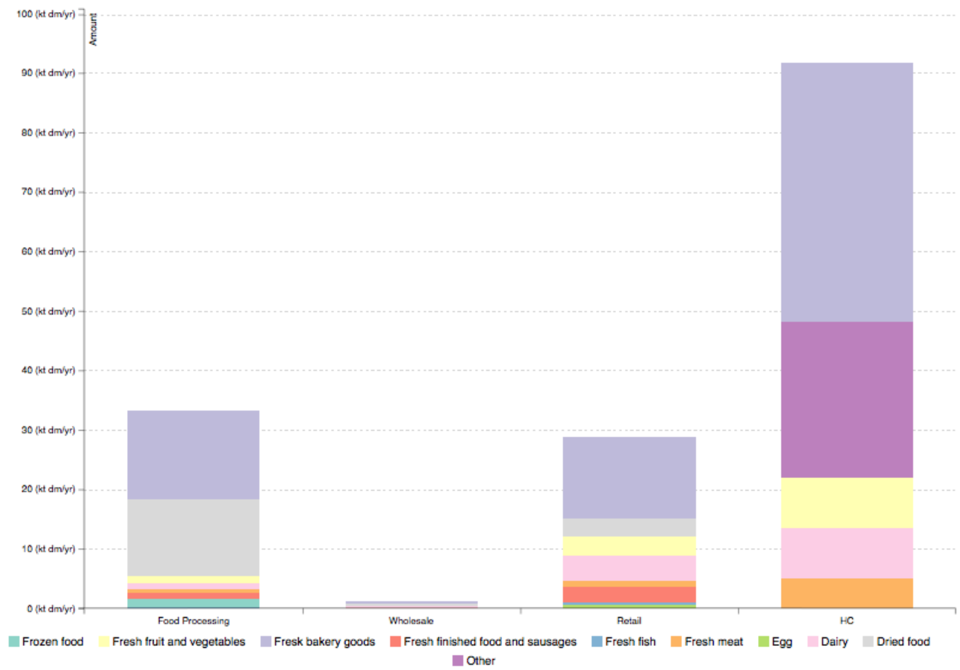


Figure 4.54: Stacked bar chart for showing the avoidable food waste measured as dry matter content

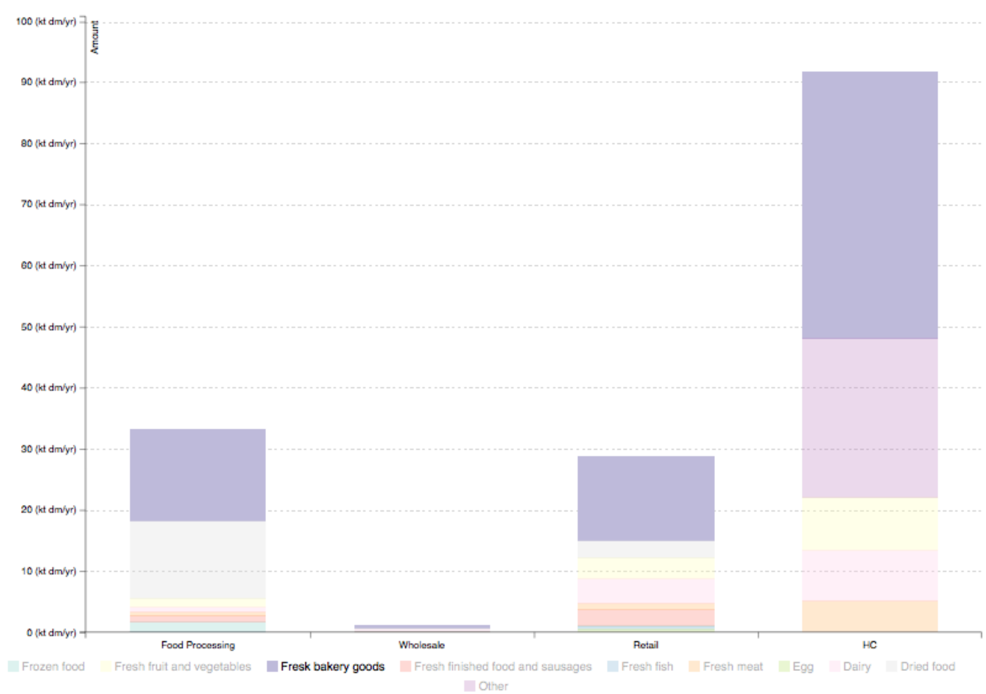


Figure 4.55: Highlight effect for the stacked bar chart

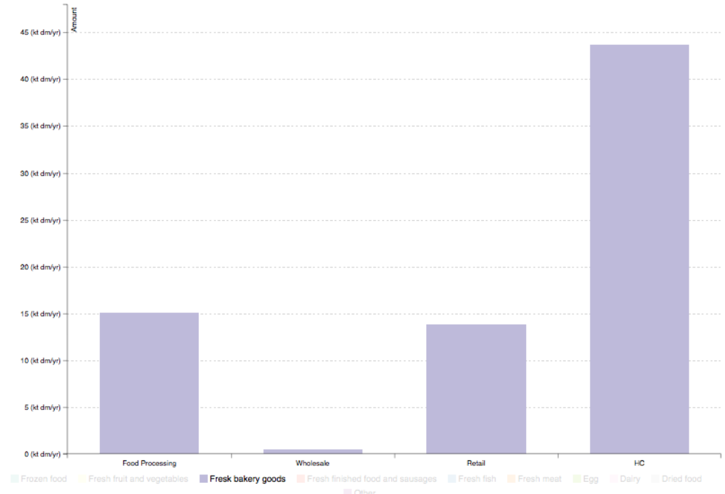


Figure 4.56: Unselecting the default food groups

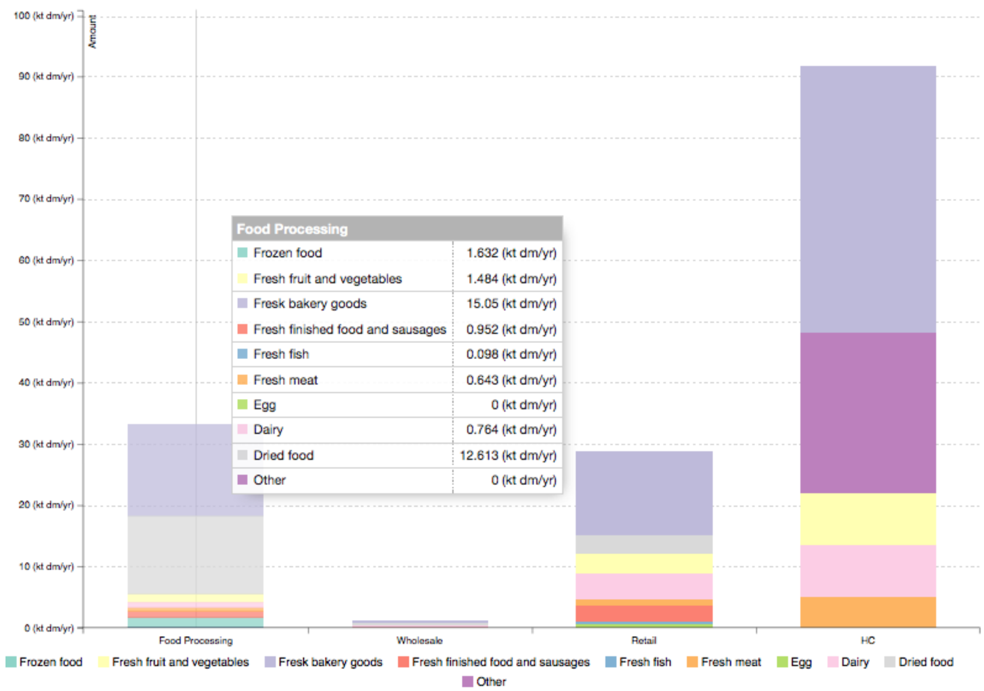


Figure 4.57: Popup table, avoidable food waste

In relation to the food waste research

In the context of informing policy makers, this diagram primarily communicates the sources of avoidable food waste among the different steps in the value chain distributed among the various food groups. This is provided in the dashboard solution in order to find out where to direct policy measures to reduce food waste. The chart provides a quick overview, showing that human consumption is the step in the value chain that by far accounts for most avoidable food waste, with 120 kiloton of dry matter per year. Upstream, retail and food processing account for about 30 kiloton of dry matter per year respectively, while wholesale is negligible compared to the aforementioned processes, with about 1 kiloton of dry matter per year. Additionally, stacked bar charts are to a large extent self-explanatory, providing a stack of subcategories, which as a whole present an absolute value for each of the steps in the value chain. This gives the user the opportunity to break information down into smaller pieces and compare quantities across the steps in the value chain.

4.2.7 Recycling versus prevention

Technical

The final visual element of the Norwegian food waste dashboard is a comparison of the two main perspectives presented by Hamilton et al. (2015b), the energy and phosphorus perspective. As illustrated in figure 4.58, two vertical bar charts compare the relative importance of food waste recycling for energy purposes versus food waste prevention for phosphorus related issues. As the aforementioned diagrams, this diagram also uses the C3.js library. Further on, the diagrams utilize data based on the energy demand in the transportation sector for 2010 (Ministry of Petroleum and Energy, 2013), and data from the research conducted by Hamilton et al. (2015b). The data for this diagram was embedded in the JavaScript source code.

The first bar chart from the left, presents the energy perspective. The chart displays the energy demand in the transportation sector for 2010 (Ministry of Petroleum and Energy, 2013) compared with the biogas potential for recycling food waste (Hamilton et al., 2015b). The comparison was done due to the fact that biogas is identified as a potential displacement for fossil fuels (Hamilton et al., 2015b). The phosphorus perspective uses the baseline scenario for phosphorus (Hamilton et al., 2015b) to compare the Norwegian demand for mineral phosphorus compared with potential reduction when preventing food waste.

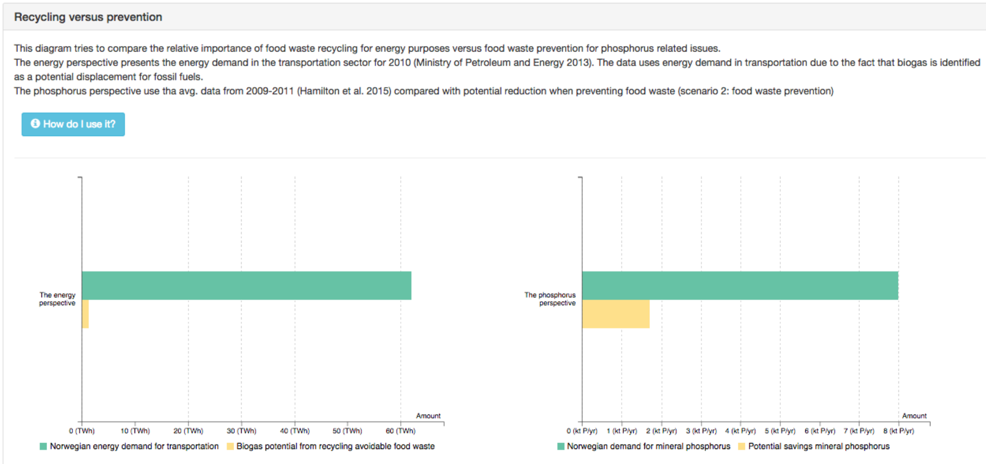


Figure 4.58: "Recycling versus prevention" diagram

In relation to the food waste research

In conjunction with informing policy makers, the two diagrams emphasize the importance of giving data a context related to the problem domain. The energy perspective demonstrates that biogas from recycling food waste, only can support energy transportation demands with 2% while import of phosphorus could be reduced 21% (Hamilton et al., 2015b), indicating that phosphorus savings from food waste prevention have a higher relative importance than energy production from food waste recycling. The overall power of communication is here demonstrated as a comparison between the importance of using food waste as an energy source versus more effective resource management of phosphorus, being an essential and scarce mineral, as well as a pollutant.

4.3 User testing

To test the usability and learnability of both the visual narrative and Norwegian food waste dashboard a number of five user tests were conducted, providing the user with a set of tasks for the user to solve in order to measure what they've learned, and a number of questions to measure the perceived usability of the tools. The outcome of the user testing indicates that the user (see Appendix C) overall got an understanding of the issues addressed related to food waste. However, the answers varied, few of them directly wrong, since the questions

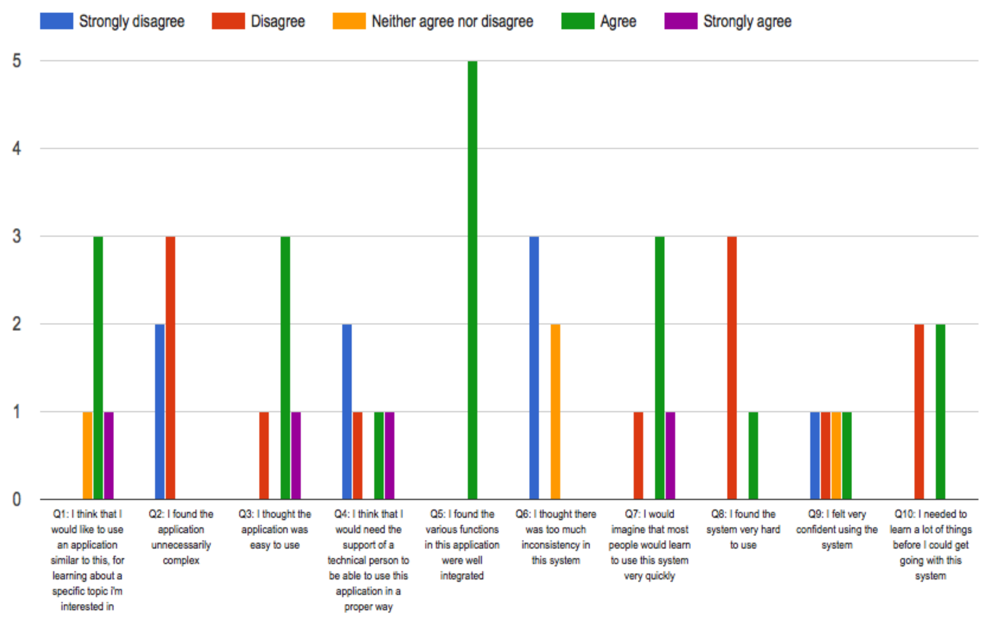


Figure 4.59: Questions from the user testing

were relatively open. Still, only one of the participants clearly touched up on the issues related to problem shifting between phosphorus and energy for the different policy scenarios.

As seen in figure 4.59, the results from the users perceived usability of the tools, indicates that the user found the application understandable and functional, and that none of the test participants ranked the usability of the application as low. It is also worth mentioning that one of the participants failed to answer Q8, Q9 and Q10, and that there were errors in the data for avoidable food waste, related to human consumption. This was first discovered after conducting the user test.

Chapter 5

Discussion

This study has, for the first time, used data visualization techniques to support the communication of a multi-layered MFA for the Norwegian food consumption, production and waste system. This project aimed at providing new insight into a multidisciplinary landscape, combining data visualization techniques and MFA. As indicated by the user testing, this project has shown to be promising in relation to the application's ability to convey the research results of Hamilton et al. (2015b), more specifically compare targeted policies, including food waste prevention and food waste recycling using interactive data visualization techniques. The added value of this project is the complimentary visualization techniques provided alongside the traditional Sankey diagram used in MFA (Brunner, 2012). In addition to this, a combination of modern web technologies, allowing for interaction and animation, arguably improves the traditional approach for visualization of MFA results.

5.1 The visual narrative

The visual narrative was developed as a means to provide a context, and lower the barrier of using the food waste dashboard. The visual narrative addresses food waste by looking at how much is thrown away both globally and locally, consequences of increasing food waste, current strategies for handling it, the implications of these strategies and at last argue why a systems approach is important. The argument for doing this was to give the user an overview of the problem domain using key concepts of storytelling, including what, who, where, when, why and how (Segel & Heer, 2010).

The visual narrative was created as an explanatory tool mainly focusing on giving the Norwegian food waste dashboard a context. According to the user testing, the visual narrative seems to be helpful in engaging the user to further explore the Norwegian food waste dashboard. Nonetheless, some improvements should be considered. First, the interactive functionality should be made clear for each diagram. Second, the visual narrative is not optimized for smartphones or tablets. Therefore, results may vary depending on the mobile device applied by the user.

Besides technical improvements, one must be aware that using data visualization storytelling techniques involves customizing a piece of information to convey a specific message using engaging graphics. Thus, the user may be subject to bias (McInerny et al., 2014). However, most of the data sources are provided as hyperlinks connecting the user to the original source, in other words, diminishing bias and improving transparency.

5.2 The Norwegian food waste dashboard

At the core of this project, the Norwegian food waste dashboard quantifies dry matter, phosphorus and energy for the Norwegian food production, consumption and waste system, providing an overview of the overall imports, throughputs, exports and losses. The dashboard was developed as an exploratory tool, letting the user investigate the MFA model provided by Hamilton et al. (2015b) using different visualization techniques. Using a traditional MFA approach for visualizing materials and substances within a specific system, flow diagrams, or more specifically Sankey diagrams (Brunner, 2012), were used as a core for providing a systems overview and creating systems-understanding for both phosphorus and energy.

5.2.1 Comparing scenarios

By visualizing the phosphorus and energy layer, as well as providing data about avoidable food waste as dry matter content in a systems perspective, concerns about diminishing sustainability due to narrow system boundaries are addressed (Hamilton et al. 2015b).

Through the comparison of the food waste prevention and food waste recycling scenario, this project shows a visual proof of prevention as the best strategy for handling food waste. As addressed through the visual narrative, budget priorities focus on strategies for recycling food waste. As argued by Hamilton et al. (2015b), production of goods, including biogas and food, profits business, and therefore the economic incentive stimulates the throughput of materials. However in an environmental context, the visual output, as especially seen in the "problem shifting" diagram, provides proof of the benefits related to food waste prevention. These benefits include more sustainable management of phosphorus through prevention strategies. For the recycling scenario, the dashboard clearly illustrates the marginal net output of energy, if total process energy requirements are accounted for. In addition, the dashboard quantifies the sources of avoidable food waste as dry matter content. This is a first step in informing policy makers where to take action. At the same time, as argued by Hamilton et al. (2015b), one must be aware that in many cases the cause and the source of food waste are disconnected due to issues upstream in the value chain. Therefore, this tool should be further developed in terms of coming up with concrete measures for reducing food waste throughout the value chain.

5.2.2 Approach

Using much of the same approach as Rud (2014) for developing Sankey diagrams, early iterations of this project investigated the use of the D3 Sankey diagram plugin, which utilizes an algorithm for creating the layout of the Sankey diagram. In later iterations of the project, with attempts to modify the algorithm, the use of the plugin was abandoned due to problems with overlapping flows. Instead, a custom made plugin was developed (Appendix A). As a result, the current Sankey diagram does not display the traditional curved flows; instead, basic lines with weighted edges were used. It is important to mention that the basic line layout of the current Sankey diagram is far from optimal in terms of visualizing imports, throughputs, exports and losses in the system, if we compare it to more refined Sankey diagrams. However, when working with animated transitions, as is the case when switching between scenarios, a basic line layout provided a more simplistic structure to work with, making the development process easier.

A more powerful way of distinguishing the effect of the different scenarios, the "Scenario comparison" diagram deemed valuable as a complementary visualization technique. First, using a simple bar chart layout, clustering all three scenarios for each individual flow, provides the user with the possibility to quickly compare the effects of the three scenarios, including the baseline, recycling and food waste prevention scenario. If we revisit the example mentioned above, concerning the "Waste to biogas" flow, the scenario comparison diagram more clearly display the difference between the scenarios.

Overall, the Sankey diagrams and "Scenario comparison" diagram provides insight into the effects of targeted policy for each respected scenario. On the other hand, these diagrams do not sufficiently communicate the tradeoffs between the phosphorus and energy layer. Looking at each layer separately does not effectively convey the issue related to problem shifting. However, this project addressed this issue using a visualization technique called parallel coordinates (Inselberg, 1985). This technique makes it possible to illustrate the interconnected nature of phosphorus and energy, by pulling apart the complexity of the multi-layered system.

Presenting the Norwegian food production, consumption and waste system in broader terms, the dry matter layer (Hamilton et al., 2015b) was used as the basis for quantifying imports, exports, domestic production and avoidable food waste through the "The Norwegian food production and consumption system quantified" diagram. Comparing the imports and domestic production with exports, consumption and avoidable food waste, the aforementioned diagram hopefully helps the user gain insight into the alternatives available if food waste is reduced. The idea behind the diagram is to communicate the opportunity cost of not reducing food waste, hence reducing import dependency or use agricultural land for other purposes. Therefore the dashboard contextualizes food waste in a broader context. However, one of the weaknesses of this diagram is that it is disconnected from the scenarios presented in the Sankey diagrams, only using the dry matter data from the baseline scenario. Therefore, integrating the diagram with all of the scenarios should be considered. Regardless, making the system more effective would be of interest to decision makers since food security is an expressed political goal (NOU 2013:10).

5.2.3 Limitations

A weakness of the dashboard solution is the absent visualization of the dry matter layer in its entirety. Only a selection of the dry matter data is presented directly in the Norwegian food waste dashboard, which is an issue, since the phosphorus and energy layers are derived from this data. A more optimal solution would likely involve visualizing the phosphorus and energy layer as fractions of the dry matter layer. However, due to the lack of data availability of dry matter for the food waste recycling and food waste prevention scenario, this was not achievable. As a result, future refinements of the application should consider the aforementioned approach, which in principle is similar to the approach proposed by Rud (2014). This would also improve the transparency of the research.

Another limitation of the food waste dashboard is the absence of avoidable food waste fractions as visual elements in relation to the Sankey diagrams. Instead, avoidable food waste is visualized separately as a stacked bar chart, quantifying the food waste among the steps in the value chain distributed among the various food groups. In the future, a more feasible approach would likely be to include food waste fractions as a part of the Sankey diagram for both the phosphorus and energy layer. This way, the source of avoidable food waste could be linked with the individual resource, making the connection more evident to the user.

For measuring the effects of phosphorus and energy in view of targeted policies, animated transitions were applied for switching between multiple policy scenarios. Seemingly, a novel way of showing the differences between scenarios, the approach has a series of challenges. First, all flows starts transitioning at the same time, likely making it difficult for the user to capture all of the changes occurring in the system due to a high level of detail. Secondly, a number of changes go unnoticed due to the scaling of the values, especially for the phosphorus data. As a result, horizontal gridlines were included during the later iterations of the project, attempting to make it easier for the user to notice the changes, hence increasing insight (Kirk, 2012). As an example, the “Waste to biogas” flow in the phosphorus layer only shows a marginal visual difference between the three scenarios, even though there is a 300% increase from the food waste prevention to the food waste recycling scenario. This result comes from the scaling of the Sankey diagram, since all of the flows involved in the system were give a minimum and maximum pixel value in the source code.

Further on, users might want to look into the largest contributors along the value chain, distributed among various food groups as illustrated in the “Avoidable food waste” diagram. However, a more valuable extension of this approach, as previously discussed, would be to integrate this diagram with the Sankey diagrams, thus providing a direct connection to the phosphorus and energy layer.

A challenge throughout this project was to compare the relative importance of food waste recycling for energy purposes with food waste prevention for phosphorus related issues. Two diagrams were provided in the last phase of this project, attempting to display the differences. However, also here, a closer integration with the Sankey diagram would be more feasible.

As mentioned in conjunction with the visual narrative, the dashboard solution is not optimized for users with smartphones or tablets. Making the application responsive across different devices should be considered as future work. Further on, a number of extensions should be considered. First, as emphasized by Hamilton et al. (2015b), uncertainty plays a major role in the research. Therefore, techniques for presenting uncertainty in conjunction with the dashboard should be implemented. This would more than likely strengthen the transparency, and also create a platform for further improving research related to the Norwegian food production, consumption and waste system.

In terms of storage, data redundancy is present, since the same data is applied multiple times using different visualization techniques. This is the case for the Sankey diagrams, “Scenario comparison” diagram and the parallel coordinates plot all applying different techniques using the same dataset. The redundancy increases the room for error, and it exposes the application for inconsistency in relation to the presentation of the data. Therefor, a centralized storage structure should be considered in the future.

5.3 Development process

As a general remark, the development process has proven to be valuable in terms of detecting errors in the data set and increasing understanding of the research (Hamilton et al., 2015b). This suggests that data visualization in itself could be a valuable tool for discovering errors, patterns, relationships and physical characteristics throughout the research phase (Kirk, 2012). As a result, this project indicates that data visualization should be considered as an integrated process when working with MFA, not only an end solution. Throughout this project the use of open source technologies for developing the application has been important. This way, others may easily reuse the source code from this project as a basis for further development or use it for a completely different application in the future.

5.4 User testing

The results from the user testing, indicates that the Norwegian food waste dashboard and the visual narrative helped the user gaining insight into the problem domain. However, judging from the results, few of the users really grasped the issues surrounding problem shifting and tradeoffs between the different policy scenarios. On the other hand, the user testing only involved a handful of people; therefore, the results could not be regarded as statistically significant. Still as argued by Nielsen (2000), the cost of having more than five users most likely exceeds the benefit.

As the user test was a part of the final iteration of the project, more elaborate user testing was not considered. Another limitation was that only users without knowledge of the problem domain were recruited. Evaluating the real communicative effect could only be done if decision makers evaluated the tools themselves. Therefore, the user testing provides a foundation for evaluating the work conducted in this project, and serves as a source for improvement. More user testing should take place before making any specific assumptions about the usability of the tools. In parallel, an iterative approach should be adopted, making sure the tools are improved. As an additional remark the user testing was conducted before errors in the data set related to avoidable food waste were discovered. Having errors in the dataset during user testing might have skewed some of the answers in the user test. Due to limited amount of time in the last phase of the project, the results from the user test were not used to revise the application. Instead, this is something that can be subject to change in future iterations of the application.

5.5 How does this project improve the communication of the research conducted by Hamilton et al. (2015b)?

For this project, three visualization techniques showed prominence. The first technique is the traditional Sankey diagram technique. This approach provides a systems overview, with the ability to easily distinguish between the different flows in terms of size (value) and color (type), for both the phosphorus and energy layer. At the same time, the Sankey diagram facilitates learning using animated transitions between the different scenarios. However, despite providing a systems overview, both the interconnected nature as well as the comparison of different scenarios where not strongly supported by this visualization technique.

The second technique is the “Scenario comparison” diagram. This visualization technique supplements the Sankey diagram by allowing the user to compare all the scenarios at the same time. This is done by clustering the scenarios as individual bars, enabling the user to see how different scenarios affect the various flows for both the energy and phosphorus layer. The third technique is the parallel coordinates plot, used for visualizing problem shifting. The parallel coordinates plot visualizes the effect of targeted policy scenarios across the phosphorus and energy layer, and thus filling the gap of both the first and second technique.

Since all three visualization techniques complement each other, it is highly advisable that these techniques are further explored in conjunction with other multi-layered MFA studies. This way, the real communicative power of these techniques could be further evaluated.

5.6 What are the main benefits and shortcomings of the tools ability to convey the research?

This project uncovers a potential for communicating research more effectively using interactive data visualization methods. The outcome, an explanatory (the visual narrative) and exploratory (the Norwegian food waste dashboard) tool, presents the user with different approaches for communicating the research, using modern web technologies and interactive data visualization techniques.

Hamilton et al. (2015) applied a multi-layered MFA when analyzing the Norwegian food waste system. Investigating multiple resources for the Norwegian food waste system increased the complexity of the results. Hence, a visual display of information strengthened the communication of the research through the transformation of complex data into visual imagery, improving the learnability of the overall MFA system. In addition, interaction was provided for exploring scenarios of the highly complex subject matter.

When trying to bridge the gap between scientists and policy makers, this project lowers the barrier for participating in the public debate through creating understanding of the data. By presenting the data from Hamilton et al. (2015b), through multiple lenses, the tool could target a wide group of decision makers, from domain experts to politicians. Aiming at improving the communication of the research, the apparent link between phosphorus and energy as highly coupled resources, seem evident.

However, the main shortcoming of this project is the lack of testing in the real world. Therefore, measuring the tools real ability to convey the research results of Hamilton et al. (2015b) could only be done retrospectively after having presented the tool to decision makers working with food waste, energy and phosphorus related issues. Even if measuring the impact is a tedious task, more extensive user testing could help to further uncover the usability of the proposed tools and techniques.

Bibliography

Bendix, F., Kosara, R., and Hauser, H. (2005). Parallel sets: Visual analysis of categorical data. *Proceedings - IEEE Symposium on Information Visualization, INFO VIS*, (1):133–140.

Bostock, M., Ogievetsky, V., and Heer, J. (2011). D 3 : Data-Driven Documents. *IEEE Transactions on Visualization and Computer Graphics*, 17(March):2301–2309.

Brekk, L. P. (2010). Forebygging av matavfall - høyt på den matpolitiske agenda.

Bringezu, S. and Moriguchi, Y. (2002). Material Flow Analysis. *A Handbook of Industrial Ecology*, pages 79–90.

Brooke, J. (1996). SUS-A quick and dirty usability scale. *Usability evaluation in industry*, 189:194.

Brunner, P. H. (2012). Substance Flow Analysis. *Journal of Industrial Ecology*, 16(3):293–295.

Cencic, O. and Rechberger, H. (2008). Material Flow Analysis with Software STAN. *EnviroInfo 2008 - Environmental Informatics and Industrial Ecology*, 2008:440–447.

Cooper, J. and Carliell-Marquet, C. (2013). A substance flow analysis of phosphorus in the UK food production and consumption system. *Resources, Conservation and Recycling*, 74:82–100.

Cordell, D., Drangert, J.-O., and White, S. (2009). The story of phosphorus: Global food security and food for thought. *Global Environ Chang*, 19:292–305.

D Stone, C Jarrett, M. W. S. M. (2005). *User Interface Design and Evaluation*. Elsevier.

Deng, C., Li, H., and Shao, Y. (2014). Research on the Drawing Method of Energy Sankey Diagram Based on Java. ICACT 2014 : The 16th International Conference on Advanced Communications Technology.

Dos Santos, S. and Brodlie, K. (2004). Gaining understanding of multivariate and multidimensional data through visualization. *Computers and Graphics (Pergamon)*, 28(3):311–325.

Elzen, S. V. D. and Wijk, J. J. V. (2014). Multivariate Network Exploration and Presentation : From Detail to Overview via Selections and Aggregations. *IEEE Transactions on Visualization and Computer Graphics*, 20(12):2310–2319.

FAO (2013). *Food wastage footprint. Impacts on natural resources. Summary Report*.

Foley, J. A., Ramankutty, N., Brauman, K. A., Cassidy, E. S., Gerber, J. S., Johnston, M., Mueller, N. D., O/'Connell, C., Ray, D. K., West, P. C., Balzer, C., Bennett, E. M., Carpenter, S. R., Hill, J., Monfreda, C., Polasky, S., Rockstrom, J., Sheehan, J., Siebert, S., Tilman, D., and Zaks, D. P. M. (2011). Solutions for a cultivated planet. *Nature*, 478(7369):337–342.

Fowler, M. and Highsmith, J. (2001). The agile manifesto. *Software Development*, 9(August):28–35.

Fox, P. and Hendler, J. (2011). Changing the equation on scientific data visualization. *Science (New York, N.Y.)*, 331(6018):705–8.

Hamilton, H. A., Brod, E., Hanserud, O. S., Gracey, E. O., Vestrum, M. I., Bøen, A., Steinhoff, F. S., Müller, D. B., and Brattebø, H. (2015a). Identifying potential cross-sectoral synergies through integrated aquaculture, fisheries and agricultural phosphorus assessments: Norway as a case.

Hamilton, H. A., Peverill, M. S., Müller, D. B., and Brattebø, H. (2015b). A multi-resource systems approach for assessing food waste prevention versus recycling.

Hanssen, O. J. and Schakenda, V. (2011). *Nyttbart matsvinn i Norge 2011 Analyser av status og utvikling i matsvinn i Norge 2010-11 - Rapport fra ForMat-prosjektet*.

Harrower, M. and Brewer, C. a. (2011). ColorBrewer.org: An Online Tool for Selecting Colour Schemes for Maps. *The Map Reader: Theories of Mapping Practice and Cartographic Representation*, 40(1):261–268.

Heer, J. and Robertson, G. G. (2007). Animated transitions in statistical data graphics. *IEEE Transactions on Visualization and Computer Graphics*, 13(6):1240–1247.

Hendriks, C., Obernosterer, R., Müller, D., Kytzia, S., Baccini, P., and Brunner, P. H. (2000). Material Flow Analysis: A tool to support environmental policy decision making. Case-studies on the city of Vienna and the Swiss lowlands. *Local Environment*, 5(3):311–328.

House of Lords (2014). Counting the Cost of Food Waste : EU Food Waste. (April):78.

Inselberg, A. (1985). The plane with parallel coordinates. *The Visual Computer*, 1(4):69–91.

Kirk, A. (2012). *Data Visualization: a successful design process*. Packt Publishing Ltd.

Klima- og Miljødepartementet (2014). Nasjonal tverrsektoriell biogasstrategi.

Kytzia, S., Faist, M., and Baccini, P. (2004). Economically extended - MFA: A material flow approach for a better understanding of food production chain. *Journal of Cleaner Production*, 12(8-10):877–889.

Lima, M. (2011). *Visual Complexity: Mapping Patterns of Information*. Princeton Architectural Press.

Mattilsynet (2013a). Mineralgjødselstatistikk 2009 – 2010. Technical report, Mattilsynet.

Mattilsynet (2013b). Mineralgjødselstatistikk 2010 – 2011. Technical report, Mattilsynet.

Mattilsynet (2013c). Mineralgjødselstatistikk 2011 - 2012. Technical report, Mattilsynet.

Mattilsynet (2014). Mineralgjødselstatistikk 2012 - 2013. Technical report, Mattilsynet.

Mattilsynet (2015). Mineralgjødselstatistikk 2013 - 2014. Technical report, Mattilsynet.

McInerny, G. J., Chen, M., Freeman, R., Gavaghan, D., Meyer, M., Rowland, F., Spiegelhalter, D. J., Stefaner, M., Tessarolo, G., and Hortal, J. (2014). Information visualisation for science and policy: engaging users and avoiding bias. *Trends in ecology & evolution*, 29(3):148–57.

Miljødirektoratet (2013). Biogass reduserer klimagassutslipp.

Miljødirektoratet (2015). Våtorganisk avfall.

Ministry of Petroleum & energy (2013). National Renewable Energy Action Plan under Directive 2009 / 28 / EC Norway. (September 2012):1–139.

Nielsen, J. (2000). Why You Only Need to Test with 5 Users. *Jakob Nielsens Alertbox*, 19(September 23):1–4.

Nielsen, J. and Landauer, T. K. (1993). A mathematical model of the finding of usability problems. *Proceedings of the SIGCHI conference on Human factors in computing systems - CHI '93*, pages 206–213.

NOU (2013). Naturens goder - om verdien av økosystemtjenester. Technical report, Norges offentlige utredninger.

Ole Jørgen Hanssen og Hanne Mø ller (2013). *Matsvinn i Norge 2013 Status og utviklingstrekk 2009-13*.

Ott, C. and Rechberger, H. (2012). The European phosphorus balance. *Resources, Conservation and Recycling*, 60:159–172.

Personopplysningsloven. (2000). *Lov om behandling av personopplysninger*.

Refsgaard, K., Bergsdal, H., Pettersen, J., and Berglann, H. (2011). Climate gas emissions from food systems – use of LCA analyses. pages 1–25.

Regjeringen (2014a). Vil redusere matsvinnet.

Regjeringen (2014b). Prop . 1 S Statsbudsjettet.

Riehmann, P., Hanfler, M., and Froehlich, B. Interactive Sankey Diagrams. pages 233–240.

Risku-Norja, H. and Mäenpää, I. (2006). MFA model to assess economic and environmental consequences of food production and consumption. *Ecological Economics*, 60(4):700–711.

Rud, R. O. (2014). Development of an interactive MFA model for the Norwegian P balance: Coupling biomass and P to visualize scenarios in "real time" !

Sandnes, F. E. (2011). *Universell utforming av IKT-systemer- brukergrensesnitt for alle.* Universitetsforlaget, 1 edition.

Schmid Neset, T.-S., Bader, H.-P., Scheidegger, R., and Lohm, U. (2008). The flow of phosphorus in food production and consumption – Linköping, Sweden, 1870-2000. *The Science of the total environment*, 396(2-3):111–20.

Schmidt, M. (2008a). The Sankey Diagram in Energy and Material Flow Management- Part I: History. *Journal of Industrial Ecology*, 12(1):82–94.

Schmidt, M. (2008b). The Sankey Diagram in Energy and Material Flow Management- Part II: Methodology and Current Applications. *Journal of Industrial Ecology*.

Segel, E. and Heer, J. (2010). Narrative visualization: Telling stories with data. *IEEE Transactions on Visualization and Computer Graphics*, 16(6):1139–1148.

Shneiderman, B. (1992). Tree visualization with tree-maps: 2-d space-filling approach. *ACM Transactions on Graphics*, 11(1):92–99.

Shneiderman, B. (1996). The eyes have it: a task by data type taxonomy for information visualizations. *Proceedings 1996 IEEE Symposium on Visual Languages*, pages 336–343.

Spears, W. (1999). An overview of multidimensional visualization techniques. *in Proceedings of the 1999 Genetic and Evolutionary Conference Workshop Program, A. Wu, Ed. San Mateo, CA: Morgan Kaufmann*, pages 104–105.

SSB (2015). *Utslipp av klimagasser, 2014, foreløpige tall.*

Statistics Norway (2013). Miljødimensjonen ved maten under lupen.

Stone, D., Jarrett, C., Woodroffe, M., and Minocha, S. (2005). *User interface design and evaluation*. Morgan Kaufmann.

Tufte, E. (1983). The visual display of quantitative information. *CT Graphics, Cheshire*, (2).

USGS (2015). MINERAL COMMODITY SUMMARIES 2015. Technical report, U.S. Geological Survey.

Wirsenius, S. (2003). The Biomass Metabolism of the Food System: A Model-Based Survey of the Global and Regional Turnover of Food Biomass. *Journal of Industrial Ecology*, 7(1):47–80.

Yuan, Z., Shi, J., Wu, H., Zhang, L., and Bi, J. (2011). Understanding the anthropogenic phosphorus pathway with substance flow analysis at the city level. *Journal of environmental management*, 92(8):2021–8.

Appendix A

Code for generating the energy and phosphorus layer

As one of the most relevant parts of this project, the custom developed code for generating the Sankey diagrams are included here. The rest of the code for both the visual narrative and the Norwegian food waste dashboard is left out due to incredibly large amounts of code. However, the remaining code is available on GitHub, see Appendix B.

A.1 Generating the phosphorus layer

```
//This (x) defines which scenario we are on var scenarioVariable = 0;

var scenarioName = "Baseline Scenario: 2009 − 2011 avg."

var tipFlow = d3.tip()    .attr('class', 'd3−tip')    .offset([−10, 0])
.html(function(d) {                if ( scenarioVariable == 0)
{                         return "<strong>Flow:</strong> <span
style='color:orange'>" + d.f_name + "</span></br><strong>Type:
</strong>" + "<span style='color:orange'>" + d.f_type +
"</span></br><strong>Value: </strong>" + "<span style='color:orange'>"
```

```
+ d.value_s0 + "</span> (kt P/yr)</br><strong>Scenario: </strong>" +
"<span style='color:orange'>" + "S0: Baseline" + "</span>";
}                 if ( scenarioVariable == 1)                      {
return "<strong>Flow:</strong> <span style='color:orange'>" + d.f_name
+ "</span></br><strong>Type: </strong>" + "<span
style='color:orange'>" + d.f_type + "</span></br><strong>Value:
</strong>" + "<span style='color:orange'>" + d.value_s1 + "</span> (kt
P/yr)</br><strong>Scenario: </strong>" + "<span style='color:orange'>"
+ "S1: Recycling for biogas" + "</span>";                    }
if (scenarioVariable == 2)                  {                   return
"<strong>Flow:</strong> <span style='color:orange'>" + d.f_name +
"</span></br><strong>Type: </strong>" + "<span style='color:orange'>"
+ d.f_type + "</span></br><strong>Value: </strong>" + "<span
style='color:orange'>" + d.value_s2 + "</span> (kt
P/yr)</br><strong>Scenario: </strong>" + "<span style='color:orange'>"
+ "S2: Preventing food waste" + "</span>";                  }    });

var width = 1450,      height = 700;

var yScale = d3.scale.linear()                          .domain([0,
12])                          .range([4, 15]);

var svg = d3.select("#sankeyContent_P")               .append("svg")
.attr("width", width)                .attr("height", height);

var scenarioLabel = d3.select("#scenarioLabel_P")
.text(scenarioName);

function readFile(file) {
```

```
d3.json(file, function(graph) {

var processes = svg.append("g").selectAll(".line")
.data(graph.processes)                          .enter()
.append("line");

var mfaProcesses = processes               .attr("id", function (d) {
return d.p_id; })               .attr("x1",function (d) { return d.p_x1;
})               .attr("y1",function (d) { return d.p_y1; })
.attr("x2",function (d) { return d.p_x2; })
.attr("y2",function (d) { return d.p_y2; })               .attr("stroke-
width", function (d) { return d.p_strokeWidth; })
.attr("stroke", function (d) { return d.p_stroke; });
//.on('mouseover', tipProcess.show)               //.on('mouseout',
tipProcess.hide);

svg.append('marker')    .attr('id', "input-arrow")
.attr('markerHeight', 2.5)   .attr('markerWidth', 2,5)
.attr('orient', 'auto')   .attr('refX', 0)   .attr('refY', 0)
.attr('viewBox', '-5 -5 20 10')   .append('path')   .attr('d', 'M 5,0
m -5,-5 L 5,0 L 0,5 Z')   .style("opacity", 0.5)   .style("fill",
"#6a51a3");

svg.append('marker')   .attr('id', "output-arrow")
.attr('markerHeight', 2.5)   .attr('markerWidth', 2,5)
.attr('orient', 'auto')   .attr('refX', 0)   .attr('refY', 0)
.attr('viewBox', '-5 -5 20 10')   .append('path')   .attr('d', 'M 5,0
m -5,-5 L 5,0 L 0,5 Z')   .style("opacity", 0.5)   .style("fill",
"#a50f15");
```

```
svg.append('marker') .attr('id', "loop-arrow")
.attr('markerHeight', 2.5) .attr('markerWidth', 2,5)
.attr('orient', 'auto') .attr('refX', 0) .attr('refY', 0)
.attr('viewBox', '-5 -5 20 10') .append('path') .attr('d', 'M -5,0
L -5,-5 L -5,0 L 0,5 L 0,-5') .style("opacity", 0.5)
.style("fill", "#08519c");

svg.append('marker') .attr('id', "linear-arrow")
.attr('markerHeight', 2.5) .attr('markerWidth', 2,5)
.attr('orient', 'auto') .attr('refX', 0) .attr('refY', 0)
.attr('viewBox', '-5 -5 20 10') .append('path') .attr('d', 'M 5,0
m -5,-5 L 5,0 L 0,5 Z') .style("opacity", 0.5) .style("fill",
"#006d2c");

var linearFlows = svg.append("g").attr("class",
"MFA_flows").selectAll(".line")              .data(graph.flows)
.enter()              .append("line");              //.on("click",
function(d) {              //      return
document.getElementById("myDialog").showModal();              //});

var mfaFlows = linearFlows              .attr("id", function (d) {
return d.f_id })              .attr("x1", function (d) {
if(d.flowDir == "loop")              {              return d.f_x1
+ ((d.value_s0 * 10)/2);              }              else {
return d.f_x1;              }              })              .attr("y1",
function (d) { return d.f_y1 })              .attr("x2", function (d) {
if(d.flowDir == "loop")              {              return d.f_x2;
}              else {              return d.f_x2 - ((d.value_s0 *
10) / 2)              }              })              .attr("y2",
function (d) { return d.f_y2 })              .attr("stroke-width",
```

```
function (d) { return yScale(d.value_s0 * 10) })
.attr("stroke", function (d) { return d.f_stroke })            .attr
("stroke-dasharray", function (d) { return d.strokeDasharray })
.attr("marker-start", function (d) {               if (d.flowDir ==
"loop")                     {                       return "url(#loop-
arrow)";                    }                 })               .attr("marker-
end", function (d) {                   if (d.flowDir == "output")
{                       return "url(#output-arrow)";                    }
if (d.flowDir == "input")                   {                      return
"url(#input-arrow)";                    }                 if (d.flowDir ==
"linear")                   {                    return "url(#linear-arrow)";
}

})                 .call(tipFlow)                 .on('mouseover',
tipFlow.show)                 .on('mouseout', tipFlow.hide);

svg.selectAll("text.process")           .data(graph.processes)
.enter()           .append("text")           .attr("id", "processText")
.attr("x", function(d) { return d.p_x1 - 70; })          .attr("y",
function(d) { return d.p_y1 - 10; })          .text(function(d) {
return d.p_name; });

var flowText = svg.selectAll("text.flow")           .data(graph.flows)
.enter()           .append("text")           .attr("id", function(d) {
return d.f_id; })           .attr("x", function(d) { return d.f_x1 + 5;
})           .attr("y", function(d) { return d.f_y1 - yScale((d.value_s0
* 10)/2); })           .text( function (d) { return d.f_name + " (" +
d.value_s0 + " kt P/yr)"; });

d3.select("#s1_p").on("click", function() {
```

```
scenarioVariable = 1;

scenarioName = "Scenario 1: Recycling food waste"

scenarioLabel = d3.select("#scenarioLabel_P")
.text(scenarioName);

mfaFlows    .data(graph.flows)     .transition()    .duration(3000)
.attr("id", function (d) { return d.f_id })    .attr("x1", function
(d) {     if(d.flowDir == "loop")    { return d.f_x1 + ((d.value_s1
* 10)/2);    }    else { return d.f_x1;    }  }) .attr("y1", function
(d) { return d.f_y1 }) .attr("x2", function (d) {  if(d.flowDir ==
"loop")    { return d.f_x2;    }    else { return d.f_x2 -
((d.value_s1 * 10)/2)    }  }) .attr("y2", function (d) { return
d.f_y2 }) .attr("stroke-width", function (d) { return
yScale(d.value_s1 * 10) }) .attr("stroke", function (d) { return
d.f_stroke }) .attr("stroke-dasharray", function (d) { return
d.strokeDasharray });

flowText .transition() .duration(3000) .attr("x", function(d) {
return d.f_x1 + 5; }) .attr("y", function(d) { return d.f_y1 -
yScale((d.value_s1 * 10)/2); }) .text( function (d) { return
d.f_name + " (" + d.value_s1 + " kt P/yr)"; });



d3.select("#s2_p").on("click", function() {

scenarioVariable = 2;
```

```
scenarioName = "Scenario 2: Preventing food waste";

scenarioLabel = d3.select("#scenarioLabel_P")
.text(scenarioName);

mfaFlows   .transition()   .duration(3000)   .attr("id", function
(d) { return d.f_id })   .attr("x1", function (d) {
if(d.flowDir == "loop")   { return d.f_x1 + ((d.value_s2 * 10)/2);
}   else { return d.f_x1;   }  }) .attr("y1", function (d) {
return d.f_y1 }) .attr("x2", function (d) {  if(d.flowDir ==
"loop")   { return d.f_x2;   }   else { return d.f_x2 -
((d.value_s2 * 10)/2)   }  }) .attr("y2", function (d) { return
d.f_y2 }) .attr("stroke-width", function (d) { return
yScale(d.value_s2 * 10)}) .attr("stroke", function (d) { return
d.f_stroke }) .attr("stroke-dasharray", function (d) { return
d.strokeDasharray });

flowText   .transition()   .duration(3000)   .attr("x", function(d)
{ return d.f_x1 + 5; })   .attr("y", function(d) { return d.f_y1 -
yScale((d.value_s2 * 10)/2); })   .text( function (d) { return
d.f_name + " (" + d.value_s2 + " kt P/yr)"; });



d3.select("#baseline_P").on("click", function() {

scenarioVariable = 0;

scenarioName = "Baseline Scenario: 2009 - 2011 avg.";
```

```
scenarioLabel = d3.select("#scenarioLabel_P")
.text(scenarioName);

mfaFlows    .transition()    .duration(3000)    .attr("id", function
(d) { return d.f_id })    .attr("x1", function (d) {
if(d.flowDir == "loop")    { return d.f_x1 + ((d.value_s0 * 10)/2);
}    else { return d.f_x1;    }  }) .attr("y1", function (d) {
return d.f_y1 }) .attr("x2", function (d) {  if(d.flowDir ==
"loop")    { return d.f_x2;    }    else { return d.f_x2 -
((d.value_s0 * 10)/2)    }  }) .attr("y2", function (d) { return
d.f_y2 }) .attr("stroke-width", function (d) { return
yScale(d.value_s0 * 10)})

/*              .attr("stroke-width", function (d) {
if (d.value_s0 < 0.1 ) { return d.value_s0 * 40};              if
(d.value_s0 > 1) {return (d.value_s0 * 10)};              })
*/

.attr("stroke", function (d) { return d.f_stroke }) attr
.("stroke-dasharray", function (d) { return
.d.strokeDasharray });

flowText    .transition()    .duration(3000)    .attr("x", function(d)
{ return d.f_x1 + 5; })    .attr("y", function(d) { return d.f_y1 -
yScale((d.value_s0 * 10)/2); })    .text( function (d) { return
d.f_name + " (" + d.value_s0 + " kt P/yr)"; });
```

```
var jsonFile1 = "data/dataPhosphorus.json"

readFile(jsonFile1);
```

A.2 Generating the energy layer

```
//This (x) defines which scenario we are on var scenarioVariable = 0;

var scenarioName = "Baseline Scenario: 2009 - 2011 avg."

var tipFlow_energy = d3.tip()   .attr('class', 'd3-tip')
.offset([-10, 0])   .html(function(d) {            if (
scenarioVariable == 0)                    {                    return
"<strong>Flow:</strong> <span style='color:orange'>" + d.f_name +
"</span></br><strong>Type: </strong>" + "<span style='color:orange'>"
+ d.f_type + "</span></br><strong>Value: </strong>" + "<span
style='color:orange'>" + d.value_s0 + "</span>
(pj/yr)</br><strong>Scenario: </strong>" + "<span
style='color:orange'>" + "S0: Baseline" + "</span>";
}
if ( scenarioVariable == 1)                    {
return "<strong>Flow:</strong> <span style='color:orange'>" + d.f_name
+ "</span></br><strong>Type: </strong>" + "<span
style='color:orange'>" + d.f_type + "</span></br><strong>Value:
</strong>" + "<span style='color:orange'>" + d.value_s1 + "</span>
```

```
(pj/yr)</br><strong>Scenario: </strong>" + "<span
style='color:orange'>" + "S1: Recycling for biogas" + "</span>";
}                if (scenarioVariable == 2)                {
return "<strong>Flow:</strong> <span style='color:orange'>" + d.f_name
+ "</span></br><strong>Type: </strong>" + "<span
style='color:orange'>" + d.f_type + "</span></br><strong>Value:
</strong>" + "<span style='color:orange'>" + d.value_s2 + "</span>
(pj/yr)</br><strong>Scenario: </strong>" + "<span
style='color:orange'>" + "S2: Preventing food waste" + "</span>";
}    })

var width = 1450,       height = 700;

var yScale = d3.scale.linear()                              .domain([0,
12])                              .range([4, 15]);

var svg_E = d3.select("#sankeyContent_E")                 .append("svg")
.attr("width", width)                 .attr("height", height);

var scenarioLabel = d3.select("#scenarioLabel_E")
.text(scenarioName);

function readFile(file) {

d3.json(file, function(graph) {

var processes = svg_E.append("g").selectAll(".line")
.data(graph.processes)                                .enter()
.append("line");
```

```
var mfaProcesses = processes .attr("id", function (d) {
return d.p_id; }) .attr("x1",function (d) { return d.p_x1;
}) .attr("y1",function (d) { return d.p_y1; })
.attr("x2",function (d) { return d.p_x2; })
.attr("y2",function (d) { return d.p_y2; }) .attr("stroke-
width", function (d) { return d.p_strokeWidth; })
.attr("stroke", function (d) { return d.p_stroke; });
//.on('mouseover', tipProcess.show) //.on('mouseout',
tipProcess.hide);

svg_E.append('marker') .attr('id', "input-arrow_E")
.attr('markerHeight', 2.5) .attr('markerWidth', 2,5)
.attr('orient', 'auto') .attr('refX', 0) .attr('refY', 0)
.attr('viewBox', '-5 -5 20 10') .append('path') .attr('d', 'M 5,0
m -5,-5 L 5,0 L 0,5 Z') .style("opacity", 0.5) .style("fill",
"#6a51a3");

svg_E.append('marker') .attr('id', "output-arrow_E")
.attr('markerHeight', 2.5) .attr('markerWidth', 2,5)
.attr('orient', 'auto') .attr('refX', 0) .attr('refY', 0)
.attr('viewBox', '-5 -5 20 10') .append('path') .attr('d', 'M 5,0
m -5,-5 L 5,0 L 0,5 Z') .style("opacity", 0.5) .style("fill",
"#a50f15");

svg_E.append('marker') .attr('id', "loop-arrow_E")
.attr('markerHeight', 2.5) .attr('markerWidth', 2,5)
.attr('orient', 'auto') .attr('refX', 0) .attr('refY', 0)
.attr('viewBox', '-5 -5 20 10') .append('path') .attr('d', 'M -5,0
L -5,-5 L -5,0 L 0,5 L 0,-5') .style("opacity", 0.5)
.style("fill", "#08519c");
```

```
svg.append('marker') .attr('id', "linear-arrow_E")
.attr('markerHeight', 2.5) .attr('markerWidth', 2,5)
.attr('orient', 'auto') .attr('refX', 0) .attr('refY', 0)
.attr('viewBox', '-5 -5 20 10') .append('path') .attr('d', 'M 5,0
m -5,-5 L 5,0 L 0,5 Z') .style("opacity", 0.5) .style("fill",
"#ec971f");

var linearFlows = svg_E.append("g").attr("class",
"MFA_flows").selectAll(".line") .data(graph.flows)
.enter() .append("line"); //.on("click",
function(d) { // return
document.getElementById("myDialog").showModal(); //});

var mfaFlows = linearFlows .attr("id", function (d) {
return d.f_id }) .attr("x1", function (d) {
if(d.flowDir == "loop") { return d.f_x1
+ ((d.value_s0 * 2 )/2); } else {
return d.f_x1; } }) .attr("y1",
function (d) { return d.f_y1 }) .attr("x2", function (d) {
if(d.flowDir == "loop") { return d.f_x2;
} else { return d.f_x2 - ((d.value_s0 *
2) /2) } }) .attr("y2",
function (d) { return d.f_y2 }) .attr("stroke-width",
function (d) { return yScale(d.value_s0 * 2) })
.attr("stroke", function (d) { return d.f_stroke }) .attr
("stroke-dasharray", function (d) { return d.strokeDasharray })
.attr("marker-start", function (d) { if (d.flowDir ==
"loop") { return "url(#loop-
arrow_E)"; } }) .attr
```

```
("marker-end", function (d) {                    if (d.flowDir ==
"output")                      {                         return "url(#output-
arrow_E)";                     }                    if (d.flowDir == "input")
{                        return "url(#input-arrow_E)";
}
if (d.flowDir == "linear")                  {                        return "url
(#linear-arrow_E)";                    }

})                   .call(tipFlow_energy)
.on('mouseover', tipFlow_energy.show)                  .on('mouseout',
tipFlow_energy.hide);

svg_E.selectAll("text.process")             .data(graph.processes)
.enter()              .append("text")            .attr("id", "processText")
.attr("x", function(d) { return d.p_x1 - 70; })            .attr("y",
function(d) { return d.p_y1 - 10; })            .text(function(d) {
return d.p_name; });

var flowText = svg_E.selectAll("text.flow")            .data(graph.flows)
.enter()              .append("text")            .attr("id", function(d) {
return d.f_id; })            .attr("x", function(d) { return d.f_x1 + 10;
})            .attr("y", function(d) { return d.f_y1 - yScale((d.value_s0
* 2)/2); })            .text(function(d) { return d.f_name + " (" +
d.value_s0 + " pj/yr)"; });

d3.select("#s1_E").on("click", function() {

scenarioVariable = 1;

scenarioName = "Scenario 1: Recycling food waste"
```

```
scenarioLabel = d3.select("#scenarioLabel_E")
.text(scenarioName);

mfaFlows .data(graph.flows) .transition() .duration(3000)
.attr("id", function (d) { return d.f_id }) .attr("x1", function
(d) { if(d.flowDir == "loop") { return d.f_x1 + ((d.value_s1
* 2)/2); } else { return d.f_x1; } }) .attr("y1", function
(d) { return d.f_y1 }) .attr("x2", function (d) { if(d.flowDir ==
"loop") { return d.f_x2; } else { return d.f_x2 -
((d.value_s1 * 2)/2) } }) .attr("y2", function (d) { return
d.f_y2 }) .attr("stroke-width", function (d) { return
yScale(d.value_s1 * 2) }) .attr("stroke", function (d) { return
d.f_stroke }) .attr("stroke-dasharray", function (d) { return
d.strokeDasharray });

flowText .transition() .duration(3000) .attr("x", function(d) {
return d.f_x1 + 5; }) .attr("y", function(d) { return d.f_y1 -
yScale((d.value_s1 * 2)/2); }) .text(function(d) { return d.f_name +
" (" + d.value_s1 + " pj/yr)"; });



d3.select("#s2_E").on("click", function() {

scenarioVariable = 2;

scenarioName = "Scenario 2: Preventing food waste";

scenarioLabel = d3.select("#scenarioLabel_E")
```

```
.text(scenarioName);

mfaFlows    .transition()    .duration(3000)    .attr("id", function
(d) { return d.f_id })    .attr("x1", function (d) {
if(d.flowDir == "loop")    { return d.f_x1 + ((d.value_s2 * 2)/2);
}    else { return d.f_x1;    }  }) .attr("y1", function (d) {
return d.f_y1 }) .attr("x2", function (d) {  if(d.flowDir ==
"loop")    { return d.f_x2;    }    else { return d.f_x2 -
((d.value_s2 * 2)/2)    }  }) .attr("y2", function (d) { return
d.f_y2 }) .attr("stroke-width", function (d) { return
yScale(d.value_s2 * 2)}) .attr("stroke", function (d) { return
d.f_stroke }) .attr("stroke-dasharray", function (d) { return
d.strokeDasharray });

flowText    .transition()    .duration(3000)    .attr("x", function(d)
{ return d.f_x1 + 5; })    .attr("y", function(d) { return d.f_y1 -
yScale((d.value_s2 * 2)/2); })    .text(function(d) { return
d.f_name + " (" + d.value_s2 + " pj/yr)"; });



d3.select("#baseline_E").on("click", function() {

scenarioVariable = 0;

scenarioName = "Baseline Scenario: 2009 - 2011 avg.";

scenarioLabel = d3.select("#scenarioLabel_E")
.text(scenarioName);
```

```
mfaFlows    .transition()    .duration(3000)    .attr("id", function
(d) { return d.f_id })    .attr("x1", function (d) {
if(d.flowDir == "loop")    { return d.f_x1 + ((d.value_s0 * 2)/2);
}    else { return d.f_x1;    }  }) .attr("y1", function (d) {
return d.f_y1 }) .attr("x2", function (d) {  if(d.flowDir ==
"loop")    { return d.f_x2;    }    else { return d.f_x2 -
((d.value_s0 * 2)/2)    }  }) .attr("y2", function (d) { return
d.f_y2 }) .attr("stroke-width", function (d) { return
yScale(d.value_s0 * 2)}) .attr("stroke", function (d) { return
d.f_stroke }) .attr("stroke-dasharray", function (d) { return
d.strokeDasharray });

flowText    .transition()    .duration(3000)    .attr("x", function(d)
{ return d.f_x1 + 5; })    .attr("y", function(d) { return d.f_y1 -
yScale((d.value_s0 * 2)/2); })    .text( function (d) { return
d.f_name + " (" + d.value_s0 + " pj/yr)"; });





var jsonFile2 = "data/dataEnergy.json"

readFile(jsonFile2);
```

Appendix B

The complete source code

B.1 Overview file structure

JavaScript	**CSS**	**JSON/CSV**	**Fonts**
problemShifting.js	bootstrap.min.css	parallelData.csv	glyphicons-halflings-regular.eot
nfws.js	c3.css	dataEnergy.json	glyphicons-halflings-regular.svg
jquery.js	d3.parcoords.css	dataPhosphorus.json	glyphicons-halflings-regular.ttf
intro.js	grid.css		glyphicons-halflings-regular.woff
FW_sankey_P.js	grid.svg		glyphicons-halflings-regular.woff2
FW_sankey_E.js	introjs.css		
flowsBarChartDashboard.js	mainStyle.css		
d3.v3.min.js			
d3.tip.js			
d3.min.js			
comparisonPolicyEffects.js			
c3.js			
bootstrap.min.js			
avoidableFoodWaste.js			

Table B.1: Files included in the Norwegian food waste dashboard

JavaScript	CSS	JSON/CSV
wetWasteToEnergy.js	bootstrap.min.css	mapData.json
wetWasteStoryline.js	c3.css	parallelData.csv
sectorEmissions.js	d3.parcoords.css	
problemShifting.js	examples.css	
PEandLossesStorylineVersion.js	jquery.fullPage.css	
P__map.js		
jquery.slimscroll.min.js		
jquery.fullPage.js		
foodWasteGlobally.js		
fertilizerTrend.js		
d3.v3.js		
d3.parcoords.js		
d3-funnel-charts.js		
c3.js		
budgetPriorities.js		
biogas.js		
avoidableFoodWaste.js		

Table B.2: Files included in the visual narrative

B.2 Link to all of the code on GitHub

The code is also provided as an attachment to this document.

B.2.1 Code: The Norwegian food waste dashboard

https://github.com/richard-rud/NorwegianFoodWasteProject/tree/master/dashboard

B.2.2 URL: The Norwegian food waste dashboard

http://folk.ntnu.no/richaror/dashboard/

B.2.3 Code: The narrative visualization

https://github.com/richard-rud/NorwegianFoodWasteProject/tree/master/storyline

B.2.4 URL: The narrative visualization

http://folk.ntnu.no/richaror/storyline/

B.3 References for programming libraries

B.3.1 MAMP

appsolute GmbH. (2015). MAMP. Retrieved from https://www.mamp.info/en/

B.3.2 Globe plugin

Bostock, M. (2012a). Globe plugin. Retrieved from https://gist.github.com/mbostock/4183330

B.3.3 TopoJSON

Bostock, M. (2012b). TopoJSON. Retrieved from https://github.com/mbostock/topojson

B.3.4 D3: Data-driven documents

Bostock, M. (2015). D3. Retrieved from https://github.com/mbostock/d3

B.3.5 Parallel coordinates library

Chang, K. (2012). parallel-coordinates. Retrieved from https://github.com/syntagmatic/parallel-coordinates

B.3.6 ColorBrewer

Harrower, M., and Brewer, C. a. (2013). COLORBREWER 2.0. Retrieved from http://colorbrewer2.org/
Mapbox. (n.d.).

B.3.7 Advanced legend

Advanced legends. Retrieved from https://www.mapbox.com/tilemill/docs/guides/advanced-legends/

B.3.8 C3

Masayuki, T. (2013). C3. Retrieved from https://github.com/masayuki0812/c3

B.3.9 intro.js

Mehrabani, A. (2012). intro.js.

B.3.10 d3-funnel-charts

Milli, S. (2014). d3-funnel-charts. Retrieved from https://github.com/smilli/d3-funnel-charts

B.3.11 fullPage.js

Trigo, A. (2013). fullPage.js. Retrieved from https://github.com/alvarotrigo/fullPage.js

Appendix C

Results: User testing

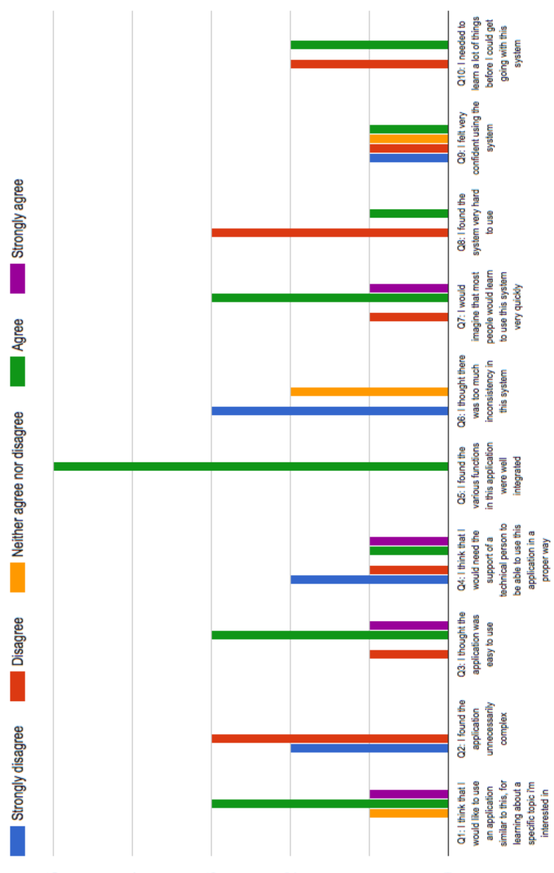


Figure C.1: Results from the users perceived usability of the tools

Tasks	Questionnaire 1	Questionnaire 2	Questionnaire 3	Questionnaire 4	Questionnaire 5
T1: Do you think there any environmental benefits associated with recycling food waste, if this is the case, what do you think these are?	The aim should be to prevent food waste. Still, some food will always be thrown. Then it can be used to fuel production.	Ja! Ved å resirkulere matavfall kan avfallet brukes som kompost/gjødsel i hager eller jordbruk.	Yes. Utilizing a energy source that oterwise would just be waste.	Yes. Sustainable development.	Fordelene er at man får utnyttet energien som det er mulig å gjenvinne.
T2: What do you think are the environmental benefits associated with food waste prevention?	less strain on land, climate, phospherous etc.	Fordelene ved dette kan være at de ikke må brukes energi på å resirkulere avfallet senere. Det vil gjøre at det produseres mindre som fører til at transport av varene minker og utslipp ved transport vil minke.	Less waste, effective food production.	Reduce resource use connected with food production, such as factories and other facilities that may also be bad for the environment	kaster man mindre, mindre energi brukt til å produsere mat, større fordeling av mat til verdens befolkning, befolkningen blir sunnere. Utfordrer logistikkhjernen til planlegging…
T3: Do you think are any major trade-offs/conflicting issues between choosing a policy focusing on recycling food waste for biogas versus a policy focusing on food waste prevention, if so, what do you think are the major trade-offs/conflicting issues?	more foodwaste and recycling will make the need to produce food greater. So by choosing a recycling policy, one will contribute to a geopolitical issue and all the negative environmental bi-effects of producing food.	Ved å redusere matavfallet så vil det være mindre matavfall å resirkulere.	Prevention is obviously better as this is the root of the problem.	By recycling the food waste can contribute to energy production, which food waste preventoin can't.	Mye penger i å produsere mat. Mange som tjener mindre penger om folk blir mer bevisste på å ikke kaste.
T4: If you were to decide, what do you see as the best scenario with regards to policy making (focusing on food waste recycling or food waste prevention)?	food waste prevention	Prevention	Stop the farms from throwing away food that does not «look good»	I believe both strategies has pros and cons, and both are difficult to make a 100% effective. By using the prevention strategy, we can't make the food contribute to the enery prodution as mentioned above, but by using the recycling policy there is a good chance that not all the waste will be recycled. I believe in a combination of the two strategies.	food WASTE PREVENTION! HELT KLART!
T5: What types of food do we in Norway throw away the most?	wet organic waste.	Fersk frukt, bakevarer og tørket mat	Fruits and vegetables?	Pastries, fruits and vegetables	Frisk frukt og grønnsaker
T6: Which step in the value chain do you think has the greatest potential for reducing food waste?	consumption	Hos forbrukerene i hvert hjem.	Farmers		Husholdningen
T7: Which process/processes (Plant Production, Animal Husbandry, Food Processing, Human Consumption, Waste Management and/or Biogas Production) do you think has the most impact on the overall phosphorus system?	human consumption	Food processing	Animal husbandry	Plant production	Husdyrhold. Fordi: Manglende husdyrhold bidrar til mindre økologisk gjødsel.
T8: Which process/processes (Plant Production, Animal Husbandry, Food Processing, Human Consumption, Waste Management and/or Biogas Production) do you think has the most impact on the overall energy system?	animal husbandry	Food processing	Animal husbandry	Human consumtion	Husdyrhold.

Figure C.2: Results from the tasks