The phosphorus cycle of Berlin-Brandenburg

From the present towards possible futures

Mark Schipper

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TU Delft
Delft University of Technology

Universiteit Leiden

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by Mark Schipper

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1st supervisor:
Dr. J.N. Quist
TU Delft, TPM faculty

2nd supervisor:
Dr. E. van der Voet
Leiden University, CML

Partner:
T. Theobald
ATB Potsdam

Contact information:
markschipper.io@gmail.com

Little garden on a sidewalk near Boxhagener Platz, Friedichshain district, Berlin.

"Eine andere Welt ist pflanzbar"

~

A different world can be planted

Preface

This thesis has been written within the Master of Science programme Industrial Ecology at the TU Delft and Leiden University. In order to perform the research I decided to live in Berlin for the duration of the research. Phosphorus recycling appeared to be of growing interest within the local scientific community already. This gave me the chance to collaborate with Tim Theobald during the first part of my research, and to present my findings at the workshop "Phosphor für die Landwirtschaft: Strategien für eine endliche Ressource", held at the ATB Potsdam institute on the 11th of June 2014.

It was the alarming paper written by Cordell (2009) that brought the issues surrounding phosphorus depletion to my attention. During that time I was doing a group project about eco-cities. I realized that the city would provide a very promising perspective to study many problems related to sustainability, including phosphorus depletion. The two subjects were combined to form the starting point of my thesis research project.

I found Dr. Ester van der Voet prepared to guide me through the modelling parts of the research. With the support of Dr. Jaco Quist I managed to devise a methodology that proved to be well-capable to study how a regional phosphorus cycle could be optimized. I would like to thank both my supervisors for their insightful feedback, patience, and support for the entrepreneurial way I was able to carry out the research.

My gratitude also goes to the friends, housemates, and neighbours who made me feel at home during my stay in Berlin, and made my endeavour an unforgettable experience: Manu, Tim, Keno, Ursula, Viktor, Ane, Alice, Iris, Wenzel, Cornel, Sosheraya, Isabel, Tonia and Christopher.

Last but not least, I would also like to thank my parents, brother Roel, and friends Leon and Arne for always being there for me.

Mark Schipper
Berlin, August 2014

Summary

The aim of this research was to explore to which extend the phosphorus cycle can become closed, and how this could be realized. Encompassing both the supply and demand side of a phosphorus cycle, the German region Berlin-Brandenburg was chosen as a case area. To carry out the research itself a methodology was created that integrates the Mass Flow Analysis (MFA) tool with the Backcasting framework of Quist and Vergragt (2006). In applying the methodology, the technical and social layers of the current system (i.e. Berlin-Brandenburg) were first analysed, followed by estimated long-term developments (i.e. forecast). This identified the opportunities for improvement of the cycle and the main issues the social network faces. The forecast and an inquiry of (theorectially) available solutions were used to create future visions of a differently optimized cycle. As a last step it was assessed how the current system could develop towards realization of the visions.

First a phosphorus MFA of Berlin-Brandenburg over the year 2011 was made. The analysis showed that the two main imports to agriculture are mineral fertilizer (4,477 t P) and fodder (4,153 t P).These amounts could be used as a reference to interpret the findings related to the optimization potential of the cycle. Post-consumption phosphorus (waste) streams were found to be very limitedly recycled in Berlin-Brandenburg. A total 470 t P is being recycled from consumer waste streams back to agriculture. Sewage sludge (2,960 t P) is by far the largest unrecycled phosphorus stream. Also currently incinerated biowaste contains significant amounts of phosphorus; 680 t P in total. Slaughterwaste (1,427 t P) is another highly rich phosphorus stream that is being exported out of the case area with unknown fate.

It was also found that Brandenburg's agricultural soils had a large deficit of 1,434 t P over 2011. Phosphorus losses to surface waters in 2011 were signifiant with 1,795 t P in total. Losses from agricultural soils amounted to 1,052 t P. Furthermore, a total of 3,176 t P was added to landfills in 2011, and both urban soils and natural soils were found to accumulate phosphorus; 205 t P and 129 t P respectively.

As part of the social analysis the main (niche) actors were identified, as well as the most important rules shaping the actions of these actors. It was found that the issues related to future phosphorus availability are well-understood by the actors in the agriculture, waste treatment, policy, and research domains. Centralized recycling of sewage sludge is seen as the main opportunity for improvement within the actor-network, but its realization is mainly hampered due to lack of financial resources. Food processors and retailers may also refuse produce grown from recycled phosphorus due to the potential negative public perception related to fears for contamination. This may in turn discourage farmers to adopt recycled phosphorus fertilizers. It was also found that the farmers are principally willing to apply recycled phosphorus to the land, but that the price/performance has to be at least equal to that of mineral fertilizers.

In the second part of the research two distinct visions for the year 2060 were created, which were based on long-term developments identified. The society in Techno-fix is imagined to be highly technologically advanced. In this vision automization processes have made most routine-based labour redundant, and an transition towards renewable electricity has taken place. In the vision Culture-fix the adoption of different mindsets of people drives the process of change. As a result, in Culture-fix the pace of the economy has slowed down, and people have organized themselves more locally.

Two criteria were applied to technologies that could feature in the two visions; the degree of centrality of the technology, and the degree to which citizen involvement is required to successfully implement the

technology. The phosphorus cycle of Techno-fix is driven by highly centralized technologies requiring little involvement of the citizen to be implemented. These include vertical farms, in vitro meat production facilities, macerators, and the Mephrec recycling process. The opposite is true for Culture-fix. In that vision organic farming, EcoFerm! manure to algae fodder, and vacuum separating toilets are the status quo. In addition to those technologies, citizens have also adopted vegetarian diets and far reduced food waste.

To test the capability of the visions to improve the phosphorus cycle, first a forecast of the 2011 MFA was made for the year 2060. The Berlin-Brandenburg population decline of 3.4% was accounted for, and the agricultural soil deficit and sewage sludge imports were eliminated. Then the properties of the solutions for each vision found were applied to the forecasted MFA. Thereby one MFA was created to represent each of the two visions. The trend and vision cycle efficiencies were subsequently calculated by relating the internal material cycle to the amount of unrecycled phosphorus i.e. waste. The forecasted MFA was found to have an efficiency of 80.7%, and the cycle efficiencies of Techno-fix and Culture-fix were calculated at 92.5% and 95.3%, respectively. This means that while a phosphorus atom cycles 5.2 times in the forecasted MFA before it is discarded, this was increased to 13.3 times in Techno-fix and to 21.3 times in Culture-fix. Both visions thereby showed a large improvement to that of the trend. Unretrievable losses to surface waters in both visions was decreased by 79%.

It was concluded that a combination of the two visions would yield the highest cycle efficiency. Vertical farms in combination with vacuum separating toilets would lead to the lowest unretrievable losses to the environment as well as the highest crop yields. In vitro meat production was found to be more efficient than livestock breeding, while the EcoFerm! process could still convert manure produced from milk cows and laying henns to algae fodder. In such a cycle Mephrec facilities without a connection to the sewage system should recycle any (food) waste produced. Additionally, a shift to vegetarism and a reduction of food waste produced would lead to further efficiency gains.

Reluctance of farmers to adopt recycled fertilizers would undermine the efforts of waste treatment actors to recycle phosphorus. Farmers, in turn, are dependent on the processing industry and retail and ultimately the consumer for the marketing of their products. It was therefore recommended that the best course of action would be to first thoroughly test a wide range of recycling products on crop growth and human health. Biological tests of each batch of recycling products should be made mandatory to ensure the quality of these products. Furthremore, actors in the waste treatment and policy domains lack the financial resources to implement many of the improvement technologies. Higher policy levels should therefore financially support the transition. Yet, because the cooperation of actors throughout the cycle are required for successful recycling of phosphorus, an implementation plan should be developed that is supported by actors from all domains directly governing the cycle.

Vertical farms and in vitro meat production are capable of realizing high phosphorus conversion efficiencies while requiring a relatively low surface area. Therefore these technologies may well hold the long-term solution for feeding the growing global population. However, it will probably take decades to develop these technologies towards mainstream application. Also a transtion to inexpensive and renewable electricity is a prerequisite for vertical farms. In the meantime conventional agriculture may have been rendered unfeasible already as a result of climate change excerbations. More organic forms of agriculture will be more resistant to these changes. In the short term it was therefore recommended to further stimulate the conversion to organic agricultural practises, as well as the research and development of renewable electricity, vertical farming and in vitro meat production.

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Chapter 1

Introduction

1.1 The phosphorus cycle: A historical perspective

Phosphorus (P) is an essental element for all life on Earth as it is a component of cell membranes, bones and teeth, genetic material and energy carriers. It can therefore be stated that without phosphorus no single organism can exist. In ecosystems phosphorus is taken up from the soil (or water) by producers (plants, algae) that convert it with other nutrients into organic matter. The organic matter is then eaten by the primary consumers (herbivores) which may in turn be eaten by secondary consumers (predators), and so on. Organic matter, including urine and faeces, not eaten by consumers is used in the metabolism of the decomposers (bacteria, fungi) which convert the organic matter back into inorganic matter that can be taken up by producers again. Phosphorus leaves ecosystem as it enters deeper soil layers and becomes part of the slower geobiochemical cycle, while it becomes available again as rocks desintegrate through weathering processes.

The first humans were hunters and gatherers, roaming through forests and grasslands in the search for food. Nomadic lifestyles was no longer necessary when man learned to cultivate food crops and domesticate animals, providing a (more) secure food supply. This both enabled and forced people stay in one place because the food crops had to harvested at exactly the right time (Steel, 2013). The first settlements emerged. Nutrients contained in the food produced by these early settlements were returned to the soil again as people threw away spoiled food, buried the dead and excreted in or nearby agricultural fields, closing the biochemical phosphorus cycle. This changed as settlements turned into towns and cities over the course of centuries, creating a division between urban and rural. During the 19th century, urine and faeces constituted the largest urban waste streams (Geels, 2006). Although a portion of this 'waste' was sold to farmers who used it as fertilizer, the majority of the people disposited their waste on streets and surface waters, removing it from sight (Geels, 2006). These unhygienic conditions lead to the outbreak of various diseases, leading to the construction of sewers which diverted the waste streams away from the city. In effect, this opened up the regional phosphorus cycle.

Similar to the urban phosphorus flows, also phosphorus flows in rural areas changed signficantly during the 19th century. After the discovery of the Haber-Bosch process in 1909, by which atmospheric nitrogen is converted to ammonia, organic fertilizer from the city became gradually replaced by mined inorganic NPK fertilizers. These fertilizers became a widespread practise after WWII. Along with pesticide use and heavy machinery to sow, irrigate and harvest, it preluded modern agriculture. Increasingly higher yields per surface area alleviated hunger in many poor parts of the world, commonly referred to as the Green Revolution, and it allowed the global population to expand further. It is estimated that to date about half of the total agricultural land is fertilized inorganically (Erisman et al., 2008), and that without inorganic fertilizers about one-third of the global food could not be produced.

Although these developments have enabled humans to advance, the (global) phosphorus cycle has become disrupted as a result. This newly created problem will be treated in the Problem definition.

1.2 Problem definition

As is the case of any raw material extracted from the Earth, also phosphate reserves are limited and will become depleted eventually (Ayres, 2007). And in contrast to metals, phosphorus leaches out to the ocean where the element becomes virtually unretrievable. Given the high importance on maintaining or even expanding current phosphate production in order to provide an adequate food supply for a growing global population, emphasis should not be put on the expected date of phosphorus depletion. Rather, the expected date of maximum, or peak phosphorus production is important because after peak production is reached production rates will inevitably start to dwindle (Hubbert, 1949), resulting in a phosphorus supply that is increasingly unable to match phosphorus demand.

For a long time, static reserves of phosphorus were estimated to be between 90 and 100 years availability (Notholt et al., 1989). However, recent analyses by Cordell et al. (2009) indicate that phosphorus reserves could be exhausted in 50 to 100 years time, and that peak phosphorus could be reached as soon as 2035. Déry and Anderson (2007) even suggest that peak phosphorus belongs to the past already and that therefore current world phosphate production is on a decline. In contrast, Van Kauwenbergh (2010) has published a survey incorporating previously overlooked data, and raised the estimate of phosphorus availability to 300 to 400 years. However, given the scarce data on phosphorus reserves as well as phosphorus demand dynamics, no reliable joint estimate of phosphorus availability can be expected in the short term (Lamprecht et al., 2011).

At the root of the phosphorus depletion problem lies a highly inefficient (global) food production and consumption system. Cordell et al. (2009) calculated that out of the 14 MT of elemental phosphorus that are applied annually as fertilizer to crops only 3 MT are actually consumed by humans, while post-consumption phosphorus flows are very limitedly recycled.

1.2.1 Additional issues related to phosphorus and the food system

An additional (geopolitical) dimension to the phosphorus depletion problematique concerns the unequal distribution of global phosphate rock reserves. Marocco/Western Sahara controls most resources (3762 MT; 38%), followed by China (2706 MT; 27.3%), South Africa (990 MT, 10%) and the United States (792 MT, 8%) (Jasinski, 2009). These figures concern reserves and are calculated in elemental phosphorus. Van Kauwenbergh (2010) survey, which raises mainly Marocco/Western Sahara reserves from 3762 MT to 33,000 MT, is not represented in these figures. Thus, only a few countries control the vast majority of global phosphate rock reserves and can therefore be expected to become increasingly subject to international political influence. Marocco has a near monopoly on Western Saharas reserves which is contrary to international law (WSRW, 2007), China is posing phosphorus export tariffs to secure domestic supplies and the United States have less than 30 years left of supplies (Jasinski, 2006).

Several other important trends that will influence the demand for phosphorus include (1) growing global population, (2) increasing affluence of mainly BRIC countries, and (3) fossil fuel scarcity.

1. By 2050, the global population is expected to grow beyond 9 billion people, resulting in an additional 2-2.5 billion more people to feed (IWMI, 2006). More people to feed will logically result in an increased demand for food and hence, phosphorus.
2. As the BRIC countries become more affluent peoples diets in these countries will shift. Meat and dairy products in particular, which require higher phosphorus inputs than other foods are becoming increasingly popular in these developing countries (Cordell et al., 2009). The International Water Management Institute has estimated that the growth of the global population and the shift in diet occurring mainly in Asia combined will require the global food production to increase 70% by 2050 to match global demand (Cordell et al., 2009).
3. Concerns about oil availability have led to a sharp increase in biofuel production over the past few years. The biofuel industry competes with food production for grains, productive land and fertilizers, and the year 2007 was the first year a clear rise in phosphorus demand could be attributed to biofuel production (Cordell et al., 2009).

1.2.2 Concluding remarks

The information compiled in this problem definition shows that phosphorus availability is influenced by a complex interaction of many interrelated factors and that crises with regards to phosphorus availability may occur long before peak phosphorus production is actually reached. Despite the uncertainty surrounding the longevity of phosphorus reserves, measures towards more efficient use and recycling of this crucial resource should be implemented in the short term, in order to counteract turbulence that can be expected in the longer term.

1.3 Phosphorus depletion literature review

In assessing the literature related to the phosphorus cycle, it seems that relatively few attempts have been made to actually map phosphorus flows running through society. Looking from a global perspective, Cordell et al. (2009) and Van Vuuren et al. (2010) have mapped the worldwide phosphorus flows, with the latter publication also including projected changes in the global phosphorus cycle up to 2050. At the level of a country phosphorus flow charts have been found of Switzerland (Lamprecht et al., 2011), the Netherlands (CBS, 2008) and China (Lui, 2005). At the regional scale, Borjestedt and Svanäng (2011) took the city of Gothenburg, Sweden as the unit of analysis for their master thesis and Schmid Neset et al. (2008) did the same for Linköping, also located in Sweden. The examples given are the only ones known to have mapped anthropogenic phosphorus flows. These researchers all used the Mass Flow Assessment (MFA) tool for their analysis. This tool will be described in section 2.1.

In addition to mapping phosphorus flows, the literature featuring the phosphorus depletion problematique has evolved towards a more solution-oriented approach. Whereas a part of the literature found mainly describes possible options for intervention (Childers et al., 2011; Cordell and White, 2013; Kabbe, 2013b; Keyzer, 2010), other papers connect several of these options to an analysis of the phosphorus cycle and assess how it affects this cycle (Borjestedt and Svanäng, 2011; Schmid Neset et al., 2008; Van Vuuren et al., 2010). In addition, Van den Berg et al. (2013) have explored global phosphorus supply and demand dynamics up to the year 2050, assessing implications for the EU. This is done using two scenarios; a trend-based scenario and a scenario featuring five strategies to reduce fertilizer demand. These researchers conclude that effective recycling of animal and human excreta offer the best potential to reduce future phosphorus demand (-32% for the EU). Malingreau et al. (2012) expand the research scope to also include nitrogen and potassium availability up to the year 2100, next to phosphorus availability. Interestingly, these authors argue that the current discourse should move away from a normative approach to sustainability towards more practical and geographically adapted solutions, also including socio-economic contexts.

Phosphorus depletion literature featuring a more regional approach in which socio-economic aspects have been included is found in a publication by Lamprecht et al. (2011), whom have analysed the societal factors influencing the utilization of phosphorus-rich bonemeal and sewage sludge by means of a historical case study in Switzerland. Another study conducted by master students of the Industrial Ecology track of the TU Delft and Leiden University looked at ways to reduce phosphate usage in the Netherlands, thereby also taking into account main actors influencing phosphate usage. These students concluded that 95% phosphate recovery is possible in the Netherlands by recycling phosphorus from animal and human excreta, for which cultural barriers seem to be the most stringent barrier.

1.3.1 Knowledge gaps: possibilities for future research

Most of the encountered publications either feature phosphorus depletion scenarios, phosphorus MFA analyses, and possible solutions or a combination of these. Issues regarding the regional implementation remain underexposed. Although Lamprecht et al. (2011) also takes into account the local (socio-economic) context, this publication is limited in the sense that the societal process is analysed whereas the policy implications and encountered barriers for actually utilizing the waste streams are not addressed. Policy implications and barriers towards improving the phosphorus cycle are addressed by IE, but this study does not assess the effect of implementing measures on the regional phosphorus cycle. A study that addresses the regional phosphorus cycle and potential solutions in combination with the socio-economic aspects that may hinder or enable the implementation is still missing. This offers a good research opportunity, which will be further described in section 1.5.

1.4 Research goal

In operationalizing the concept of sustainability for the purpose of this thesis, I follow Graedel and Allenby, 2010, p.46 who state that sustainability ultimately requires that nonrenewable, nonabundant resources are used no faster than renewable substitutes can be found for them. In the case of phosphorus this means that this resource is extracted not faster than the amount made available through the geobiochemical cycle, implying that the remaining portion of (global) phosphorus used should be recycled. However, it is highly uncertain if this can be realized in the long term as phosphorus leaches out of agricultural soils that sustain high food production. Dealing with this uncertainty, the main goal of this thesis is to close the phosphorus cycle as far as possible, thereby adding an exploratory element to the research. Using a timeframe of 54 years from present to future, the year 2060 is chosen as the time at which the goal should be fulfilled.

1.5 Thesis statement

With the main goal of the thesis stated in section 1.4, it is deemed that taking a regional perspective spanning a city or metropolitan area could to provide a fruitful direction to work towards this goal. Since 2008, more people live in urban areas than in rural areas and by 2050 more than 70% of the global population is projected to live in urban areas (UN-Habitat, 2008). An increasingly larger part of the global food produced is transported to the city where it is stored, consumed, and converted to waste which is subsequently treated, constituting a major part of the anthropogenic phosphorus cycle. The city can thus increasingly be seen as the place where phosphorus accumulates, providing possibilities for effective phosphorus management. It is realized, however, that despite urbanization trends the agricultural sector remains the largest phosphorus sink (Cordell et al., 2009). The focus of research will therefore lie on food production, which could be partly optimized by also including the city as part of the system. The city and its direct (agricultural) environment will be chosen as the area of research, with the added benefit that the focus on a specific area allows for a tailored solution towards effective phosphorus management. Relating to the Problem definition, even though the research features a case, its results could contribute to more efficient phosphorus cycles in and around other (Western) cities.

The phosphorus cycle is understood to be part of a technological system, governed and influenced by a social system. However, an identified limitation in the current literature on phosphorus depletion studies is the exclusion of the social system. Yet, exactly the inclusion of the social system in the research is important because it enables or constraints the adoption of options to improve the phosphorus cycle. Therefore, within this thesis the effect of possible solutions on the regional phosphorus cycle will be analyzed, as well as the socio-economic issues in relation to their practical implementation. How these socio-economic issues may be resolved will be addressed through creating pathways featuring proposed (policy) measures that could enable the change, and can be viewed as the end-result of this thesis. These pathways will be described only superficially, however. A transition, and certainly one spanning multiple regimes in the case of the phosphorus cycle, is a highly complex process that should be studied in its own right.

1.5.1 Case area

The city under research of this thesis will be the Berlin-Brandenburg area, as shown in Figure 1. This area provides a good research opportunity with regards to localized cycling of phosphorus. Berlin lies in the center of the relatively rural Brandenburg province. As such, the research can encompass both the demand and supply side, and its interlinkages. Both areas are administrative entities.

Figure 1: Map of Germany with Berlin and Brandenburg highlighted.

1.6 Research questions

As described in sections 1.4 and 1.5, the goal of this thesis is to find out to which extend the phosphorus cycle can become closed, taking the city and its surrounding agricultural environment (Berlin-Brandenburg) as a case area. This leads to the formulation of the following main research question:

RQ To what extent is a closed phosphorus cycle for the Berlin-Brandenburg region possible in the long term?

The main research question will be answered through answering the following sub-questions:

1. How is the current socio-technical system related to phosphorus built up?
2. Which future developments will likely shape the socio-technical system related to phosphorus?
3. What are the main opportunities for improving the phosphorus cycle?
4. Which components could feature in an improved regional phosphorus cycle?
5. Which barriers and opportunities exist towards realizing the improved phosphorus cycle?
6. What pathway and (policy) measures could lead to the improved phosphorus cycle?

Methodologies and literature required answer these research questions is treated in Chapter 2, and the methodological framework used to answer the research questions is discussed in Chapter 3.

Chapter 2

Theory

2.1 Mass Flow Accounting

Material Flow Accounting (MFA) is a methodology to analyze the flows of a specific material through a system. The methodology is based on the Law of Lavoisier stating the conservation of mass, meaning that at the level of each process and at the level of the whole system, inputs are equal to outputs (Schneider et al., 2002). Material balances have been used to study the metabolism of cities as well as that of industries. In the 1990s, MFA branched in to two main applications; material flow accounting and material or substance flow analysis (Bringezu et al., 1997). The former focuses on creating a picture of a societys overall material metabolism based on statistical data, while the latter focuses on flows of individual materials or chemicals in, out and through the system and its subsystems. Material flow analysis is often initiated from concerns related to a pollutant, or in some cases, resource scarcity Binder et al. (2009).

The MFA methodology consists of three phases (Van der Voet, 1996):

1. System definition. Here, the aspects space, function, time and materials are to be defined. With regards to space and function, a choice must be made for a regional or functional approach. The former relates to a geographically bounded area in which all flows and processes are analyzed. Within the latter, the fulfilment of functions is the point of departure, regarding consumption as a first step to take the whole cycle into consideration. As such, this approach focuses on the extent to which the entire substances life cycle serves for the benefit of the region, regardless of location. Material imports for consumption are therefore included for the funcitonal approach, whereas these are excluded within the regional approach. The third aspect, time, is already implicated when regarding material flows; amounts of material per unit of time. From the view of data availability and policy formulation, the time-frame of one year is usually chosen. Lastly, the material of study is defined. The material of choice can a single material, a coherent group of materials or the entire metabolism of a certain region in which flows and stocks of all materials are considered.
2. Quantification of the overview of flows and stocks. After the system has been defined, data can be collected and the system can be modelled. There are three possible ways of modelling with each having its own data requirements;
   (a) Bookkeeping: The combination of acquired data with application of the mass balance principle leads to the desired overview of flows and stocks within the system.
   (b) Static modelling: The systems flows and stocks are defined as variables dependent on others. This results in a set of equations to be solved for the time-frame defined earlier.
   (c) Dynamic modelling: Similar to static modelling, with the addition of changes in the systems stocks and flows over time.
3. Interpretation of the results. Three types of interpretation can be distinguished;
   (a) Evaluation of the robustness of the overview quantification. Uncertainties in data may lead to larger or smaller uncertainties in the quantified overview, which can not always be

predicted beforehand. A sensitivity analysis (case-by-case) can be conducted to find out how inaccuracies in data influence the results.

(b) Translating the overview into policy relevant terms, as the MFA often serves as a basis for policy. In some cases the unit of analysis may need to be converted into a more interpretable unit such as kg. In other cases, especially in the case of pollutants, a conversion can be made towards contribution of the pollutant to a certain environmental problem e.g. acidifying potential. In addition, flows and stocks could also be linked to an economic model.

Furthermore, a definition of indicators can provide a powerful help for the evaluation of the overview. A specific flow or stock can be singled out and serve as the one to folow. Possibilities include the efficiency of the system or groups of processes, secondary versus primary material use, and comparing the system of study to other systems.

(c) Linking the overview to policy instruments, such as the coupling of a certain emission to a tax or subsidy.

While the MFA tool is well-equipped to model material flows and show where the main opportunities for improvement lie, it is not able to include societal aspects that may hinder system improvements.

2.2 Structural Agent Analysis

One methodology that seeks to integrate the MFA with socio-economic aspects is Structural Agent Analysis (SAA), developed by Binder (2007). SAA is based upon Giddens' social structuration theory, according to which actions of actors shape the environment which in turn enables or constraints future action (Giddens, 1984, cited in Binder (2007)). As such, it provides a cross-level analysis as it allows for analyzing the impact of social structures (e.g. norms, traditions) on action as well as the feedback from action on social structures (Binder, 2007). In doing so, it is also able to capture the economic perspective, which views individuals as atomized agents acting rational and benefit maximizing, into a larger social context (Granovetter, 1985, cited in Binder (2007)). Binder (2007) suggests that before starting the SAA, first a thorough MFA should be made by which the following information is revealed;

a. Optimization needs and goals from a material perspective.
b. The main variables which, from a material point of view, allow goal fulfillment.
c. First potential options for improving material flows.

With this information as input to the SAA, the following steps are undertaken by the researcher;

1. Identification of all relevant agents affecting the system both directly and indirectly.
2. Analysis of relevant structural factors affecting the action of each agent.
3. Weigh the current impact of the relevant structures on agents actions.
4. Draw an agent-structure diagram.
5. Identify options, constraints, and facilitators for successful material flow management.
6. Identify interferences amongst agents.
7. Analyze the potential effects of agents actions on structure.

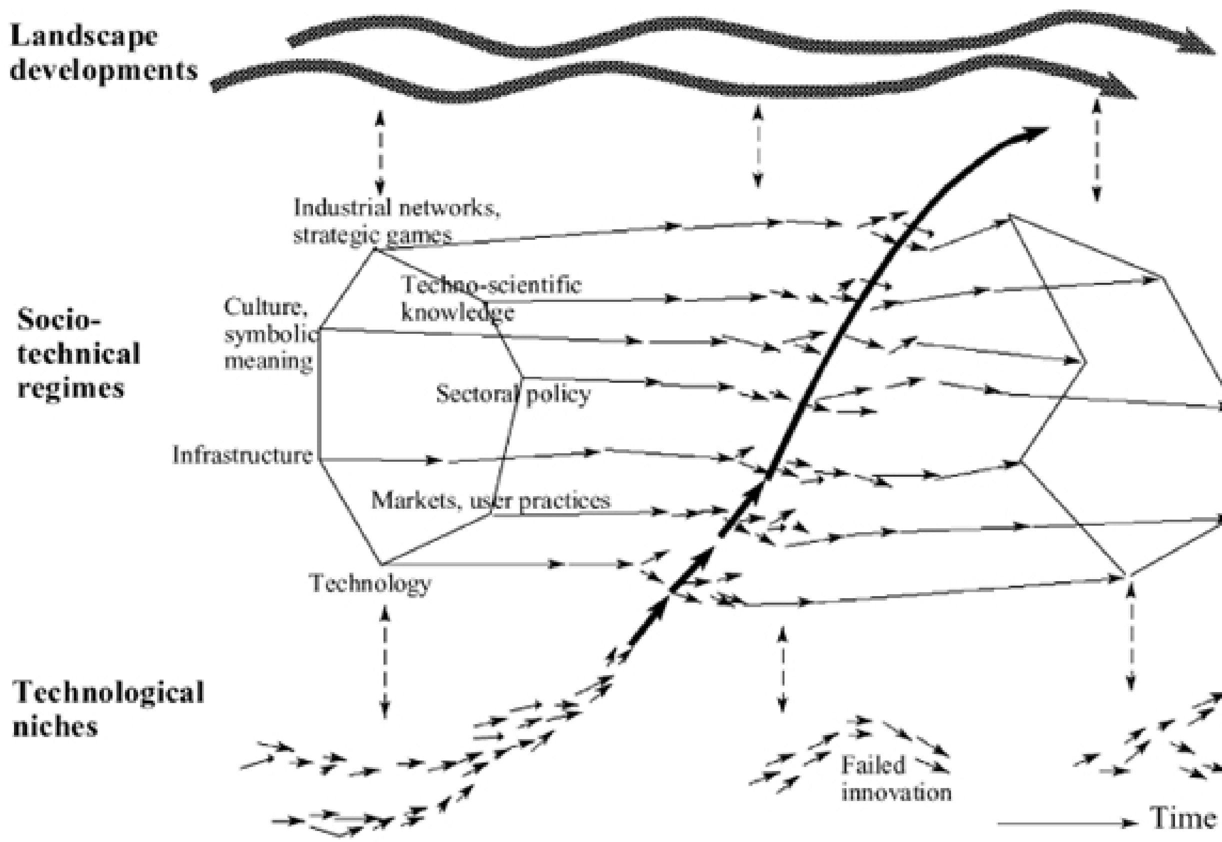
In short, by performing the SAA opportunities and barriers for certain techniques and measures are identified. Depending on how promising the opportunities are and how constraining the barriers are, certain techniques and measures will turn out to be more feasible than others. Subsequently, recommendations for material flow management can be made to policy makers and other stakeholders.

Although the SAA tool can be used to the identify barriers and opportunities, the use of structuration theory to represent social aspects is questioned for use in this thesis. Geels (2004) three analytical dimensions is deemed more suitable because it explicitly includes the technological system. This will be described in section 2.4, which will be preceded by section 2.3 to enhance theoretical understanding and also for use in the final methodology.

2.3 Multi-Level Perspective

A socio-technical system can be described as the combination of (sectorally) interrelated technological artifacts on the one hand and the stakeholders related to these artifacts on the other hand. The characteristics of a socio-technical system will be explained in detail using the Multi-Level Perspective (MLP) (Geels, 2002). The MLP (Figure 2) can be understood as a nested hierarchy of three levels technical system within a socio-technical system that provide structuration to local practices; micro (niches), meso (socio-technical regimes) and macro (landscape developments).

Figure 2: The multi-level perspective (Geels, 2002).



The socio-technical regime at the meso level can be seen the part of the wider socio-technical system that is currently embedded into society. Any regime exists and is maintained because it fulfills a specific societal funtion (De Haan and Rotmans, 2011). Different functions relate to different regimes, examples are mobility, energy generation, food production, etcetera. The seven domains (e.g. regulatory framwork, users and markets) shown in the figure can be seen as the subsystems or components of the regime. The domains are strongly interconnected and together these form configurations that work (Rip and Kemp, 1998), i.e. the functionality of the regime is derived from how the various domains are aligned to one another.

The micro level comprises the (technological) niches which are nested in a socio-technical regime. Technological niches can be seen as protected spaces in which niche actors can experiment, such as R&D laboratories, subsidised demonstration projects, or small market niches where niche actors are willing to work voluntary and/or users are willing to pay extra for the product (Geels, 2011). Actors present in the niche work on radical innovations that deviate from practises present at the regime level. By differentiating from the status quo, they hope that their promising novelties are used at the regime level, or even replace parts of the regime. This is hard, however, due to the lock-in mechanisms and overall inertia present at the regime. Yet niches are crucial for transitions because they provide the seeds for systemic change. Within Strategic Niche Management (SNM) literature, three core processes are deemed vital for successful niche development (Kemp et al., 1998);

1. The convergance and articulation of expectations and visions, which provide guidance to the innovation activities and can serve to attract funding from external actors;
2. The formation of networks allows more actors to enroll, enlarging the resource base of the niche;
3. Learning and articulation processes to enhance knowledge about the needs, problems and possibilities of the novelty.

Niches gain momentum if the expectations of the various actors become more precise and broadly accepted, when the learning and articulation processes result in a dominant design and if the network around the niche becomes larger and more aligned to the needs of the niche (e.g. supply chains) (Geels, 2011).

The macro level relates to the socio-technical landscape , in which the socio-technical regimes are nested. Socio-technical landscapes can be seen as a set of deep structural trends external to regime development. In general, these trends also work on a slower timescale than regimes do. Landscapes contain various heterogeneous factors such as material and energy prices, spatial arrangements of cities and highways and economic growth (Geels, 2002). Van Driel and Schot (2005) have formulated three distinct landscape categories:

1. Rapid shocks such as wars or fluctuations in the price of oil;
2. Long-term trends such as demographic changes;
3. Factors that do not change or change very slowly such as the climate or geobiochemical cycles.

2.4 Material system, actors and structures

As an alternative to the functional approach of the seven domains of Geels (2002), Geels (2004) proposes three dimensions that are more useful for analytical purposes. To avoid confusion it should be noted that Geels (2002) and Geels (2004) use the term 'socio-technical system' in different manners. While the former publication views such a system as a seamless webb of technological and social components, the latter publication excludes actors (and rules). I shall refer to the non-actor side of the socio-technical system as the 'material system' and maintain the original definition of the socio-technical system. The three dimensions can be described as following:

1. *Material system.* Geels (2004) defines a material system as the linkages between elements necessary to fulfil societal functions (e.g. transport, nutrition, communication). He sees technology as a crucial element in modern societies to fulfil these functions, and distinguishes production, use and distribution of technology as sub-functions of the material system. In order to fulfil the sub-functions, the elements required can be characterized as resources including artefacts, knowledge, capital, labour, cultural meaning, etc.
2. *Actors.* Socio-technical systems do not function autonomously, but are the result of activities from human actors. These human actors are embedded in social groups which share certain characteristics (e.g. norms, responsibilities). Geels (2004) stresses that not only firms and industries are important actors in the ST-system, but also users, societal groups, public authorities, etc. Social groups can be seen as relatively autonomous entities that interact with one another, thereby forming mutual dependencies. Due to this interdependence the activities of social groups become aligned to one another. Aligned social groups that together govern resources in order to fulfill a societal function constitute a regime.
3. *Rules.* Regimes and niches can be seen as similar kinds of structures that differ in size and stability (Geels and Schot, 2007). These structures share certain rules that coordinate action. On a less aggregated scale, this also applies to social groups and even individuals. Whereas these rules are stable and articulated within regimes, they are unstable and 'in the making' for niches. Scott (2005) distinguishes three types of rules; regulative, normative and cognitive. Regulative rules are explicit and formal, constraining behaviour and regulating interaction. They include property rights, contracts and laws. Normative rules relate to as how one ought to behave, including values, norms, role expectations, duties, rights and responsibilities. Finally, cognitive

rules constitute the nature of reality and the frames through which meaning or sense is made. For these purposes, individuals use frames, schemas, and belief systems to select and process information.

According to Giddens (1984, cited in Geels (2004)), rules stem from social structures that are both the medium and outcome of action. On the one hand actors follow rules to structure their actions, while on the other hand actors actions resulting from these rules change the social structures in which they are embedded and the rules change accordingly. Rules can be both constraining (e.g. making some actions more legitimate than others) and enabling (e.g. creating trust, reliability). While niches and regimes as well as social groups work through sociological structuration, landscape developments influence action differently. Landscape developments do not determine, but provide gradients of force that make some actions easier than others (Geels and Schot, 2007).

Iveroth et al. (2012) note that any change in any of the three dimensions will cause changes in the other two dimensions. Furthermore, these authors identify three challenges for systems integration from the framework, that can also be seen to apply to any system's transition. First, existing socio-technical configurations may constrain the process of change. Second, creating a shared vision or goal towards which actors can align their efforts may prove to be difficult as every group of actors will have different routines, norms and priorities. Third, once system improvements have been implemented it may be difficult to change the system further as the socio-technical system stabilizes, leading to increased lock-in.

2.5 Dynamics and transitions

2.5.1 Transitions: introduction

The most important insight from the MLP is that the direction and outcome of (technological) change are not the result of dynamics at any specific level, but at linkages between the different levels (Raven, 2005). A combination of ongoing regime processes with landscape pressure imposed on the regime creates a window of opportunity, allowing the niche to enter the regime (Geels, 2002). In case the regime is being replaced by the niche, a transition unfolds in which process the functioning of the whole socio-technical system is changed (De Haan and Rotmans, 2011).

Rotmans et al. (2001) define a transtion as a gradual, continuous process of change where the structural character of a society (or a complex sub-system of society) transforms. The processes of change take place in different interconnected domains including technology, the economy, institutions, behaviour, culture, ecology and belief systems, that co-evolve and form new configurations continuously. A transition can then be seen as a spiral in which the various processes reinforce each other, leading to a new system-state (Rotmans et al., 2001). Transitions are not uniform; the various processes of change vary in speed, magnitude and time span over which they take place. Neither are transitions deterministic. Due to the inherent complexity of (socio-technical) systems, transitions can be steered and influenced but never entirely predicted nor controlled by the embedded actors (Rotmans et al., 2001).

Rotmans et al. (2001) differentiate between four different phases the system goes through as it transitions from its initial state to its end-state:

1. A predevelopment phase of dynamic epuilibrium in which the status quo does not visibly change while processes below the radar do take place;
2. A take-off phase where the regime change gets under way as the state of the system begins to shift;
3. A breakthrough phase where structural change accelerates as a result of an accumulation of changes in different regime domains;
4. A stabilization phase where the speed of change decreases and a new dynamic epuilibrium is reached, i.e. a transition has taken place.

2.5.2 Transition dynamics

In line with Rotmans et al. (2001), Geels (2002) states that the step from niche to regime does not occur at once, but gradually, through niche-cumulation (i.e. accumulation of niches). Niches enter regimes through series of changes and adaptations over time, and a stepwise reconfiguration of the regime takes place as niches gradually enter the regime. Through this process old regimes evolve into new regimes, i.e. a transition has taken place. Geels (2002) proposes two mechanisms by which niches enter the regime level:

1. Technological add-on and hybridisation. New technologies initially link up with established technologies forming symbioses, often to solve particular bottlenecks. The hydrid car is a good example thereof, and can be seen as an intermediate between the fossil fueled car and electric car.
2. New technologies break out of niches by riding along with growth in particular markets.

Whereas Geels (2002) focusses on the linkages between niche and regime for transitions, Smith et al. (2005) have critizised this approach for leaving no room for (regime) agency and a bias towards bottom-up change in which influences of landscapes remain underexposed. These authors argue that regime transformation is a function of the following three factors:

- The degree to which selection pressures are articulated towards a specific problem or direction of transformation;
- The extent to which the response to selection pressures is coordinated across regime actors;
- The degree to which resources required for regime change are available to the regime, either from within or from outside the regime.

Counter to Geels (2002), Smith et al. (2005) do not differentiate between the sources of selection pressure, but simply state it as a requirement for regime change. If these pressures are sufficiently strong the regime will seek to adapt itself. The regimes capacity to adapt is determined by the availability of resources and how these resources are coordinated by the regime actors. Using the degree of coordination and origin of resources as two axis, Smith et al. (2005) propose four idealized typologies of regime change:

1. Endogeneous renewal (coordinated response, internal adaptation) occurs in the context of regime members utilizing internal resources, in response to clearly articulated threats to the regime. Given that change is shaped from within the regime itself decision about future choices will be guided by past experiences, resulting in (successive) incremental changes.
2. Re-orientation of trajectories (uncoordinated response, internal adaptation) is often sparked by an experienced shock that is solved internal to the regime. The response is uncoordinated because the selection pressures are not clearly articulated, resulting in a highly unpredictable process of change. Although the trajectories could be radically altered, embedded actors, networks and institutions may not experience discontinuity in their activities, exactly because the problems are solved from within the regime.
3. Emergent transformation (uncoordinated response, external adaptation) is the result of technological advances or waves external to the regime, e.g. Kondrieff cycles. Their impact of often so great that they do not only influence one regime, but can be seen to spark many parallel transitions from a common technological basis. The effect it has on the regime is again highly unpredictable and is different for every regime, depending on its configuration. Some (parts of) technologies may catch on, while others do not. Given the invasive character of these technologies the regime response is uncoordinated at first, but could be seen to become more coordinated over time (Geels, 2007), for example through mutual learning and imitation.
4. Purposive transitions (coordinated response, external adaptation) differ from emergent transformations in the sense that they are deliberatetely intended and pursued from the outset. Driven by an explicit set of societal expectations or interests, actors within and beyond the regime

negotiate about the pathway that should be followed. It involves the formulation of a guiding vision through which selection pressures become clearly articulated, leading to a coordinated efforts towards regime transformation.

Geels and Schot (2007) critisize the four idealized typoplogies for regime change by Smith et al. (2005) in stating that all types of regime change become coordinated at one point. They argue that coordination is a phenomenon that should be investigated rather than been seen as a variable on which to base typologies, thereby discarding the use of agency in formulating typologies for transitions. Geels and Schot (2007), however, do acknowledge Geels (2002) bias towards bottom-up change and propose that a transition is the result of two types of interaction between the three MLP levels:

1. Timing of interaction, and in particular the timing of landscape pressure on regimes with regards to the state of niche developments. Under the influence of landscape pressures a window of opportunity may arise at the regime level, but when niches are not sufficiently developed yet they will not be able to take advantage and the regime will seek to resolve the instability using interal resources;
2. Nature of interaction between landscapes and regimes, and between niches and regimes. With regards to the landscape-regime relationship, reinforcing landscape developments stabalize the regime and form no driver for transition. A disruptive relationship, on the other hand, destabilizes the regime and a window of opportunity appears for niches to enter. De Haan and Rotmans (2011) further divide a disruptive relationship into structural and cultural tension; the former relates to problems with physical, economical, legal aspects of the relation with the environment, whereas the latter relates to cognitive, normative, ideological aspects of that relation. Both types of tension can be simultaneously present; Niches have a competitive relationship with the regime when they seek to replace it, but have a symbiotic relationship when they can be adopted as add-on in the regime to enhance performance and solve problems.
3. A condition for change not mentioned by Geels and Schot (2007) is that of stress internal to the regime (De Haan and Rotmans, 2011), where the dominant way of functioning of the regime is in itself inconsistent. This occurs when the regime structure mismatches with the regime rules or culture. Signs of stress would be that the actions of the regime cross with the philosophy behind it, or when means have become goals.

2.5.3 Typologies of pathways

Various authors have proposed pathways describing a transition. Geels and Schot (2007) propose four basic types of transition pathways, a zero-proposition, and an option for concatenation of the aforementioned pathways. In doing so, they draw upon four dimensions of external change; frequency, amplitude, speed and scope of change, and combine it with the two types of criteria for change (i.e. timing and nature of interaction) described earlier:

0 Reproduction process: In the absence of external landscape pressure the regime remains dynamically stable and will reproduce itself. Niches have no opportunity to enter the regime;

1 Transformation path: If moderate landscape pressure is exerted upon regime at a moment when niches have not yet been sufficiently developed, regime actors respond by modifying the direction of development paths;

2 De-alignment and re-alignment path: Large and sudden landscape changes induce increasing regime problems and regime actors may cause regime actors to lose faith; the regime starts to erode (de-alignment). If niches have not sufficiently developed there is no clear substitute, creating space for the emergence of multiple co-existing niche innovations. In the end, through (market) selection, one niche-innovation becomes dominant, forming the core for a new regime (re-alignment);

3 Technological substitution: If strong landscape pressure is exerted at a time when niches have developed sufficiently, the latter will break through and replace the existing regime;

4 Reconfiguration path: If moderate landscape pressure exists and niches have a symbiotic relationship with the existing regime, the regime will adopt the niche to solve local problems. Niche adoption subsepuently triggers further adjustments in the basic architecture of the regime;

5 If landscape pressure becomes increasingly disruptive over time (i.e. trends such as climate change), a sepuence of transition pathways is likely. At first, landscape pressure is moderate regime actors respond by adressing internal resources (transformation path). When landscape pressures increase and problems excerbate, regime actors adopt symbiotic niches. This can either leave the basic regime architecture intact (transformation path) or trigger further adjustments (reconfiguration path). If landscape pressure becomes more disruptive previous regime improvements are insufficient. When niches are sufficiently developed they replace the regime (technological substitution), if they are not multiple niches co-exist for a while until one becomes dominant (reconfiguration path).

De Haan and Rotmans (2011) propose that a concatenation of patterns make up transitions. These authors denote the subsystems of the socio-technical systems as constellations which can comprise both niches and regimes, arranged in a certain composition. A total of three pattern types are distinguished, based on the two extremes forced from outside the system and risen from within the system:

1. Reconstellation Top-down constellation change; New constellations emerge or existing constellations scale up through influences from outside the system. These influences could be governments but also other socio-technical systems. Typical processes are reformative legislation, installation of infrastructure and regional reorientation (e.g. land reforms);
2. Empowerment Bottom-up constellation change; A new constellation emerges, or an existing one (niche) gains power, either by itself or through interaction with other constellations in the system. As such, the niche becomes a viable alternative to the regime through processes of acquiring attention (e.g. patents, standards), forming unions and professionalisation (e.g. specialisation, R&D);
3. Adaptation Internally induced constellation change: A constellation alters its functioning through interacting or merging with other constellations from within or outside the socio-technical system. Adaptation can be seen as the typical regime response to problems, processes entail re-positioning (e.g. new identity, new markets), re-organising and innovation.

Based on these three building blocks for transitions, De Haan and Rotmans (2011) distinguish eleven types of transition pathways, each based on one of the patterns. These will not be explained in detail. Interesting to mention are the differences between pathways of De Haan and Rotmans (2011) and those of Geels and Schot (2007). The first observed difference is that the latter authors view landscape pressure on the regime as a requirement for (transitional) change, whereas in De Haan and Rotmans (2011) internal regime problems but also niche superiority can form the driver for change. Secondly, De Haan and Rotmans (2011) also consider failed transitions as a possibility. Similarities in both pathway approaches is that they are able to describe transition pathways either by following one specific pathway, or by viewing the transition as a concatenation of pathways.

2.5.4 Implications for governance

Although the exact conditions and dynamics of transitions remain a matter of debate, it can be concluded that at least some form of (technological) renewal i.e. niche is required for a transition to take place. The niche(s) could either develop internal or external to the regime. This results in a problem of uncertainty for formulating policies, because it is often unclear which niche innovations have the best chances in practise, as well as their potential for system improvement (Van den Bergh et al., 2006). This makes the choice for a specific niche development hard. It is therefore recommended to stimulate and foster a wide range of niche innovations (Van den Bergh et al., 2006), although this still does not completely resolve the choice dilemma.

Niches are especially vulnerable during their initial stages of development and should therefore receive strong support during this period (Van den Bergh et al., 2006). These initial stages can be seen to overlap with the pre-development phase of a transition. According to Rotmans et al. (2001) the government should play the role of catalyst and director during this phase, organizing and stimulating discussions amongst actors. Organizing and stimulating discussions could help accelerate the three core niche processes; vision alignment, network formation and learning. Rotmans et al. (2001) also stress the importance of a wide playing field, although its definition and conditions remain somewhat vague. A more thorough elaboration of this concept may be offer by Van den Bergh et al. (2006) who introduce the term extended level playing field, suggesting that competition between niche and regime should be on equal basis, while also stimulating niche developments. These authors argue that in order to create an extended level playing field niches should receive special support, prices should reflect external costs and all external and internal stimuli of the dominant regime should be removed. Although seemingly straighforward, its application in practice may prove to be difficult. Internalizing externalities requires significant research efforts and weighing of environmental impacts involves normative choices. Also the removing of stimuli from the regime should be done with care as many actors will be dependent upon these for their survival. Even if an extended level playing field is realized doubtful, however, if these measures are sufficient to neutralize the competitive advantage established regime actors have over niches as the former have access to significantly larger resources.

Indeed, actors incumbent to the regime will try to prevent niches from entering the regime, as this compromises the position of the regime actor(s). Nevertheless, regime actors may be forced to change their trajectories in response to selection pressures. Based on the four idealized types of regime change from Smith et al. (2005), these authors suggest also four types of governance that are advisable in each of the cases:

1. In the case of endogenous renewal (coodinated, internal resources), if the renewal is desired, governance should monitor and implement measures to sustain and further enable the renewal. If appraised negatively, governance should try to intervene. Note that this trajectory will probably result in only incremental changes and is hence not sufficient the spark a transition.
2. Governance is more difficult when trajectories become re-orientated (uncoordinated, internal resources). Here, no consensus about the deployment of internal resources exists. In such a case governance should focus on creating a selection environment that favours sustainable alternatives, leading to a sustainable development. This type of governance can be seen as similar to the extended level playing field proposed by Van den Bergh et al. (2006).
3. A transition resulting from an emergent transformation (uncoordinated, external resources) is accompanied by a lack of clearly articulated selection pressures and coordination. This obscures particular end-points of the transition. Here, the governance challenge lies in assessing the end-points of contrasting transition pathways such that a desired end-point i.e. guiding vision may be chosen towards which regime efforts can become coordinated. If the regime draws upon internal resources to coordinate the transition, the situation moves towards endogenous renewal. When external resources remain utilized, a purposive transition is the result during which a more radical transformation process unfolds.
4. Finally, governance guiding a purposive transition (coordinated, external resources) should lie in stimulating interaction amongst actors within and beyond the regime, thereby closely relating to Transition Management (Rotmans et al., 2001). In all four cases the governance of regimes can be understood as altering the context of selection pressure and adaptive capacity, thereby modifying and guiding the transformation process.

Given that regimes only change when they face selection pressures (Smith et al., 2005), governance should also seek to address this issue in addition to managing regime change. Geels and Schot (2007) regard landscape pressure as a requirement for a transition to take place and assume the development of niches and its relation to the regime as variables that lead to various pathways. Although landscape pressures will excerbate over time due to the unsustainability of current regimes, it seems worthwhile to also consider enhancing landscape pressures bearing upon the regimes as a means of governance.

2.6 Backcasting

Whereas traditional forecasting deals with the questions "How will the future look like?" and "How could the future look like?", in backcasting the question "How should the future look like?" is posed. Backcasting can thus be seen as an explicitly normative methodology (Robinson, 1990). Quist and Vergragt (2006) defined backcasting as "generating a desirable future, and then looking backwards from that future to the present in order to strategize and to plan how it could be achieved". Thus, whereas desired futures form the focal point in backcasting studies, the results are to be used in the present. Another characteristic of backcasting is the use of teleology (i.e. agency) as a principle (Dreborg, 1996), meaning that actors are able to purposefully take action in response to their environment according to their beliefs and values.

The normative nature of both backcasting and sustainability problems make backcasting suitable to deal with these complex problems (Vergragt and Quist, 2011). This is supported by Dreborg (1996) who states that backcasting is particularly useful in the case of complex societal problems, when there is a need for major change, when dominant trends are part of the problem and when future alternative require a longtime horizon to develop. A typical time horizon used in backcasting is 50 years (Vergragt and Quist, 2011). Such a time horizon is appealing because it is realistic and yet far enough away to allow major changes to take place in society, thereby relating well to the scale of change needed to solve contemporary sustainability problems.

Backcasting was developed in the late 1970s in response to dominant practices of energy forecasting, which emphasised large-scale electricity production and assumed a strong growth in energy demand. Driven by environmental awareness, several researchers (Lovins, 1977, cited in Quist and Vergragt (2006); Robinson (1982)) proposed soft enegy pathways towards alternative and envisaged energy futures, for which Robinson (1982) coined the term backcasting as opposed to forecasting. Later, backcasting was also applied to sustainability problems and to make organizations more sustainable (Holmberg, 1998). Sincs the 1990s, backcasting has evolved towards a more participatory approach (Quist et al., 2011).

2.6.1 Backcasting: Differences and similarities

Although the various backcasting approaches vary in terms of their application and outcomes, their differences remain relatively small and should not be exaggerated (Höjer et al., 2011). In line with this, Robinson (1990) notes that a backcasting study always starts with the definition of future goals and objectives, which are then used to construct desirable future scenarios. These scenarios are then evaluated for their feasibility and reiterations may be required to resolve possible inconsistencies in the scenarios.

Yet, there remains a large variety of interpretations. One main difference between approaches is the relative emphasis on whether the image of the future needs to be goal-fulfilling or not, and whether this is seen as crucial or optional to construct pathways of the transition (Wangel, 2011). Another important feature is whether the scenarios are developed by mainly experts or through stakeholder or citizen participation (Wangel, 2011). Although this variety may be seen as confusing it also highlights the strength of the backcasting methodology, namely that the backcasting framework can be adjusted according to the purpose of the study.

According to the conceptual differences between backcasting studies stated, Wangel (2011) identifies the following backcasting approaches:

- Target-oriented backcasting, where the emphasis is on the need to develop future images as goal-fulfilling. These are typically expressed in a quantitative manner and aim to challenge the imagination in order to identify unconventional solutions towards goal-fulfillment. As such, target-oriented backcasting seeks to explore the variety of options available;
- Pathway-orientated backcasting, where instead of goal-fulfillment, the gap between the future image and today becomes the focus of the study. Emphasis is thus put on how change can take place and how this process can unfold. Given the focus on the process of change, non-technical measures should be included and additionally the actors that bring about the change;

- In action-oriented backcasting the overall aim is to develop an action plan or strategy. Both the objects and process of change, as well as who could make the change happen should be adressed in the study. These backcasting studies typically use a predetermined set of actors and the scenarios used are limited to what is possible within these actors' scope of influence;
- Participation-oriented backcasting distinguishes itself from the other approaches by including stakeholders in the backcasting process. This approach will be further discussed in section 2.6.2.

2.6.2 Participation-oriented backcasting

As mentioned earlier, backcasting has evolved towards more a participation-oriented approach recently, of which Transition Management (Rotmans et al., 2001) and participatory backcasting can be seen as examples. Participation-oriented backcasting can be seen to rely on three main pillars (Quist, 2012) that will be subsequently discussed:

1. Development and analysis of future visions;
2. Participation of actors and stakeholders;
3. Learning by actors.

Future visions can be seen to function as social constructs in the minds of actors (Quist and Vergragt, 2006), guiding their actions and determining their problem agendas and search heuristics. In most societal sectors (common) future visions are assumed to exist, providing guidance for the development of socio-technical systems through the interaction and actions of actors (Grin and Grunwald, 2000). Grin and Grunwald (2000) further state that given the role of future visions, it is important to critically discuss them as a prerequisite for changing the development trajectory. Furthermore, future visions may have the potential for dealing with problems for which no rules or institutions are available, of which sustainability problems are good examples (Quist and Vergragt, 2006). Future visions developed as part of the backcasting excersise may influence or even substitute the dominant vision(s) in the socio-technical system, thereby changing the course of development. Finally, depending on the subject of the backcasting excercise, future visions can be defined at many different scales, including that of an organization, production chain, economic sector, societal domain such as mobility or energy, or for a geographic area ranging from local to global (Quist, 2012).

The legitimacy of the vision and the support for the vision are enhanced when stakeholders participate in the process of vision creation by building consensus (Quist, 2012). When multiple visions are created these can be used to compare the alternative futures and evoke discussions (Quist, 2012) as well as stimulating actors' imagination and exposing them to previously overlooked options (Höjer and Mattsson, 2000). However, in practise, some actors may seek to disrupt the backcasting experiment because changing the status quo conflicts with their interests. Therefore, enrolling actors that are motivated and willing to develop and discuss future alternatives is essential, next to the participation of relevant actors (Quist and Vergragt, 2006). Quist (2012) notes that apart from making future visions it is also important to evaluate and analyze the visions, and to define action agendas and possible pathways that can be followed to reach the desired future. These can be used by the actors to take strategic action in the short term.

Learning processes and empowerment can be seen as the most important outcomes of participation-oriented backcasting (Quist and Vergragt, 2006). By continuously involving stakeholders in the process of defining future visions and the necessary actions to achieve them, stakeholders not only learn about possible solutions (i.e. first order learning), but their fundamental beliefs and mindsets may also be altered. In such a case higher order learning has taken place, thereby further broadening the range of actions and solutions available to these stakeholders (Quist and Vergragt, 2006). Higher order learning also seems to be strongly related to follow-up and spin-off after the backcasting experiment, for which networks of actors also require to mobilize sufficient resources (Quist et al., 2011).

With the importance of stakeholder participation in mind, Quist and Vergragt (2006) state that the goals of a participation-oriented backcasting study can include the following:

- Generation of normative options for the future and putting these on the agenda of relevant societal and political arenas;

- Future visions or normative scenarios that are analyzed on their environmental improvement, opportunities and other consequences;
- A follow-up agenda containing activities for different groups of stakeholders that contributes to realizing the desirable future;
- Stakeholder awareness and learning about options, the consequences and other stakeholders' opinions;
- Stakeholder support and commitment to the vision and follow-up agenda.

2.6.3 Participatory backcasting framework

In this section the participatory backcasting approach as developed by Quist and Vergragt (2006) will be discussed. It consists of five steps:

Step 1. Strategic problem orientation;

Step 2. Develop sustainable future visions;

Step 3. Backcasting analysis;

Step 4. Elaboration and defining follow-up agenda;

Step 5. Embedding of action agenda and stimulating follow-up.

Although the framework is linearly depicted, iteration cycles may exist, as well as mutual influence between steps.

Quist and Vergragt (2006) have identified four groups of tools and methods that can be utilized during each step of the framework:

- Participatory tools and methods, comprising of all tools and methods that are useful for involving stakeholders and generating and guiding interaction and dialogue amongst stakeholders;
- Design tools and methods for scenario construction, detailing future systems as well as for the design of the stakeholder involvement process;
- Analytical tools and methods for assessing scenarios and designs including consumer acceptance methods, environmental assessments, economic analyses and stakeholder analyses;
- Tools and methods for management, coordination and communication, consisting of tools that are relevant for project management and the stakeholder involvement process.

Participatory backcasting thus offers significant freedom in the selection of tools in order to execute the backcasting exercise.

The framework also distinguishes three types of demands (Quist, 2013):

1. Normative demands relate to the the goal-related requirements for the future vision, how sustainability is defined, and how this definition is turned into principles or criteria the future vision should meet. In addition, these demands could also include trends that are included in the development of the future vision (Quist, 2012).
2. Process demands concern requirements with regards to stakeholder involvement, how much influence they have on the results, and how potential issues and problems are framed and resolved.
3. Knowledge demands can be divided into scientific and contextual (i.e. stakeholder) knowledge that needs to be found. These do not only encompass specific knowledge, but also choices with regards to the number of visions created, time horizon, and how elaboratedly the visions and analyses will be made (Quist, 2012).

The steps of the participatory backcasting framework will now be elaborated upon, using Quist (2013) and Quist (2012) as complementing sources unless referenced otherwise.

Most of the demands need to be specified at the beginning of the strategic problem orientation step, which could be done by the organizers of the study but the demands can also be determined through early stakeholder involvement. Normative demands could also be defined during the next step. After that the problem under study is explored from a systemic viewpoint. Possible solutions, main unsustainabilities, and relevant stakeholders are identified for which use can be made of system/regime analyses as well as actor/stakeholder analyses. During this step it is also important to involve stakeholders in the backcasting study. It should be analyzed how the stakeholders perceive and judge the problem according to their own mind set, values, and interests, and how stakeholders throughout the systems' network are related to one another. In addition, stakeholders are also valuable for their expert knowledge of the system under study.

The results of the strategic problem orientation step form the starting point for the development of future visions, in which the main unsustainabilities and other problems have been solved. Step 2 starts by setting normative demands, if not done yet previously. After that ideas that could feature in the visions are articulated, clustered and elaborated upon with the stakeholders, for which creativity techniques are suitable. If the generated ideas have enough potential to solve the problems identified, a team of non-stakeholders can start developing the future visions. For this purpose it is recommended to use core dimensions that can be used as variables in developing different future visions. In doing so, it is important to take into account that good future visions meet a set of quality criteria; visions should be visionary (e.g. has utopian thoughts, includes surprises), sustainable, systemic, coherent (i.e. logical), plausible (i.e. realistic), tangible (i.e. imaginable by stakeholders), relevant, nuanced, motivational and shared (Wiek and Iwaniec, 2013). Finally, the future visions can be expressed in many different ways, ranging from story boards to maps.

During the Backcasting analysis the researcher looks backward from the desired future situation. Although the traditional explanation of the backcasting analysis is to determine stepping stones every five or ten years towards the future vision, in practise it is hard to make the stepping stones detailed enough and therefore only rarely done. Rather, it is recommended to first make a What-How-Who-analysis, in which an answer is sought to the questions "What changes are needed to realize the vision?", "How can changes be realized?", and "Who could or should contribute to realizing the vision and what activities should they do?". Additionally, the analysis can be extended by posing the question "Who would oppose the required changes and how can this opposition be dealt with?". After the What-How-Who-analysis is done and the information tabulated, possible drivers and barriers that exist for reaching the vision can be found and it can be subsequently determined how these can be used or alleviated. At last, if multiple visions were made these could be compared to each other, for example by a SWOT analysis.

The performance of step 4, Elaboration and defining follow-up agenda, depends strongly the budget and time available. The required changes identified during the previous step are often further elaborated upon, working them out into detailed scenarios. Multiple scenarios could be made for one future vision. The elaboration could be qualitative and quantitative, where the latter is more common for large backcasting studies. During the second part of this step follow-up activities and agendas for stakeholders are to be defined, where the What-How-Who-analysis of the previous step can be used for. Additionally, transition pathways towards the future visions can be described. Also for this purpose the What-How-Who-analysis can provide a good start.

At last, efforts are made to embed and implement the results of the study during step 5. In order to spread the results to stakeholders externally, a communication plan can be made. This is especially important for backcasting studies that involved only few or no stakeholders and actors. Also symposia, seminars, public reports or brochures can be made to further spread the results of the study. Finally, an evaluation of the stakeholder process and what the stakeholders learned can be made, using interviews and questionnaires.

2.6.4 Other backcasting frameworks

Two other interesting backcasting frameworks are those of Robinson (1990) and Giurco et al. (2011), which will be briefly discussed.

Robinson (1990) explicitly includes steps encompassing the descriptions of the present system and landscape developments in his framework. A description of the present system, and thereby identfying main unsustainabilities is also implied in Quist and Vergragt (2006) strategic problem orientation step, but landscape developments are excluded in the latter framework. Landscape developments are included in Robinsons framework due to his focus on more quantitative results, which form the context for his scenario construction; the more detailed landscape developments are specified, the less detail needs to be put on describing the pathway followed during the scenario. Yet, Quist and Vergragt (2006) note that in-between timesteps are rarely included in professional backcasting practise.

Giurco et al. (2011) sought to combine industrial ecology (IE) principles with backcasting. Their visions entailed three potential technological clusters revolving around the resources found in the present system/region. In creating these visions, they first analyzed the present system and structural drivers for change which defined the criteria for visions. These authors then drew lessons and inspiration from IE cases, and listed potential core technologies which could be used in the visions. Interestingly, only proven technologies were used as these would create more support amongst the participants. Although logical in the case of Giurco et al. (2011), one may question the use of only proven technologies. A vision describes a possible future; in due time technologies may have advanced and matured. In addition, visions are often used to trigger the imagination of people. The use of unproven (niche) technologies in vision creation is therefore deemed justified, and even desirable.

2.6.5 Concluding remarks

Often the actual backcasting step involves the assessment of what needs to change and how it should change in order to reach the vision/goal. In addition, Quist and Vergragt (2006) also note that the question of who should make which change should also be addressed during the backcasting step. Nevertheless, social structures and agency are often excluded from backcasting studies (Wangel, 2011). Social structures and agency become represented only implicitly and/or are maintained according to the status quo, thereby restricting the radical change required to solve sustainability problems (Wangel, 2011). It is therefore paramount to also include social structure and agency in the study.

Concluding, the frameworks of Quist and Vergragt (2006), Robinson (1990) and Giurco et al. (2011) show significant similarities as they all follow the sequence; exploration of the present situation e.g. (sustainability) problem, vision creation, scenario construction, assessment of the results. However, how each step is performed, the methods and tools deployed, and the degree of emphasis put during each step, vary. As such, the researcher has a significant degree of freedom in excercising backcasting, depending on the purpose of the study.

Chapter 3

Methodological framework and application

3.1 Combining Backcasting, MFA, SAA and Transition theory

As a basis for constructing the methodology the backcasting framework of Quist and Vergragt (2006) will be used. However, not every (sub)step of this framework will be performed due to resource contraints. Steps 1 to 3 will be included, with the development of pathways added as part of Step 3 rather than as part of Step 4. Steps 4 and 5 are thereby excluded from the methodology. The remaining steps are the following:

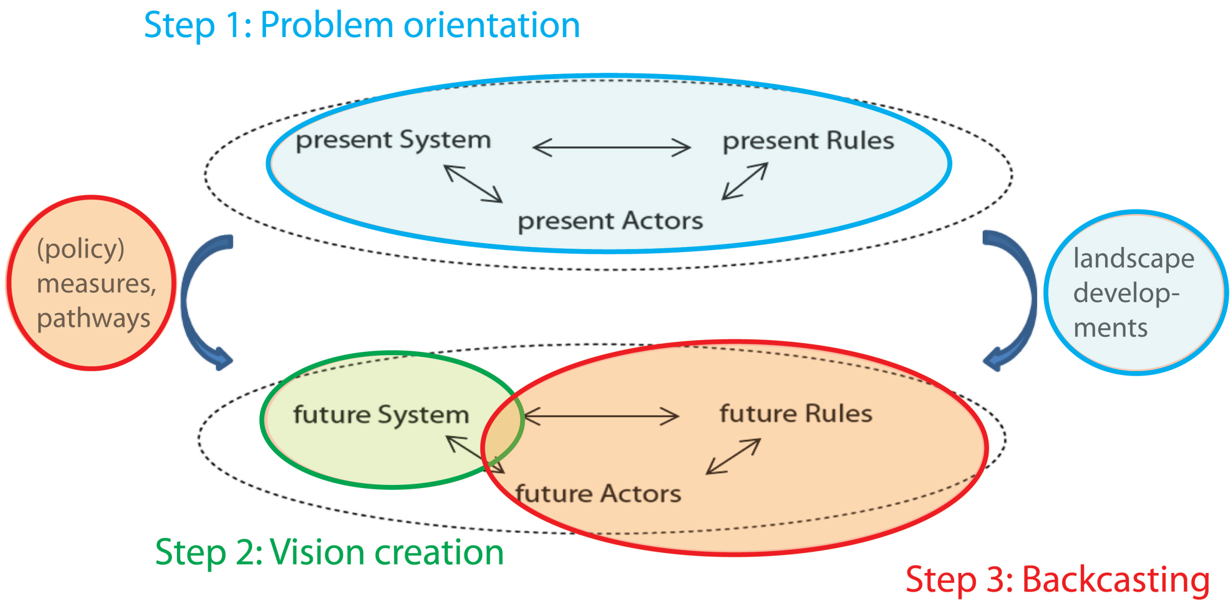
Step 1 Strategic problem orientation;

Step 2 Develop sustainable future visions;

Step 3 Backcasting analysis.

Following Geels (2004) division of a socio-technical system in three analytical dimensions (material system, actor-network, and rules), the first three steps of the backcasting framework can be applied as depicted in Figure 3.

Figure 3: Framework applied to Geels (2004) analytical dimensions (own figure).



During Step 1 the present socio-technical system is analyzed in order to gain understanding of the study area, to identify the main unsustainabilities, and to find possible solutions to improve the system. The material system dimension is seen to consist of regional phosphorus flows and components (i.e. technologies, practises) that physically influence these flows, which will both be analyzed. For the assessment of the two other dimensions, actors and rules, Steps 1-4 of Binders (2007b) SAA framework will be followed. Note that while Binder (2007b) makes use of Giddens (1984) structuration rules, Scott's (1995) rules will be used in the newly created methodology to analyze the social structure. In addition, current developments and landscape developments will also be assessed as part of Step 1. From the assessment of current developments and components (niches) possible solutions can be identified. Main unsustainabilities and possibilities for improvement are derived from the MFA (i.e. phosphorus losses) as well as by combining insights from the assessment of landscape developments and regime components.

The identification of the main unsustainabilities and possible solutions will be used as input for the development of visions during Step 2. The list of possible solutions will first be expanded and categorized based on criteria set for each vision. Subsequently, the potential solutions are assessed for their ability to reduce phosphorus losses, after which the most promising solutions are adopted in the visions based on criteria. A description of the visions and criteria can be found in section 3.3.2.

The gap between the present socio-technical system and the desired future system is the subject of Step 3. First should be found out what needs to change, how it could change and who should implement the changes. The results are then combined with current developments, landscape developments and insights from transition theory presented in section 2.5 to draw pathways leading to the visions.

3.2 Application of the methodological framework

The tasks necessary to carry out the research are depicted in Table 1. In the table these can be seen as part of one of the chosen three steps of the Backcasting methodology. Note that although the tasks are linearly depicted, iteration cycles are bound to take place. The following sections describe how the tasks are performed. The normative, knowledge and process demands required to execute these steps are explained in section 3.3.

Before elaborating upon the tasks per step, distinctions used to describe (parts of) the socio-technical system are first explained. The socio-technical system related to phosphorus is seen to be made up out of a total six regimes: agriculture, food distribution, consumption, waste management, policy and science regimes. The division of the socio-technical system between regimes and analytical dimension is complementary; the regimes (and niches) are seen to be built up out of the three dimensions. An exception exists for the policy and science regimes, which are seen to only consist of actors and rules. The first four regimes, agriculture, distribution, consumption and waste treatment will be termed as 'cycle chain regimes', relating to their direct governance of phosphorus flows.

3.2.1 Performance of Step 1: Strategic problem orientation

An assessment of the number and type of components present in the system will result in descriptions and a quantification of these components. This includes components as part of the cycle-chain regimes, but also relatively developed niches (i.e. niche-regimes) such as organic agriculture and vegetarism. Not only does the asssessment of components create an understanding of the present system, it will also be used to structure the MFA (Task B) accordingly in order to ease the process of future vision creation during Task I.

After all required phosphorus flow-related information has been found a 'static modelling' MFA of Berlin-Brandenburg will be made using STAN software. Once the MFA model is made the main unsustainabilities are assessed as part of Task D.

Task E can be seen as the social analysis of the research. During this task the main actors related to the Berlin-Brandenburg phosphorus will be identified, and the most important regulative (i.e. external) and internal rules assessed. In addition to actors and rules related to the subregime, also niche actors and rules will sought to be found. The information will be collected through both interviews held with local experts and stakeholders, and through assessing regional reports and papers. Where Scott (1995) distinguishes regulative, normative, and cognitive rules, this is found to be unnecessarily complicated. Rather the main external (i.e. regulative) and internal (i.e. normative and cognitive) rules will be identified. Also Binder's (2007b) rule weighting procedure is deemed to be too elaborate for the aim of this research. Such a procedure is omitted from the analysis, thereby focussing only on the main

Table 1: Methodological framework related to sub-questions.

Task	Description	Related sub-questions
Step 1: Strategic problem orientation		
A	Describe the number and type of components present in the socio-technical system	1. How is the current technical system related to phosphorus built up?
B	Analyze the quantity and fate of phosphorus flowing through the system	
C	Create the MFA model	
D	Identify main unsustainabilities, opportunities and possible solutions	2. What are the main opportunities for improving the phosphorus cycle?
E	Analyze the rules and actor-network	3. How is the current social system related to phosphorus built up?
F	Assess current and landscape developments	4. Which future developments will likely shape the socio-technical system related to phosphorus?
Step 2: Develop sustainable future visions		
G	Identify potential solutions	4. Which components could feature in an improved regional phosphorus cycle?
H	Assess the phosphorus conversion efficiency of each potential solution	
I	Create future visions	
Step 3: Backcasting analysis		
J	Identify barriers and opportunities towards realizing the future visions	5. Which barriers and opportunities exist towards realizing the improved phosphorus cycle?
K	Draw pathways from the present to the visions	6. What pathways and (policy) measures could lead to the improved phosphorus cycle?

internal and external rules per subregime and niche. When all information is gathered an actor-network map will be created to provide an overview of the actor-network.

Once Task E is performed most current developments will be known. Task F will therefore mainly involve an assessment of landscape developments. The assessment will be mainly performed qualitatively. A population projection towards the year 2060, necessary to perform Task I, will be made in a quantitative way. Information about landscape developments will mainly be retrieved from forecasts and scientific papers.

3.2.2 Performance of Step 2: Develop sustainable future visions

During Task G potential solutions that could (partly) overcome the main unsustainabilities will be identified and described. Preliminary found solutions per subregime can be viewed in Table 34. After having identified the solutions a morfological approach is taken to categorize the potential solutions as belonging to each vision, using the two criteria stated in section 3.3.2. Although these criteria are hard to quantify, it is deemed to be relatively easy to estimate the characteristics of each solution accordingly, based on their descriptions. Subsequently the phosphorus conversion properties of each solution is assessed by means of a literature search.

Task H entails the simulation of the solutions per vision. Before the solutions are simulated, the MFA model made during Task C is modified to account for changes that will have taking place by 2060. The results of Tasks E and F will have identified these changes. Once the forecasted, or trend MFA has been made the potential solutions per vision will be simulated. The simulation itself done by replacing the conversion characteristics of current components with those of the potential solutions, assessing the reduction in mineral fertilizer input into the system. Solutions that lead to the largest reduction in mineral fertilizer input into the system become adopted in the visions as part of Task I.

3.2.3 Performance of Step 3: Backcasting analysis

Task J will be performed by means of a What-How-Who-analysis as proposed by Quist (2012), finding out what needs to change to realize the visions, how the change could be realized, and who should be responsible for the changes. The 'What' will be derived from the social analysis (Task E) and through interpreting the descriptions of the solutions. The identification of possible measures as part of the 'How' to overcome the barriers will be done on own insight. Also 'Who' should be responsible for implementing the measures will logically follow from the measures themselves.

Using the results from Task J, pathways that lead to the visions are created during Task K. For each vision one 'master pathway' will be created in which the barriers are overcome by introducing measures and actions. Landscape developments described in Task F will serve as the backbone for these pathways, using the transition theory and the pathway typologies from Geels and Schot (2007) in particular. Following Geels and Schot (2007), the nature of interaction between the landscape developments, (sub)regimes (i.e. present system) and niches (i.e. visions) is first assessed. This is done per niche/solution and the regime it seeks to become part of. Then, through assessing the development stages of the solutions the timing of niche-regime interaction will be found out. Also this is done per niche/solution, leading to the creation of one or more pathways per solution. Finally, the intensity of landscape development pressures (e.g. climate change) will be varied to provide a coherent and credible structure to the pathways. In combining the pathways per solution one 'master pathway' is created per vision. The 'master pathways' are subsequently translated into storylines.

3.3 Demands

3.3.1 Knowledge demands

Knowledge required to carry out the research is divided in scientific knowledge (Table 2) and contextual knowledge (Table 3), with the latter being acquired through expert and stakeholder involvement. The first columns in both tables show the type of information needed with the necessary quality of the information stated in brackets, and the second columns indicate how the information will be collected. With the quality of the information required explained, it is deemed unnecessary to also explain how detailed the analyses will be made as these can only be as detailed as the information used to make them. The process demands for the contextual knowledge are described in section 3.3.3.

Table 2: List of scientific knowledge and quality required, and methods used to collect the information.

Scientific knowledge (information quality)	**Collection method**
Number of components: niches and regimes (estimated)	Web-based search and review of regional discussion papers
Workings of components: niches and regimes (superficially)	Web-based search and review of regional discussion papers
Phosphorus flows (elaboratedly, exact)	Web-based search, literature search, regional and nationwide statistics. Any knowledge gaps will be filled by adjusting the data of other similar regions to the case area. The information found will then be translated, if needed, to phosphorus values using existing literature.
Landscape developments (superficially, mainly qualitative)	Review of forecasting reports and documentaries, web-based and literature search
Potential solutions (listing)	Input from current developments, complemented by web-based search and literature search
Phosphorus conversion data of solutions (estimated average values)	Literature search

Table 3: List of contextual knowledge and quality required, and methods used to collect the information.

Contextual knowledge (information quality)	**Collection method**
Power relationships and knowledge flows between actors (superficially)	Interviews with local experts and stakeholders
Regulative and mental rules per subregime (elaboratedly)	Interviews with local experts and stakeholders, review of regulatory documents, mission statements
Current developments and plans (superficially)	Interviews with local experts and stakeholders, review of regional reports
Change: What (elaboratedly)	Own insight based on previously performed analyses
Change: How (estimated)	Own insight based on previously performed analyses
Change: Who (estimated)	Own insight based on previously performed analyses

The amount of information to be collected, especially as part of Step 1, is large and it should be kept in mind that not all required information may be found using the methods described. While some actors may not wish to be interviewed, other information may not be available on the internet or in the literature. The researcher will need to be creative in his search for data. Collecting data in an integrated manner seems like a good way to overcome some of the data collection hurdles as cross-fertilization between these tasks likely takes place; searching information on a certain component might also reveal the actor governing the component, as well as the size of related phosphorus flows.

3.3.2 Normative demands

The two visions will be based on the two paradigms that exist for a sustainable food supply; high-technological and intensive on the one hand, and ecological and extensive on the other (Westhoek et al., 2013). Although these paradigms relate to agriculture, their characteristics can be expanded to include the entire socio-technical system. An important difference between both paradigms, except for the role of technology, is that the consumer plays a passive role in the technological paradigm and a (pro-)active role in the ecological paradigm. Relating to the technological paradigm, the first vision contains a continuation of the consumerist society where economies of scale dominate and sustainability problems are solved through strong technological development. This vision will be called 'Techno-fix'. The second vision is the result of a strong and visionary bottom-up citizens' movement as advocated by Vergragt (2012). In this vision society has a slower pace, consumption levels are low, and diversity and locality are celebrated. It will be called 'Culture-fix'. The trend scenario created to quantitatively compare the visions during Step 2 will not be further treated in Step 3.

Two fundamental differences between the two visions are distinguished, which will be used as criteria for the selection of solutions. The first criterium entails the degree to which citizens need to change their routines and consumption behaviour to successfully implement the solutions; low for Techno-fix and high for Culture-fix. The second criterium relates to the application scale of the solutions, distinguishing between centralized solutions for Techno-fix and decentralized solutions for Culture-fix.

3.3.3 Process demands

The process demands for this thesis are somewhat different as those for other Participatory backcasting studies because in the latter stakeholders are actively involved, determining the outcomes of the study with stakeholder learning as a major goal. In this thesis stakeholders and experts are consulted to fulfill the knowledge demands required to carry out the study; any stakeholder learning taking place is seen as an extra benefit. Stakeholder and expert influence on the study is therefore characterized as medium; although their information serves as crucial input, this information will be interpreted and translated into results by the researcher.

Stakeholders will be involved at the start of the research during Step 1. The type of stakeholder interviewed will differ per subregime. For subregimes consisting of a large number of actors a representative organization will be contacted, which will be the case for the agriculture, food processing, retailing, and consumption subregimes. The waste treatment subregime only consists of a handful large organizations of which at least one will be interviewed. If representing organizations are not available for an interview then several actors operating in the regime will be interviewed (e.g. farmers, consumers, supermarket managers). If this proves to be unfeasible experts with related expertise are interviewed instead. As a last resort a web-based and literature search can be carried out.

Inviting the stakeholders and experts for an interview will mainly be done by mailing. Maximum use of networking should be made to involve all required actors in the research. Interviewed people will be asked if they know other stakeholders or experts that can be approached. A good start for this is already provided through my involvement in the ATB institute and contact to Dr. C. Kabbe of the Kompetenzzentrum Wasser Berlin. If necessary, consumers and supermarket managers will be approached in person.

Finally, in order to make the results of this thesis more valuable than merely serving as an educational tool for the researcher, the final results will be communicated to the actors that were involved during the research. How the communication will take place is decided after the research has been carried out, for which a presentation and sending (parts of) the final report are deemed good options.

3.4 Organizational aspects

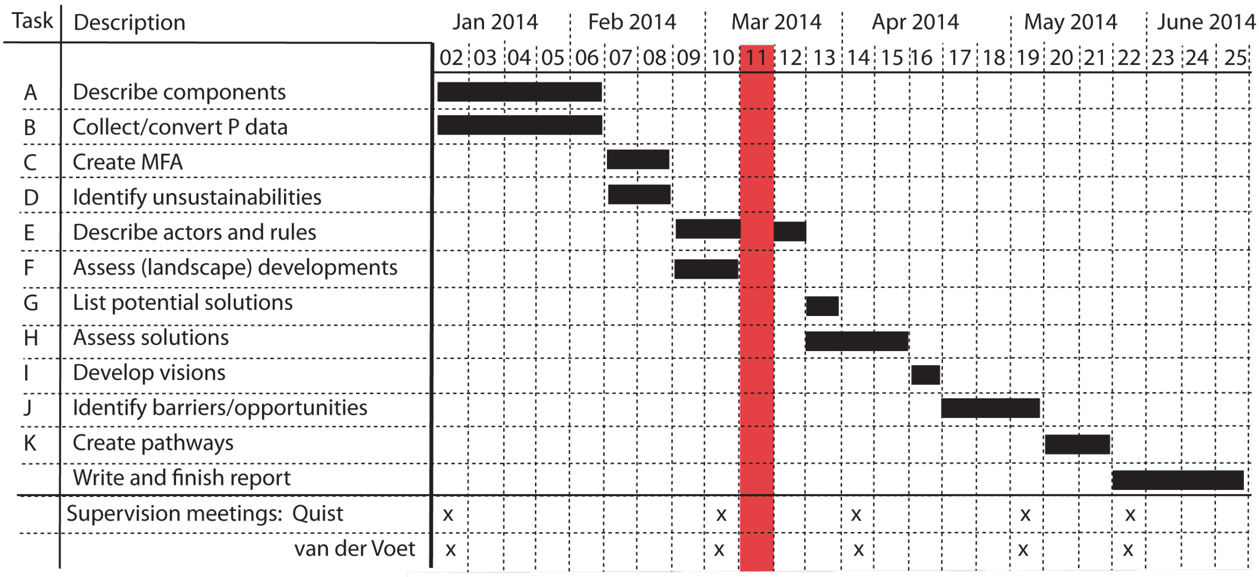
3.4.1 Cooperation and partners

The MFA of phosphorus flows in Berlin-Brandenburg will be made in cooperation with T. Theobald, who is a PhD student at the ATB institute in Potsdam. The division of tasks that was maintained during the creation of the MFA can be read in section 4.8.3. T. Theobald's PhD work is part the ELaN project, in which he researches the impact of MAP on soil fertility. The results of the MFA will be used to write a paper of which T. Theobald will be named as first author, and I as second author.

3.4.2 Workplan

The thesis research is scheduled to be performed from January 6th until June 23th, thereby spanning five months excluding a week of holidays in the second week of March. The workplan, structured per task, is shown in Figure 4. Supervision meetings with both supervisors take place about once per month, mainly via Skype. No extra funds are required to carry out the research.

Figure 4: Workplan.



Chapter 4

Analysis of the technical system: Components and MFA

4.1 Introduction

In analyzing the phosphorus flows in Berlin-Brandenburg a representation of the system as depicted in Figure 5 will be used. As a reference year 2011 was chosen, because not all relevant data was available for more recent years. For the calculation of phosphorus flows, the system has been divided into five compartments; plant production, animal production, food processing and retailing, consumption, and waste (biowaste and wastewater treatment). These compartments will be individually treated in the following sections.

4.2 Plant production

In this section the processes 'Soil processes', 'Harvesting', 'Digestion' will be treated, with related flows 'Fertilizer' import, 'Grass', 'Feed crops', 'Crops', 'Energy crops', and 'Digestate'.

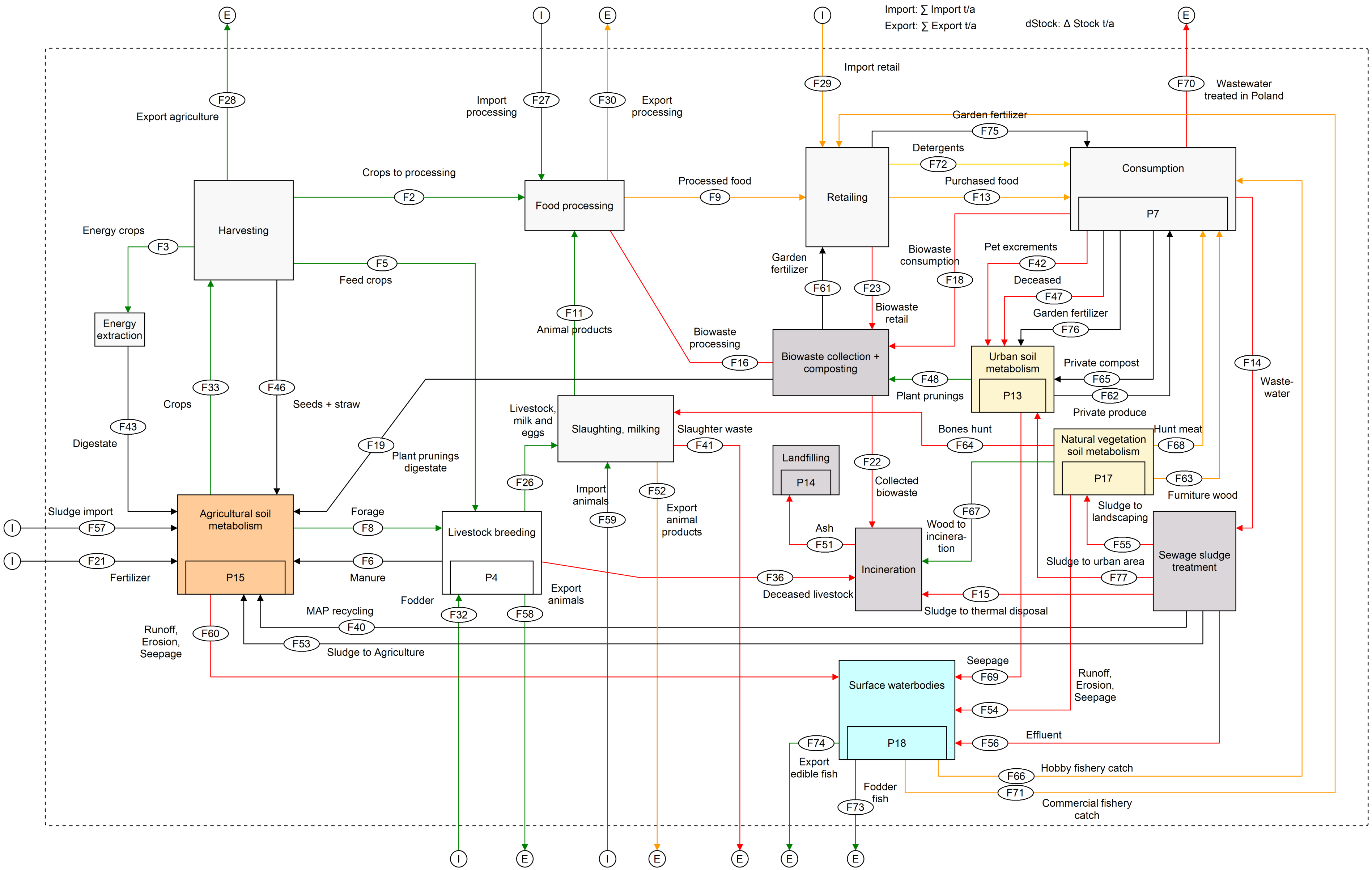
At the end of 2011, the total agricultural land in Brandenburg spanned circa 1.45 million ha agricultural land (DeStatis, 2012a), of which circa 1 million ha (LVB, 2012) was used as crop land. It can be assumed that the vast majority of the remaining land was used as pasture. Although Berlin is a city state, also some agriculture takes place near its borders. However, because Berlin's agricultural area is rather small with 3,738 ha (DeStatis, 2012a) compared to that of Brandenburg, it will be excluded from the analysis.

Plant production in Brandenburg serves three different purposes; human consumption, fodder and forage for cattle, and energy generation. All output from the Agricultural soil metabolism process goes to the Harvest process with the exception of biomass produced from Forage, which travels to the Livestock breeding process i.e. is eaten by cattle directly. During the Harvesting process the crops are seperated from the rest of the plant, leaving the straw. The phosphorus contained in energy crops are fed to the Digestion process, with the exception of oil fruits which residue pulp is fed to livestock after oil extraction. The oil extraction is modelled as though it takes place during the Harvesting process and therefore both oil fruit pulp and fodder crops flow to the Livestock breeding processes after Harvesting. Crops destined for human consumption either flow to the Food processing process or are exported. These latter flows will be treated in section 4.6.1.

As a general procedure, the 2011 yields for all crops were obtained from MIL and LELF (2012). The straw yields for each of these crops were then calculated by multiplying the crop yield with the ratio straw:crop, indicated as HNV-value, described in a publication from Von Wulffen et al. (2008). The crop and straw yields were subsequently multiplied with the respective phosphorus contents also from Von Wulffen et al. (2008) for each crop and straw type to obtain the amount of phosphorus contained in the crops and straw.

Brandenburg's total plant production has been divided amongst the following categories; Grains, 'Whole plant production', 'Hack fruits' (i.e. potatoes and sugar beets), Oilfruits, Fruits, Vegetables, Legumes, Forage, and Seeds production. Grains are mainly grown for human consumption, but also

Figure 5: Lay-out of the phosphorus system.



a part is fed to livestock (see section 4.2.2) and used for energy production (see section 4.2.1). The categories 'Whole plant production' and Oilfruits are only being grown for energy production, and additionally sugar beets from the 'Hack fruits' category are also grown for this purpose. All crops contained in the categories Fruits and Vegetables are produced for human consumption, as well as potatoes part of the 'Hack fruits' category. Forage production solely serves Livestock breeding, and seeds produced are assumed to be used for crop production during the next season, returning these to the land again.

The aggregated 2011 phosphorus content of crop and straw yields as belonging to each category, as well as the phosphorus values, are summed up in Table 4. From the data presented it can be concluded that in 2011 18,847.7 (crops) + 3,557.3 (straw) = 22,405.1 t P was extracted from the soil in Brandenburg. From the total harvest, the seeds and straw are returned to the land afterwards. This amounts to 119.6 (seeds) + 3,557.3 (straw) = 3,676.9 t P.

Table 4: Aggregated phosphorus content of crops and straw per plant production category.

Category	**Crop yield 2011 [t P]**	**Straw yield 2011 [t P]**
Grains	7,486.8	2,277.3
Whole plant production	4,165.9	
Hack fruits	457.6	195.9
Oilfruits	2,321.4	1,021.5
Fruits	1.4	
Vegetables	39.3	
Legumes	130.8	35.4
Forage	4,125.0	
Seed production	119.6	27.2
Total	**18,847.7**	**3,557.3**

4.2.1 Energy extraction process

Crops destined for the Energy extraction process include encompass silomaize, sugarbeets, and 'Whole plant production'. In the year 2011, 6,408,300 t silomaize (whole plant weight), 519,000 t of sugar beets, and 87,600 t of whole plant grains were produced in Brandenburg. These contained 3,845.0, 207.3, and 49.9 t P, respectively. This adds up to 4,102.2 t P. Although this amount of phosphorus is destined for the Energy extraction process, it remains unclear if this amount is actually being digested in Brandenburg, for it may well be that some of the silomaize and oilfruits are exported to other provinces and vice versa, depending on what the farmers view as most beneficial. The same applies to the output of the Energy extraction process. A part of this flow is certainly recycled back to the land (LBV, 2014, pers. comm.), but its quantities as well as the fate of the non-recycled part are unknown. Despite these uncertainties, for the MFA model it is assumed that the given amount of phosphorus enters the Energy extraction process in Brandenburg itself, and that it is returned to the soil afterwards.

4.2.2 Feed crops flow

Fodder grown for the Livestock breeding process includes both crops and whole plants. Both are first being harvested and then fed to the animals, but the former category excludes straw which travels back to Soil processes, whereas the latter encompasses both crop and straw. In the latter case it is assumed that the livestock eats the whole plant. Whole plants grown for fodder include the subcategories 'Legumes for whole plant harvest' and 'Grass from crop land'. Crops grown as fodder include 'Rye and winter-mixed-grains', 'Summer-mixed-grains', and Sweet lupins. In addition, Oilfruits are first converted to pure oil and oilfruit pulp. Pulp from oilfruits is highly nutricious and is therefore fed to livestock (LBV, 2014, pers. comm.). The oil contains virtually no phosphorus and hence this flow is of no interest for the MFA. Forage grazed by the livestock includes the subcategories Meadow and pasture, which flow travels directly from the Agricultural soil metabolism to Livestock breeding. The phosphorus contents of each category fodder consumed by Brandenburg livestock can be viewed in Table 5.

Table 5: Phosphorus contents of fodder and forage production.

Category	**Posphorus content [t P]**
Fodder crops	2,133.34
Whole plant fodder	271.0
Forage	4,125.0
Oil fruit pulp	2,321.4
Total without forage	**4,725.7**
Total	**8,850.7**

A problem with the data contained in the 'rye and winter-mixed-grains' subcategory is that rye may be used for human consumption, whereas the subcategory consitutes an aggregated value. No data was found on processing rye to rye flour in Berlin-Brandenburg and, in addition, the estimated purchases of rye flour in Berlin and Brandenburg in 2011 is rather small (52,778 tonnes) compared to the total yield from 'rye and winter-mixed-grain' (589,456 tonnes). It is therefore assumed that the total yield from the latter subcategory is being used as fodder. Of course, this does not rule out the option that rye is exported in its crop form, but it is simply not possible to find out its amount. An explanation of the calculations on food purchases in Berlin-Brandenburg can be read in section 4.4.

Adding up the phosphorus contained in oilfruit pulp, fodder crops, and whole plant fodder results in a total of 4,725.7 t P that flow from the Harvesting process to the Livestock breeding process. As mentioned before, this flow excludes phosphrous contained in Forage which travels from Soil processes directly to Livestock breeding. Adding up the phosphorus contained in meadow and pasture production of 2011, the latter flow amounts to 4,125.0 t P.

4.2.3 Crops for human consumption

Phosphorus contained in crops destined for human consumption can be attained by subtracting the phosphorus values for Brandenburg's 2011 total harvests from those of energy crops including straw, and fodder and forage crops. Thus, the 2011 harvests devoted to human consumption contained 22,405.1 (total extraction) - 4,102.2 (energy crops) - 4,780.5 (feed crops) - 4,125.0 (forage) - 3,676.9 (seeds and straw) = 5,720.4 t P. The fate of this output from the Harvesting process is treated further in section 4.6.1.

4.2.4 Fertilizer import flow

The Fertilizer import flow was calculated through converting the amount of mineral fertilizers purchased in Berlin-Brandenburg from DeStatis (2012b). The data did not include garden fertilizers and the production of ornamental plants. The averages of the two reporting years 2010/2011 and 2011/2012 were taken to compensate for purchasing behaviour (e.g. storage of the fertilizers). It was assumed that the mineral fertilizers were not further trade or stored for the longer term. Assuming that all mineral fertilizers bought were used in the agricultural sector only, the Fertilizer import flow to Agricultural soils amounted to 4,477.0 t P.

4.2.5 Sludge import flow

Next to mineral fertilizer, also sewage sludge is being imported into Brandenburg from other German provinces and applied as fertilizer on the agricultural land. In the absence of a 2011 value, the amount of sludge applied in 2010 was used which amounted to 10,059 t dried sludge (MIL and LELF, 2012). In determining the phosphorus concentration of the sludge, the median of all phosphorus concentrations found through probes was taken from a data sheet provided by Bundesgütegemeinschaft-Kompost (2014, pers. comm.). This amounted to a concentration of 4.53% PO_4 which translates to a concentration of 1.48% phosphorus. Applying the values found, the Sludge import flow was calculated at 149.0 t P.

4.3 Animal production

This section encompasses the processes Livestock breeding and Slaughting & milking and the related flows Manure, Export animals, Import animals, Slaughterwaste, and Deceased animals. Also stock present in the Livestock breeding process was determined. In quantifying these flows over 30 livestock subcategories were distinguished, and presenting all data found related to the subcategories was deemed unnecessary. Therefore only the procedures followed and sources used will be presented in this section, while the data itself can be requested by contacting the author.

4.3.1 Livestock

Population sizes of Brandenburg livestock per (sub)category were taken from statistical data published by the Berlin and Brandenburg states (ASBB, 2011, 2012a,b,c; LELF, 2013). For the categories 'Cattle', 'Pigs', 'Fenced game', and 'Sheep' data over 2011 was available, while for the categories 'Goats', 'Poultry', and 'Horses' data for 2010 had to be used. 'Fenced game' was assumed to be fallow deer only because it can be expected that these have the largest share in this category (Kästner, 2013).

The average liveweights per livestock (sub)category were taken from KTBL (2009), and livestock phosphorus concentrations were obtained from Antikainen et al. (2005), Georgievskii et al. (1981), and Oslage (1964). Category-overlapping values were averaged for use in the calculations. No data about phosphorus concentrations of horses and goats was found. To calculate horse phosphorus contents the coefficients found for cattle were used. For goats the values found for sheep were used.The phosphorus concentration values can be seen in Table 6. The livestock population sizes were multiplied with the average liveweights and body phosphorus concentrations in order to determine the phosphorus stock in livestock. This amounted to 2,344.7 t P in 2011. No differences in stock were determined.

Table 6: Coefficients used for every livestock category.

Category	**Phosphorus concentration [%]**	**Dressing [%]**	**Carcass cutting yield [%]**	**Boneash fraction of liveweight [%]**
Cattle	0.73	62 (males), 59 (females)	58	4.257
Calves	0.73	62		4.482
Pork	0.48	74	73	2.669
Sheep	0.51	54	68	3.106
Lams	0.51	54	68	3.155
Poultry	0.66	70		

4.3.2 Deceased animals flow

To calculate the phosphorus contained in Deceased animals, the livestock animal loss percentages of all livestock except geese, sheep, goats, and horses were used from KTBL (2009). For geese the values found for ducks were used. For 'Sheep', 'Goats', and 'Fenced game' an annual loss of 1.0% was assumed, and for horses a 0.5% annual loss was assumed. The animal loss percentages found were multiplied with average weights of livestock, and with phosphorus concentrations for each livestock category (Table 6) to determine the Deceased animals flow at 105.1 t P.

4.3.3 Manure flow

Phosphorus excreted by livestock was calculated by multiplying the total weight of the livestock population found (see section 4.3.1 with standardized livestock phosphorus excretion values from KTBL (2009). Different excretion values for different types of fodder were available (e.g. 'Standard fodder', 'Reduced phosphorus and nitrogen content', 'Mixed'). For the calculation the values found for 'Standard fodder' were used. This led to the outcome of 9,146.4 t P Manure.

4.3.4 Non-meat animal products

In 2011, Brandenburg farmers held a total of 146,800 milkcows that on average produced 9,107 kg of milk per cow in that year (MIL and LELF, 2012). The total amount of milk produced thus amounted to 1,329,622 tonnes. In calculating the amount of phosphorus contained in the milk, it is assumed that fresh cowmilk is identical to regular milk having a fat content of circa 3.5%. The latter milk type has a phosphorus content of 0.92 mg/gram (Kirchhoff, 2014). The phosphorus contained in cowmilk thereby amounted to 1230.0 t.

In additon to milk, 679 million eggs were produced in 2011 (MIL and LELF, 2012). An average egg was found to weight 66.24 grams (KTBL, 2009). Based on this value, the total weight of the eggs produced was 44,977 t. Kirchhoff (2014) found that the liquid part of an egg has a phosphorus concentration of 2.1 mg of phosphorus per gram. Ghişe et al. (2010) concluded that an eggshell contains on average 0.02 grams of phosphorus and that this represented 0.33% of the eggshell weight. The weight of an eggshell is thus 6.06 grams, and the liquid part has an average weight of 60.18 grams. Multiplying the concentrations with the weights and amount of eggs produced in 2011 results in an egg production of 99.7 t P.

Also wool a total of 202.5 t wool from sheep was produced in Brandenburg in 2011 (LELF, 2014, pers. comm.). Wool from different sheep species has a P concentration of 0.805 g/kg (Zheljazkov, 2005). Then 202.5 t x 0.805 g/kg / 1000 = 0.16 t P. The wool is assumed to enter the global market and therefore exported out of the study area with the Export animal products flow.

4.3.5 Fate of bred livestock

Based on the population sizes of the livestock held an estimation of the amount of livestock being destined for slaughter in 2011 could be made. For cattle this was done by assessing the difference between the different age groups of 2010 and 2011. Milk cows were assumed to live an average 4.5 years and for the other cows a lifetime of 7 years was assumed as the latter group consists of mother cows. For cows over 1 year old that did not give birth (i.e. heifers) a 50% slaughter rate assumed. For bulls and oxen the 50% slaughter rate was only assumed for those older than 2 years.

For pigs bred for meat it was assumed that three rotations take place per year. For sows and boars, used for reproduction purposes, the average lifetime was estimated at 3 and 5 years, attaining a rotation rate of 33% and 20%, respectively.

Sheep give birth at the age of 1, and these live up to 7 years (Schafzuchtverband-Berlin-Brandenburg, 2014, pers. comm.). As such, 1/(7-1) = 16.7% of these sheep go to slaughter annually. All lams born are assumed to be slaughtered within the same year. The number of lams born was calculated using an average 0.8 lams born per sheep per year (Schafzuchtverband-Berlin-Brandenburg, 2014, pers. comm.), and multiplying the figure with the number of sheep present. For goats the same values as those for sheep were used, and for the poultry categories the amount of rotations per year were calculated from single rotation lenghts from KTBL (2009).

After having identified the rotation rate of every livestock category, the phosphorus contents of livestock destined for slaughter in 2011 could be estimated. This was done by multiplying the rotation rates with the slaughterweights belonging to each category. The slaughterweights were based on the national German average as found in BMELV (2012a, p. 495). The outcome was multiplied with the phosphorus concentration of the respective livestock. Having followed the procedure it was concluded that livestock destined for slaughter contained 2,422.8 t P in 2011.

With the phosphorus content of livestock destined for slaughter found, the amount of actually slaughtered livestock in Brandenburg still had to be determined. Amounts of animals slaughtered in Brandenburg were taken from nationwide statistics (DeStatis, 2014), which were also recalculated into phosphorus contents using the slaughterweight and respective phosphorus concentrations. Unfortunately, the poultry category was not included in the data and it was therefore assumed that poultry destined for slaughter equals poultry actually slaughtered in Brandenburg. It was found that 2,095.5 t P livestock was slaughted in Brandenburg in 2011.

The phosphorus contents livestock destined for slaughter and livestock actually slaughtered in Brandenburg were subsequently compared per category in order to determine the fate of the livestock flows. From the comparison it was estimated that 1,677.7 t P livestock grown in Brandenburg would also be slaughtered in Brandenburg. The remaining 2,422.8 (destined for slaughter) - 1,677.7 = 745.1 t P livestock would be slaughtered outside the study area, comprising the Export animals flow. The comparison also indicated that 418.0 t P more livestock is slaughted in Brandenburg than Brandenburg's livestock breeding could deliver. These 418.0 t P were thus assumed to be imported for slaughter, being the Import animals flow. The Cattle, milk, eggs flow contains the livestock bred and slaughtered in Brandenburg (1,677.7 t P), and milk (1,230.0 t P) and eggs (99.7 t P) produced, making a total of 3007.4 t P.

4.3.6 Livestock components and slaughting procedure

During the Slaughting & milking process the livestock is essentially split into different components (e.g. meat, bone). Tissue and bone have very different phosphorus concentrations. It is therefore important to calculate the sizes of these individual components. Before proceeding to calculating the outputs of the Slaughting & milking process, information necessary to carry out the calculations is treated first in this section.

The weight an animal has when it enters the slaughting house is called the liveweight. After treatment in the slaughterhouse the carcass remains, which weight is referred to as the carcass weight. The weight contained in the carcass in relation to the original liveweight is called the dressing percentage (Wulf, 1999). Thus, by multiplying the liveweight with the dressing percentage the carcass weight is obtained. Similarly, the carcass cutting yield is the percentage of the carcass that ends up as meat (Raines, 2008).

Carcasses from different livestock categories are treated differently in the slaughterhouse. Livestock from all categories are disemboweled and bled out, and the ends of the legs are removed. Cattle, pork, and sheep carcasses are skinned but this is not the case with poultry, although the feathers are removed. Cattle and sheep carcasses exclude the head; pork and poultry carcasses include the head.

Coefficients that will be used to calculate the outputs of the Slaughting & milking process can be viewed in Table 6. For data on dressing percentages Wulf (1999) is used for all categories except poultry. For poultry dressing percentages Verheijen et al. (1996) were used. Carcass cutting yield percentages from Raines (2008) were used. The sources found on dressing percentages, liveweight and carcass cutting yield only give values for livestock categories and not the livestock subcategories. Therefore the values found on animal categories are assumed to apply to all subcategories of that category. The information found with regards to phosphorus contents of the livestock was treated in section 4.3.1.

About 80% of phosphorus contained in mammals resides in bone tissue, including hoofs, horns and hairs (NRC, 2000, p. 57). Bones thereby act as a phosphorus (and calcium) reservoir for vertibrates. The rest of the 20% is contained in the soft tissue (e.g. muscles, organs and fat). Fresh bones of mammals contain circa 20% water, 45% bone ash, and 35% organic matter (Carter and Spengler, 1978). Phosphorus contributes 18.5% of the ash content (Carter and Spengler, 1978), from which it can be calculated that fresh bones of mammals contain 8.325% phosphorus. Different values were used to determine the phosphorus concentration in poultry bones. A study (Field et al., 1974) found that fresh bones of 2-3 month old poultry consist of 49.88% dry matter, which in turn contains 47%

ash. According to Grynpas et al. (1984), the ash in bones of ten-week-old chickens contain circa 12.5% phosphorus. From this data it was calculated that fresh poultry bones contain 2.93% P.

4.3.7 Outputs of the Slaughting & milking process

Given the high phosphorus content in bones, and the focus on meat (and to minor extend, organs) as the marketable end-product of the Slaughting & milking process, it is necessary to find the phosphorus contents of bones, meat, and the remaining soft tissue (e.g. organs, fat, blood). For the assessment is was assumed that all soft tissue has an equal phosphorus concentration.

The weight of the meat to be gained from the carcasses was first calculated by multiplying the number of livestock slaughtered in 2011 for each category from DeStatis (2014) with the average liveweight of livestock in each category from BMELV (2012a, page 495). Then the values gained were multiplied with dressing percentages for each category (BMELV, 2012b, p. 238) and the carcass cutting yields from Raines (2008).

The liveweights were then multiplied with bone ash contents as a percentage of the liveweights from Lawes and Gilbert (1859). The outcome was divided with the aforementioned 45% ash content of (fresh) bone to acquire the amount of bone contained in the slaughtered livestock. Offal weight was determined by substracting the liveweights with bone and meat weights. At this stage the weight ratios of bone : meat : offal for each subcategory was found.

The phosphorus contained in the bone was subsequently determined by multiplying the total amount phosphorus contained in every livestock subcategory slaughtered in Brandenburg (as calculated in section 4.3.5) by the 80%. The latter value respresents the share of phosphorus present in bone tissue in relation to that of the whole animal. Meat and offal thus contained the other 20% phosphorus present in the animals. This remaining phosphorus share was divided according to the weight ratio of meat : offal found earlier, thereby having identified the phosphorus contents of bone, meat, and offal.

Phosphorus contents of poultry subcategories were calculated slightly different than that of the livestock mammals because the 80 : 20 ratio of phosphorus contained in bone : tissue could not be used. First the carcass weights were calculated by multiplying the liveweights with respective dressing percentages. The weight lost in that process is assumed to comprise of offal as opposed to meat and bone. Lewis et al. (1997) found that an average poultry carcass consists of 26.2% fresh (i.e. wet) bone. The carcass weights were multiplied with that percentage to find the bone weights. The other 72.8%, consisting of skin and meat, was used to determine the meat weight. Thereby skin is also accounted for as meat.

The phosphorus content of the poultry bone weights found was determined as follows. Field et al. (1974) found that poultry bones have a dry matter content of 49.88%, which dry matter content has an ash content of 47%. Additionally, the phosphorus concentration of poultry bone ash is 12.5% (Grynpas et al., 1984). Multiplying the fresh bone weights with dry matter content, ash content of dry matter, and phosphorus content of ash, led to the determination of phosphorus present in poultry bone. After that the phosphorus contained in offal and meat was calculated by dividing the non-bone phosphorus according to the weight ratios found.

Poultry sold to the consumer often still contains significant amounts of bone (e.g. chicken wings). To overcome this issue, it was assumed that half of the bone is slaughterwaste, and that the other half is sold to the consumer along with the poultry meat.

Following the procedure as described, it was found that through slaughting livestock a total of 686.5 t P meat, 144.1 t P offal, and 1,263.9 t P bone was created. Note that the value found for meat is relatively high because poultry meat also contains bone. Adding the offal and bones produced would lead to a Slaughterwaste flow of 1,408.0 t P. However, it also had to be taken into account that 3.13 t P intestines is processed in Berlin-Brandenburg (see section 4.4.2), which is assumed to be taken from offal produced in Brandenburg. Also as a result of hunting 20.75 t P bones are produced (see section 4.3.8), which bones are assumed to be treated further via the slaughterhouse. The final Slaughterwaste flow were thereby determined at 1,409.0 - 3.1 + 20.8 = 1,426.7 t P. Having the 3.1 t P offal as edible product in mind, the total amount of food exiting the Slaughting & milking process is 3.1 (intestines) + 686.5 (meat) + 1,230.0 (milk) + 99.7 (eggs) + 0.2 (wool) = 2,019.5 t P. The fate of this edible output as part of either the Export animals products flow or as part of the Animal products flow is treated in section 4.6.

4.3.8 Hunt

In order to calculate the phosphorus contained in animals hunted, the number of killed animals per category was retrieved from Dobias and Seweron (2011). Average weights were used from (Bach, 2014) for 'Deer', and(Wildhüter-St.-Hubertus-e.V., 2014) for 'Wild sheep'. For the remaining categories minimum and maximum weights were averaged from Wikipedia.

For all categories, except 'Wild boars' and 'Wild sheep', the liveweight phosphorus concentration was attained by averaging the phosphorus concentration values used for livestock calculations; 0.6265%. For wild boars and wild sheep the phosphorus concentrations of 'Pork' (0.456%) and 'Sheep' (0.51%), respectively, were used. The numbers of hunted animals per category were multiplied with their respective average weights, and multiplied with the phosphorus concentrations. Phosphorus contained in animals hunted then amounts to 28.43 t P; 0,25 t P 'Small game', 1,833 t P 'Predatory animals', 0.656 'Fallen game', and the remaining 25.693 t P is 'Large game'. 'Fallen game' comprises animals that died of natural causes.

The fate of hunted animals was difficult to assess. It is assumed that 'Fallen game' and the predators are left in the forest; 1.83 + 0.66 = 2.49 t P. Then for the remaining categories, bones are assumed to be delivered to the slaughterhouse, that the offal is buried in the forest, and that the meat is consumed. Applying the earlier discussed 80 : 20 phosphorus ratio for bone : soft tissue, the bones should contain (28.4 - 2.49) x 0.8 = 20.75 t P. This leaves 5.19 t P rest tissue, which is assumed to consist of 50% meat and 50% offal; 2.59 and 2.59 t P, respectively. The 20.75 t P, comprising the Bones hunt flow, travels from Natural vegetation soils to the Slaughting & milking process. From there it is exported together with the other slaughterwaste.

4.3.9 Fish caught in Berlin-Brandenburg

Amounts (i.e. whole body weights) of fish caught from professional and hobby fishers was retrieved from Brämick (2011). Amounts of fish bred from aquaculture in Brandenburg in 2011 was retrieved from AfS (2012b).

For each fish species the phosphorus concentration from Schreckenbach et al. (2001) was multiplied with the amounts of fish caught for hobby fishing, professional fishing, and aquaculture to acquire phosphorus contained in the fish of those categories. For crabs the phosphorus concentration from Evans-White et al. (2005) was used. Using this method the total phosphorus for each category was; 5.3 t P (aquaculture), 5.1 t P (hobby fishing), 20.1 t P (professional fishing). These value represent whole fish weights.

Fish produced through aquaculture is believed to sold on the (inter)national food market and leaves the study area. Hobby fish are assumed to be consumed, flowing to the Consumption process. The category 'Professional fishing' contains a subcategory 'Fodderfish' corresponding to 16.50 t P. 'Fodder fish' are assumed to be exported, and the remaining 3.61 t P is assumed to be sold directly to retail for human consumption. According to Brämick (2011) 90% of professionally caught fish in Berlin is marketed in the city itself. Assuming that this also applies to Brandenburg, 10% of the remaining fish professionally caught is exported. This corresponds to 3.61 t P x 10% = 0.36 t P. This export joins export from aquaculture to comprise the Export edible fish flow; 5.61 t P. The other 3.25 t P commercially caught fish then flows from Surface waterbodies to the Retailing process.

After arriving at the Retailing process, it is assumed that only offal is taken out of the fishes, and the remainder sold to the customer. For Eel, the second-most locally caught fish, the dressing percentage with head-on is 90% of the weight (Crapo et al., 1993). Total weight of fish caught through fishery is 550,920 t, and thus 55,092 t (10%) is offal. It is assumed that phosphorus concentration of Eel flesh corresponds with that of the Eel offal. With a phosphorus concentration of 250 mg per100 gram (Kirchhoff, 2014), phosphorus in the offal amounts to 0.14 t P. The fish flesh and bone sold to the customer contain then 3.25 - 0.14 = 3.11 t P.

4.4 Supply chain

4.4.1 General procedure

The flows related to processes Food processing, Retailing, and Consumption had to be determined in an integrative and iterative manner. First of all, no data regarding import and export of food to and from Berlin-Brandenburg could be found, with the exception of imports and exports to other countries. Because also significant trade will take place between Berlin-Brandenburg and other German provinces, it was not possible to calculate these flows solely from statistical data. However, statistical data about the amount of regionally processed food could be found, as well as the average amount of food purchased per German citizen. As the amount of crops produced in Brandenburg could also be found, the total (economized) output of the Harvesting, Food processing, and Retailing process was known. In the absence of data regarding food imports and exports, it was decided that the best course of action would be to give food trade within the system boundaries priority over food exports. For example, potatoes grown in Brandenburg would first supply Food processing, which was the case for potato starch. The remainder would then be exported (i.e. Export agriculture). Similarly, any required input that could not be delivered from within the system was assumed to be imported.

However, an extra complication was that (regional) data about biowaste flows was only limitedly available, and that in addition no distinction was made between the origins of the biowaste (e.g. retail, households). Yet, the sizes of those individual biowaste flows would also influence all flows related to the Harvesting, Food processing, and Retailing processes. For example, the amount of Biowaste processing influences the sizes of flows entering the Food processing process; the larger the inefficiencies that process, the more input is required to deliver a certain output. Without data about neither food imports nor biowaste produced, the flow sizes related to the supply chain processes could not be determined from the process balances. Another approach therefore had to be taken.

Luckily, an extensive German study about nationally produced food waste carried out by Kranert et al. (2012). This source distinguished biowaste produced by processing, retailing, households as well as large users. Although this allowed for determining the amount of biowaste produced by the various supply chain processes, the phosphorus concentration of biowaste found in the literature were incoherent. This is explained in more detail in section 4.4.6. Due to the uncertainty surrounding the amount of phosphorus contained in the biowaste flows, it was decided that the ratios between the various biowastes from Kranert et al. (2012) would be used, and that the exact quantification would be derived from the Consumption process balance. In this process the unknown flow, Biowaste consumption, would be derived from the balance, and in turn that would lead to the quantification of all other biowaste flows. Based on that, the sizes of all other flows related to the supply chain processes could be quantified.

Thus, as a first step all non-biowaste flows were quantified, in addition to the total economized output of the Food processing and Retailing processes. This will be treated in the following (sub)sections, whereafter the (bio)waste flows will be treated in section 4.5, leading to the determination of all flows related to the supply chain processes.

4.4.2 Output of the Food processing process

The main statistical sources used for determining the amount of food being processed in Berlin and Brandenburg were the 'Verarbeitendes Gewerbe: Produktion', published by the AfS (2012c,d). It was assumed that identical food processing categories for Berlin and Brandenburg did not overlap. For most food categories the food weight of the processed food was indicated, but in some cases only monetary (turnover) values were given. In some cases (e.g. beef (salted, dried, smoked), and cola) the weight could be calculated from similar categories. In other cases (e.g. poultry meat, cocao, apple wine, beer, flour, pastry, and all milk products) this was not possible and thus the monetary values had to be translated into weights using mainly internet sources. Other categories had to be dismissed because they were too vaguely described (e.g. starch, 'other food', and 'other animal goods, unconsumable'). Each of the food categories were first related to food categories found previously, and if needed, extra categories were created (e.g. beer, cola, chocolate, backery goods).

The weights, with the exception of meat products, were translated into phosphorus weights using Kirchhoff (2014). For meat products the phosphorus concentrations calculated in section 4.3.7 were used. Exceptions to this procedure are explained in the following paragraphs.

The processing of meat was divided into the categories 'processed meat' and 'unprocessed' meat, and it was not clear to what extend both categories were overlapping. To make the calculations easier and more coherent it was believed that one of the categories should be dismissed. The category 'unprocessed meat' included carcasses and parts of carcasses, while for the MFA model it is assumed that all meat-cutting takes place in the Slaughting & milking process. This category was therefore excluded from the analysis.

Also vast amounts of fodder were found to be processed in Brandenburg, amounting to about 1,500 t P. However, it was unclear if the fodder was produced from Brandenburg's plant production, or if the raw materials were imported. Additionally, it was unknown what the destination of the fodder was. Therefore, this data was not used, thereby assuming that all fodder required to feed the livestock is imported into the region.

The category 'Milk and milk products' presented a special case, because here only a large monetary value (338 million euro) was given and no subcategories were described. Translating the monetary value to into milk weight would lead to a potentially large over-estimation as some milk products are significantly more valuable per weight unit than pure milk (e.g. cheese, milk powder). The amount of cheese produced in Brandenburg could be calculated by multiplying the amounts of cheese being produced in Germany in 2011 (BLE, 2013a) by Berlin's and Brandenburg's combined share of 2011 Germany cheese production BLE (2013b). For the remaining subcategories (e.g. milk, coffee milk, cream, yohurt, whole milk powder, skimmed milk powder, and butter) the price per kg was first determined by writing down several cheapest and most expensive variants of the subcategories in Real supermarket at February 2nd of 2014, and averaging the values found. Then for each of the subcategories the share in Germany's milk production was calculated from BLE (2014). The weights of each subcategory were then calculated by using the production weight for cheese as a reference. The results were checked by comparing the sum of supermarket prices for each subcategory with the monetary value presented in the food processing data (AfS, 2012c,d). The results showed that retail has a 35.08% value added over food processing, which seemed plausible.

Not contained in the statistics from AfS (2012c,d) is the production of beer in Berlin-Brandenburg. Gertler (2009) reported that 301,400 t of beer was produced in Berlin-Brandenburg in 2008 and it is assumed that this also applies to 2011.

AfS (2012c,d) reported values for processed cocaomass and chocolate. After calculating the phosphorus contents of both it turned at that both categories contained similar amounts of phosphorus. Milk used to make chocolate contains relatively little phosphorus, and it therefore seemed plausible that both categories describe the same material (i.e. cocaomass is first processed and then used for the production of chocolate). The cocaomass category was therefore excluded from the analysis.

Applying the assumptions and procedures as stated, the result is that a total of 2,788.2 t P food exits the Food processing process, being the sum of the Processed food and Export processing flows. Of that amount 956.2 t P are meat products (34.3%), 150.6 t P milk products (5.4%), and 1,681.4 t P plant-based products (60.3%).

4.4.3 Purchased food flow

In estimating the amount of food (and drinks) purchased in Berlin and Brandenburg in 2011, figures from the Statistisches Jahrbuch 2013 were used (BMELV, 2013), which source also shows data of previous years. The figures are presented in a 'kg per person' fashion, distinghuising between a myriad of food and drink categories. In order to calculate the total amount of phosphorus captured in the 2011 food purchases of Berlin and Brandenburg, the 2011 'per person' purchases for each food category were multiplied by the number of inhabitants (5,779,182; (Destatis, 2011a)), which figure was multiplied again by the phosphorus contents of each food category from Kirchhoff (2014). In doing so, it is assumed that the size of the Berlin-Brandenburg population was constant throughout 2011, that the inhabitants of Berlin-Brandenburg reflect the average German citizen, and that the number of visitors and people leaving for trips cancel each other out.

It was thereby calculated that the total food and drink purchases amounted to 3,929.7 t P in 2011.

4.4.4 Pet excrements flow

Unfortunately, the amount of petfood purchased was not assessed by the BMELV (2013), which quantification would be necessary to determine phosphorus contained in Pet excrements. However, nation-wide petfood purchases were found in IVH (2011), presented in turnover per petfood category (i.e. in monetary terms). For both dog- and catfood the types dried, wet, and snack petfood were discerned, in addition to single categories for bird-, fish-, and 'other' petfood. The monetary values were translated into weights per petfood category by assessing the price per kg of different petfood sold online at www.idealo.de, accessed 29th of January 2014. For every category the cheap, regular, and expensive offers were noted and averaged. For the 'Other petfood' category the average price per kg of the other petfood categories was taken, amounting to 21.21 euro/kg. In the absence of a better source, the phosphorus contents of petfood are based on an online article about phosphorus contents of various wet and dried dogfood products of the Wellness brand (CRF-Dogs, 2010). From there it was determined that wet and dried dogfood of the Wellness brand have an average phosphorus concentration of 0.35% and 1.06%, respectively. These concentrations were then multiplied with the quantities of petfood categories derived from IVH (2011), while adjusting for the Berlin-Brandenburg population size. In doing so, the wet dogfood phosphorus concentration was applied to both wet dog- and catfood, and the dried dogfood phosphorus concentration to all other petfood categories. The values used for the calculations are given in Table 35.

Importantly, pet food (see section 4.4.4) is assumed to be already included in the data of the Statistisches Jahrbuch, because the data was generated through comparing total food imports and exports to and from Germany (Pfeiffer, 2014, pers. comm.).

The calculations indicate that a total of 262.8 t P petfood was purchased in Berlin-Brandenburg in 2011, which exact amount is also assumed to be excreted, thereby neglecting pet growth. To overcome difficulties regarding the fate of the pet excrements it is assumed that all dogs and cats excrete on urban soils, and that the excrements of birds, fish, and other pets ends up in the household waste bin (i.e. Biowaste household flow). Pets thereby excrete 262.8 (total) - 4.3 (other pets) - 19.7 (birds) - 0.5 (fish) = 238.2 t P to urban soils based on pet food purchases. It was assumed that no biowaste is generated in the process of feeding pets. However, also food waste is fed to pets and therefore the Pet excrements will be higher than 238.2 t P. Foodwaste fed to pets will be treated in section 4.5.3.

4.4.5 Detergents

Shower gels, shampoos, soaps, and washing powders and gels for laundry may no longer contain phosphates, and hence phosphorus. However, this does not apply to tablets used in dishwashing machines and cleaning agents used in industrial washing operations (Kabbe, 2014b, pers. comm.). Based on a report published by IKW (2013), Kabbe et al. (2014) has calculated the amount of phosphorus contained in detergents per capita in Berlin. This data is presented in Table 7.

Table 7: Amounts of phosphorus-containing constituents of detergents used in Germany, taken from Kabbe et al. (2014).

Constituent	**Total amount [t]**	**Phosphorus contained [t P]**	**Use per capita [g P/cap]**
Phosphate	30,226	7,639	93
Phosphonate	4,115	494-1,481	6-8
Phosphoric acid	326	103	1
Average total	**34,667**	**8,730**	**106**

In order to calculate the phosphorus concentratation in phosphates Kabbe et al. (2014) used pentanatriumtriphosphate as representing substance, containing circa 25% phosphorus. For phosphonates the latter authors took the phosphorus concentrations of the most common substances in this category, which contain 12-36% phosphorus.

Multiplying the amount of phosphorus contained in detergents used per capita with the number of inhabitants of Berlin-Brandenburg yields 106 x 5,779,182 = 6.13^8 grams of phosphorus, which is 612.6 t P. This flow is assumed to be imported by Retail, sold to the consumer, and leaving the Consumption process with the Wastewater.

4.4.6 Garden fertilizer and Plant prunings digestate

No data was found on actual purchased or applied amounts of Garden fertilizer. However, according to a BSR correspondent (Nogueira, 2013, pers. comm.) all separated biowaste and plant prunings from Berlin-Brandenburg are digested in Brandenburg, after which it is used for fertilization purposes with unknown fate. In addition, a correspondent LBV (2014, pers. comm.) stated that it is unlikely that biowaste digestate is applied to agricultural soils due to its impurities (e.g. plastics), whereas this does not hold for digestate from plant prunings.

To still be able to estimate the amounts of garden fertilizer sold and applied in Berlin-Brandenburg, it was assumed that all separated biowaste in Berlin-Brandenburg was converted to garden fertilizer, and that it is sold and applied within Berlin-Brandenburg. Furthermore, fertilizer from digestion of plant prunings is assumed to be used as fertilizer in Brandenburg agriculture.

The amounts of produced plant prunings and separated biowaste in Berlin and Brandenburg in 2011 can be seen in Table 8. Data about the sizes of plant prunings and separated biowaste was extracted from BSR (2012) for Berlin, and from MUGV (2012) for Brandenburg. Data about Berlin's residual waste was also present in BSR (2012), but similar information was not found for Brandenburg and therefore not used in the assessment.

Table 8: Amounts and phosphorus contents of plant prunings and separated biowaste in Berlin-Brandenburg.

	Amount Berlin [t]	**Amount Brandenburg [t]**	**Phosphorus conc. [kg P_2O_5/t]**	**Total [t P]**
Plant prunings	64,300	103,605	1.23	90.1
Biowaste separated	62,230	5,916	2.09	62.2

Determining the phosphorus content of the biowaste streams proved difficult. Not only was data about biowaste phosophorus concentrations hard to find, the values found were also very different. According to a presentation given by Leifert (2011) biowaste contains 0.9 kg P_2O_5/t, whereas according to Gütegemeinschaft-Kompost (2014, cited in bifa (2013)) this is 2.09 kg P_2O_5/t. However, the source quoted by Leifert (2011) could not be found, and in addition Gütegemeinschaft-Kompost (2014, cited in bifa (2013)) also calculated the phosphorus concentration of plant prunings; 1.23 kg P_2O_5/t. The latter source was therefore used to determine the phosphorus contents of the flows. Thereby the Garden fertilizer flow was determined at 62.15 t P and the Plant prunings digestate flow at 90.1 t P.

4.4.7 Deceased people flow

In 2011, 27,851 people died in Brandenburg and 31,380 people died in Berlin (AfS, 2012f). When assuming an average body weight of 70 kg, and using the phosphorus body content from Frieden (1972), then a total of 45.6 t P was added to the cemeteries of Berlin and Brandenburg.

4.4.8 Human stock

The amount of phosphorus present in Berlin and Brandenburg people in 2011 was determined by multiplying the number of people living in Berlin and Brandenburg in 2011 per age class and gender, by people's average body weights per age class and gender from Destatis (2011b) to obtain the sum of body masses. Humans, on average, consist for 1.1% out of phosphorus (Frieden, 1972). After multiplying the abovementioned figures it was found that in 2011 the total phosphorus stock of humans amounted to 4,377.7 t P. It was assumed that the Consumption process stock remains constant.

4.5 Biowaste and sewage treatment

As explained in section 4.4.1, the Biowaste consumption flow was derived from the balance of the Consumption process, from which the other flows related to the supply chain processes could also be derived. In order to make the balance, the Wastewater flow remains to be calculated, which procedure will be explained in section 4.5.1.

4.5.1 Wastewater

In order to calculate the total amount of affluent (i.e. wastewater) a distinction is made between the Ruhleben WWTP, which is the only plant operating within the borders of Berlin, and the other WWTPs present in Brandenburg. In doing so, use is made of the retention capacity of the treatment plants i.e. which share of the affluent is retained, or captured, as sewage sludge.

Following MUGV (2013), WWTPs located in Brandenburg released 259 t P effluent to the environment, with a retention capacity of 91.2%. From there it follows that the affluent amounted to 2,943 t P, and the sludge output to 2,684 t P.

In the Ruhleben treatment plant 24 hour measurements indicated that 16 t P was processed at a loss of 0.36 t P (BWB, 2014), which represents 2.25% of the incoming sludge total. The retention capacity is thereby 97.75%. In 2011 the Ruhleben plant produced 44,351 t (dried) sewage sludge (Destatis, 2014). Sludge phosphorus concentrations vary per plant, but for determining the affluent a concentration of 4.44% PO_4 (Bundesgütegemeinschaft-Kompost, 2014, pers. comm.) i.e. a concentration of 1.44% phosphorus was taken. This translates to 642.1 t P sewage sludge exiting the Ruhleben plant. Using the retention capacity, the affluent of the plant was 656.6 t P.

In determining the total affluent i.e. the Wastewater flow, one also needs to take into account people without a connection to the sewage network. 3.4% of the people (i.e. 84,962 people) in Brandenburg do not have such a connection and treat their wastewater by means of package plants (MUGV, 2013). In general these plants do not eliminate phopshorus from the wastewater and it is therefore assumed that all phosphorus captured is thereafter discharged to the surface waters. Using the standard average phosphorus intake value of 1.8 gram/day/cap (Kabbe, 2014b, pers. comm.), then the 84,962 people excreted a total of 55.82 t P of wastewater in 2011. This flows to the package plants and subsequently released to the surface waters as effluent.

Summing up the affluents discussed, a total 2,943 + 656.6 + 55.8 = 3,655.4 t P would comprise the Wastewater flow. However, looking at hindsight, a minor calculation error was made and the Wastewater flow used in the MFA amounts to 3,675.3 t P.

In the city Guben, located in Brandenburg and having 24,000 inhabitants, the wastewater is treated in Poland (MUGV, 2013). The flow thereby leaves the study area i.e. is exported. Again using the standard average intake value of 1.8 gram phosphorus/day/cap (Kabbe, 2014b, pers. comm.), a total of 15.8 t P wastewater comprised the Wastewater treated in Poland flow.

4.5.2 Outputs of the Sewage treatment process

Also in the determination of the Effluent flow a minor calculation error was discovered afterwards, unfortunately. As stated before, effluent from Brandenburg WWTPs was 259 t P in 2011. That of the Ruhleben WWTP is 656.6 x (100% - 97.75%) = 14.8 t P, whereas an erroneous 20.0 t P was found during the creation of the MFA. Summing up those amounts of effluent together with the 55.8 t P released directly from package plants to the surface waters a total of 329.6 t P effluent was discharged, while due to the error 334.8 t P was used as Effluent flow in the MFA.

The fates and phosphorus quantities of the sludge outputs were determined using statistical data from Destatis (2014), in which the fates and quantity of dried sludge in Berlin and Brandenburg were presented. These are summarized in Table 9. Given that only Brandenburg's sewage sludges are used for other purposes than incineration, the earlier determined phosphorus content of Brandenburg sludge

Table 9: Fate and sizes of sewage sludge flows in Berlin and Brandenburg

Fate of sludge	Brandenburg [t]	Berlin [t]	Brandenburg [%]	Berlin [%]	Total P [t]
Agriculture	18,560	0	21	0	363.2
Incineration	53,172	44,351	58	100	2,384.2
Landscaping	15,788	0	18	0	517.3
Other	1,883	0	2	0	61.7
Total	**93,196**	**41,320**	**100%**	**100%**	**2,589**

output of 2,684 t P was used. Following MUGV (2013) the sludge recycled back to agriculture has a PO_4 concentration of 6%, which corresponds to a phosphorus concentration of 1.96%. Multiplying that concentration with the amount of sludge recycled back to agriculture yields a Sludge to agriculture flow of 363.2 t P. The concentration of the other sludges is unknown, and therefore the mass ratios in combination with the total Brandenburg sludge output of 2,684 t P was used to determine the phosphorus content of the other sludge flows. As such, 2,684 - 363.2 = 2,320.8 t P was divided over the remaining dried sludge quantities. This yields 517.3 t P Sludge to landscaping, and 61.69 t P sludge being used for other purposes. With the knowledge that sludge is also used in the creation of urban soil for construction, it was assumed that the 'other sludge' travels to the Urban soil metabolism, comprising the Sludge to urban area flow.

Finally, also small quantities of MAP, also known as struvite, are produced by the BWB in the Waßmannsdorf treatment plant. According to (Lengemann, 2014, pers. comm.) this amounted to 191 t in 2011. Using an approximate 9% phosphorus content of the MAP, the MAP recycling flow was determined at 17.2 t P. Because the MAP is extracted during sewage treatment, it will slightly affect the phosphorus present in the resulting sewage sludge. Due to the two minor calculation errors described earlier, and because it is unknown which sludge fate the MAP extraction affected, the Sludge to incineration flow was taken as the balancing flow of the Sewage treatment process. Therefore, rather than 2,384.2 as would follow from the procedure being stated in Table 9, its new value became 2,381.1 t P.

4.5.3 Biowaste treatment

As mentioned in section 4.4, the biowaste flows could only be determined once the other flows related to the Consumption process were known. With the Wastewater flow and Wastewater export to Poland flows quantified, this balance can be made.

From the large German study on food waste (Kranert et al., 2012) introduced earlier it was estimated that consumers contribute 78%, retail 5%, and the processing industry 17% to the total amount of organic waste in Germany. Whereas the amounts of organic waste from households and retail could be determined within a relatively small margin of error, the calculated amounts of organic waste from the processing industry had a extremely large range (minimum 210,000 t/a and maximum 4,580,000 t/a). The median was determined at 1.9 million t/a, comprising the aforementioned 17% of the total. In addition to the values found for biowaste in garbage, Kranert et al. (2012) also estimated that an annual 0 to 18 kg food waste per person is being privately composted, 4 to 19 kg per person ends up in sewage, and that 0 to 3 kg per person is being fed to pets. The data is summarized in Tables 10 and 11.

In applying the data to the MFA, the Industry food waste was applied to Biowaste processing, the Trade food waste to Biowaste retail, and food waste from Large users and Households to biowaste as output of the Consumption process. Here it is important to point out that Furniture wood (78.8 t P) is assumed to also be present in the Biowaste consumption flow, and that food discarded in sewage is already present in the wastewater streams. The total amount of food waste as output from the Consumption process, except that entering sewage, is thereby; 3,929.7 (Purchased food) - 3,078.5 (Wastewater + Wastewater export to Poland - Detergents) - 238.2 (Pet excrements from cat- and dogfood) - 45.6 (Deceased people) + 5.1 (Hobby fish) + 2.6 (Hunt meat) + 14.5 (Private produce) =

Table 10: Amounts of food waste per sector in Germany (Kranert et al., 2012) and application to the MFA.

Origin	Median of nationwide amount [t]	Share of total food waste [%]	Food waste in Berlin-Brandenburg [t P]
Industry	1,850,000	16.86	142.4
Trade	550,000	5.01	42.4
Large users	1,900,000	17.32	146.3
Households	6,670,000	60.80	513.7
Total	**10,970,000**	**100**	**844.8**

Table 11: Amounts of household food waste per capita in Germany (Kranert et al., 2012) and application to the MFA.

Fate	Median of nationwide amount [kg/cap]	Share of household food waste [%]	P content study area [t P]
Residual waste	42.7	50.95	261.8
Separated waste	19.1	22.79	117.1
Private compost	9	10.73	55.2
Sewage	11.5	13.72	70.5
Pets	1.5	1.79	9.2
Total	**83.8**	**100**	**513.7**

589.6 t P. From this figure, using the types of household waste ratios from (Kranert et al., 2012) and taking into account the exclusion of food waste entering the sewage system, all biowaste flows exiting the Consumption process could be determined as stated in Table 11.

Adding the Food waste present in Residual waste (261.8 t P), Separated waste (117.1 t P), Wood waste (78.8 t P), and food waste from Large users (146.3 t P), the Biowaste consumption flow amounts to 604.0 t P. Note that by calculating the Separated waste using the Consumption process balance in combination with the Kranert et al. (2012) study its value far exceeds the value found using regionally available data (i.e. Garden fertilizer flow of 62.2 t P). Separated biowaste amounts are highly region-specific and therefore the phosphorus content of Separated biowaste and Residual waste combined will be a more accurate representation of the case area.

Also the Pet excrements flow can now be determined by adding the food waste fed to pets (9.19 t P) to pet food purchased for dogs and cats (238.2 t P); a total of 247.4 t P. Food waste privately composted was given a dedicated flow; 55.2 t P comprising the Private compost flow.

The Biowaste retail flow was assumed to comprise the biowaste eminating from Trade (42.4 t P), as well as bones and offal of regionally caught fish that was assumed to be sold to local retail (0.14 t P), making a total of 42.5 t P. For simplicity reasons it was assumed that all meat waste was already generated during the Slaughting & milking process. The adjusted Biowaste processing flow thereby became 96.2 t P as opposed to 142.4 t P.

4.6 Remaining flows and stocks

4.6.1 Remaining flows of supply chain processes

With the sizes of the Biowaste processing and Biowaste retail flows identified as done in section 4.5.3 it became possible determine the required input into the Food processing and Retailing processes. As such, in addition to columns created for food (i.e. crops, milk, eggs, and meat) produced, processed, and purchased, two new columns for required Food processing and Retailing input were added. Following the procedure that local produce would be supplied to local food processing, and local food processing would supply local food retailing, the differences between supply and demand were calculated. These were subsequently used to determine the sizes of flows Export agriculture, Crops to processing, Import processing, Export processing, Processed food, Animal products, Export animal products, and Import retail. Although the flow Purchased food was determined before by means of BMELV (2013) statistics, the actual consumption also comprised the flows Private produce (14.5 t P), Hunt meat (2.6 t P), and Hobby fish (5.1 t P). The final sizes of these flows can be viewed in section 4.7. An exhaustive list of the sizes of all food categories, 51 in total, per flow are not included in the report but can be requested through contacting the author.

4.6.2 Wood

Volumes of wood species harvested in Brandenburg in 2011 were retrieved from MIL (2013). These were categorized in 'Quality wood', 'Industrial wood', and 'Energy wood'. The first two categories are used for the production of furniture, and the latter category is incinerated.

The 2011 wood harvests volumes found were multiplied with the densities from TU-Dresden (2014) to calculate the weights of wood harvested. These were subsequently multiplied with phosphorus concentrations of the different wood species from Göttlein and Weis (2013). This led to the determination of phosphorus contained in the three wood categories; Quality wood (25.0 t P), Industrial wood (53.8 t P), and Energy wood (9.2 t P). The energy wood travels from Forest soil processes to Incineration, and the remaining two categories together comprise the Furniture wood flow of 78.8 t P which flows to the Consumption process. Due to lack of data it was assumed that all wood produced in Brandenburg is locally consumed and that no wood imports take place.

4.6.3 Private produce flow

In both Berlin and Brandenburg a relatively large share of the land is devoted to allotment gardens and to a (far) lesser extend to urban agriculture. The latter is neglected. In the Rahmengartenordnung (Gartenfreunde-e.V., 2007), a law applying to allotment gardens, people are obliged to devote at least one-third of the allotment garden land to food production. In Berlin a total of 3,030.4 ha land was devoted to allotment gardens AfS (2012e, p. 335), whereas this was 2,444.8 ha in Brandenburg. The latter surface area was determined by multiplying the average allotment garden surface of 370 m^2 with the 66,075 allotment gardeners active in Brandenburg (BDG, 2014). Assuming that exactly one-third of the allotment garden land entailed crop production as prescribed by the Rahmengartenordnung, crops would be grown on a total of 1,825.1 ha land.

Because no data is available regarding the types of crops produced, an educated guess was made which entailed strawberries, blackberries, raspberries, 'vegetables', and potatoes. The yields of these crops in kg/ha were 1.24, 0.39, 2.94, 9.29, and 25.83, respectively. Taking the average of 7.94 kg P/ha, it was estimated that a total of 14.5 t P was extracted from Urban soils, comprising the Private produce flow going to the Consumption process.

4.6.4 Balances of soil processes

Finally, soil phosphorus losses could be identified with the aid of the MONERIS model (Behrendt, 2000). The data itself was kindly provided M. Matranga of the Leibniz-Institute für Gewässerökologie und Binnenfischerei (IGB), and summarized in Table 12. No data was available for the year 2011 and therefore the average was taken of the three latest years 2007, 2008, and 2009.

Table 12: Types of phosphorus losses to the surface waters and origin.

	Runoff [t P]	**Erosion [t P]**	**Seepage [t P]**	**Drainage [t P]**	**Total [t P]**
Crop land	276.5	30.2	290.3	9.0	606.0
Forage land	358.5	0.7	67.9	18.0	445.1
Urban areas			162.7		162.7
Other land	152.5	0.6	67.4		220.5

The phosphorus losses of crop land and forage land were summed up, identifying a total of 10,51.1 t P leaking from the Agricultural soil metabolism. Only seepage took place in urban areas, amounting to 162.7 t P and eminating from the Urban soil metabolism process. The 'Other land' category comprises non-agricultural non-urban land, entailing forest land and land used to purify sewage sludge; the Natural vegetation soil metabolism. Here unfortunately a calculation error was made; a total of 276.8 t P was used in the MFA whereas the actual Runoff, erosion, seepage flow amounts to 220.5 t P.

With all flows entering and exiting the soil processes identified the soil balances can be made up. It can thereby be concluded that the Agricultural soil metabolism had a stock deficit of 1,434.1 t P, and that the Urban soil metabolism and Natural vegetation soil metabolism had stock surplusses of 204.7 t P and 129.1 t P, respectively. Accounting for the error made, the Natural vegetation soil metabolism actually had a surpluss of only 72.8 t P. Lastly, net stock added to the Surface waters process, comprising the unretrievable phosphorus losses, turns out to be 1,794.9 t P in 2011. Accounting for the error, this should have been 1,738.6 t P.

4.7 Results: Phosphorus MFA of Berlin-Brandenburg

The final 2011 phosphorus MFA of Berlin-Brandenburg can be viewed in Figure 6. Colours were given to flows with different characteristics to make the figure more easy to interpret. Four quality categories are used which match the colours given to each flow; raw materials (black), half-fabricates (green), waste (red), and end-products (gold). Flows entering the Retailing process are seen as end-products, while flows entering the Food processing process are seen as half-fabricates. Flows that may be potentially end-products, such as exports from agriculture are counted as half-fabricates.

4.7.1 Imports, exports, and stocks

It can be deducted that a total 13,160.0 t of P flowed into Berlin-Brandenburg in 2011. Of these imports, 3,870.5 t P remained in the system in the form of stock added, and the other 9,289.5 t P left the system. From the 13,160.0 t P imported into the system, 2,859.3 t P (21.7%) was imported as end-product, 5,674.68 (43.1%) as half-fabricate, and 4,626.0 t P (35.2%) as fertilizer. The amount of phosphorus exported consisted for 2,238.8 t P (24.1%) out of end-products, 5,608.4 t P (60.4%) half-fabricates, and 1,442.4 t P (15.5%) as waste.

A total of eight processes with stock were modelled in the system. For two of these, Livestock breeding and Consumption, the size of the stock itself was calculated; 2,344.7 t P and 4,377.7 t P, respectively. For the other processes the stock was given a zero value to assess the stock changes. Given the enormous size of these compartments (i.e. soils, surface water bodies, landfilling sites) the actual stocks of these processes can be assumed to be in the order of magnitudes higher than Livestock and Consumption.

With the help of the MONERIS model the stock differences of the various soil processes could be determined. From the process balances it was determined that Urban soils accumulated 204.7 t P in 2011 and that Natural vegetation soils added 129.1 t P. Agricultural soils were found to have a netto deficit of 1,434.1 t P. As a result of phosphorus losses from the soils, a netto 1,794.9 t P was added to Surface waterbodies' stock. Finally, a total of 3,175.8 t P was added to the Landfilling/Cement process.

4.7.2 Process efficiencies

When making a balance for each process it becomes possible to assess the efficiency of the processes. These results are summarized in Table 13. The Harvesting and Incineration processes are not included in the assessment because the losses taking place from these processes were not determined. Agricultural soil metabolism, Food processing, and Retailing all produce less than 5% waste streams during conversion and can therefore be seen as relatively efficient processes. In calculating the efficiency of the Agricultural soil metabolism also the soil stock deficit was counted as an input, because also the deficit was converted into output.

Figure 6: Phosphorus MFA of Berlin-Brandenburg of 2011.

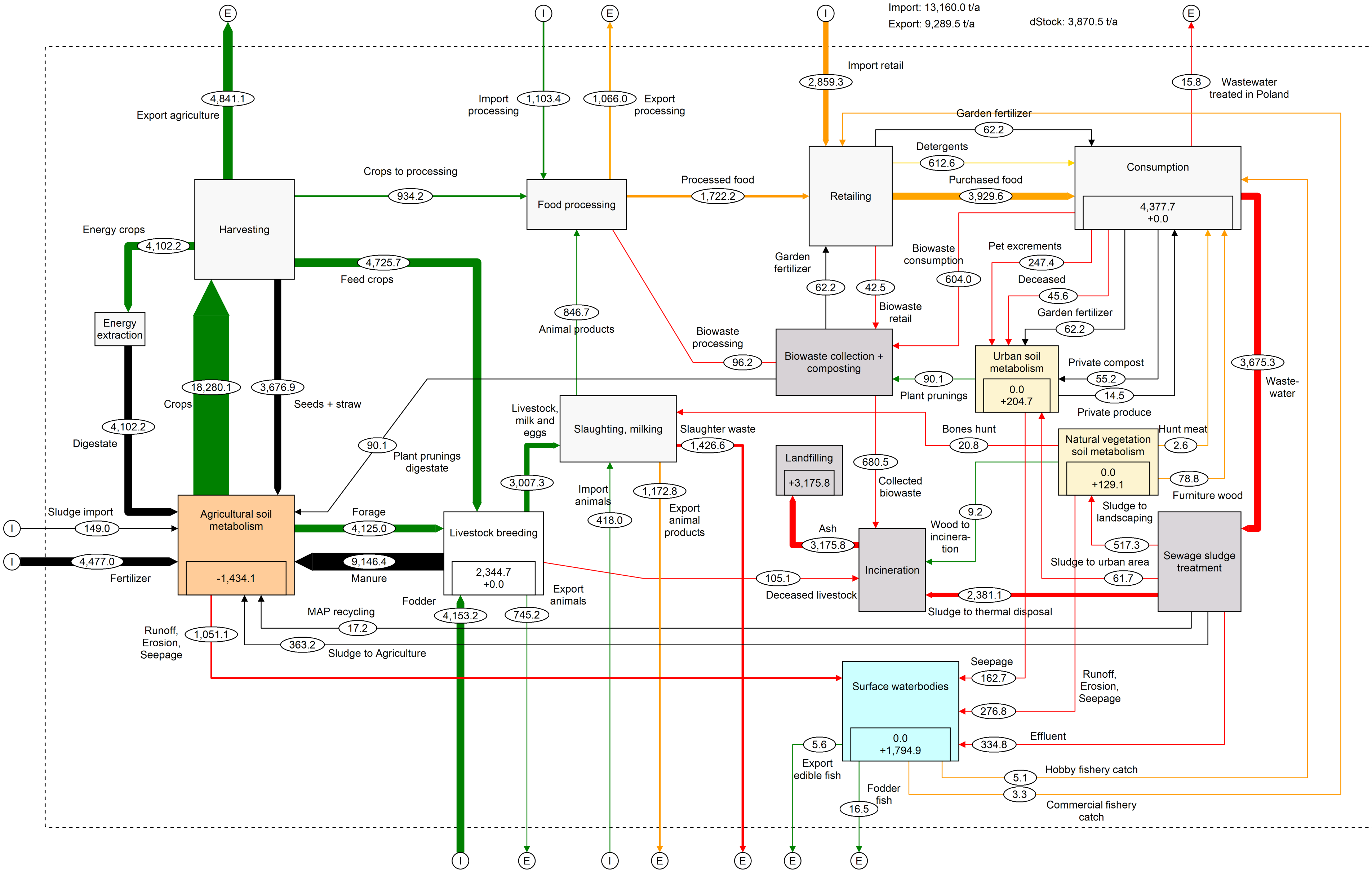


Table 13: Balances for each process.

Process name	Input [t P]	Output [t P]	Waste [t P]	Efficiency [%]
Agricultural soil metabolism	22,022.1 + 1,434.1	22,405.1	1,051.1	95.5
Livestock breeding	13,004.0	3,752.5	9,251.5	28.9
Slaughting, milking	3,425.3	2,019.5	1,426.6	58.4
Food processing	2,884.3	2,788.2	96.15	96.7
Retailing	4,646.9	4,604.4	42.5	99.1
Consumption	4,705.4	117.3	4,588.1	2.5
Biowaste collection + digestion	832.7	152.3	680.5	18.3
Sewage sludge treatment	3,675.3	380.4	3,294.9	10.3

Livestock breeding, on the other hand, is rather unefficient (26.5%) although the manure produced is being used as fertilizer again. When assessing Manure as a valuable output the Livestock breeding process can be seen as highly efficient with Deceased animals comprising only 0.8% of the total output. The output from Livestock breeding travels to the Slaughting & milking process where again significant losses (58.4% efficiency) take place. Note that for calculating the efficiency of the latter process the Bones hunt flow was excluded to find the actual efficiency of the process. The Livestock breeding and Slaughting & milking processes taken together will have a lower efficiency that either of the processes. The Livestock, milk, eggs flow consists of, as the name already implies, of animal tissue, milk, and eggs. If one would consider only the conversions required for meat production the inefficiencies would be significantly higher as no losses from milk and eggs during the Slaughting & milking processes were modelled.

The Consumption process as the raison d'etre of the (antropogenic) phosphorus cycle and, logically, after consumption all input except Garden fertilizer is converted to waste. The efficiency of the Consumption process was calculated using Garden fertilizer and Private compost as valuable outputs because also the latter is used as a fertilizer. The process efficiency was thereby calculated at 2.5%. Yet, which output from consumption is valuable remains a matter of perception because also Deceased people and Pet excrements could be seen flows fertilizing the Urban soils.

Finally, the Biowaste collection + digestion and Sewage sludge treatment processes can be seen as the recycling processes within the scheme. Both processes are extremely inefficient at doing so, with efficiencies of 18.3% and 10.3%, respectively. Note that the Sewage sludge treatment process will be more efficient when counting the Sludge to landscaping flow as a recycled flow, instead of waste flow. For the present assessment it is counted as a waste because its quality is not high enough to be recycled back to agricultural soil.

4.7.3 Current recycling

Although in small amounts, some phosphorus recycling did take place in Berlin-Brandenburg in 2011. MAP (17.2 t P) and sludge (363.2 t P) were recycled from the Sewage sludge treatment process back to Agricultural soil processes. Plant prunings (90.1 t P) were digested during the Biowaste collection + digestion process and applied to agricultural soil. Another 62.15 t P was digested from the Biowaste consumption flow and sold as Garden fertilizer. In addition, consumers also compost also a significant share of their biowaste; 55.2 t P. Finally, Digestate (4,102.2 t P), Seeds + straw (3,676.9 t P), and Manure (9,146.4 t P) are applied as fertilizer to the agricultural land and can therefore also be seen as recycled flows.

4.8 Discussion

4.8.1 Main modelling uncertainties

A model is always an approximation of reality therefore it can never be perfect. The main uncertainties will now be discussed.

1. First of all, the absence of statistics concerning trade between Germany's provinces creates an inherent uncertainty when it comes to the sizes of import and export flows. As mentioned before, the import and export flows from and to foreign countries does exist, but this data was not regarded because the total imports and exports of Berlin-Brandenburg are highly uncertain anyway. Adding the latter data would have relatively little value compared to the complexity it would add to the calculations. Thus, within the model only the bare minimum imports and exports are presented, which flows could be significantly higher.
2. Related to the former point of uncertainty is the effect it has on the other flows to and from the Food processing and Retail processes. It is possible that, for example, all of Brandenburg's produce is being exported and that all required input for Food processing and Retail processes, and even the Livestock breeding process is being imported. Nevertheless, it does seem logical for farmers to sell their produce locally, and for the processing industry to sell its products to local retail as the price excludes unnecessary transportation costs.
3. Thirdly, an inherent uncertainty lies in the way the amount of phosphorus contained in food has been calculated. The data from Kirchhoff (2014) only contained values for edible food contents. This means that, taking the example of an egg, only the phoshporus concentration of the inside was measured, and not the scale. Another example can be given for fruit. Often the seeds of a fruit are not eaten whereas seeds will have a much higher phosphorus concentration than the rest of the fruit due to its function as starting material for an organism. It could therefore be that the inedible parts of food have a higher phosphorus concentration, but this was not researched.
4. Another main factor of uncertainty lies in the assessment of phosphorus contained in biowaste. The Biowaste consumption flow was derived by balancing other flows connected to the Consumption process. In turn, the sizes of the Biowaste retail, Biowaste processing, and Private composting flows were derived from the size of the Biowaste consumption flow, creating a 'magnifying effect' of any inaccuracies. In addition, the study done by Kranert et al. (2012) leaves a huge margin of error for the amount of biowaste generated by the processing industry. Especially the efficiency of the Retailing process (99.1%) seems too high.
5. Any losses taking place during the Harvesting process were not modelled due to large uncertainties. One is issue was the unknown fate of these losses (e.g. on-farm, during transport), and another issue was that different crops have very different loss ratios (e.g. grains versus fruit). Overall the losses were said to be in the order of 10% (LBV, 2014, pers. comm.).

4.8.2 Comparison with literature values

As can be read in section 4.7, phosphorus losses taking place in agriculture as modelled in the MFA are relatively low. A total of 22,022.1 t P entered agricultural soil in 2011, which resulted in an output of 22,405.1 t P, soil stock decrease of 1,434.1 t P, and 1,051.1 t P losses to the surface waters. Relative to the input, the soil losses thereby comprise 4.77%. Compared to agricultural soil throughput the losses to the environment comprise 4.48%.

It is generally believed that agriculture is responsible for the main phosphorus losses to the environment. Therefore, the phosphorus losses to the environment found can be seen as relatively low i.e. the Brandenburg agricultural soil metabolism is relatively efficient. So, apart from the uncertainties described in the previous section, how do the values found relate to the literature? In order to answer this question a literature comparison was carried out (see Table 14), featuring MFAs with system boundaries; Global, Europe, and Switzerland. MFAs without a division between soil stock change and erosion were not included. The chosen systems are seen to adequately reflect the composition of the Berlin-Brandenburg system, given that consumption, crop production, and animal production take place in the areas. In order to indicate the size of the animal husbandry sectors in the compared systems, the size of the manure flow as part of the soil throughput is also included in the table.

Table 14: Literature comparison of agricultural soil balances.

System boundary, year	**Total input**	**Soil stock change**	**Losses to water bodies; % of throughput**	**Source**
Berlin-Brandenburg, 2011	22,022.1 t	-1,434.1 t	1,051.1 t; **4.48%**	Present study
Europe (EU 15), 2006-2008	7.474 kg/cap/yr	+2.9 kg/cap/yr	0.236 80% kg/cap/yr; **3.15%**	Ott and Rechberger (2012)
Switzerland, 2002	30,900 t	+4,000 t	2,000 t; **6.47%**	Lamprecht et al. (2011)
Global, 2000	75 mln t	+15 mln t	7 mln t; **9.3%**	Van Vuuren et al. (2010)

The main indicator or means of comparison used is the phosphorus loss to the environment in relation to the throughput of the agricultural soil processes, printed bold in Table 14. Overall it can be stated that the found phosphorus loss percentages a relatively spread out, ranging from 3.15 to 9.3%. The found value for Berlin-Brandenburg can be seen to lie about 30% lower than the average literature value of 6.3%. Surprising is that the European value is about three times smaller than the global value, where it has be be noted that in the study of Ott and Rechberger (2012) P losses have a 80% uncertainty. At the high end phosphorus losses would not exceed 6% in that case. Furthermore, based on relative size of the manure flows, Berlin-Brandenburg has a small livestock sector.

Contrary to the other studies, the Brandenburg soils were found to be depleting. This is confirmed by estimations of local farmers, as well as an EU study which mapped the land over multiple years (LBV, 2014, pers. comm.). Wind erosion is claimed to be severe in Brandenburg than in the rest of Germany as the soils are naturally sandy and nutrient-poor. While Brandenburg loses phosphorus through wind erosion, the loss may thus not be replaced by wind erosion from other provinces. Some of the wind erosion wil land on the surface water and other Brandenburg agricultural land, thereby captured in the MFA. Other wind erosion may be captured in forests, comprising a third of the total land surface, adding phosphorus to forest soil stocks. In that case agricultural soil deficits may be more severe as identified.

A relatively low application of fertilizers could explain lower losses to the environment than would be the case under higher fertilization. Also the amount of manure applied to Brandenburg soil is low compared to the other studies (39% of soil input). For the Netherlands it was even found that manure comprised 79.5% of input to the soil, based on a 2010 MFA made by the CBS (2011). Combined soil stock change and P environmental losses as output were calculated to be 30.8% of the total soil input for the Dutch case.

The idea that agricultural soils are mainly responsible for phosphorus losses is probably conceived by the low crop production in comparison to phosphorus input to soils. For the Europe MFA it was found that only 58% of phosphorus input to soil leaves as valuable output, while this is 69.2% for the Netherlands in 2010 (CBS, 2011). For Europe the phosphorus stock added is indeed very high compared to P losses to the environment. Whether this also holds for the Dutch case cannot be derived from the data found. Yet, it does seem that in the Netherlands there is a significant manure surplus, leading to overfertilization of the soils. This is contrary to the situation in Brandenburg, where access to manure is limited and the remaining soil phosphorus requirements have to be supplied through mineral fertilizers, which are often more expensive than manure.

4.8.3 Task division

As mentioned before in section 3.4.1 the MFA was made together with partner T. Theobald of the ATB institute. The division of tasks between T. Theobald and me will be briefly explained in this section.

Given T. Theobalds expertise on the agriculture and sewage treatment subregimes, he mainly focussed on the processes and flows as part of those subregimes. I focussed on the processes and flows related to the processing, retailing, and biowaste treatment subregimes. Flows and processes related to the consumption subregime were a mixed effort. In addition, I also created and continuously modified the MFA model itself.

Because T. Theobald is a native German speaker and because of his access to a larger network of people, he in most cases mailed and called people to acquire additional data. Via this route the phosphorus concentrations of sewage sludge and biowaste were found, as well as all phosphorus losses to Surface water bodies within Berlin-Brandenburg.

While T. Theobald calculated all outputs and stock of the Livestock breeding process, I did the same for the Slaughting & milking process. Regarding the Consumption process, I calculated the flows Plant prunings digestate, Garden fertilizer, Private compost, Pet excrements, Detergents, and Purchased food. T. Theobald calculated all flows related to fish and wood, as well as Private produce, Deceased, Hunt meat, Wastewater treated in Poland, and Wastewater. T. Theobald also calculated the phosphorus stock contained in humans, as well as that in livestock.

Overall the division of tasks is seen as evenly distributed. A major benefit of the cooperation was that the accuracy of the data and modelling choices could be discussed, which certainly benefitted the quality of the final MFA. Similarly, through the cooperation many calculation errors could be identified in an early stage, and the capacity to find the necessary data was larger.

4.9 Conclusions: Opportunities for improvement

Before drawing conclusions, it is necessary to first explain the ideology behind an optimized phosphorus cycle. Phosphorus is seen first and foremost as an element required to continuously produce food (and fodder) for the global society. Given that phosphorus is limitedly available, it should cycle continuously through the food system, without any losses to the environment. On the other hand, phosphorus extraction from the environment should also be avoided to ensure ecosystems do not desintegrate. From this it follows that phosphorus may flow in and out Berlin-Brandenburg, as long as it remains in the technosphere. In addition, it is believed that any other application of phosphorus such as cement production, or even the production of energy, should be avoided.

The opportunities for improvement are categorized into three types;

1. Making processes more efficient i.e. minimizing the generation of residual flows;
2. Making processes more effective, by changing the process such that the quality of the output increases and/or by changing the quality requirements of the input;
3. Using residual flows more efficient, by finding more suitable applications depending on the quality of the flow.

4.9.1 Making processes more efficient

Where Cordell et al. (2009) found that about a third of all inputs to (global) agricultural soil are lost in the form of erosion, this certainly does not apply to the case of Berlin-Brandenburg. In fact, it can be concluded that although some losses (1,051.1 t P) do take place in Brandenburg's agricultural soil processes, these are almost negligible compared to the throughput (23,456.2 t P). However, these results should be carefully interpreted because neither the agricultural soil stock change, nor the amount of digestate returned to the soil is known. The Erosion flow may therefore be significantly larger (or smaller) than modelled. Because it is commonly known that agricultural soil processes are responsible for significant phosphorus losses to the environment, its optimization is marked as an opportunity for improvement. In addition to reducing erosion, also the amount of energy crops as well as straw produced could be minimized.

A second option for process efficiency improvement is the Consumption process. About 16.7% of the phosphorus contained in all food consumed is thrown away. Although a portion of the biowaste is unavoidable (e.g. eggshells), some of it is partly avoidable (e.g. potato peals), there remains a large fraction of the biowaste being completely avoidable (Kranert et al., 2012). In reducing food waste, small reductions in losses from other processes (e.g. soil processes, food processing etc.) can also be expected as smaller throughputs generally result in smaller waste flows.

Thirdly, the Sewage treatment process could be optimized such that less phosphorus is lost in the form of effluent.

Also the Livestock breeding process could be made more efficient by reducing the amount of manure generated per amount of animal, milk and eggs produced. In, addition, the meat : offal+bone ratio could be increased. In other words, the enhancement of phosphorus conversion from plant biomass into animal products.

Additional options could be to make the Food processing and Retail processes more efficient through reducing the generation of residual streams; Biowaste processing and Biowaste retail. These options will not be treated further because it is believed that these processes are already very efficient.

4.9.2 Making processes more effective

In addition to throwing away less food, another major opportunity for improvement can be found in the current diets of people. If people would shift towards a less animal product-intensive diet, and reduce meat consumption in particular, then efficiency gains throughout the system could be realized. Firstly, the throughput of the Livestock breeding process would be reduced, and as a consequence the required fodder input, slaughter waste, deceased animals, as well as the manure flow would be smaller. Although manure fertilizes the agricultural soil, also less crops would have to be grown for livestock, which would allow more people to be fed and/or less intensive agriculture would be required. The latter aspect would likely result in fewer phosphorus losses to the environment through erosion. In short, smaller residual phosphorus streams would be generated, and more food could be produced for people.

Related to the former improvement option is to enhance the quality of the outputs from the Consumption process, such that downstream (recycling) processes are able to produce raw materials, instead of waste.

It turned out that the Green space soil processes accumulate large amounts of phosphorus that can be seen as inefficient allocation of resources, as well as a source of untapped potential. Therefore one option is to try to bring Pet excrements, Deceased people, and Garden fertilizer back into the techno-cycle. Another option would be to produce products (e.g. food) from the accumulating phosphorus stock.

4.9.3 Using residual flows more efficient

Another main opportunity for improvement relates to the way sewage sludge and biowaste are currently handled. Both waste flows are predominantly incinerated and the ashes either landfilled or used in the production of cement. Whereas one may question if incineration of these streams is the most beneficial option, it does not necessarily compromise the recycling potential. Rather, the act of landfilling and using phosphorus for cement production does seem to be a clear waste of a valuable resource. As the processing of sewage sludge and biowaste also holds implications for its use afterwards, both are seen as a single opportunity for improvement.

A last improvement opportunity is found in slaughter waste; both bone and soft tissue waste (1,426.6 t P). It is certain that the flow is exported, but its fate is not known. Possibilities include incineration, landfilling, and fertilizer production. Given the uncertainties and the relatively large size of the flow, it nevertheless presents a good opportunity to help close the phoshporus cycle at a regional scale.

Chapter 5

Analysis of the social system: Actors and rules

The information used for the analysis for the social system was aqcuired from both interviews and a literature study. Three interviews and a meeting were held with actors related to the cycle chain subregimes. Interview questions of interviews with Dr. K. Lorenz (LBV), Dr. A. Ochs (BVE), and Dr. E. Hoffmann (IÖW) can be viewed in Appendix B. The recordings of these interviews can be requested, if permission if given by the interviewee. From a meeting with Dr. C. Kabbe of the Kompentenzzentrum Wasser Berlin also much knowledge was gained. That meeting was not intended as an interview and therefore neither interview questions, nor a recording was made.

5.1 Agriculture subregime

The information compiled in this section was retrieved from an interview with Dr. K. Lorenz of the LBV, unless stated otherwise.

5.1.1 Status quo

In Brandenburg about 1.3 million ha are used as agricultural land, and about 1.1 million ha are forests. Of the agricultural land about 68% is arable and about 29% is pasture land. However, a large portion of the pasture land is being used because the size of Brandenburgs livestock sector has halved over the past decades (LBV, 2014, pers. comm.). In addition, the soil fertility of the arable land is very poor; Where most provinces achieve yields of 60-80 kg/ha, in Brandenburg the harvest does not amount to more than 40-50 kg/ha (LBV, 2014, pers. comm.). Therefore, three quarters of the agricultural land of Brandenburg has been classified as a less favoured area (BonnEval, 2010).

In 2008 the EU started charting the state of Brandenburgs arable land. After the second measurement four years later the results were compared, confirming the farmers' presumption that the land is indeed subject to strong erosion (LBV, 2014, pers. comm.). Although the land is naturally sandy and hence already susceptible to erosion, more extreme weather as a result of climate change are making the problem more severe.

Whereas nationwide 6.1% of crop land is farmed ecologically, in Brandenburg this share amounts to 10.6% (Wimmer et al., 2012).

5.1.2 Actors: mainstream

About 7,000 farmers are active in Brandenburg. These can be divided into conventional (crop) farmers, meat and dairy farmers, large industrial farmers, and ecological farmers. The conventional farmers mainly engage in grain production, which crop type covered about 519,000 ha out of the total 1,031,000 ha crop land in 2011 (LVB, 2012). In addition to crop land, about 286,000 ha consists of pasture land (LVB, 2012), of which to date about half is being used by meat and dairy farmers for livestock breeding purposes. Brandenburg's livestock sector can thereby be seen are relatively small. Over the past decades this sector has be steadily shrinking, resulting in half of the pasture land remaining unutilized at present.

Another main agricultural sector in Brandenburg is energy crop production (e.g. mais and rapeseed) which is dominated by 5-6 German industrial stock-listed actors. Each industrial actor controls over 20,000 ha of land, which taken together accounts for about a third of the Brandenburg cropland. Digestors in which the energy crops are converted to biofuels are also operated by these actors. To a lesser extend, the industrials also grow tomatoes and other fruits in greenhouses. These actors often use technologies that closely resemble the concept of Industrial Ecology, for example by transferring the heat produced in the digestor to dwellings and offices.

The Landesbauernverband Brandenburg e.V. (LBV) can be seen as the main agricultural branche organization in Brandenburg. Of the total 7,000 farmers in Brandenburg, about 5,000 are member of the LBV, including conventional crop farmers, meat and dairy, as well as ecological farmers. Industrial farmers are not member of the organization. The tasks and responsibilities of the LBV are mainly advisory, including fertilization, plant protection (pesticides), seeding, animal husbandry, legal matters, and education.

5.1.3 Actors: niche

The ecological farms that the circa 650 eco-farmers in Brandenburg (MIL and LELF, 2012) operate show large variations in size. As a remnant of the Cold War period there remain farms that control over 1,000 ha of land with several of these being eco-farms (Nölting and Boeckmann, 2005). In comparison, the average East-German farm has a size of 198.7 ha, from which it can be concluded that both the conventional and ecological farms show great variations in size. Interestingly, the average West-German farm only controls 38.1 ha of cropland. East-German farms, including those in Brandenburg, are thereby relatively large on average.

In addition to the eco-farmers themselves, also the eco-organizations are important actors in this niche by acting as eco-certification authorities and by advising eco-farmers. The most important West-German organizations having gained foothold in Brandenburg are Bioland, Demeter and Naturland (Nölting and Boeckmann, 2005). The two main East-German organizations are Gäa - Vereinigung ökologischer Landbau e.V. and BIOPARK e.V. (Nölting and Boeckmann, 2005). In Brandenburg these organizations have been cooperating closely with one another for years already, forming an alliance against the Brandenburg agriculture ministry (MLUV) to stand up for the interests of eco-farmers (Nölting and Boeckmann, 2005). About 42% of the eco-farmers in Brandenburg are member of an eco-organization (IÖW, 2007).

5.1.4 Cognitive and normative rules

The LBV and the farmers follow highly similar structuration rules given that the former serves the latter. A major exception exists for the industrial actors, which will be discussed later in this section. For all farmers the continuation of the farm is the main priority, from which it follows that the farm has to be profitable. Apart from supporting the family, many farmers also have employees which also need to be paid. In order to remain profitable, the farmers seek to achieve a yield as high as possible against minimal costs. This includes costs related to fertilizers, seeds, pesticides, and water for irrigation, amongst others. Given the aforementioned poor quality of the land and induced climate change, the farmers often face dilemma's between achieving a high yield on the one hand, and minimizing costs on the other hand. Especially in maintaining soil fertility one requires to add fertilizer and take erosion-prevention measures, both of which induce extra costs.

In general, the farms are passed on from father to son, often spanning multiple generations. As such the farm has more value to the farmer than merely supporting the family; it is a part of the identity and family heritage. The farmers therefore take pride in their profession and seek to take good care of the land such that it can be successfully passed on to the next generation. In addition, the farmer not only feel he/she has a responsibility for the land, but also for the region in which he/she lives. Especially in the light of the demographic change take place in Brandenburg, the farmers also find it important to preserve the social life and activity within the region itself. This could be achieved by providing employment opportunities related to farming, food processing, and retailing as well as by avoiding concentrations of monocultures which are believed to reduce the appeal of the region. As young people leave the countryside for the city, the farmers find it increasingly hard to find successors for operating the farms, posing a threat to the continuity of the farms and hence the livability of the region.

A major exception to the dominant cognitive and normative rules applies to the industrials farmers. The primary reason for these actors to engage in agriculture is to create a steady flow of income, satisfying their shareholders. In doing so, the long-term quality of the land, (social) welfare of the region, and other cognitive and normative rules are only of minor importance to these actors. These actors view land purchases as a safe investment, and believe they can sell it again after exploitating for prices similar to the purchase price.

More severe weather events as well as phosphorus i.e. fertilizer price rises have been observed by the farmers in recent years. Furthermore, it is expected that both will increasingly pose a threat the feasibility of the farms in the mid-term. More climate change (i.e. drought) resistant methods of farming and alternative sources of fertilizers are therefore desired. To this end the LBV is working together with its members to test more drought-resistant crops, wind breaks and perennial crops. A good strategy to counter the increasing dry periods could be the use of effluent for irrigation. Although there are no claims for this type of irrigation, the farmers showed a basic interest.

Related to future fertilizer availability, the LBV views animal manure and phosphorus waste flows from Berlin as good alternatives to mineral fertilizers. However, at present, farmers prefer manure as fertilizer over treated sewage sludge mainly because of the contamination risks involved (Nölting and Daedlow, 2012). According to Nölting and Daedlow (2012), the following farmers' criteria in descending order apply for using MAP as fertilizer, which likely also applies to alternative fertilizers in general; same or lower price as conventional fertilizer, sufficient quantity, compatible with existing fertilizing practises, and a good uptake by the crop. However, even if these requirements are met, it is not clear whether the food processing and retail actors and consumers accept food that was grown with a fertilizer orgininally derived from waste (Nölting and Daedlow, 2012).

Reasons for farmers to engage in ecological farming over conventional farming are manifold. According to Nölting and Boeckmann (2005), for many farmers that converted to ecological farming, including the 'mega' farms of 1,000 ha or more, the perceived economical advantage over conventional farming will have been the primary reason. Not only do eco-farmers receive more subsidies, also their products can be sold for higher prices. Other people may have started an eco-farm to realise their ideals, while for others the scenetic beauty of the region may have been an important reason Nölting and Boeckmann (2005). Mainly for the eco-farmers seeking to realize their ideals a clear additional normative rule over conventional farmers can be distinguished.

For eco-farmers particularly the limited access to appropriate pesticides is seen as problematic, as only one type of pesticide fits the criteria stated by the eco-certification authorities. Sadly, this pesticide contains significant amounts of copper and causes reduced availability of phosphorus in the soils. Similarly, ecological poultry farmers do not have access to ecologically certified sources of protein-rich fodder, reducing the competitiveness of their farms. Finally, MAP (as well as other recycled P products, eds.) could be a good source of fertilizer particularly for eco-farmers whom have no access to mineral fertilizers (Nölting and Daedlow, 2012). However, MAP is currently not accepted by the eco-certification organizations (Nölting and Daedlow, 2012).

5.1.5 Regulative rules

The regulatory rules related to fertilizer application by farmers are stated in the Düngemittelverordnung (Von Wulffen et al., 2007), which ordinace is a combined effort of Brandenburg, Mecklenburg- Vorpommern and Sachsen-Anhalt state authorities i.e the LVLF, LFBMV, and LLFG, respectively. The ordinance forbids to apply more nitrogen and phosphorus as was extracted in the form of plant biomass the previous year, except when the soils are nutrient-deficient. In the latter case the farmer is obliged to fertilize his/her land until satisfactory levels of P and N are reached. After revision of the ordinance in 2007, also compost, digestate, biowaste and sewage sludge have become recognized as fertilizers in addition to mineral fertilizers and manure. One implication is that, whereas the industrial farmers overfertilized their land with digestate from their digestors for economic reasons, this is no longer allowed.

In Brandenburg the Ministerium für Ländliche Entwicklung, Umwelt und Verbraucher- schutz (MLUV) is repsonsible for the agriculture subregime. As part of the EU-Directive 1257/99 stimulating rural areas, the MLUV initiated the KULAP program with the goal of protecting the environment (Nölting and Boeckmann, 2005). Many farms are located in protected natural areas (IÖW, 2007). Within the KULAP subsidies are provided to ecological farmers, whose practises are apparently seen as being able to contribute to environmental protection. The height of the subsidy depends on the farm size and farming practises deployed (Nölting and Boeckmann, 2005). In 2005 and 2006 the MLUV stopped adopting new eco-farmers in the program due to lack of financial resources. It is not known what the current status is.

Another environmental protection measure is that farmers are obliged to keep at least 10% of their land fallow each year (LBV, 2014, pers. comm.). In addition, farmers that delay their seed application receive additional subsidies (LBV, 2014, pers. comm.).

5.2 Food processing and retailing subregimes

The distribution subregime is seen to consist of the food processing sector on the one hand, and the retailing sector on the other hand. Both will be discussed in this section.

5.2.1 Status quo

The food industry plays an important role in Berlin and Brandenburg, being the fourth largest employer in Berlin and the largest employer in Brandenburg in 2004 (Hammel, 2004, p. 19/20, cited in IÖW (2007)). The turnover of this sector in 2005 amounted to 2.5 billion euro in Brandenburg, and 11.4 billion euro in Berlin, making it the largest industrial sector in both regions in economic terms (IÖW, 2007).

In general, the farmers sell their agricultural produce to the German food market exchange where the prices are determined by the economic interplay of demand and supply. In doing so, the farmer makes a contract for several months which provides him/her a fixed price for the produce, although this price is often rather low (LBV, 2014, pers. comm.). As such, via this mechanism the agricultural produce travels to the purchaser (i.e. the food industry), and after that to retail.

The main foods being processed in Berlin are coffee and tea (34%), sweet foods (19%), and backery goods (9%) (Hammel, 2004, p. 23, cited in IÖW (2007)). In Brandenburg the livestock slaughter and meat processing (37%) holds the largest share, followed by milk and milk processing (19%), backery goods (12%) and fruit and vegetable processing (10%) (MLUV 2006).

Only a small share of all milk produced in Brandenburg is being processed in Brandenburg itself. According to (LBV, 2014, pers. comm.) most milk leaves the provinces for processing, after which it is transported back to retail. The competition from industrial actors in neighbouring provinces, such as Campina, was too strong for the smaller local dairies in Brandenburg (LBV, 2014, pers. comm.). However, in the biofood processing sector particularly the dairies seem to be gaining ground in recent years with the additions of the Gläsernen Molkerei Münchehofe (2010), Bio-Molkerei Lobetal (2010), and the Hofmolkerei des Ökodorfs Brodowin (2011) (FÖL, 2014a).

In recent years the dominance of the full-range supermarkets in bio-food has decreased in the favour of discounters and drugstores. Also the openings of new bio-supermarkets contributes to this development. The bio-supermarkets sell on average twice as many regional bio-products as the conventional supermarkets; 14% versus 7% (FÖL, 2010).

5.2.2 Actors: mainstream

Structurally the sector consists of several large companies and many middle and small companies; 80% of the people in the sector worked for a company having less than 500 employees, while companies with fewer than 200 employees employed 50% of the people (Hammel, 2004, p. 21, cited in IÖW (2007)).

In Brandenburg only one large slaughterhouse is present, called the NFZ Norddeutsche Fleischzentrale GmbH located in Perleberg. In addition several small local slaughterhouses are active, whose combined share compared to the former is rather insiginificant. The slaughter waste from the NFZ slaughterhouse is transported by SecAnim GmbH, which is a subsidiary of the stock-listed company SARIA Biotechnology.

Companies in the food industry are often member of professional associations, according to the type of food the company processes. In turn, these associations are member of the umbrella organization of the German food industry called the Bundesvereinigung der deutschen Ernährungsindustrie (BVE), representing about 90% of the German food industry. The main task of the BVE is to improve the competitiveness of German food industry through lobbying at the German government as well as the EU for less regulations, bureaucracy, and more freedom in performing business activities (BVE, 2014).

The German retail sector is dominated by five large supermarket chains. In 2010 their market shares nationwide were as follows; Edeka (19.5%), Rewe (16.3%), METRO Group (13.5%), Schwarz-Gruppe (Lidl and Kaufland) (12.5%), Aldi (11.4%) (Warch, 2011). Although such data could not be found for Berlin-Brandenburg, it can be assumed that the shares are more or less similar. In 2005, Berlin-Brandenburg counted over 2,600 supermarkets of which most are discounters based on sheer numbers as well as total surface area (IÖW, 2007). Looking at the two largest retailers, Edeka and Rewe, an important difference in the style of management becomes apparent; while a part of the supermarkets are centrally directed, others are more independent in decision-making. In the latter case, the local manager is in charge of product purchasing, personel management and product positioning. As a result, the product assortment in such stores can differ from 5 to 20% from other supermarkets in the holding (Correll, 2006, p. 27, cited in IÖW (2007)). In the case of Edeka, about 80% of the supermarkets were of the independent-type in 2005, while Rewe operated its the supermarkets mainly centrally (IÖW, 2007).

5.2.3 Actors: niche

In addition to the circa 650 ecological farms in Brandenburg in 2012 (MIL and LELF, 2012), there were 199 bio-companies active in the province at the end of 2009 (FÖL, 2010). The amount of the bio-processing companies in Brandenburg rose strong with 22% in 2009 compared to the bio-farm growth which amounted to 7% in 2009 (FÖL, 2010). In addition, there are also many bio-supermarkets and health stores which are not counted as eco-companies in statistics; a total of 59 in Brandenburg and 197 in Berlin in 2004 (FÖL, 2004, cited in Nölting and Boeckmann (2005)).

There are several dairies in Brandenburg, of which the four new ones mentioned in section 5.2.1 are the latest additions. No bio-certified slaughterhouses are present in Brandenburg.

Fresh bio-products in Berlin is essentially delivered to bio-supermarkets via four main traders of which three are from the region; Terra Naturkost, Midgard Naturkost, and Kormoran Naturwaren. Additionally, Frucht-Express Import Export GmbH is also a main distributor of fresh bio-food, but contrary to the others it also trades in conventional food (IÖW, 2007).

In 2005 about 14% of nationwide bio-foods were sold direclty to the consumer (IÖW, 2007). This share is estimated to be higher for Brandenburg, and lower for Berlin. Whereas in Brandenburg consumers may directly visit the farm, in Berlin the direct-selling takes place via weekly markets with bio-products, as well as so-called Abo-Kisten which entail a weekly delivery of bio-foods to the consumer's home (FÖL, 2006). In Berlin in 2006 there were 14 of these weekly markets and 22 providers of Abo-Kisten (FÖL, 2006).

In 2007 the following bio-supermarket chains were active in Berlin, with the amount of stores indicated; Bio Company (10), eo Komma AG (6), LPG-Bio Markt (6), and Viv BioFrische Markt (7) (IÖW, 2007). These supermarkets have a relatively large product assortment, ranging from 3,000 to 5,000 products, have a modern appearance, and floor surfaces over 200 sqm (IÖW, 2007). In Brandenburg the bio-supermarkets are less available to the consumer; whereas in Berlin there is one bio-supermarket for every 26,000 people, in Brandenburg this number is almost threefold with 71,000 people per bio-supermarket (IÖW, 2007). Still, also in Berlin the bio-supermarket chains only has a very small share of the total retail market as there were over 2,600 retailers active in Berlin-Brandenburg in 2005 (IÖW, 2007).

Apart from branche organizations uniting eco-farmers, there is also the Märkischen Wirtschaftsverbund which stimulates the cooperation and information exchange between bio-food companies across the regional supply chain (Nölting and Boeckmann, 2005).

5.2.4 Rules

Similarly to any economic sector, also the in the food processing and retail sector maximizing profits against minimized expenditures will be the guiding principle. Particularly for the large companies in the conventional retail sector attaining a higher market share will be the primary goal. This they seek to do by offering a large variety of products at a competitive price, and positioning these optimally.

Bio-processing and bio-retailing companies may have additional normative rules related to the various perceived benefits of ecological farming over conventional farming, as well as preferred regionality of the economic activities. However, this may not hold for all companies. Similarly to the eco-farms, also in this area the perceived economic potential may be the most important driver.

It has been observed that whereas the eco-agricultural sector in Brandenburg is relatively strong, the regional bio-food processing sector is still relatively underdeveloped and the demand for bio-products comparatively weak (Nölting and Boeckmann, 2005). Also regional cooperation across the bio-product supply chain can be improved (Nölting and Boeckmann, 2005). These issues are likely part of the problem agenda of these companies.

For both the conventional and bio-retail sector a reliable and sufficient supply of products is important (LBV, 2014, pers. comm.). This poses a problem especially for smaller eco-farmers which are not able to produce in large volumes.

Although many regulative rules will be applicable to the food processing and retail sectors, these are considered of only minor importance for this thesis and are therefore not treated further.

5.3 Consumption subregime

5.3.1 Actor and rules: the consumer

The main actor in the consumption subregime is of course the consumer, which category can be subdivided in households and large users such as schools, hospitals, and offices. Concerning the heterogeneity of the citizens, a good characterization of consumers is difficult. Moreover, within this thesis the consumer is not only a buyer of food, he/she also disposes of food waste and excretes. In this sense, the behaviour of the consumer relevant for this thesis is multi-dimensional and his/her food purchasing behavior does not necessarily imply a certain waste disposal routine.

Concerning consumer nutrition, the Institute für sozial ökologische Forschung (ISOE) researched strategies for socio-ecological transitions in the field of environment-food-health (Nölting, 2008). Following the projects' results, consumers do not form their nutritional routines towards economic cost-benefit maximization or comprehensive information (Nölting, 2008). Rather, consumers manage their nutrition within the constraints of a complex everday life (Hayn 2007, Nolting 2008), as well as according to a deeply rooted nutritional culture (Raabe 2007, Nolting 2008). Within the project a characterization of different nutrition styles was made (ISOE, 2006), distinguishing the following groups and the respective population share in Germany;

- *Uninterested fast-fooder (12%).* Mostly younger singles and couples indifferent to nutrition-and health-related issues who like to eat out.
- *Cheap- and meat-eaters (13%).* Primarily young and middle aged singles, couples and families, whom prefer inexpensive and relatively easy-to-cook food. These people break with traditional nutrition routines and shared meals lost their importance.
- *Joyless habitual cooks (17%).* Mainly retired singles and couples whom barely associate food with enjoyment and pleasure. They also have little awareness of nutrition issues.
- *Ambitious fitness-oriented (9%).* Can be found amongst working couples and families with young children whom prefer high-quality food and follow a disciplined diet.

- *Stressed-out daily life-managers (16%).* Mainly young women having a strong interest in nutrition issues, paying attention to quality, freshness, and origin.
- *Conventional health-oriented (20%).* Middle-aged people connecting food to enjoyment whom prefer good food and have a strong interest in nutrition.

Given the ambivalent role of the consumer in this thesis, a more overarching characterization of the consumer is also nessecary to encompass the 'supply-side' of the Consumption process e.g. biowaste, excrements, private compost. For this purpose a total of four 'target groups' (Scholl and Hage, 2004, p. 25), based on ten consumer typologies from a Consumption style study by the ISOE can be of use. The following groups are distinguished;

- *Environmentally receipient.* People having a strong environmental orientation, including 'eco-families' and the 'creatives'.
- *Priveleged.* Status-oriented, successful people and young profession-oriented people which demand high quality products. They often act as an example for the other groups.
- *Hardly reachable.* Over-loaded, consumption-annoyed people having little interest in environmental issues.
- *Ambivalent traditionals.* Rural, traditional, inconspicious people mistrusting eco-products in general.

5.3.2 Other actors and rules

Apart from the consumers' relationship with policy and retail actors, housing-owners can be seen as an important additional actor. For households owning the house the previous description of 'The consumer' will suffice. However, particularly in Berlin many people rent their appartment from land lords owning multiple appartments and/or appartment blocks. The latter can thus be regarded as a distinct actor acting between the renter and waste-treatment companies and the state authorities. Similarly to the other economic actors, also land lords will have maximize their income while minimizing costs, and acting within the regulatory framework as main guiding principle.

Other noteworthy actors are consumer-protection organizations, including the Verbraucherschutzzentrale Berlin and Brandenburg for general matters including nutrition and housing, and the various renter associations for rental matters. A relevant consumer organization in the bio-food niche is the Fördergemeinschaft Ökologischer Landbau in Berlin-Brandenburg e.V. (FÖL). This is an umbrella organization for the bio-food supply chain in Berlin-Brandenburg (FÖL, 2014b). Other than the Märkische Wirtschaftsverbund, the FÖL acts as intermediate between the consumer on the one hand, and the regional bio-food supply chain on the other hand. The goal is to enhance the regional bio-food supply chain by focussing on the demand-side, for example by providing information about regional supply chain and its bio-products as well as by lobbying.

5.3.3 Niche: Vegetarism and veganism

In Germany there are an estimated 7 million vegetarians (Stragies, 2014) which is about 8-9% of the population. The number of vegan people grew from 600,000 people in the begin of 2013 towards 800,000 at the end of that year, comprising the fastest growing subgroup (Stragies, 2014). In addition, the VEBU (2011) found through a survey that in Germany about 42 million people live partly vegetarian, entailing people that refrain from eating meat at least three days per week.

In Berlin the share of vegetarians is slightly higher with 10% of the population (Stragies, 2014). Also here vegans have a share of 10% (Stragies, 2014).

According to Sebastian Zösch, director of the Vegetarierbund Deutschland (VEBU) the number of vegetarians and particularly vegans will continue to rise (Stragies, 2014). As an example he states that at the end of 2013 there were 23 vegan restaurants in Berlin, while in March 2013 there were still only 13. Also the number of annually published vegan cookbooks rises, from 12 in 2011, to 23 in 2012 and over 50 in the year 2013.

5.3.4 People's diets

Using the data gathered during the creation of the MFA as performed in Chapter 4 and data presented in section 5.3.3, the phosphorus contents of different diets could be determined. The results are shown in Table 15. The 'Regular', 'Vegetarian', and 'Vegan' diets were derived from the 'Average' diets, assuming that consumed amounts of phosphorus are equal in all diets. The difference between an average and regular diet is the absence of vegetarism and veganism in the latter.

Table 15: Calculated compositions of different diets regarding phosphorus consumption.

	Average diet [kg P/cap]	**Regular diet [kg P/cap]**	**Vegetarian diet [kg P/cap]**	**Vegan diet [kg P/cap]**
Consumed meat	0.1463	0.1599	0	0
Consumed milk/egg	0.2163	0.2134	0.2752	0
Consumed plant	0.3213	0.3106	0.4088	0.6841
Total	0.6841	0.6841	0.6841	0.6841

The results show that meat and milk consumption as part of the 'Average' diet cover over 53% of the total phosphorus consumption. In that diet meat and dairy products have a share of 21.4% and 31.6%, respectively. In 'Regular' diets the share of meat is slightly higher (23.4%) and that of diary products slightly lower (31.2%). For the 'Vegetarian' diet the meat component was removed which results in a higher dairy consumption (40.2%) than both the 'Average' and 'Regular' diets. This implies that when more people become vegetarian milk consumption would increase. Whether vegetarians in reality consume more milk than people following a 'Regular' diet remains unclear. One could argue that meat is often refrained from due to its perceived relation to animal suffering and hormones in animal products, and the same argument could be a motivation for vegetarians to also reduce milk and egg consumption. Finally, vegans only consume plant-based food.

5.3.5 Niche: Urban agriculture

Figure 7: The Himmelbeet, a community garden in the Schulstraße, Berlin (own photo).

Urban agriculture can be seen as part of both the agriculture and consumption subregime given that is entails food production by consumers. Although food produciton is a inherent characteristic of urban agriculture, it social element seems to be far more important than its productive element. Here it is important to distinguish different types of urban agriculture; allotment gardens and community gardens. Whereas the former seems to act more as a private place to spend leisure time, the community garden defines itself by its open character. Another difference is that allotment gardens were created out of necessity decades ago for the production of food. Community gardens, on the other hand, are relatively recent phenomena. For example the Himmelbeet, a community garden shown in Figure 7, witnessed its first growing season in the year 2013.

Due to the relatively short existence of the community garden, much remains to be learned about this topic. Yet food production in community gardens seems to follow the principles of organic farming. For example, most often use is made of compost rather than mineral fertilizer as a nutrient supply, crop production is mixed, and no pesticides are applied. Urban agriculture, like organic agriculture, thereby seems to be a reaction to the flaws of the global food regime. In relation to the public character of community gardens it is therefore believed that these could serve as a medium of social change. In the absence of a study actually researching this claim, its validity will be proven as the future unfolds.

5.4 Waste subregime

Within the waste management subregime the sewage treatment and (bio-)waste treatment sectors can be identified. Given their public tasks these are strongly related to the policy subregime, which will be discussed in section 5.5.

5.4.1 Actors

Concerning the sewage treatment sector, the Berliner Wasser Betriebe (BWB) is the only actor treating wastewater in Berlin. This they do with a total of 6 sewage treatment plants; Ruhleben, Wassmannsdorf, Schönerlinde, Stahnsdorf, Münchehofe, and Wansdorf (Kabbe et al., 2014). These also treated a significant amount of sludge from Brandenburg; 14% of the total (Kabbe et al., 2014). Due to Brandenburg's dispersed inhabitation, its wastewater treatment plants (WWTPs) are smaller and more plentiful than in Berlin. This also holds for the organizations operating these plants. In this light the BWB is the strongest sewage treatment actor, having more financial resources as well as a higher technological level (Nölting and Daedlow, 2012). Unlike the smaller WWTPs, the BWB has introduced a additional (fourth) cleaning step in its facilities due to the concentration of hospitals and other contaminating sources in Berlin (Nölting and Daedlow, 2012).

An important difference between the BWB and the smaller WWTPs is that the former incinerates all of the produced sludge, of which circa 59% is incinerated at the MHKW Rubleben and the remaining 41% is co-incinerated in coal-power plants and used for cement production. Many of the smaller WWTPs have financial difficulties and cannot afford the incineration path, rather they bring the sludge on non-agricultural land as a last cleaning step. For this they pay farmers owning these lands whom gain extra income and fertilizer but cannot use the land for food or fodder production anymore (Nölting and Daedlow, 2012).

Interestingly, the BWB has started to produce MAP from its treatment plant in Wassmannsdorf, which is currently being piloted as replacement of mineral fertilizer (Kabbe, 2014b, pers. comm.). Also here, although minor, a link to the regional farmer can be observed.

For the treatment of waste the Berliner Stadtreinigung (BSR) is mainly responsible in Berlin. The seperated biowaste is digested and sold as a garden fertilizer to retail. The other (bio-)waste is treated at the MPS Pankow, MPS Reinickendorf, MA Grünau, Umladestation Süd, and incinerated at the MHKW Ruhleben after which it is landfilled. The latter is owned by the BSR.

Similarly to the sewage treatment sector, also the waste treatment sector in Brandenburg is characterized by more and smaller treatment plants, and many local associations operating these. A notable exemption here is the ALBA-Gruppe, an internationally operating company having several subsidiaries in Berlin and Brandenburg. It is, however, unclear which share of the regional waste treatment sector the ALBA-Gruppe has.

As mentioned earlier, SecAnim GmbH, subsidiary of SARIA Biotechnology, is handling the vast majority of slaughter waste in Brandenburg. In the absence of more information, it is assumed that this waste is transported and treated outside Brandenburg.

In the sewage treatment sector the Deutsche Vereinigung für Wasserwirtschaft, Abwasser und Abfall e.V. (DWA) is probably the most important branche association for public WWTP organizations. Its department 'Nord-Ost', having 1,160 members, is responsible for the provinces Mecklenburg-Vorpommern, Brandenburg, Berlin, and Sachsen-Anhalt (DWA, 2014). Dealing with overarching water-related issues, the DWA's main goal is to stimulate a sustainable national water treatment sector by means of education, knowledge exchange and research.

In addition to the DWA, the Bundesverband der Deutschen Entsorgungs- Wasser- und Rohstoffwirtschaft e.V. (BDE) is the strongest European branche organization for the private wastewater and waste treatment organizations (Ochs, 2014, pers. comm.).

5.4.2 Rules: normative and cognitive

The information presented in this section is based on an interview with Dr. C. Kabbe (Kabbe, 2014b) of the Kompetenzzentrum Wasser Berlin, unless stated otherwise.

For the wastewater as well as solid waste treatment organizations the compliance with the existing legal framework will be the primary duty. Moreover, apart from being obligatory, it is conceived that the minimization of the contamination (e.g. heavy metals, hormones) from sewage sludge and waste treatment is also an important cognitive (i.e. intrinsic motivation) rule within the subregime (Kabbe, 2014b, pers. comm.). This also applies to minimizing eutrophication i.e. minimizing phosphorus and nitrogen present in effluent. In addition, Kabbe (2014b, pers. comm.) states that current methods for detecting heavy metals and hormones are not sufficient due to cocktail effects; he argues that the tests should be complemented with a bio-test.

Next to acting within the legal framework, the financial costs associated with the treatment are sought to be minimized. This can be seen as the primary reason for the BWB to retrieve MAP from the wastewater (Kabbe, 2014b, pers. comm.), and for the smaller WWTPs to use sewage sludge for landscaping (Nölting and Daedlow, 2012). Here it should be noted that the BWB also brings some sludge back to the land for the same reasons, albeit in relatively small quantities (Nölting and Daedlow, 2012).

Concerning normative rules, the concept of the waste-hierarchy (i.e. recycling over incineration over landfill) is well-established within the waste subregime. In the case of phosphorus, particularly the wastewater treatment actors, at least those operating in Berlin (Kabbe, 2014b, pers. comm.), feel a responsibility to recycle the element. They believe that phosphorus will become increasingly scarce, inducing higher costs in the mid-term future. These actors also estimate that sewage sludge offers by far the largest potential for phosphorus recycling in the region (Kabbe, 2014b, pers. comm.). Phosphorus containing in biowaste is seen as of minor importance. According to Ochs (2014, pers. comm.) of the BDE biowaste should be primarily recycled for its soil quality enhancing potential (e.g. humus), rather than closing the phosphorus cycle.

The recycling of phosphorus seems to have a lower priority for the WWTPs operating in Brandenburg. These actors are heavily debted, and the current method of sewage sludge deposition on the land entails significant costs already due to the high transportation costs. Not only is there hardly room for investment, also their customers, the households, are obliged to pay premium prices for wastewater discharge (Nölting and Daedlow, 2012). These financial issues will likely be more prominent on the problem agenda of these actors than phosphorus recycling, although the two do not necessary contrast each other.

Additionally, stricter regulations will impact both the wastewater and waste treatment sectors in the near future, which requires them to change their current activities, as will be discussed in section 5.4.3. These issues will also be most likely on the problem agenda of these actors, too.

5.4.3 Regulative rules

The relevant regulations concerning wastewater treatment and waste treatment are captured in the Klärschlammverordnung (BJV, 2012) and Bioabfallverordnung (BioAbfV) (Bund-Länder-Arbeitsgruppe, 2014), respectively. For using sewage sludge and biowaste as fertilizer the same regulations as the DüV are applicable. It follows that raw sewage sludge application on crop land and pastures is forbidden (BJV, 2012). In addition, before first agricultural application, sewage sludge (products) need to be tested which needs to be repeated every 10 years (BJV, 2012). This has to be paid by the operator of treatment plant (BJV, 2012).

At the moment the application of sewage sludge to (uncultivated) land for cleaning purposes is still allowed. However, a new Klärschlammverordnung coming into effect in 2016 will feature a lower pollution allowance or even a complete disallowance for applying sewage sludge on land Nölting and Daedlow (2012). This may force the mainly smaller WWTPs to find other uses for their sludge, inducing more costs.

Waste treatment organizations in Berlin-Brandenburg face another upcoming problem. From the year 2015 onwards organic waste in consumer waste has to be completely separated (Ochs, 2014, pers. comm.). Ochs (2014, pers. comm.) states that particularly for Berlin this will be very hard realize in time. Furthermore, it is estimated that phosphorus in cleaning products (e.g. dishwasher tablets) is no longer allowed by 2018 (Kabbe, 2014b, pers. comm.).

Finally, MAP is since April 2008 approved as a fertilizer for wholesale according to the EU regulation Nölting and Daedlow (2012). However, to meet the requirements of the German Fertilizer Ordinance justice to the BWB currently working on the reduction of the average grain size of the MAP (Nölting and Daedlow, 2012).

5.5 Policy subregime

5.5.1 Status quo

In general it can be stated that the state authorities have moved from a managing role to a more regulating and monitoring role (LBV, 2014, pers. comm.). Furthermore, there appear to be more referenda (Volksentscheid) enforced by citizen groups in recent years (Hoffmann, 2014, pers. comm.). Such a referenda can be enforced through the collection of 20,000 or more signatures. Two recent examples in Berlin include the reclamation of the regional energy infrastructure to the public authority in November 2013, and the future of the Tempelhofer Freiheitspark in May 2014. The proposal to reclaim the energy infrastructure did not receive sufficient votes, and construction plans for the Tempelhofer Freiheitspark were successfully rejected.

5.5.2 Actors

In Brandenburg the Ministerium für Umwelt, Gesundheit und Verbraucherschutz (MUGV) is the supreme authority in Brandenburg concerning the matters water, environmental protection, soils and waste, amongst others. Related to water matters, this actor supervises the Upper Water Authority, which is the Landesambt für Umwelt, Gesundheit und Verbraucherschutz (LUGV) in Brandenburg (Nölting and Daedlow, 2012). The LUGV, in turn, supervises the lower water and soil authorities (WBV) which are located in the counties and cities of Brandenburg. In Berlin the Senatsverwaltung für Stadtentwicklung und Umwelt (SenStadt) is the Upper Water Authority, and the various district offices fulfill the role of lower water authority (Nölting and Daedlow, 2012). Whereas the upper water authorities act as decision-supporters in complicated cases, the lower water authorities are directly responsible for the water and soil quality of their respective area. Due to their legal position, the water authorities have significant impact on water use and wastewater treatment companies (Nölting and Daedlow, 2012).

The Ministerium für Infrastruktur und Landwirtschaft (MIL) is the supreme authority concerning agriculture in Brandenburg. Subordinate to the MIL are the Landesambt für Ländliche Entwicklung, Landwirtschaft und Flurneuordnung (LELF), amongst others, which is responsible for rural economical and social development, agricultural subsidies, crop protection, and regulative councelling concerning agriculture. The LUGV, part of the MUGV, is responsible for permits regarding new fertilizer use.

The GVVB is a governmental organization that was raised after the end of the Cold War in 1990. With the Soviet Union previously controlling a total of five German provinces, including Brandenburg, the land had to be redistributed. To this end the GVVB was raised. The revenue generated flows back into the German treasury which is sought to be as high as possible; the land is sold or rented to the highest bidder being able to fulfill the administrative requirements (LBV, 2014, pers. comm.). It is estimated that within maximum five years all the land is sold, after which the GVVB will no longer have a role in Brandenburg.

Overall it can be stated that the Berlin and Brandenburg states work together in formulating policies for the benefit of the Berlin-Brandenburg area. For example, the Brandenburg state not only makes policy for Brandenburg agriculture, but also for that of Berlin. Yet, the relationships between the different policy actors also depends on the issues they face. The different departments partly cooperate, but sometimes compete with one another in the case of diverging interests (Nölting and Daedlow, 2012).

5.5.3 Rules: normative and cognitive

Overall, the public administrations have to carry out the statutory requirements (e.g. laws, regulations) and make approvals, notifications, authorizations and permits according to the regulatory framework.

It can be assumed that problems related to the developments described in chapter 6 are on the problem agenda of the respective ministries. Particularly the migration of young people from Brandenburg in combination with an ageing population must be seen as critical for the future of the province. In addition, many of Brandenburgs municipalities (Nölting and Daedlow, 2012) as well as the Berlin state are in debt.

Concerning water, the water authorities of the two provinces have different problem agendas (Nölting and Daedlow, 2012). In Brandenburg the authorities see a main task in restoring the ground water balance after decades of decline. Some grassland soils show great degradation in soil structure which makes the outflow of water on the surfaces difficult. Although the situation is not urgent at the moment, it is clear that only the effluent from sewage treatment is not enough to stabilize the water table. Additonally, the existing practise of sludge application is seen as a threat to the groundwater quality. In Berlin the quality of the surface waters is seen as problematic by the water authorities. The river Spree and surrounding rivers run relatively slow such that effluent discharge has a relatively large impact on the surface water quality. This water is being filtrated for the production of drinking water by the BWB. In addition, in summer the supply to the Berlin surface waters is insufficient leading the water authorities to hold back the water, which excerbates the water quality problems.

It can be stated that at the provincial level there is little interest for water matters, where the politicians view these a 'niche issue' (Nölting and Daedlow, 2012). Nevertheless, SenStadt in Berlin is working together with the Kompetenzzentrum Wasser Berlin and the BWB towards phosphorus recycling from sewage sludge. For the time being, the SenStadt only focusses on phosphorus potential in sewage sludge, disregarding other possibilities. Certainly with regards to consumer (purchasing) behaviour and public opinion, the authorities seem reluctant to engage. Interferance with matters concerning people's freedom may be received very negatively, as a recent public debate sparked by the political party Die Günen has shown (Hoffmann, 2014, pers. comm.).

5.5.4 Regulative rules

Currently, the quality of the surface waters is insufficient to meet the requirements of the EU Water Framework Directive in 2015 (Nölting and Daedlow, 2012). To counter the issues related to surface water quality, the minimum requirements for effluent released will be tightened in an update of the Oberflchengewsserverordnung (Nölting and Daedlow, 2012), also in 2015. This will require all sewage treatment companies in Berlin-Brandenburg to induce a costly 4th purification step in their facilities.

Smaller WWTPs mainly change technologies because of legal requirements. (regulative) New Klarschlammverordnung in 2016 will feature a lower pollution allowance, or even complete disallowance of sludge on agricultural land. In this case the smaller WWTPs have to find other uses e.g. incineration and landfill, for their sludge, due to the possible risk of exceeding the values. Similarly, the land owners, food industry, and consumers increasingly fear pollution from sludge. The BWB already incinerates and landfills its sludges.

5.6 Research subregime

Although regional research activities are being performed, most research seems to focus on a (inter)national audience. In this section only the research actors that are present in Berlin-Brandenburg and have a relation to this thesis will be discussed.

5.6.1 Status quo

A main development taking place within the research subregime is the shift in the way the research actors are funded. Often the research actors receive a steady flow of funding directly or indirectly from the central government, while gaining extra income for specific projects carried out for the German state, the EU, or the UN. In recent years the income share of funding recieved through the participation of (supra)national initiated research to becoming larger and more important (Hoffmann, 2014, pers. comm.).

5.6.2 Actors

Research actors present in Berlin-Brandenburg having a main focus on agricultural techniques are the following;

- Fachhochschule Eberswalde, department Landschaftsnutzung und Naturschutz
- Hochschule Neubrandenburg, department Agrarwirtschaft und Lebensmittelwissenschaft
- Humdoldt Universität, department Landwirtschaftlich-Gärtnerische Fakultät
- Humdoldt Universität, Institut für Wirtschafts- und Sozialwissenschaften des Landbaus (WiSoLa)
- Leibniz-Zentrum für Agrarlandschaftsforschung e.V. Müncheberg (ZALF)
- Leibniz-Institut für Agrartechnik Potsdam-Bornim e.V. (ATB)

Whereas both colleges (i.e. Hochschule) and the Humboldt Universität conduct some research related to Brandenburg itself, it seems that at present only relatively few agricultural research activities have a regional focus (LBV, 2014, pers. comm.). A notable exception here is the ELaN project, described in section 5.6.4.

Concerning local research actors related to conventional food processing and retailing research, only the Innovationszentrum Gesundheit und Ernährung (IGE) of the TU Berlin was found. However, it is lkely that also the collages have departments in this research area.

Furthermore, there are a number of research actors with a (partial) focus on the supply chain for ecological produce, including the consumer. Already mentioned is the FÖL, whom gather data from their regional network upon which other researchers can draw. Two other institutes in publishing in the field of ecological supply chains are the Zentrum für Technik und Gesellschaft (ZTG) of the TU Berlin and the Institut für ökologische Wirtschaftsforschung GmbH (IÖW).

In the area of water management the Kompetenzzentrum Wasser Berlin can be seen as the main research actor. No regional research actors related to waste management were found.

Additionally, several research actors were found related to sustainability and/or future research. Amongst these is the already mentioned IÖW, the Institut für Zukunftsfähiges Wirtschaften Berlin (SUSTAINUM), and the Institut für Zukunftsstudien und Technologiebewertung (IZT).

Finally, organizations collecting statistical data can also be seen as important research actors. The Amt für Statistik Berlin-Brandenburg (AfS) is a statistical office brought into life in 2007 after the merger of Berlins and Brandenburgs separate statistics offices. On the national level the Statistisches Bundesambt (Destatis) is the main actor for statistics.

The research actors discussed vary in organizational structure. Some institutes are part of one of the three universities in Berlin (e.g. IGE, WiSoLa, ZTG), others are independent (e.g. IÖW, SUSTAINUM, IZT), and yet others are part of a research umbrella organization. The ZALF and ATB are both part of the Leipniz Gemeinschaft which organization is a network of multiple dozens of German research institutes having divergent research domains. Another such umbrella research organization is the Fraunhofer-Gesellschaft. Although it bears little relation to the actors discussed here, it does coordinate the Deutschen Phosphorplatform (DPP) which will be discussed in section 5.7.

5.6.3 Rules

Any research actor requires funding to carry out its activities. Apart from matters such as objectivity and scientific relevance, the continuity of funding will therefore be a main objective for the research actors. It is therefore important for research actors to show their (annual) accomplishments to the funding actor. Especially in the light of shifting sources of funding discussed in section 5.6.1, it is plausible that the research actors are increasingly stimulated to 'market' their capabilities and work to the (policy) actor that offers the research project.

Furthermore, Nölting (2008) has reviewed a total of six German nationally-initiated research projects related to the German (ecological) food supply chain. He notes that all projects shared;

- An explicit reference to the normative concept of sustainable development;
- An integrative perspective in dealing with sustainability problems;
- An participatory approach that addresses practical problems.

Nölting (2008) further notes that this degree of thematic overlap is unprecedented in the Social-ecological research programma of the Bundesministerium für Bildung und Forschung (BMBF), indicating that research actors in Germany find these elements increasingly important in sustainability-related research.

5.6.4 Research projects

A large research project having a regional focus is the ELaN project, initiated and funded by the German Ministry of Education and Research (BMBF). Within this project, researchers from Berlins three universities (Freie Universität, TU Berlin, Humboldt Universität) as well as a myriad of research institutes (ZALF, ATB, etc) and the Berliner Wasserbetriebe (BWB) combine their efforts in order to develop an integrated solution for future land- and watermanagement in North-East Germany, and Brandenburg in particular. The emphasis lies on the integration of knowledge from various disciplines. Focal points are wastewater management and its relation to water quality and reuse to agriculture, land use, and the organizational challenges related to both wastewater mangement and land use.

Another research project in the sewage treatment domain is the P-Rex project (Kabbe, 2013a). Within the P-Rex project, funded by the EU and coordinated by Dr. C. Kabbe, a total of fifteen partners from seven countries participate, including Germany. Essentially, the partners pilot different sewage treatment technologies aiming to recycle phosphorus from sewage sludge. Goals of the project include the demonstration of technologies at full-scale use, quality assessment of the recycling products, analysis of market barriers and potential of these products, and the development of strategies and recommendations for wide-spread phosphorus recycling in sewage treatment.

5.7 Actor-network: Connecting the dots

A visual representation of the actor-network related to the Berlin-Brandenburg phosphorus cycle can be viewed in Figure 8. As indicated in the figure, the top layer represents the policy subregime, the middle layer the cycle chain subregimes, and the bottem layer the research subregime. Also attention was paid to the horizontal orientation within the figure. Moving from left to right, the agriculture subregime is depicted first, followed by the food processing, retailing, consumption, and the waste treatment subregimes. Actors present in the policy and research subregimes were also positioned to follow this sequence.

The representation is by no means exhaustive. Whereas the most important actors are deemed to be included, their interrelationships will most likely be far more complex than depicted. Through information acquired through interviews and through assessing the purposes and goals of the actors, a superficial assessment of these relationships could nevertheless be made.

One main observation is that the supply chains for conventional food and organic food are fairly segregated. Organic farmers mainly deliver food to bio-food processors and bio-food wholesalers, which in turn deliver the food to bio-supermarkets. However, both organic farmers and conventional farmers are represented by the LBV, and in addition also the conventional supermarkets sell large volumes of organic food. Also one regional wholesaler was found to supply both types of food. The segregation seems to originate from the organic movement itself. Here the eco-certification authorities will play a dominant role in preserving the identity of organic food, seeking to maintain the difference between conventionally grown food and organic food.

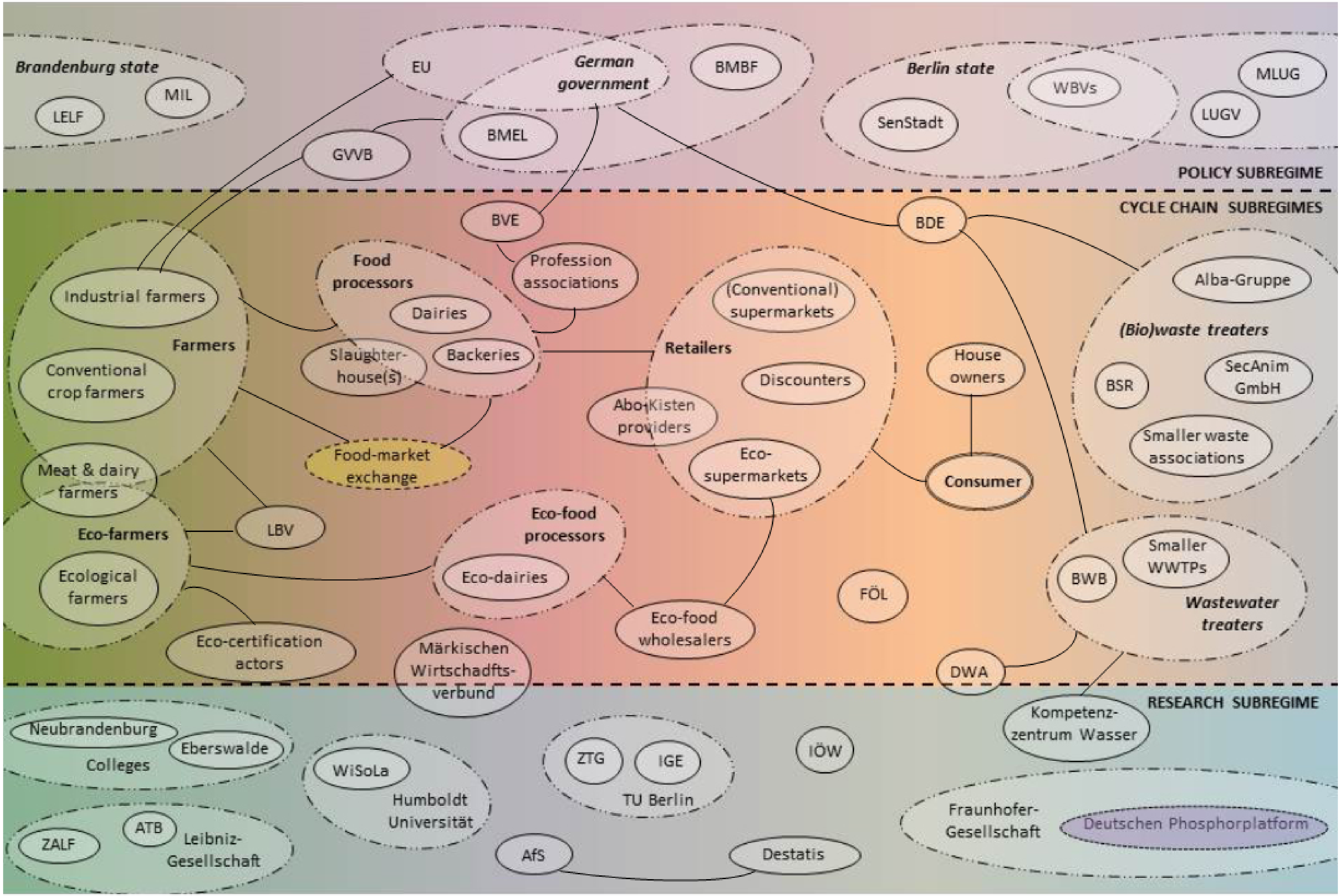
It was also observed that the food processors and actors present in the waste treatment subregimes are well-represented by profession associations. These are seen as strong organizations having access to politicians at the European level. No such representing organization was found for farmers and retailers. Given that a total of only five large retail holdings control over 70% of the national market, such a representing organization may not be necessary. The same applies to the industrial farmers, which are stock-noted companies where most turnover is derived from other economic activities. Mainly the conventional farmers and the actors present in the organic food supply chain are seen as under-represented. Although these actors are united through the LBV, FÖL, and Märkische Wirtschaftsverbund, these organizations can be expected to yield only limited political influence.

In addition to the interlinkages between actors previously discussed, the Deutschen Phosphorplatform (DPP) is the main network related to phosphorus recycling in Germany. The DPP was initiated after an annual meeting of (provincial) environmental ministers on June 7th, 2013. The DPP will be developed by the Fraunhofer Project Group Material Recycling and Resource Strategies IWKS, part of the aforementioned research umbrella organization Fraunhofer-Gesellschaft. The objectives of the DPP are the following (Fraunhofer-ISC, 2013);

- Networking of participants from the applied fields of agriculture, foodstuff, construction and detergent industries, and high-tech, recycling and waste disposal companies;
- Coordinating scientific and technical project to optimize phosphorus use and recycling methods;
- Developing and maintaining an interactive information and monitoring database;
- Establishing a cross-sector phosphorus forum to stimulate interaction between technology developers, entrepreneurs, and policy actors.

Based on information stated on the DPP website the platform seems to be still in the process of starting up. No activities other than the founding of the DPP are reported, and no list of its members was found. Given the DPP's support from powerful actors, and its ambitious goals, the platform is nevertheless seen as a promising means to strongly improve the efficiency of the phosphorus cycle.

Figure 8: Actor-network map related to phosphorus flows in Berlin-Brandenburg.



Chapter 6

Developments

6.1 Introduction

In this chapter both current developments, as well as the longer-term landscape developments will be analysed. The information presented on current developments will also contain summarized information retrieved from Chapter 5. Both types of developments will be will be structured using the PEST(EL) macro development analysis framework (Peng and Nunes, 2007). The abbreviation of the framework resembles the categorization used for the analysis; Political, Economical, Social, Technological, Environmental, and Legal. Legal developments will not be treated due to their perceived minor contribution to this thesis.

6.2 Technological developments

6.2.1 Current technological developments

Encountered current technological developments taking place in Berlin-Brandenburg, relevant for this thesis, were mainly found for the agricultural and sewage treatment subregimes.

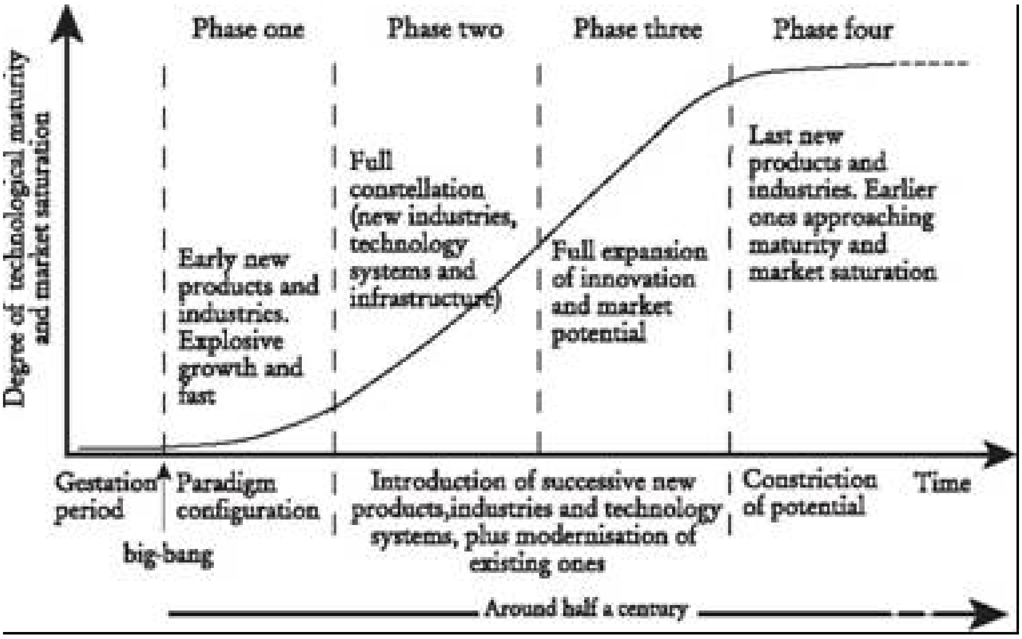
In Brandenburg, the farmers are currently experimenting with new farming techniques and crops in response to expected climate change excerbations (LBV, 2014, pers. comm.). The main aim of these experiments is to be able to withstand more extreme weather events such as droughts, heavy rainfall, and stronger winds. These may not only destroy the crops, but also cause damage to the soil i.e. cause erosion. Examples of experiments include drought-resistant crops, wind breaks, and perrennial elephant grass as an energy crop. In addition, several farmers are also testing struvite (i.e. MAP) fertilizers as replacement of mineral fertilizers. The struvite is produced in the Waßmansdorf sewage treatment plant, operated by the BWB nearby Berlin.

In the sewage treatment subregime the experiments carried out as part of the EU-funded P-Rex project will be the most important technological development (see also section 5.6.4). Within the P-Rex project a large variety of phosphorus recycling technologies are currently being tested, and the project results will likely determine which technologies will be finally implemented. However, Dr. C. Kabbe of the Kompetenzzentrum Wasser Berlin is a strong proponent of the installment of a mono-incineration plant for the recovery of phosphorus from sewage sludge. Additionally, in the recent past experiments have also carried been out with gravity- and vacuum separating toilets in households and an office as part of an EU demonstration project (Peter-Frohlich et al., 2007). The project also featured the production of fertilizers from diverted urine and faeces, and its effect on soils.

6.2.2 Kondratieff cycles as a framework

The technological facet of the landscape developments will be analysed using Kondratieff cycles. Kondratieff cycles, or 'Kondratieff long waves', describe long-term economic development as a cyclical phenomenon; "periods of sustained growth of output and trade of about 25 to 30 years are followed by periods of slow or stagnating growth of analogous duration" (Reati and Toporowski, 2009). It is important to note that the long wave theory is still subject of debate amongst scientists and that so

Figure 9: Phases part of a single Kondratieff cycle (Perez, 2002, p. 20, cited in Reati and Toporowski (2009)).



far no scientific proof has been presented to validate the theory. Yet, a growing number of economic historians agree that the observations indeed describe a real phenomenon (Reati and Toporowski, 2009).

Commonly, the Kondratieff waves have two main characteristics; technological (and scientific) revolutions are at the root of each wave, which in turn result in structural crises of adjustment of society itself (Reati and Toporowski, 2009). As such, the Kondratieff waves greatly influences society in all domains over a large timescale (i.e. 50-60 years).

Perez (2002, cited in Reati and Toporowski (2009)) has identified four phases as part of a single Kondratieff wave, see Figure 9. The first phase marks the early establishment of the new paradigm, which overlaps with the last phase, dominated by economic stagnation of the previous wave. During this phase plenty of capital, generated by firms of the old paradigm, is available and is being invested in new promising technologies. As a result of the investment, science and technology have developed far enough to yield applications during phase 2, in which the new paradigm has become fully apparant. The economy grows fast and the wealth generated becomes concentrated at relatively few actors. This wealth is greater than what can be absorbed by real investment, resulting in financial speculation causing financial 'bubbles' and economic recessions. Although chaotic, this process is also one of intense exploration for possibilities offered by the technological revolution, leading to new applications. The end of phase 2 takes place as institutional recomposition reregulates the market in response to the economic recessions. The system becomes rerouted and enters phase 3, where focus of capital is put on production, rather than novelty and speculation. This leads to (full) employment opportunities, and the technological revolution takes hold in every aspect of society. The driver of the fourth phase, the maturity phase, is the exhaustion of technological possibilities for the paradigm. The diffusion of the technological revolution is complete and productivity can not grow significantly anymore. As a result, the economy stagnates, people become unemployed, and social struggles take place. This redirects the focus of the system to new concepts and technologies, opening the doors for a new wave.

So far, a total of five Kondratieff waves have taken place (Wonglimpiyarat, 2005). The first one (1780s-1840s) marked the start of the Industrial Revolution, featuring water-powered mechanisation of the industry using iron, raw cotton, and coal as its key inputs. The second one (1840s-1890s) was driven by steam-powered mechanization of industry and transport, followed by a third wave (1890s-1940s) of electrification of industry, transport and the home. The fourth wave (1940s-1990s) featured the motorization of transport (e.g. cars, air planes), civil economy, and war. Finally, the age of computerization including the Internet entails the fifth wave (1990s onwards), which is still dominant today.

Where (Wonglimpiyarat, 2005) estimated the fifth wave to start in the 1990s, Devezas et al. (2005), on the other hand, state that this cycle started in the 1960s. Of course, the starting and ending dates of the cycles are arbitrary as the cycles overlap one another. It can also be stated that earlier periods of research and development preceded the actual start of the wave as described earlier. For example, research in computers started as early as the 1950s (Devezas et al., 2005). Using Kondratieff cycles as predictors of the future for the chosen timeframe (2014-2060) is therefore strongly subject to the researcher's own interpretation.

6.2.3 Nanotechnology

Nano-technology will probably be (one of) the driving force(s) of the next Kondratieff cycle. As Wonglimpiyarat (2005) summarizes, "Nano-technology is a cross-border technology transforming the worlds economy. The supramolecular architectures represent a new revolutionary approach in the research and production". Indeed, strong investment of research, governmental, as well as industry actors into nano-technology is currently taking place (Wonglimpiyarat, 2005; Miyazaki and Islam, 2007). Especially after the discovery of graphene in 2004 (APS, 2009), nano-technologies and notably graphene itself, seemed to have attracted huge investment ever since. According to a first creator of graphene, Andre Geim, graphene is probably the fastest developing material ever, reaching experimentation already 10 years after discovery (CNN, 2013).

An often mentioned characterization of nanotechnology is that it encompasses structures in the region between 1 and 100 nm. Although this is theoretically correct, it does not fully grasp the real intention, and potential, of nanotechnology. This is perhaps best explained by the following citation: "Nanoscience deals with functional systems either based on the use of subunits with specific size-dependent properties or of individual or combined functional subunits" (Gethmann and Grunwald, 1996, cited in Schmid (2011)). Thus, nanotechnologies seek to exploit the unique properties that arise at the nanoscale, such as extremely efficient electricity and heat conductivity, very high strengths in combination with very low weights, quantum properties (e.g. electron spin), et cetera.

With nanotechnology being a platform technology, it is impossible to describe all technological potential, much of which is still beyond the imagination itself. It is, however, possible to identify a few distinct fields in which nanotechnologies will likely have strong impact in the future. This includes energy production and storage, enhanced computation including quantum computation, and robotics.

6.2.4 Energy production and storage

Amongst the most widely anticipated applications of nanomaterials is the development of more efficient energy sources (Krug, 2008, p. 147). This includes 2D materials such as the recently discovered graphene, which exists purely out of carbon atoms. Experiments have shown that this material is capable of conducting electricity virtually without losses in the form of heat. Its application in solar cells, as well as batteries, is therefore foreseen.

At present, it is not possible to produce nanomaterials such as graphene on a large scale. However, Samsung, the leading patenting actor for graphene, recently announced it had a breakthrough in the production process of graphene. With graphene having a relatively simple and homogeneous stucture, it has the potential to become mass-produced at relatively low cost in the future. This is in line with the characteristics of the Kondrieff waves themselves, where the (core) technologies become mass-produced over time and thereby become available to virtually all layers of society. As such, it is envisoned that more efficient solar panels and batteries become inexpensive so that these will replace the dominant energy infrastructure over time. This essentially implicates a paradigm shift towards renewable electricity.

6.2.5 Robotics

Currently, robotics is still dominated by military applications, such as drones, and this is likely to remain the case in the short term. Forge and Blackman (2010) argue that professional and service robots are the segments that have the greatest potential for growth in the robotics sector in the

EU. Forge and Blackman (2010) see significant opportunities in the medical/care, manufacturing, transport, and agricultural sectors, amongst others.

Applications for the medical sector could be robotized surgery, smart capsules, and intelligent prosthetics (TNO, 2008, cited in Forge and Blackman (2010)). Especially in the light of an aging population, care robots could greatly serve in elderly care as household helpers, as well as robot-assisted mental, cognitive and social therapy, and robotized patient monitoring systems (TNO, 2008, cited in Forge and Blackman (2010)).

Although robots are already being widely used in manufacturing (e.g. cars, integrated circuits), they can and probably will take over many more manufacturing processes. An interesting example here is the 3D printer, which is currently becoming commercially available. These printers can be expected to revolutionize the manufacturing industry, where very small batches of products at low costs become a real possibility. Not only can these serve in factories, applications in the household can also be expected on the longer term as the technology matures.

With regards to transport, the applications include automated guided vehicles (AGVs) (Forge and Blackman, 2010). Not only can these serve in industrial areas (e.g. fork-lift trucks), but also in commercial transport and logistics, as well as in personal transport. Google, amongst others, has been experimenting with self-driving cars for years already. These cars may enter the market from 2017 onwards, but it has to be noted that several institutional hurdles (e.g. regulations, insurances) have to be taken (Rosenbush, 2013).

Finally, robots are also foreseen to play a larger role in the agricultural sector. Although currently robots for milking cows and slaughting animals are already in use, in the future robots may also help in monitoring crops and even harvesting (Forge and Blackman, 2010).

Forge and Blackman (2010) indicate by means of a roadmap that low-cognitive functioning robots will be common use by 2030. More sophisticated robots that can effectively interact with humans (e.g. humanoids) are expected to still be in the pilot/demonstration phases by 2030. This, of course, largely depends on computation hardware (and software) development, which will be discussed in the next section.

6.2.6 Computation

So far advances in the speed of computation have relied on improving production processes for applying silicon-based semiconductions in ever-smaller scales and densities. This development is likely to continue in the next 5-10 years (Welser et al., 2011). After this period semi-conductors based on silicon are expected to reach their limits as future size-reductions impose ever-higher cooling demands, as well as more accurate production processes that are presently already operating on the nano-scale (Welser et al., 2011).

Achievements in computation speeds for the mid-term future therefore have to rely on other principles and materials. Carbon nanotubes (CNTs) in particular have been studied intensely over the past 10 years, leading to successful demonstrations showing high carrier mobility and low heat dissipation for use in the next generation of chips (Welser et al., 2011). However, the fabrication of CNTs on a large scale with minimum defects remains a key obstacle. Requirements for integrating CNTs in thin film transistors (TFTs) are signficicantly lower, and therefore a mesh structure of these two technologies in (flexible) electronics can be expected before sole use of CNTs (Welser et al., 2011).

A theoretically far more powerful computer could be built using quantum physics; the quantum computer. Whereas traditional computation logic relies on bits having two distinc states (i.e. 1 and 0), quantum bits (called 'qubits') are capable of showing four different states (Bandyopadhyay, 2011, p. 119). As such, whereas three sets of bits can together form $2^3 = 8$ different outcomes, three qubits can provide $4^3 = 64$ possible configurations. A quantum computer can thus be exponentially faster than the conventional computer, resulting far greater modeling and calculating capacities. However, according to fundamental quantum laws the observer has an impact on the state of the qubits (Ladd et al., 2010). Any interaction with the environment (e.g. heat, wind) will therefore result in a loss of data i.e. the qubits change their states. Apart from that, far more (fundamental) research is required to move from proof-of-principle demonstrations to the engineering of devices based on quantum principles (Ladd et al., 2010). As Ladd et al. (2010) put it "A quantum computer is perhaps the most ambitious goal of this new science (i.e. quantum science, red.), and it will probably require a few more decades to come to fruition...As we proceed, we will tame the quantum world and become inured with a new form of technological reality".

6.2.7 Concluding remarks

To summarize, in the medium term we can expect faster and faster computers that enhance the capabilities of robots. Advanced cognitive robots are expected to be mainstream by 2060, helping people in a myriad of ways, from simple household tasks, to automated transport, to harvesting crops.

Also in the medium term, energy production and storage, as well as flexible and transparent electronics are likely to penetrate society. In terms of sustainable development, the benefits can potentially be enormous. Not only could solar energy be far more efficiently and cost-effectively harnessed, also the applications themselves will require less or comparable energy at higher performance. In addition, products (e.g. cars, air planes) can be far lighter than these are nowadays.

For witnessing a 'mainstream' quantum computer embedded in society, the time scale is probably too short. However, it could be that by 2060 this type of computer is already being used by powerful actors to compute complex models such as the human brain. If that were to occur, robots having human intelligence and conciousness may leave the realm of science-fiction.

Perhaps more extreme is the potential of nanotechnology assemble itself, as is being done in our very cells and bodies. This would mean that nanostructures could replicate themselves, as long as they are designed to do so. However, whereas a manufacturing industry without active human intervention could well be reality by 2060, nanoparticle self-organization into actual products and buildings is probably part of the successive 7th Kondrieff cycle.

6.3 Economic developments

6.3.1 Economic developments in Berlin-Brandenburg

The structure of the economy in Berlin and Brandenburg is dominated by the services sector, producing about 70% of the Gross Value Added (GVA) (BonnEval, 2010). This is seen as one of the causes Berlin and particularly Brandenburg are lagging behind the average European economic development, reaching 94% and 78% of the average in 2006, respectively (BonnEval, 2010). On the other hand, due to the economic structure, Berlin and Brandenburg were relatively unaffected by the global financial crisis in 2007-2009, which struck manufacturing industries particularly hard. In 2009, the nominal GDP of Berlin experienced a growth rate of 1.7%, totalling 90.1 billion euro. In contrast, that same year the German economy shrinked by 3.5% (Reuters, 2009).

With so many great features one would expect Berlin to be a wealthy city, but the opposite is true. At the end of 2012, Berlin state had a debt of 61.2 billion euro (Destatis, 2013) which is about 17,500 euro per inhabitant. In contrast, Brandenburg closed the year 2012 with a debt of 'only' 2.26 billion euro (Destatis, 2013). The causes of Berlin's enormous debt can be traced back to the WWII, which left a large part of the city destroyed. It was not until the end of the Cold War in 1989 that the city was being restored and modernized, resulting in the large debt.

To lower the debt, the Berlin senate seeks to sell its ground to investment companies, which in some cases compromises the available public space (e.g. construction plans for the East side gallery river shore and Tempelhofer Freiheitpark) and hence, the livability of the city.

Although many real-estate projects are being realized in Berlin, appartments remain a scarce and desired good, resulting in a strong growth of ground prices and rents. This particularly true for 8-10 districts around Berlin Mitte, the city center. The ground prices of several of these districts (e.g. Friedrichshain, Kreuzberg) have already experienced many years of price rise and continue to grow steadily with an annual 6%. Other districts (e.g. Wedding, Neukölln) are currently becoming hotspots resulting in housing rent rises of a staggering 10% annually. On the one hand, it can be deducted that the Berlin senate favours these developments because more money can be raised in the form of (housing) taxes, which would enable it to reduce its debt faster. On the other hand, the poorer, original inhabitants are slowly driven to the outer districts, a phenomenon commonly called gentrification. Ironically, amongst them are also many younger people and artists that helped create the appealing living in these districts in the first place.

6.3.2 The Eurocrisis

The information presented in this section was retrieved from the documentary 'Het Duitse alternatief' (Tegenlicht, 2013) about the Eurocrisis, featuring the economists Ewald Engelen, Bernard Connoly, and George Soros.

Currently the European Union is not only politically, but also economically united through a shared currency; the Euro. The introduction of the Euro preluded the creation of a common European market. Using Germany and Greece as examples of richer and poorer countries of the Eurozone, in this economic system the Greek euro is equally valuable as a German euro. In practise, however, this is not the case because Germany is far more competitive than Greece, as it is able to produce more products for the same amount of labour. Germany's currency should thus be more valuable than that of Greece. Under normal circumstances a country having a overvalued currency (e.g. Greece) will sell its 'inferior' products too expensive, resulting in less demand. Less demand would lead to a devaluation of the currency until the country becomes competitive again; when the value of the currency reflects the actual value of the product. Conversely, this also applies to Germany. This country sells its products relatively cheap (e.g. undervalued currency) which makes it highly competitive on the global market.

Through the introduction of the Euro, the economic 'buffer' mechanism of (de-)valuation of currencies has been taken away from individual countries within the Eurozone. The absence of exactly this mechanism lies at the root of the Eurocrisis. Because the products of Southern-European nations are overvalued, it is hard for them to sell these products to other nations and generate enough income to pay back their loans. As a result the richer European nations have to constantly transfer money to the Southern-European nations to avoid insolvency of these nations, as is currently being done for Greece and Portugal. These transfers of money will have to continue as long as the difference in competitiveness of Northern-European versus Southern-European countries remains, which will likely be the case for decades to come given the huge differences in competitiveness.

Unfortunately, there seems to be no painless solution. There are essentially two types of pathways. In the first the current situation continues to exist, in which the Northern-European citizens continuously have to pay the debts of South-European countries. A second option would be for one or more countries to leave the Eurozone, which would in huge capital losses for these countries.

Whereas the EU was originally meant as a free cooperation between European countries, the Eurocrisis has led to a signficiantly different outcome. A situation has arisen where the nations in the Eurozone are divided into two classes; creditors and debitors. Being in a more powerful position, the creditors are in charge, stating (financial) demands to the debitors in order to acquire new loans. Effectively, the debitors have become degraded to a subordinate position within the European Union. Severe budget cuts leading to mass (youth) unemployment in debitor countries have not only led to the return of fascism, but has also created distrust between the Nortern- and Southern-European countries. Ironically, where the Euro was originally introduced in order to further strengthen European unity, it can be reliably stated that it has led to the opposite.

6.3.3 Long-term economic development

Following the Kondratieff cycle theory, it can be stated that the economy expands as new (platform) technologies gain foothold in society, creating employment and wealth. After the innovation potential of these technologies wears off, the economic growth slows down until eventually the economy undergoes a recession having a similar duration as the the economic growth period. Although the phase in which the Western economies currently operate can be roughly estimated based on Kondratieff cycle theory, and thereby a projection for future economic development, it is yet deemed that no good projection for long-term economic development can be given. One reason for this is the unprecedented situation presented by the Eurocrisis, of which the outcome is greatly determined by future political choices made. The second reason is that whereas Kondratieff cycles seems to have taken place since the birth of capitalism, its influence is country-specific. As the historical analysis of Reati and

Toporowski (2009) shows, where some countries are frontrunners during one Kondratieff cycle, these were not able to benefit from the successive Kondrarieff cycle. As such, although it is plausible that nanotechnology features in the 6th Kondratieff cycle, it is by no means certain that Western regions, including Berlin-Brandenburg, will be able to benefit from it.

The variability of economic development will be used for the creation of pathways towards the visions in Chapter 8.

6.4 Political developments

In Brandenburgs agricultural subregime, political actors have steadily withdrawn themselves from active interference with the economy and society, towards a more 'enabling' and 'steering' attitude. This was also observed in Berlins sewage treatment subregime. In doing so, the policy actors have their own priorities and problem agendas, of which regional environmental problems are an important part. Despite the will to solve these problems and improve the nutrient cycle, financial means often seem to be a major barrier not only for the policy subregime, but for cycle chain subregimes as well.

An interesting recent development in Berlin-Brandenburg is the use of local referenda to change and influence political decision-making. More then ever to people have the tool to communicate with one another to raise awareness and attain support for such an initiative.

Despite the citizen's involvement in regional politics, according to sociologist Colin Crouch (Tegenlicht, 2014) the energy and dynamism of the political system are moving away from the democratic arena and become increasingly concentrated in small circles of political and economic elites. This phenomenon he termed 'postdemocracy'. He states that the political elite finds itself detached from its voters and relates to them in increasingly artificial ways, trying to sell a political product or service. Crouch continues in stating that the most common response of the citizen is ritualism; people voting out of habit ratherthan because they expect to have any influence. Another reaction, mainly amongst younger people, is passivity where people are no longer voting in the first place.

Whether this trend continues and the political power of the citizen is hollowed out more and more, remains to be seen. In the longer term a new form of democracy may arise when citizens, enabled by communication technologies, reclaim their role as dominant player in the political arena.

6.5 Social developments

6.5.1 Current social developments in Berlin-Brandenburg

The relatively rural Brandenburg encircles the urban Berlin. After Brandenburg's reunification with the rest of Germany in 1990 its population size declined moderately due to a population growth in the areas directly adjacent to Berlin (BonnEval, 2010). At present, about 40% of Brandenburgs total population lives in these areas. Projections indicate that future immigration to these districts will level off, while the population decline in the more remote parts of Brandenburg is expected to continue. With Berlin having a strong attraction to young people in particular, the demographic structure of Brandenburg is changing dramatically; projections are ranking Brandenburg in 2020 as one of the ten 'oldest' regions amongst the 281 EU NUTS 2 regions (BonnEval, 2010).

Although Brandenburg's unemployment rate has been decreasing over the years, from 18.2% in 2005 to 12.3% in 2009, it is still higher than the German average (2009: 8.2%). Especially amongst young people in Brandenburg unemployment is high and seen as one of the most serious social problems (BonnEval, 2010). The development of Brandenburg's roads and internet access is lagging behind, creating a disincentive for companies as well as people to settle in the province. Agriculture thereby remains an important source of jobs for the Brandenburg. However, as the Brandenburg population ages and young people leave, many farmers in the province are unable to pass on their land to the next generation (LBV, 2014, pers. comm.). This is a reason for concern amongst the farmers. On the one hand their farm, which has been passed on for generations and thereby has a special value to the farmer, may cease to exist. On the other hand, as the agricultural sector shrinks, not only local employment opportunities are reduced, but also the overall activity and livability (e.g. social life) of Brandenburgs outer regions.

While Brandenburg sees its population decline, Berlin's population size is steadily increasing (by 41,147 in 2011 (AfS, 2012a)). Not only does Berlin have a 'pulling effect' on (mainly young) people from Brandenburg, but also on people other parts in Germany, as well as outside Germany. This can be seen as a part of the wider European and even global development of migration from rural to urban areas.

6.5.2 Berlin-Brandenburg demographics

Germany's total population is projected to shrink significantly over the coming decades due to increasingly lower fertility rates. Whereas in 2011 the total German population amounted to 80.33 million people (Statista, 2014), in 2060 this number is projected to lie somewhere between 65 and 70 million people (Destatis, 2009). Taking the mean of the projection of 67.5 million people in 2060, the nationwide population is projected to drop by 15.97% between 2011 and 2060. The population forecasts for Germany's five 'new' provinces excluding Berlin (i.e. Mecklenburg-Vorpommern, Brandenburg, Sachsen-Anhalt, Sachsen, and Thüringen) combined is even more grim. This area, presently home to about 12 million people is estimated to lose a staggering 33.8% of the population between 2009 and 2060.

When zooming in to the case area, it is evident that particularly Brandenburg's population will decline dramatically over the coming decades. One study estimates that between 2004 and 2030 Brandenburg will lose about 13% of its population (IBE, 2007, p. 4), indicating that population decline in Brandenburg will be more severe than the German average. Another population forecasting study projects that Berlin will grow from 3,452,000 in 2010 to 3,571,000 in 2030, while Brandenburgs population drops from 2,511,000 in 2010 to 2,315,000 in 2030 (Giannakouris, 2010). These indicate 2010-2030 population dynamics of +3.447% and -7.805%, respectively. The latter study will be used because it contains projections for Brandenburg as well as Berlin, making the whole more coherent.

Population projections up to the year 2060 for Brandenburg and Berlin were not found. Yet, an indication of Berlin and Brandenburgs population dynamics for the year 2060 is required for use in the visions. For this purpose the 2030 projections for Berlin and Brandenburg will be extended to the year 2060. A complication for the calculations is that the 'history' of German population statistics were revised recently due an overestimation of the German population discovered through the Zensus 2011. German population studies before this date thus worked with overestimated data. Therefore the population growth rates between 2010 and 2030 are calculated from the study by Giannakouris (2010) and used to make projections based on the newer Zensus 2011 population data (Destatis, 2011a). In doing so, it is assumed that the projected revised population size in 2030 continues linearly to the year 2060.

In order to acquire an approximation of the sizes of the population of 2010, the difference between that of 2011 and 2012 is first calculated and then substracted from the 2011 values. According to Destatis (2011a), Berlin counted 3,326,002 inhabitants in 2011 and 3,375,222 in 2012; a growth of 50,220 inhabitants. Calculating these values back to the year 2010 yields that in this year Berlin had about 3,326,002 - 50,220 = 3,275,782 inhabitants in that year. Brandenburg counted 2,453,180 inhabitants in 2011 and 2,449,511 in 2012 (Destatis, 2011a); a decrease of 3,669 people. Projecting that trend to 2010, Brandenburg had 2,453,180 + 3,669 = 2,456,849 inhabitants in 2010. These values for the year 2010 for both provinces will be used as the basis for the projections up to 2060, with the results shown in Table 16. The 2060 population projection will be used for the construction of visions in chapter 7.

6.5.3 Long-term employment

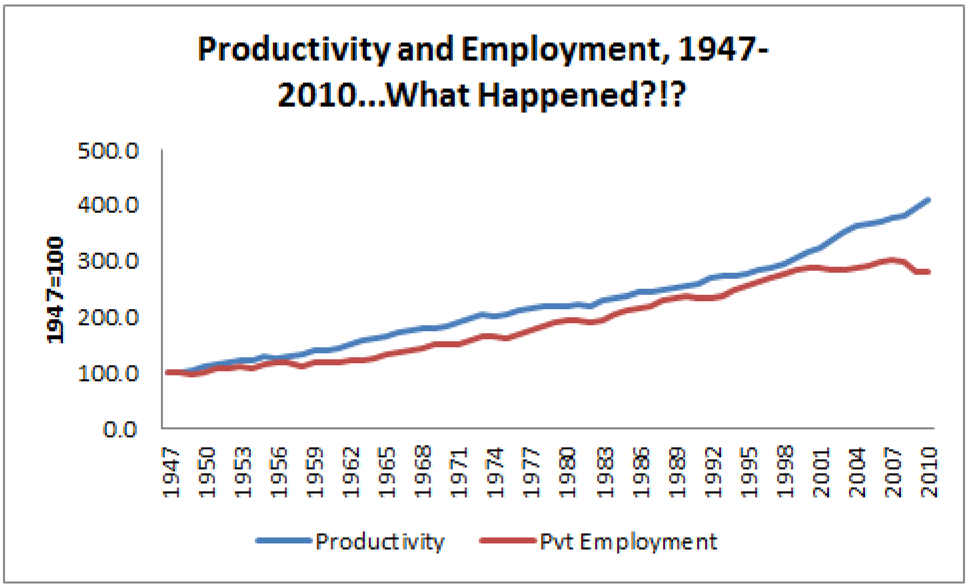
For (most) companies labour costs comprise a significant share of the final cost of a product. Therefore, in order become more competitive and attain a higher market share, companies continuously seek to reduce labour costs through gains in productivity. As a result, products become cheaper and more abundantly available than before. As people buy the products the economy grows, creating

Table 16: Berlin and Brandenburg population base and projections.

	Revised population size 2010 (e.o.y. count)	**Growth factor to 2030**	**Adjusted population projection 2030**	**Population projection 2060**
Berlin	3,276,782	1.034	3,389,742	3,559,181
Brandenburg	2,456,849	0.921	2,265,076	1,977,416
Total	5,733,631		5,654,818	5,536,597

new employment opportunities. Thus, people that became unemployed as a result of automization processes, become re-employed as the economy grows. In essence, this is how capitalism has led to higher wealth and higher standards of living over the last centuries, at least for people in the developed world.

Figure 10: Employment plotted against productivity in the United States from 1947 to 2010 (Bernstein, 2011).



However, it seems that a new era of capitalism is emerging where rising productivity does not necessarily lead to more employment opportunities. This phenomenon is illustrated in Figure 10, showing the case for the United States. Although scholars disagree about the exact driving forces behind the recent jobless growth, Brynjolfsson and McAfee (2012) argue that ongoing computerization of the economy is a plausible explanation. This is in line with findings from a study by Frey and Osborne (2013). These authors have estimated that a staggering 47% of all jobs in the United States face redundancy over the coming two decades as a result of ongoing automation. Given the similarities in economic structure between the United States and Europe, this most likely also applies to the future European labour market.

Frey and Osborne (2013) find that mainly middle-income jobs will be subject to computurization, including jobs in office and administration support, logistics, production, and services. This is in line with the technological developments discussed in section 6.2. Although a part of these jobs will be replaced by new jobs, the fact remains that a significant amount of the population faces unemployment in the coming decades and that mainly occupations requiring high cognitive and/or social skills will continue to exist. Interestingly, this phenomenon has been predicted by John Maynard Keynes in the 1930s already when he stated that "due to our discovery of means of economising the use of labour outrunning the pace at which we can find new uses for labour" (Keynes, 1933, p. 3, cited in Frey and Osborne (2013)).

Related to the previous is another interesting (institutional) phenomenon. Up to the 1980s increases in productivity have enabled people to have more free time. However, from the 1980s onwards, the average amounts of working hours have remained more or less the same while wages increased (Bregman, 2013).

6.5.4 Concluding remarks

Gains in productivity should enable people to work less and less while having increasingly higher standards of living. An almost inevitable final outcome of capitalism should be an fully automized economy where people no longer have to work in order to attain a high standard of living. However, paradoxically, instead of celebrating the redundancy of labour, it is viewed as a major problem. From the agruments given previously it can be stated that, rather than being a future economic problem, it is a future institutional problem. Perhaps stating the obvious, large employment and large differences in wealth always lead to reduced societal cohesion and increasing social struggles. The future institutional measures taken will therefore greatly determine the fates of the developed nations.

6.6 Environmental developments

6.6.1 Current environmental developments in Berlin-Brandenburg

Berlin-Brandenburg currently faces two main problems related to the environment. The first environmental problem is related to the surface waters in the region. Many sewage treatment operators in Brandenburg apply sludge to the land as a final cleaning step. Although the soil will capture most of the nutrients, still some nutrients leach to the surface waters. Not only does in combination with a naturally slow waterflow cause eutrophication, also the production of clean drinking water from surface waters by the BWB is compromised due to the hormone and medicine residues present in the sludges.

Firstly, the agricultural land is rapidly losing its fertile topsoil. This can be supported by the findings from the MFA (section 4.7, from which it was concluded that the agricultural soil stock lost about 1,400 tons of phosphorus in 2011. Whereas the land was already relatively infertile (i.e. sandy), more extreme weather events excerbate the problem. Prolonged droughts reduce the moisture content of the soil, which in turn becomes more vulnerable to stronger winds, and hence erosion.

In the past local research actors were closely involved in improving Brandenburg farmers' practises. Today, even though these actors are still present (e.g. ATB, ZALF, Humboldt University), their research focus has largely turned away from the case area (LBV, 2014, pers. comm.). Yet, within the current ELaN project different land use techniques together with regional struvite recycling are researched.

6.6.2 Climate change

The IPCC (2014) projects that by 2100 the global average temperature will rise between 2.6 and 8.5 degrees as a result of elevated greenhouse gas emissions, depending on how ambitious the measures taken are. On a global level, this leads to acidification of the oceans, melting of the ice caps, more extreme weather events, and reduced fresh water availability amongst others.

Europe is projected to face a 2 to 4 degrees temperature rise towards the year 2100 (IPCC, 2014). As a result, peak river discharges increases and sea level rise will cause floodings in river basins and coasts. Also, there will likely be a significant reduction in (fresh) water availability from rivers and groundwater, while water demand increases (e.g. irrigation, domestic use). In agricutlure, the evaportative demand of the land increases, leading to higher irrigation demands and decreased run-off and water drainage. Lastly, with medium confidence it can be stated that more extreme heat events will impact air quality, crop production, labour productivity, and the health and well-being of people.

6.6.3 Phosphorus scarcity

Studies on estimated phosphorus reserves and the peak phosphorus presented significantly different results. Cordell et al. (2009) predicted peak phosphorus to take place in the year 2035, while

Van Kauwenbergh (2010) finds that the reserves will last for hundreds of years. Yet, most publications on this topic estimate a longer-term availability of phosphorus, and to date Cordell et al. have not been able to reject the study by Van Kauwenbergh (2010). It is therefore likely that phosporus scarcity is of no concern in the mid-term.

6.6.4 Conclusion: Sustainability linkages

Energy, material, water, and land use are strongly interlinked components of the global ecosystem in which the socio-economic sytem is embedded (**?**). A basic example is that climate change lowers the available water supply and increases demand. But in turn an important cause of climate change is society's material, energy and land use, which depend on technological efficiency and resource scarcity. Due to the complexity of the system is virtually impossible to predict the interplay between these components.

Although the phosphorus reserves suffice based on the current system properties, scarcity in one of the system components (e.g. energy, water) will also impact phosphorus availability and induce fertilizer higher prices for farmers. Furthermore, climate change already imposes constraints on farmers and these will become increasingly severe. More frequent peak river discharges will likely lead to more effluent releases to the surface waters and further lower the surface water quality.

Concluding, the choice for technologies enhancing the phosphorus cycle of Berlin-Brandenburg should also perform well on the other sustainability indicators.

Chapter 7

Solutions and visions

7.1 Introduction

This chapter builds onto the opportunities for improvement derived from the MFA of Berlin-Brandenburg in section 4.9, as well as the current and landscape developments discussed in Chapter 6. Firstly, the technologies featuring in both visions are briefly introduced in section 7.2. Subsequently the integration and societal embedment of these technologies within the visions is explained in the sections 7.3 and 7.4 by means of a narrative.

Section 7.5 discusses the details of the MFA created as the trend, or forecast model which functions as a basis for the solution assessment. From hereon that MFA will be referred to as the 'Trend MFA'. The sections 7.6 to 7.12 encompass the individual solution assessment. Within the solution assessment only the effect of the respective solution on the Trend MFA is being modelled, unless stated otherwise. A comparison with the trend and the two vision solutions applied to the sectors plant production, animal production, and waste recycling can be found in section 7.13 Finally, the solutions are combined for each vision and compared to the baseline vision in sections 7.14 and 7.15.

7.2 Solutions for visions

In this section the opportunities for improvement as identified in section 4.9 are taken as a basis for the identification of solutions that can improve the phosphorus cycle of Berlin-Brandenburg. Given that two different visions will be developed the solutions applied per improvement opportunity will vary.

The visions differ from one another in two fundamental ways; (technological) centrality and consumer involvement. The first vision, named Techno-fix, will feature centralized solutions where the consumer is assumed to play a passive role. As such, the consumer is only very limitedly required to change his/her routines to any (technological) adaptation to the system. In addition, any moral and ethical matters such as animal welfare are only of minor importance to the consumer. In the second vision, named Culture-fix, the solutions have a decentralized character in which the consumer is actively involved. These latter two vision features relate nicely to one another because decentralized solutions often require the consumer to adapt his/her routines. In the Culture-fix vision it is assumed that the consumer has a high willingness to do so, enabling the implementation of the decentralized solutions. A more elaborate explanation of the methodology regarding the visions can be read in section 3.3.2.

An review of the opportunities for improvement can be seen in Table 17. In the same row the conceptual application to the two visions is described. Not all opportunities for improvement can be exploited in both visions as a result of the criteria imposed on each vision. The absence of a solution is marked by a '-' in that particular case.

Table 17: Overview of the opportunities for improvement and application per vision.

Improvement opportunity	Solutions Techno-fix	Solutions Culture-fix
Minimization of erosion taking place	Vertical, closed-loop greenhouse system	Organic agriculture
Reduction of energy crop production	Absence of energy crop production	Continued energy crop production
Enhancement of phosphorus conversion from feed to animal products	In vitro meat production	Local recirculation of nutrients; EcoFerm! concept
Minimization of biowaste from consumers	-	Prevention of avoidable biowaste
Shift towards a less animal-product intense diet	-	Reduction in meat, milk, and egg consumption, increase in plant-based consumption
Reallocation of phosphorus flows exiting the Consumption process	-	Source-separation of biowaste
Reduction of phosphorus in effluent from sewage treatment	Enhanced treatment of effluent; Algae treatment	Source-separation and treatment of yellow-, black-, and greywater
Recycle sewage sludge and biowaste	Centralized recycling; Mephrec process	Source-separation and treatment of yellow, brown, and grey water
Recycle slaughter waste and deceased animals	Centralized recycling; Mephrec process	Reduction of slaughterwaste and deceased animals through adoption of vegetarian and vegan diets

7.3 Techno-fix narrative

7.3.1 Setting the scene

In the year 2060 technological advances in computation in combination with robotics have made most routine-based labour obsolete. This includes the larger share of past labour in Berlin-Brandenburg; goods and person transortation, agriculture, nursing, and processing and manufacturing. The institutional framework has been successfully adapted to the new reality by providing people a basic income independent of labour activities carried out. Whereas some of the displaced workers continued studying to be able to perfrom work demanding high-cognitive abilities, others simply live from their basic income and engage in leisure activities. In effect, labour has become a choice rather than a necessity.

The imminent shortage of nurses due to the strong growth of the elderly especially in Brandenburg was mitigated through the introduction of robots capable of performing household and nursing tasks, as well as tasks related to the mental well-being of people.

Strong technological development in nano-technologies have enabled society to produce high-performance solar cells and batteries at very low costs. These have displaced the previously dominant fossil fuel-based energy regime, and are installed on the previous agricultural fields in Brandenburg. As such, the energy demands of society are fulfilled through the generation of electricity and energy crop production has been made obsolete.

7.3.2 Agriculture subregime

Electricity is not only generated for use in households, transportation and manufacturing, but also for the vertical greenhouses and in vitro meat production facilities that supply the population with food. Particularly for the greenhouses significant electricity is required as the crops are grown with artificial LED lighting. Both the in vito meat facilities and vertical greenhouses are completely computer-controlled to regulate the indoor climate and demand-supply logistics. Human intervention is only required in special circumstances.

For the production of in vitro meat specially-bred algae are first cultured, then sterilized and hydrolyzed in order to serve as energy and nutrient source for the muscle cells. This process has not yet been optimized unfortunately. About half of the original algae biomass cannot be used for stem cell multiplication, and in addition a portion of the cultured meat is unsuitable for consumption. Also the artificial production of milk and eggs has not been accomplished yet; for this purpose the presence of milk cows and laying hens is still required. The laying hens and a share of the milk cow stock are fed with the discarded algae biomass, which provides a protein-rich feed source. The remaining feed requirement is supplied through forage production from grasslands. These two sources of fodder suffice; feed crops are no longer grown.

7.3.3 Processing, retail, and consumption subregimes

From the production facilities onwards the food is processed and packaged fully autonomized. Inevitable losses still take place as not all biomass produced can serve as food. With the consumer having stated his/her preferences beforehand online, delivery drones fly the food to the households, effectively having replaced the traditional supermarket. Because a small share of these deliveries still fail, there remain retailing losses. Whereas all crops destined for human consumption are produced in vertical greenhouses , some people still demand a piece of meat that was once part of an animal. For this purpose the milk cows and laying hens that reach the end of their lifetime are slaughted, and the resulting meat is sold to these customers.

Having reached the household, the food is prepared and eaten. Any food waste produced is disposed of by means of a macerator placed in the sink, which diverts the food waste together with urine and faeces towards a centralized sewage treatment plant.

7.3.4 Waste treatment subregime

During sewage treatment the solid component of the wastewater (i.e. sludge) is separated from the liquid component. Before releasement to the surface waters, the 'effluent' is first led to a bath where algae convert biomass from the nutrients. After filtering out the algae the cleaner effluent is released. The algae biomass will be contaminated with hormones and other substances, and can therefore not be fed to livestock. Rather, the algae are exported out of the system and used in the production of bioplastics.

The sewage sludge is subjected to a dewatering process in order to produce briquettes. These briquettes, wood waste, and briquettes made from slaughterwaste and deceased animals are then treated with the Mephrec process. Within this process cement and limestone are added to the briquettes and the mixture is heated to 2,000 degrees Celcius, from which phosphorus-rich slag is obtained which can serve as a fertilizer in the vertical greenhouses. A minor share of the phosphorus (i.e. 20%) cannot be retrieved and is landfilled.

Biowaste from processing and retail is digested rather than fed to the Mephrec process. The digestate produced, as well as the manure from milk cows and laying hens, is first mineralized as a necessary pre-treatment step for use in the vertical greenhouses. The mineralized fertilizer produced together with the fertilizer obtained from the Mephrec process is finally converted to a nutrient solution which is injected into the circulating water of the vertical greenhouses to close the phosphorus cycle.

7.4 Culture-fix narrative

7.4.1 Setting the scene

Whereas previously people's norms and values were more materialistic (i.e. extrinsic) in nature, in the year 2060 these old norms and values will have made way for new ones involving a deeper relation to nature, the community, and the phyche. As such, the attainment of status through material goods and welfare as a goal in life has been largely replaced by nourishing the environment, bonding with the community, and personal development.

As people no longer seek satisfaction through purchasing products and services, the demand for these has reduced significantly. This has led to a labour market transition towards mainly part-time jobs, which suffice as a source of income for people. In turn, more time can be spent on voluntary activities, such as urban gardening and nursing the elderly. With people devoting more of their time to these activities, the formal economy has reduced in size matching lower consumption levels, whereas the informal economy grew significantly.

Due to the significantly reduced emphasis on material welfare and economic growth at a societal level, technological development in Culture-fix has taken a different pathway than that of Techno-fix. Whereas in Techno-fix electricity in combination with batteries are the main energy carriers, in Culture-fix this is hydrogen and biogas. Therefore, in Culture-fix energy crops production remains a vital component of the energy infrastructure.

7.4.2 Agriculture subregime

As people's norms and values shifted, the demand for more environmentally-friendly produced food grew. This gave way to an agricultural transition towards organic agricultural methods, such as biodynamic farming and permaculture. Rather than being a key obstacle for such a transition, the higher labour input was provided by many people from Berlin volunteering to spend one or more days per week on farms in Brandenburg. With people providing a helping hand to the farmers, the people in turn gained knowledge about the land, crop varieties and farming techniques, as well as new experiences and acquintances.

Although a large share of the population has converted to vegetarism, and even veganism, many people still demand meat and dairy products. As such, the animal husbandry sector shrunk, but did not vanish altogether. In reaction to rising costs for imported fodder, the animal farmers implemented the EcoFerm! concept in their farms. Whereas manure was previously sold to other (crop) farmers, in the new situation the manure is collected underneath the stable. Once collected the manure is digested and a part of the phosphorus extracted. The latter is fed to an algae pond on top of the stable providing the nutrients for algae growth. In turn the algae are collected and used as a protein-rich feed source for the livestock. The phosphorus not extracted from the digestate is sold as a fertilizer to other farmers. Through the conversion to EcoFerm!, the animal farmers effectively reduced their dependency on fodder imports while maintaining forage from grasslands as a major part of the livestock diet.

7.4.3 Processing and retailing subregimes

As the bonds between farmers and citizens strenghtened, the farmers were able to sell more of their produce via direct sales and novel forms of retailing such as Abo-Kisten. Although the volumes of processed food decreased as people engaged more in cooking, still a significant part of the food consumed had to be processed first (e.g. cheese, bread production).

7.4.4 Consumption subregime

Fueled by on-farm experiences and facilitated by policy actors, people began converting empty urban plots and rooftops to urban farms. Not only were people able to produce more of the food themselves, the communities in which these projects took place also became more vital and socially cohesive.

As people became more involved in the community, their feeling of responsibility towards the society grew, as well as their awareness of sustainability issues. This has resulted in an almost 100% biowaste separation rate at the level of the household, and an elimination of avoidable food waste at the consumption level. In addition, people were prepared to change their 'toiletting' routines such that the a successful implementation of vacuum separating toilets became possible.

7.4.5 Waste treatment subregime

Supported by citizens, landlords, and policy, waste and sewage treatment actors, vacuum separating toilets were installed in every household. The urine and faeces are separatedly stored underneath the dwellings in the basements, where these streams are converted to fertilizers and biogas. The biogas is used in the same households (and offices) directly for heating and cooking applications, and the fertilizers are collected once per week together with the household waste. The greywater from originating from showers, the washing machine, and the tap is first cleaned by means of reverse osmosis filters after which the purer water is reused in (dish) washing applications. The unpure fraction is diverted to constructed wetlands located in one of the nearby parks, where the plants absorb the nutrients and clean the water.

The collected biowaste from households, retail, and processing is digested. The digestate together with the fertilizers produced from urine and faeces are sold back to the organic farmers which use it to fertilize their crop land and grasslands, thereby closing the phosphorus cycle.

7.5 Trend MFA: A basis for solution assessment

Before the effect of the solutions contained within the visions can be assessed it is first necessary to construct a trend, or baseline vision for the year 2060. The new phosphorus flow chart resulting from these changes will be referred to as the Trend MFA. Within the Trend MFA only generally expected changes and necessary changes for modelling will be adopted, and thereby it can serve as a platform upon which the solutions mentioned in section 7.2 can be assessed. An additional function of the Trend MFA is to serve as a means of comparison between the two visions and the baseline i.e. Trend MFA. This is done in section 7.13.

It is important to note that although improvements or at least changes in agricultural production, processing, and retailing efficiencies can be expected, these are not featured in the Trend MFA. The same holds for changing consumption patterns. The main reason for this is that these kinds of changes cannot be predicted realiably enough. For example, one could extrapolate past efficiency gains in the agricultural sector, but how can one predict its interaction with future climate change excerbations? Can past efficiency gains be extrapolated in the first place? Rather than speculating about these issues, it is deemed best to preserve the current effiencies and keep production and processing levels the same.

The main foreseen and required changes influencing the 2011 phosphorus cycle of the case area are the following:

1. A different population size;
2. The absence of phosphates in detergents;
3. Elimination of sewage sludge imports to Brandenburg agricultural land;
4. The absence of agricultural soil phosphorus deficits.

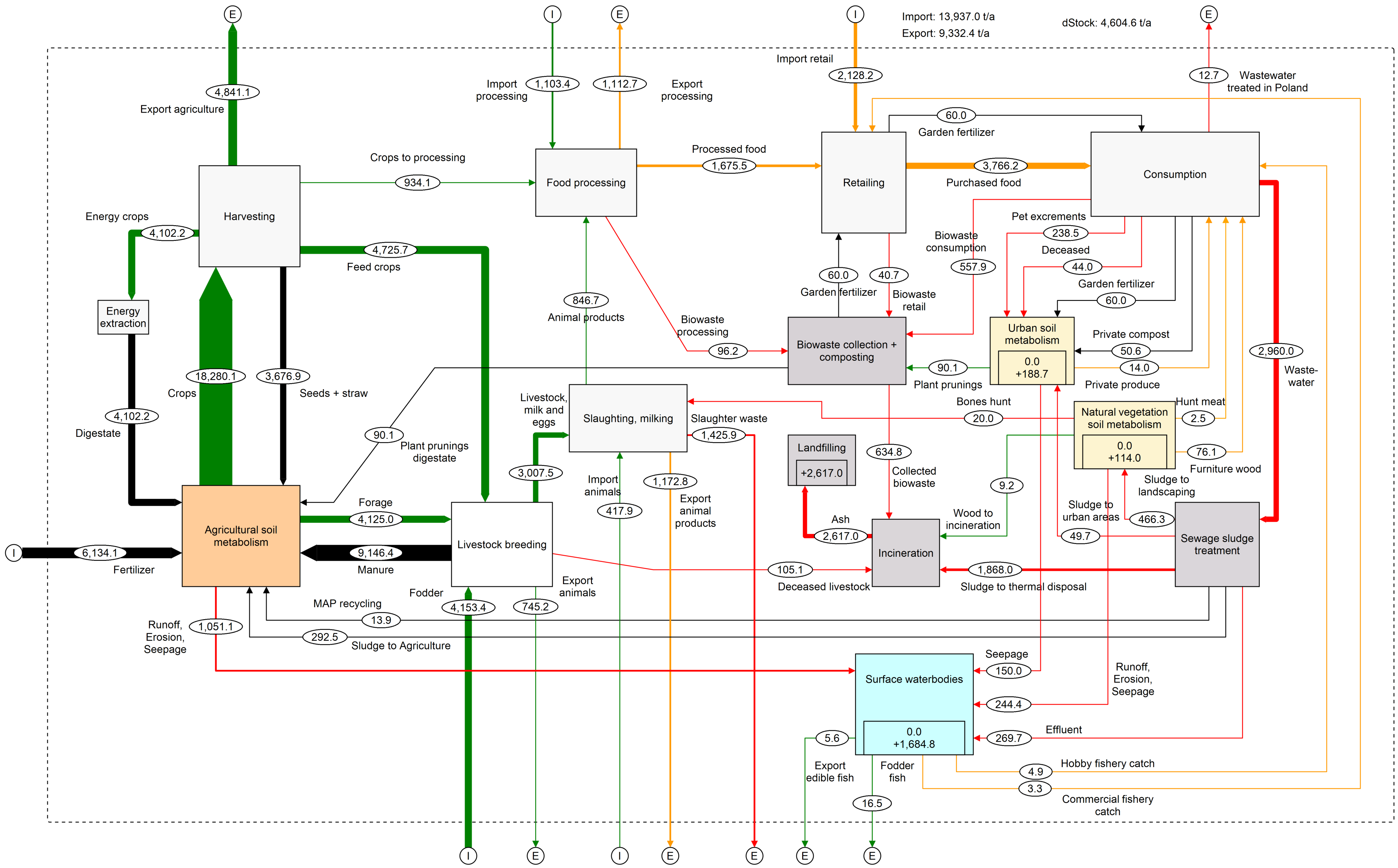
These changes and their impact on the MFA are discussed in the sections 7.5.1 to 7.5.4. Section 7.5.5 discusses the modelling details of the Trend MFA. The Trend MFA itself can be viewed in Figure 11.

7.5.1 Population dynamics

Firstly, given the large timespan between year for which the MFA was made (2011) and the year 2060, the size of the Berlin-Brandenburg population will be different. As a result also the consumption levels will vary, which affect the sizes of flows related to the Consumption process. As the amount of Purchased food would decrease, so would the throughput of the Retail process and subsequently the Biowaste from retail. The latter was assumed to linearly decrease according to the decrease in throughput, with the exception of bones originating from the Commercial fish flow which was assumed to be a fixed value of 0.14 t P.

A forecast of demographic trends was presented in section 6.5.2. Based on those figures it was calculated that the combined Berlin-Brandenburg population will decrease by 3.436% from 2011 to 2060. Subsequently, all flows entering or exiting the Consumption process were decreased by the given percentage. Processes related to production and processing were kept equal.

Figure 11: Phosphorus flow chart of the Trend MFA.



7.5.2 Phosphorus in detergents

Kabbe (2014b, pers. comm.) estimated that phosphorus will no longer be allowed as constituent of detergents from 2018 onwards. Although such a regulation has not been published yet, based on the information given it can be assumed that by 2060 all detergents are indeed phosphorus-free. Therefore the Detergents flow (612.6 t P), and its fate to wastewater is removed from the Trend MFA. Calculations used to determine the Detergents flow can be read in section 4.4.5.

7.5.3 Imported sludge

Sewage sludge imports are assumed to not take place anymore in the Trend MFA. One reason is that sludge application to agriculture land be more strictly regulated or even forbidden in the future (see section 5.4.3). The second and main reason is that the continued existence of the Imported sludge flow will mask the results gained from analyzing individual options in the waste subregimes. An important goal of the solution assessment is to find out to which extend recycling options can replace phosphorus imports, and with the Imported sludge flow included it will seem as if less phosphorus needs to be recycled to fulfill the fertilizer requirements of agriculture. By excluding the Imported sludge flow, Mineral fertilizer imports rise with 149.0 t P.

Sewage sludge recycling from the Sewage treatment process within the system will continue to take place in the Trend MFA. Although this operation may no longer be allowed in the future, through maintaining it a comparison can be made between the current situation and the sewage sludge recycling options in the visions.

7.5.4 Agricultural soil deficits

Agriculture soil phosphorus deficits are assumed to be no longer present in the Trend MFA mainly because the model does not allow stock changes when working with transfer coefficients. These transfer coefficients need to be inserted in certain processes, including Agricultural soil metabolism, in order to assess the impact of the solutions featured in the visions. This model choice can be additionally justified by pointing at the new Klärschlammverordnung (see section 5.4.3), which states that any phosphorus leaving the soil needs to be compensated such that the soil phosphorus balance is maintained.

By excluding Imported sludge and soil deficits from the Trend MFA, the Mineral fertilizer imports will become higher to maintain the balance of the Agricultural soil metabolism process. However, these can not be simply added up to acquire the new required Fertilizer import flow, because a decreased population in Berlin-Brandenburg and the absence of phosphorus detergents has resulted in reduced recycling of MAP and sewage sludge to agricultural soil. With these changes taken into account, the new required Mineral fertilizer import flow becomes 6,134.2 t P.

7.5.5 Modelling details of the Trend MFA

In order to assess the individual and integrated solutions featured in the visions not only the above-mentioned changes had to be integrated, but the MFA also had to be remodelled into a set of equations. In essence, the Bookkeeping MFA of 2011 had to be remodelled to a Static modelling MFA comprising the Trend MFA. That means that whereas formerly most flows were given a certain value, and the other flows were determined by the process balance, in the Trend MFA the sizes of the flows were determined through transfer coefficients set for the processes. For processes that only have one output, or those that act as a sink this was not necessary.

When adjusting the MFA in such a way, one can choose between a demand- and a supply-driven system. In the former the demand (i.e. consumption) side of the system is set as a fixed variable upon which the other flows depend, and in the latter type of system the production-side is taken as a fixed variable. For the solution assessment it was deemed that a supply-driven system would be best because the production and consumption sides of the system barely have a relation to one another. As such, a change in demand would in practise not lead to a change in production of the system, but rather in a change of imports and exports to and from the system.

Furthermore, only one balancing flow can be chosen per process; the others have to be inputs or fixed variables. If more than one balancing flow are chosen per process the system cannot be solved with the sets of equations. The balancing flow acts as the medium of change for a process, and can be used to assess the outcomes of changes implemented in the system. The processes for which a balancing flow was chosen can be viewed in Table 18.

Table 18: Processes and related balancing flows chosen.

Process	**Balancing flow**
Agricultural soil metabolism	Mineral fertilizer import
Harvesting	Export agriculture
Livestock breeding	Fodder import
Food processing	Export processing
Retailing	Import retail
Biowaste collection + composting	Collected biowaste

Finally, the Wastewater flow becomes smaller due to the population dynamics, with the output flows of the Sewage treatment process reducing accordingly. Thereby less input is supplied to the Urban soil metabolism and Natural vegetation soils, affecting these processes. For the Trend MFA, as well as the vision MFAs, the stock added in relation to the phosphorus losses (e.g. seepage) is maintained. In doing so, the new stock added and phosphorus losses for the Urban soil metabolism are +188.7 t P and 150.0 t P, and for the Natural vegetation soil it is +114.0 t P and 244.4, respectively. The total stock addition to Surface waterbodies thereby becomes 1,684.8; a reduction of 6.1%.

7.6 Vertical farms and grasslands

As mentioned in section 7.3, for the Techno-fix vision the crops will be grown by means of vertical farms whereas forage is still produced on grasslands. Because a energy transition has taken place energy crops are no longer produced. Energy crops are normally digested with straw included and will therefore not influence the straw flow back to the land. However, less seeds and related straw will be required. Assuming that the phosphorus-in-seeds requirements for energy crops+straw are similar to the other crops+straw, the new Seeds flow becomes 91.6 t P and the new Straw flow becomes 3,369.2 t P. This will in turn affect the Crops flow which will shrink to 13,961.5 t P.

The vertical farm can be viewed as a closed greenhouse sytem (Despommier, 2011). In closed greenhouse systems the nutrient solutions is recirculated back to the plants (Hultberg et al., 2013), which would imply that no erosion takes place. However, closed greenhouse systems often face problems related to pathogen growth (Ehret et al., 2001) as well as salt accumulation (Hultberg et al., 2013). The drainage solutions there needs to be renewed at a certain point in time. Nevertheless, according to Despommier (2009) the vertical farm does hold the potential to largely eliminate fertilizer run-off. For the present solution assessment it is assumed that no erosion takes place in vertical farming as its exact erosion as a percentage of throughput is unknown, while yet it is expected to be very low.

Concerning forage production from grasslands it is assumed that the same amount of forage is produced and that it is still being supplied to livestock (i.e. 4,125.0 t P). With regards to erosion from grassland soil it is assumed that phosphorus erosion is equally distributed amongst all plant production taking place in the Trend MFA, which then amounts to 193.5 t P. As the livestock still grazes on grasslands, the primary source of fertilizer will be manure. However, the amount of manure produced far exceeds the nutrient requirement of the grassland soils. It is therefore assumed that the remainder, 4,827.9 t P, is captured in the stable and used to fertilize the vertical farms.

The vertical farms require mineralized fertilizers contained in a nutrient solution. Its exact properties are unknown and will be crop-specific. For the present assessment it is assumed that manure, compost, and sewage sludge are first mineralized and prepared for application in the vertical farm.

For MAP and mineral fertilizer imports it is assumed that this extra step is not necessary.

When entering these parameters in the model, the result is that an additional 5,276.3 t P is required to fertilize the vertical farms.

7.7 In vitro meat production

In vitro meat, also known as 'cultured meat', is meat produced from stem cells in a closed environment. In essence, during cultured meat production the stem cells multiply continuously into new stem cells and muscle cells while absorbing externally added biomass for their energy and nutrient requirements.

7.7.1 Data input for the In vitro meat production

For the calculations and assumptions regarding in vitro meat production the Life Cycle Analysis performed by Tuomisto and Teixeira de Mattos (2011) and Tuomisto and Teixeira de Mattos (2009) will be used as a guide. These authors describe the process as follows. First cyanobacteria are being cultured with urea and diammonium phosphate as nutrient sources. These are then sterillized and hydrolyzed as preparation for their use as feed source for the muscle cells. After preparation only 50% of the cyanobacteria biomass can be used for muscle cell cultivation, the remainder can serve other purposes (e.g. cosmetics, food supplements). Then, during muscle cell cultivation another 50% is lost whereas the other 50% is cultured meat. Unfortunately, Tuomisto and Teixeira de Mattos (2011) and Tuomisto and Teixeira de Mattos (2009) do not mention what the fate of phosphorus within each step of the process is, but rather the weight in biomass. To still be able to model In vitro meat production, it is assumed that the phosphorus concentration in each product and waste is the same.

In this case for every 1kg of cultured meat produced there is 1kg of 'meat waste' and 2 kg of algae waste. For the model it is assumed that the algae waste can still be fed to livestock, and that the meat waste is incinerated due to its potential risk of contamination. Furthermore, milk and eggs are assumed to still be produced by livestock. The meat resulting from these animals is assumed to still be processed, retailed, and consumed. To be able to make a fair comparison with the Trend MFA, the quanty and fate of the production of meat, milk, and eggs is kept equal. As the livestock staple will shrink its feed crop, forage and fodder requirements decrease as well. For the model it is assumed that the obsolenence of these flows is in the order; Fodder imports, feed crops, forage. Decreases in crops and forage grown are modelled as a lineairly decreasing erosion.

7.7.2 New Livestock breeding and Slaughting & milking processes

In order to assess the impact of In vitro meat production on the model first the altered Livestock breeding and Slaughting & milking processes are calculated, as summarized in Table 19. In doing so, the amount of animals slaughted in Brandenburg, the Export animal products, and Animal products (to processing) flows and their content are kept exactly the same. In the Trend MFA, similarly to the 2011 MFA, a total of 288.2 t P of milk cows were destined for slaughter, whereas only 71.5 t P of the animals are actually slaughted in Brandenburg; the remaining 216.7 t P milk cows are exported prior to slaughting. The 1,230.0 t P milk produced and the 71.5 t P milk cows slaughted in Brandenburg go to the Slaughting & milking process. Due to lack of data all bird livestock were assumed to be slaughted in Brandenburg for the 2011 and Trend MFA, including the laying hens producing eggs discussed in this section. The eggs produced (99.7 t P) and laying hens to slaughter (30.0 t P) join the milk and milk cows to Slaughting & milking process, comprising the Livestock, milk, eggs flow (1,431.2 t P).

The 71.5 t P milk cows and 30.0 t P laying hens slaughted in Brandenburg yielded 4.5 t P and 16.0 t P meat, respectively. These go to Processing via the Animal products flow. Here it is important to note that chicken meat still contains 50% of the bones in liveweight and therefore its (phosphorus) yield ratio is higher compared to milk cows. This would create 71.5 + 30.0 - 4.5 - 16.0 = 81.0 t P slaughter waste. However, the Animal products flow also contains 3.13 t P intestines which is substracted from the slaughter waste generated. Also accounting for the Bones hunt flow yields a Slaughting waste flow of 81.0 - 3.1 + 20.0 = 97.9 t P.

Table 19: Adjusted flows related to the Livestock breeding and Slaughting & milking process.

	Milk cows [t P]	**Laying hens [t P]**	**Other [t P]**	**Total [t P]**
Milk/eggs produced	1,230.0	99.7		1,329.6
Slaughted in BB	71.5	30.0		247.2
of which meat	4.5	16.0		20.5
of which offal	67.0	14.0		81.0
Export animals	216.7	0		216.7
Manure	3,025.7	591.2		3,616.9
Deceased livestock	27.1	2.8		29.9
Export animal products	1071.5	99.7		1,171.1
Slaughter waste	67.0	14.0	-3.1, +20.0	97.9
Animal products	163.0	16.0	3.1	182.2

No eggs comprise the Animal products flow and therefore these (99.69 t P) leave the system with the Export animal products flow, whereas the Animal products flow contained 158.5 t P milk. The excess milk (1071.5 t P) leaves the system together with the eggs. Concluding, the Slaughting & milking process delivers 158.5 (milk) + 3.1 (intestines) + 4.5 (cow meat) + 16.0 (chicken meat) = 182.2 t P to the Animal products flow, whereas 846.7 t P is required. The remaining 664.6 t P will therefore be supplied through In vitro meat production.

Finally, by adding up all the newly calculated output flows from the Livestock breeding process it can be concluded that a total of 3,616.9 (manure) + 1,431.2 (livestock, milk, eggs) + 29.9 (deceased livestock) + 216.7 (export animals) = 5,294.7 t P fodder needs to be supplied to the livestock. Its source(s) will be discussed in section 7.7.3

7.7.3 In vitro meat production process

As calculated from section 7.7.2, a total of 664.6 t P In vitro meat needs to be supplied to the Processing process. The new Export animal products flow became 1,171.1, which is only marginally smaller than the one in the Trend MFA (1,172.8 t P). The difference of 1.6 t P can be attributed solely to the production of wild, horse, sheep, and goat meat which was not processed in the case area. Therefore, a total of 664.6 + 1.6 = 666.2 t P meat has to be produced through In vitro in order to maintain the same production levels. In that case the 1.6 t P will join the Export animal products flow.

Following the In vitro meat production characteristics described in section 7.7.1, for the production of 666.2 t P In vitro meat a total of 2,664.8 t P algae need to be grown which require 2,664.8 t P diammonium phosphate. Algae nutrient conversion efficiency is assumed to be 100%. The other source of algae nutrients, urea, does not contain any phosphorus and is omitted from the assessment. After algae sterilization and hydrolyzation 1,332.4 t P algae biomass is fed to the muscle cells, and the other 1,332.4 t P leaves the process as residual biomass. Given that algae can serve as a protein-rich food source for livestock, this flow is rerouted to the Livestock breeding process. Finally, from the amount of biomass supplied to the muscle cells half is converted to cultured meat (i.e 666.2 t P cultured meat), and the other 666.2 t P meat waste generated goes to the Incineration process.

By reusing the algae residual biomass as input for the Livestock breeding process, the remaining feed requirement is 5,294.7 - 1,332.4 = 3,962.3 t P. Although this could be provided through Forage alone, during energy extraction from Energy crops a total of 2,321.4 t P rapeseed residue is generated and subsequently fed to livestock in the Trend MFA. Because the rapeseed residue will be produced anyway, it is assumed that this fodder will be given to livestock before Forage. As such, only an additional 3,962.3 - 2,321.4 = 1,640.8 t P Forage is required to feed the livestock. In this case a total of 4,725.7 (feed crops) - 2,321.4 (rapeseed) = 2,404.3 t P feed crops are made redundant. This redundant share of the feed crops was accompanied with 709.3 t P straw, and an additional (2,404.3 +

709.3) / 18,280.1 x (119.6 + 27.2) = 25.0 t P seeds and related straw no longer need to be produced. Then, the new Crops flow becomes: 18280.1 (crops+straw) - 2,404.3 (feed crops) - 709.3 (feed crop straw) - 25.0 (seeds+straw) = 15,141.5 t P, and the new Forage flow becomes 1,640.8 t P.

Entering the abovementioned parameters into the model results in an increase of required Mineral fertilizer from 6,134.2 t P to 6,511.5 t P (+6.2%), as well as an increase in Landfill stock change from +2,617.0 t P to +3,208.0 t P (+22.6%). Furthermore, erosion has decreased from 1,051.1 t P to 787.3 t P (-25.1%), and the Fodder import flow became 0 t P. While Fodder imports have been reduced by 4,153.4 t P, there is 2,664.8 t P diammonium phosphate import required for the production of algae and cultured meat.

7.8 Mephrec process, macerators and algae treatment

The Mephrec process can be seen as the most important solution featuring the waste treatment sector in the Techno-fix vision. This process is capable of extracting phosphorus from virtually any (waste) stream provided that its water content has been greatly reduced (Kabbe, 2014a, pers. comm.). However, the process was designed to retrieve phosphorus from sources containing pathogens, hormones, and heavy metals, such as deceased animals and sewage sludge. According to Scheidig et al. (2010) the process is capable of extracting 80% of the phosphorus input into the process. The other 20% are assumed to be landfilled, and the efficiency of the Mephrec process is assumed to be similar for every waste stream fed to it.

A technology that can be expected to function well in combination with the Mephrec process is the macerator, which would revert the biowaste from consumption to wastewater, and hence to sewage sludge. The Mephrec process can then extract fertilizer from the sludge containing additional biowaste. Finally, effluent can be treated with algae as a last cleaning step. The latter treatment will be discussed in section 7.8.3.

Althought in the model the Biowaste consumtion flow can be directly fed to the Mephrec process, for the Techno-fix vision it is assumed that this is not feasible. In practise the efficiency and feasibility of the Mephrec process will depend on the phosphorus concentration in the waste stream. Given that people will only very limitedly change their routines in the Techno-fix vision, still a significant amount of biowaste will still not be separated and end up in the residual waste which has a very low phosphorus concentration. Therefore the installment of macerators in households is deemed more favourable for the Techno-fix vision.

Biowaste streams from the processing industry and retail will probably have a higher phosphorus concentration than (bio)waste from consumption, and could serve as input to the Mephrec process. However, given the likely very low levels of pathogens and heavy metals in these streams it would be more favourable to digest them, which process yields a far higher efficiency (virtually 100%). The impact of this solution on the model is treated in section 7.8.2.

7.8.1 Mephrec process

For the solution assessment the effects of feeding individual waste streams to the Mephrec process are assessed, as well as their combinations. The individual streams modelled are the following; sewage sludge only, sewage sludge + macerators, and slaughterwaste + deceased animals. Modelling the effect of macerators in combination with slaughterwaste + deceased animals to Mephrec is not performed as the addition of the macerator only functions when the sewage sludge is also treated in the Mephrec process. The impact of the different configurations on Landfill stock change, Fertilizer derived from the Mephrec process, and the required Mineral fertilizer imports is summarized in Table 20. The 'Mephrec all + macerator' category not only entails waste from animal husbandry, and the enlarged sewage sludge flow, but also wood waste (from consumption) and wood to incineration (from natural vegetation).

Table 20: Effect of different waste streams fed to the Mephrec process.

	Landfill stock change [t P]	**Mephrec to fertilizer [t P]**	**Mineral fertilizer import [t P]**
Trend MFA	+2,617.0	0	6,134.2
Mephrec sludge only	+1,287.1	2,152.3	4,288.3
Mephrec animal waste only	+2,818.2	1,224.7	4,909.4
Mephrec sludge + animal waste	+1,488.2	3,377.0	3,063.5
Mephrec sludge only + macerator	+892.5	2,501.1	3,939.4
Mephrec all + macerator	+1,025.4	3,794.0	2,646.5

7.8.2 Digestion of retail and processing waste

The phosphorus conversion before and after the digestion of the retail and processing waste is, similarly to Energy crop digestion, assumed to be 100%. Digestion of both biowaste streams then yields 40.74 + 96.15 = 136.89 t P digestate which is subsequently applied to agricultural soil. The required Mineral fertilizer import flow thereby decreases from 6,134.15 to 5,997.26 t P.

7.8.3 Effluent treatment with algae

Effluent can be treated with algae, whereby nutrients are extracted by algae from the waste water before release to the environment as effluent. The algae could then be filtered out and possibly be used in other applications. Although not a mainstream technology, its first applications already date from the late 1950s (Hoffmann, 1998). According to Hultberg et al. (2013) nutrients in a nutrient solution used in (closed-loop) greenhouses can be removed by algae with an efficiency ranging from 60 to 100%. Although an effluent stream will be larger and have a different composition than a nutrient solution, the removal efficiency is assumed to be the same, taking the median of 80%. For the present assessment it is assumed that the algae produced are being exported, mainly because stock addition will be used later on as indicator for system efficiency.

In the Techno-fix vision the only source of variation regarding the size of the Effluent flow is the inclusion and exclusion of macerators. With the addition of macerators the Wastewater flow will be larger and induce a higher Effluent stream. The results of this modification to the model can be viewed in Table 21.

Table 21: Effect of effluent treatment with algae.

	Effluent input [t P]	**Effluent output [t P]**	**Algae production [t P]**
Excl. macerators	269.7	53.9	215.7
Incl. macerators	313.4	62.7	250.7

7.8.4 Integration

Have the individual solutions for the waste treatment sector treated, it can be assessed what their integrated effect on the model would be. For the integration it is assumed that also wood waste (76.1 t P) from the Consumption process is fed to the Mephrec process. Wood waste is often contaminated (e.g. paint) and therefore cannot be composted or digested. This change would deprive the Garden fertilizer output from the Biowaste collection + composting process from its necessary input. To maintain Garden fertilizer production within the system, it is assumed that a part of the Plant prunings will be digested to Garden fertilizer. In effect, the Plant prunings digestate flow to agriculture is reduced to 30.1 t P.

In the new integrated situation the Collected biowaste flow is reduced to 0, and the waste from the Mephrec process (946.7 t P) together with incineration ashes from the Wood to incineration flow (9.2 t P) result in +955.9 t P landfilled phosphorus.

The fertilizer produced through the Mephrec process amounts to 3,786.7 t P, and the digestate from Biowaste processing + retail remains to be 136.9 t P. Taken together the recycled fertilizer potential is 3,923.6 t P (without Plant prunings digestate), but it has to be kept in mind that the Plant prunings digestate flow is reduced by 60.0 t P. Consequently, the required mineral fertilizer import is reduced to 2,576.9 t P, a 58.0% reduction compared to the Trend MFA.

Interestingly, the integration without changing the fate of the wood flow (and hence Plant prunings digestate) would lead to an addition of only 0.8 t P extra imported mineral fertilizer. Although the gain is very small, the solution is more realistic as one is hardly able to produce Garden fertilizer with wood waste.

Regarding effluent treatment the situation with macerators included still applies when the solutions become integrated. These results are shown in Table 21.

7.9 Organic farming

Organic farming techniques are generally known to yield lower harvests compared to conventional agriculture. On the positive side, soil properties of organically farmed soils are often better which, provided that the farm is adequately managed, would result in less erosion taking place.

Unfortunately, the actual trials and research efforts made to compare organic agricultural techniques with conventional agriculture are sparse. One major difficulty is that the effect of farming techniques on the soil (and yield) can only be properly measured in long-term field trials. The only study found comparing erosion taking place from organic and conventional farming techniques was performed by Reganold et al. (1987). In their 21-year-trial erosion of organically farmed soil amounted to 8.3 t/ha and that of conventionally farmed soil 32.4 t/ha. Unfortunately, phosphorus in the erosion was not measured. For the model it is therefore assumed that the phosphorus concentration in erosion from both soils is equal, using the ratio to calculate the erosion originating from organic farming.

Related to yields, the study of Reganold et al. (1987) also compared winter wheat yields which on average amounted to 4.50 t/ha for the organic farm and 4.90 t/ha for the conventional farm. In addition, Hepperly et al. (2006) compared corn yields from an organic animal-based system, organic legume-based system, and a convention system as part of a Rodale field trial of 5 and 20 years, respectively. For the current assessment the winter wheat and corn yield differences are used to calculate the yield in the model. As both wheat and corn are grown in large quantities in Brandenburg the data should adequately represent the impact of a transition to 100% organic farming.

From the literature data ratios of erosion and yield between organic and conventional farming were first calculated, as depicted in Table 22. Then, using the 10.6% share of organic farming plots in Brandenburg (Wimmer et al., 2012), the Trend MFA erosion and yields were calculated for organic farming and conventional farming. These were subsequently extrapolated to match the vision demand of 100% organic farming. The input parameters and the most interesting changed flows can be viewed in Table 23. Taking into account the current share of organic farming plots in Brandenburg, the multiplier for all yields becomes 0.8466 and that for erosion 0.2781.

Table 22: Literature data used to calculate erosion levels and yields for 100% organic farming.

	Erosion [t/ha]	**Winter wheat yield [t/ha/yr]**	**Corn yield [t/ha/yr]**	**Average yield [t/ha]**
Conventional farming	32.4	4.90	5.903	
Organic farming	8.3	4.50	4.222 and 4.743	
Ratios	**0.256**	0.918	0.759	**0.831**

Table 23: Input data and main output data for 100% organic farming.

	Trend [t P]	**Vision [t P]**	**Difference [%]**
Input data	*10.6% org. farm.*	*100% org. farm.*	
Erosion	1,051.08	292.3	-73.2
Crop production	18,280.1	15,476.0	-15.3
Forage production	4,125.0	3,492.2	-15.3
Output data			
Fodder import	4,153.4	5,511.0	+32.7
Import fertilizer	6,134.2	3,131.8	-48.9

7.10 EcoFerm!

Within the EcoFerm! concept (Van Liere et al., 2011) manure from livestock breeding is used to produce algae on-farm, which are subsequently fed to the livestock again. This concept thereby presents an promising, decentralized way to close the nutrient cycle on the animal farm itself. In order to apply this concept in the model, the process steps related to phosphorus will be briefly explained and calculated, based on the Sustec route example as shown in (Van Liere et al., 2011, p. 96).

Within the example a total of 75.428 t P enters the process in the form of animal manure. The thick fraction is separated from the thinner watery fraction which flows contain 30.084 and 45.344 t P, respectively. Nitrogen is first stripped from the thin fraction and then using reverse osmosis relatively pure water and thickened brine are obtained. The 'pure' water still contains 0.436 t P and is fed to the livestock again. The brine containing the remaining 45.344 - 0.436 = 44.908 t P is then added to the orginal thick fraction which add up to 44.908 + 30.084 = 74.992 t P. This mixture is then digested after which again the thinner watery fraction (48.832 t P) is separated from the thicker fraction (26.16 t P). Lime milk is then added to the (2nd) thin fraction so that it precipitates with the phosphorus after which the sediment is extracted and a phosphorus-poorer thin fraction remains. The phosphorus-poorer thin fraction still contains 17.004 t P and is added to the (2nd) thick fraction again to produce 26.16 + 17.004 = 43.164 t P fertilizer.

The sediment containing the extracted phosphorus is fed to the algae pond for the production of algae which are afterwards fed to the livestock to complete the nutrient cycle. The sediment should contain 48.832 (2nd thin fraction before lime milk) - 17.004 (2nd thin fraction after removal of sediment) = 31.828 t P. However, according to (Van Liere et al., 2011, p. 96) the algae only take up circa 24 t P, and no explanation is given about this imbalance and the fate of the remaining 7.828 t P. Yet, the authors do note that whereas phosphorus is sufficiently available to the algae, there exists a nitrogen shortage. It is therefore plausible that the phopshorus in the algae pond accumulates and that the excess phosphorus is drained as the pond water is refreshed.

7.10.1 Impact on the model

For the model it is assumed that the EcoFerm! concept will be perfected towards the year 2060, and that the problem with nitrogen shortages for algae growth is no longer present. In that case all the phosphorus will be converted to algae biomass. For the model it is then assumed that out of the 100% (75.428 t P), 57.22% (43.164 t P) fertilizer, 42.20% (31.828 t P) algae fodder, and 0.58% (0.436 t P) drinking water for the livestock are produced.

The input and output of the EcoFerm! application in the model, modelled as one process, can be seen in Table 24. The manure flow originally flowing completely to agricultural soil became partially rerouted towards the Livestock breeding process. This results in a larger required Fertilizer import flow of 10,046.5 t P (63.8% increase), and a significantly reduced Fodder import flow of only 241.0 t P (94.2% decrease).

Table 24: Input data and main output data from EcoFerm! process.

	Size of flow [t P]
Input	
Manure	9,146.4
Output	
Fertilizer	5,234.1
Algae	3,859.5
Purified water	52.9

7.11 Vegetarism and veganism

7.11.1 Parameters

As mentioned in section 5.3.3, out of the total German population about 8.5% of the people live a vegetarian lifestyle, of which 10% are vegan. Thus, 7.65% of the people live as vegetarians, and 0.85% as vegans. The same percentages are assumed to apply to the Trend MFA. Assuming that people still consume the equal amounts of phosphorus, the diets of people with a regular diet, vegetarians, and vegans were calculated based on the phosphorus consumption per food category as explained in Chapter 4. The calculated annual amounts of phosphorus consumed per diet are shown in Table 15.

For Culture-fix it is assumed that by 2060 67.5% of the population is vegetarian, and that 7.5% of the people are vegan, such that a total of 75% of the people refrain from eating meat. Using Table 15 as a basis, the total amount of phosphorus consumed per type of food (i.e. plant, milk/egg, meat) was calculated for the Trend MFA, and for Culture-fix. The results are summarized in Table 25. Here it should be kept in mind that food is not only reaches the people via retail, but also via hobby fishing, private produce, and hunting. Therefore, the total amount of food consumed was first calculated, and afterwards the increases and decreases of the food categories was calculated for the purchased food flow. Thereby the amounts of food acquired via hobby fishing, private produce, and hunting was kept equal.

Table 25: Calculated amounts of phosphorus consumed per food category for different scenarios in Berlin-Brandenburg.

	Consumption Trend MFA [t P]	**Consumption Culture-fix [t P]**	**Culture-fix purchased food [t P]**	**Factor**
Consumed meat	810.5	221.4	214.0	0.266
Consumed milk/egg	1,197.9	1,324.1	1,324.1	1.105
Consumed plant	1,779.3	2,242.1	2,228.1	1.262
Total	**3,787.6**	**3,787.6**	**3,766.2**	

7.11.2 Vegetarism and veganism: Supply-driven

As can be concluded from Table 25, the increase in vegetarism and veganism leads , besides a reduction in meat consumption, not only to an increase in plant-based consumption but also to an increase in milk and egg consumption. When only applying the changes in to the purchased food flow, only differences in the sizes of Import retail and Processed food flows will become visible as the amounts of food processed remain equal. Changing the Trend MFA as such, the new Import retail flow increases from 2,128.2 t P to 2,450.4 t P and the Processed food flow decreases from 1,675.5 to 1,353.3. With similar amounts of food processed, the Export processing flow increases accordingly from 1,112.7 to

1,434.5 t P.

Essentially, through assessing vegetarism supply-driven, the relationships between the Berlin-Brandenburg retailing, and the internal and external food processing systems have changed while all other processes and flows have remained the same. In order to capture the actual potential of vegetarism, the system is modelled in a demand-driven way, as explained in the next section.

7.11.3 Vegetarism and veganism: Demand-driven

Although the analysis is performed with Berlin-Brandenburg as case area, mindset changes as envisioned in Culture-fix will certainly not be an isolated phenomenon. One can imagine that Germany as a whole, and large parts of Europe will likely undergo similar mindset changes. Thereby also the amounts of food produced and processed will be affected accordingly. As such, for the influence of vegetarism and veganism as modelled in the Culture-fix vision (i.e. demand-driven), the factors shown in Table 25 have not only been applied to the Purchased food flow, but also to the meat and milk/eggs produced and processed. Milk- and egg-related animals and related flows (e.g. manure, slaughter waste) were adjusted with the factor for milk/eggs (i.e. 1.105), and the same was done for animals reared for meat with the factor for meat (i.e. 0.266). As for meat and milk/eggs, also crop processing has been scaled up (i.e. 1.262), whereas crop production was kept the same as the available land for crop production will not increase.

Adjusting the Trend MFA accordingly, it turns out that the Imported fodder flow becomes negative. To balance this out, it is assumed that the Forage flow reduces, and not the Feed crops flow. Resulting reductions in erosion from Agricultural soil processes were applied as being linearly depending on the throughput. The most interesting flow changes can be viewed in Table 26.

The comparison shows that the efficiency of the cycle barely increases due to shift to vegetarian and vegan diets. The amount of slaughterwaste generated is significantly reduced, but this also applies to the amount of manure produced and recycled. The formers was counted as waste [D] and the latter was used to calculate the size of the internal material cycle [M]. When applying the formula [1-(D/M)] to calculate the cycle efficiency, both decreases largely cancel each other out. More information about the calculation procedures regarding the cycle efficiency can be found in section 7.15.

Table 26: Comparison of results found during a demand-driven impact assessment of a shift to vegetarism and veganism.

Flow	**Trend MFA [t P]**	**Culture-fix [t P]**	**Trend diff. [%]**
Fertilizer import	6,134.2	8,821.5	+43.8
Manure	9,146.44	5,472.3	-40.2
Erosion agriculture	1,051.1	1,006.9	-4.2
Forage	4,125.0	3,182.5	-22.8
Fodder import	4,153.4	0	-100
Livestock, milk, eggs	3,007.5	1,942.3	-35.4
Slaughter waste	1,425.9	406.6	-71.5
Crops to processing	934.2	1,169.0	+25.1
Animal products	846.7	372.2	-56.0
Processed food	1,675.5	1,451.3	-13.4
Total import	13,937.0	12,409.5	-11.0
Total export	9,332.4	7,875.5	-15.6
dStock	4,604.6	4,534.0	-1.5
Cycle efficiency [1-(D/M)]	80.7	81.0	+0.4

7.12 Separating vacuum toilets, reduced biowaste, and digestion

First the influence of the sole introduction of vacuum separating toilets is assessed, followed by an assessment of the effect of reduced biowaste production and enhanced biowaste separation. Finally, the combined impact is assessed.

Whereas separating vacuum toilets and digestion mainly alter the route of waste flows within the MFA, reduced biowaste production at the consumer level will likely lead to less purchased food. Similarly to vegetarism, if this takes place on a large scale the whole supply chain will also be affected as well. For the individual solution assessment this is assumed not to be the case, thereby maintaining the throughput of food processing and crop and animal production processes. As less food will be purchased, the Retailing process is nevertheless changed.

7.12.1 Vacuum separating toilets

In the Culture-fix vision the urin (yellowwater), faeces (black- or brownwater), and other household water streams (greywater) are separated at the source, the household and office. Peter-Frohlich et al. (2007) conducted a trial in Berlin and Brandenburg with two different sanitation concepts; vacuum separation toilets and gravity separation toilets in offices, and only gravity separation toilets in households. The results showed that whereas vacuum toilets performed a full separation of urine and faeces, the gravity separation toilets were only able to retain 50% of the faeces due to technical problems. Therefore, only vacuum toilets are adopted in the vision.

According to Otterpohl et al. (1999, cited in (Peter-Frohlich et al., 2007)), the phosphorus present in the three streams is divided as follows: greywater (10%), yellowwater (50%), brownwater (40%). However, it is likely that the ratio of greywater calculated by Otterpohl et al. (1999) still contains phosphorus from detergents, which stream has been eliminated from the Trend MFA. For the solution assessment it is therefore assumed that the only source of phosphorus in greywater is biowaste disposed of through the sink. This fraction of the biowaste is estimated at 10.68% of the total biowaste (household + large users) (Kranert et al., 2012), amounting to 64.7 t P in the Trend MFA. In doing so, phosphorus orginating from the human body (e.g. hairs) is neglected. The remaining amount of phosphorus orginating from urin and faeces in the wastewater was calculated using the 50 : 40 ratio, respectively. The latter wastewater flow also includes wastewater (previously) treated in Poland, as separating toilets make wastewater transportation redundant.

Following the trial of Peter-Frohlich et al. (2007), the greywater is led through a constructed wetland after treatment with a membrane bio-reactor and septic tank. In the constructed wetland the phosphorus is taken up by plants, resulting in an addition of stock to this process. For simplicity reasons and because stock addition will be later used to determine system efficiency, it is assumed that the plant biomass is exported. The yellowwater is treated in a urine tank and the blackwater is treated in a thermophile biogas plant. Both processes yield a (theoretical) 100% conversion to fertilizer applicable on agricultural soils (Peter-Frohlich et al., 2007). When adapting the model as described, it provides the results as described in Table 27. It is important to note that the MAP recycling and Sludge to agriculture, as well as Effluent have been made obsolete due to the seperation toilets.

Table 27: Results of simulating seperating toilets only.

	Streams [t P]	**Fertilizer potential [t P]**	**Remaining fertilizer requirement [t P]**
Greywater	64.68	0	6,440.5
Yellowwater	1,615.6	1,615.6	4,824.9
Blackwater	1,292.4	1,292.4	5,148.1
Combined	**2,972.7**	**2,908.0**	**3,532.5**

7.12.2 Biowaste digestion and reduced biowaste production

Kranert et al. (2012) found that 35% of the biowaste produced is unavoidable, 18% is partly-avoidable, and 47% is avoidable. These percentages apply to biowaste actually thrown in the waste bin, as well as the total amount of biowaste produced (e.g. including pet feeding, private composting, etc.). For the solution assessment only the 47% avoidable biowaste is taken into account because the partly-avoidable biowaste is unambiguous. It is assumed that the 47% savings apply to the total amount of biowaste generated, and that a reduction of the biowaste fed to pets and composted for private use does not lead to higher pet food and garden fertilizer consumption.

Furthermore, for the model it is assumed that the amount of pet food purchased remains the same. The potential reduction of pet food waste is probably very low as pets generally have a monotone diet (i.e. less spoiled pet food), and usually eat everything served.

As such, the (non-wood) biowaste from household and large users, (non-pet-)food to pets, private compost, and biowaste to sewage are subject to the 47% decrease in waste. The total waste decrease is thereby 284.6 t P, from which it follows that the purchased food flow becomes 3,766.2 - 284.6 = 3,481.6 t P; a 7.6% decrease. The Biowaste retail flow is being modelled as having a linear relationship to the throughput, except for Commercial fish waste (0.138 t P, fixed variable), and becomes 37.7 t P. Biowaste from processing is unaffected as the throughput remains the same, whereas Export processing increases and Processed food (to Retail) decreases. The results are summarized in Table 28. In interpreting the results it is important to keep in mind that only food waste decreases. As such, the wood waste of 76.1 t P contained in the Biowaste consumption flow remains unaffected. Similarly for the Pet excrements flow, only the share of food waste that is fed to pets decreases, and not the pet food purchased.

Table 28: Impact of eliminating avoidable food waste (-47%) on the Trend MFA model.

	Trend MFA [t P]	**Culture-fix [t P]**	**Change [%]**
Export processing	1,112.7	1,194.7	7.4
Processed food	1,675.5	1,593.4	-4.9
Purchased food	3,766.2	3,481.6	-7.6
Biowaste consumption	557.9	332.1	-40.5
Biowaste retail	40.7	37.7	-7.5
Pet excrements	238.5	234.5	-1.7
Private compost	50.6	26.8	-47.0
Waste water	2,960.0	2,929.0	-1.0
Wastewater treated in Poland	12.7	12.6	-1.0
Collected biowaste	634.8	406.0	-36.0

7.12.3 Reduced food waste, biowaste recycling, and separating toilets

In this section the influence of the system improvements of the previous two sections complemented with biowaste recycling will be discussed. It is assumed that all the collected biowaste is recycled with 100% efficiency into fertilizer applicable to agricultural soil. The size and fate of Garden fertilizer flow is maintained.

Combining these solutions mainly features a change in the Greywater flow (i.e. food disposed via waste water) and hence stock addition to the Constructed wetland, which has been reduced by 47% to 34.3 t P.

The amounts of fertilizer produced through treatment of urin and faeces remains the same as no changes have taken place in excretion; 2,907.3 t P. The Collected biowaste flow previously flowing to Incineration contains 406.0 t P, which taken together results in a total of 3,313.3 recycled phosphorus. This in turn reduces the Mineral fertilizer imports from 6,134.2 t P in the Trend MFA to 3,127.3 t P, a

49.0% decrease. Interestingly, with most of the previously incinerated waste flows recycled, the stock change of the Landfill process has been reduced from +2,617.0 t P in the Trend MFA to only +114.2 t P. In interpreting the latter figure, it should be taken into account that also in the integrated waste treatment system, still an additional 1,425.9 t P slaughterwaste is exported.

Furthermore, due to the biowaste reduction Seepage from Urban soil metabolism is reduced from 150.0 t P to 128.0 t P, while stock added reduced from a surplus of 188.7 to a surplus of 161.1. The stock surplus to Surface waterbodies thereby becomes 1,462.1 t P.

7.13 Discussion: Solution comparison

In this section the solutions discussed earlier are compared with one another, providing an overview in Table 29. In doing so, the solutions for crop and animal production are compared on an individual basis, whereas the solutions for the waste subregimes are compared in an integrated matter. The results from the introduction of vegetarism (demand-driven) were already given in section 7.11, and will be briefly discussed in this section.

7.13.1 Crop production

For Techno-fix the production of energy crops with the exception of rapeseed travelling to Livestock breeding was made obsolete. The effect this had on the Crops flow is stronger than did the transition to 100% organic farming as part of Culture-fix, which also results in lower yields. Particularly for export from crop production, the conversion to organic agriculture would result in a far reduced Export agriculture flow; a 18.2% decrease compared to Techno-fix and the Trend MFA. Because overall food and fodder crop production is lower in Culture-fix, it needs to import more fodder as well (32.7% increase).

Although crop production in Culture-fix is lower, as well as erosion from soils, in Techno-fix a lower total erosion from agricultural soil is realized, which is solely due to the zero erosion from vertical farming. In addition, grasslands can be seen as permaculture systems as these have permanent plant presence. In reality the erosion from those soils will be significantly lower than for crop production soils, whereas in the assessment it was assumed that erosion for all agricultural soils is equal. Taking this into account, the particularly the Techno-fix solutions cause far lower phosphorus losses to the environment, while being able to maintain food production. Here the Techno-fix solutions can thus be seen as being far more efficient to the Trend MFA and Culture-fix solution.

Nevertheless, with regards to fertilizer requirements, the superior efficiency of Techno-fix does not balance the needs of a higher food production compared to Culture-fix. As such, also with extra fodder import requirements Culture-fix can be seen as the more independent crop production system, and Techno-fix as the most efficient crop production system.

7.13.2 Meat production

Through the introduction of EcoFerm! in Culture-fix the actual efficiency of the livestock breeding and slaughting, milking processes has remained unchanged. Rather, the Manure flow has become rerouted, now largely replacing the Import fodder flow which has thereby decreased by 94.2%. EcoFerm! can therefore not be seen as a solution towards enhancing the phosphorus cycle per se, but it does make the farmer far less dependent from international fodder price changes. And although not noticable in the regional system, externally less erosion from fodder production will take place.

In vitro meat production can be seen to be the by far more efficient solution as 48.1% less meat and animal-related waste is produced while maintaining equal meat, milk, and egg production levels. And although Culture-fix still imports a small amount of fodder (241.0 t P), its fertilizer import requirements are higher compared to Techno-fix (9.5% decrease), thereby also taking into account the diammonium phosphate required for in vitro meat production. Required fertilizer imports in the Trend MFA are lowest, but there the Fodder import flow is far higher. These import flows combined equal in size for the Trend MFA and Culture-fix, and are slightly lower in Techno-fix (10.8% decrease).

Interesting to note is that the EcoFerm! can coexist with In vitro meat production, converting only the manure of milk and egg producing livestock.

7.13.3 Consumption

The only solution assessed for the Consumption system is vegetarism and vegansim as part of Culture-fix, with the results summarized in Table 26. Consumer biowaste reallocation (i.e. macerator) and reduction also take place in the Consumption subregime, but are seen as solutions belonging to the waste recycling system. In this section only demand-driven vegetarism and veganism will be discussed as the supply-driven way does not yield changes internal to the system.

A shift to vegetarism and veganism results in a higher demand for crops, milk, and eggs, and a lower demand for meat. Overall, the animal production sector shrinks significantly, resulting in a 40.2% decreased Manure flow and a with 35.4% decreased Livestock, milk, eggs flow. As the Feed crops flow remained unchanged, less Forage was required (22.8% decrease) while Fodder import was made redundant. As less Forage is required, required fertilizer imports are reduced in this respect, but these increase overall with 43.8% as far less Manure is supplied to the soil. On the brighter side, a reduction in Forage will result in less erosion from agricultural soils (4.2% decrease), while it should again be noted that grasslands generally cause less erosion than crop lands do.

While Animal products delivered from Slaughting, milking to the Food processing decreases in size dramatically (56.0% decrease), the Crops to processing flow moderately increases (25.1% increase). Also in absolute numbers the reduction in Animal products is higher as the increase in Crops to processing (474.5 t P decrease versus a 234.9 t P increase). Because in the Trend MFA the total share of meat processed was relatively high (33.1%) and its decrease far larger than the increase of crops processed, the total amount of food processed decreases with 7.6%. Due to individual demand-supply relations between the food categories of food processed and food purchased, the Processed food flow decreases comparatively more with 13.4%.

Furthermore, the Biowaste processing flow increased from 96.2 t P to 121.7 t P (27.9% increase). This is due to choices made in the original modelling of the MFA. Here it was assumed that all meat biowaste takes place in the Slaughting, milking process, and thereby that meat is not represented in Biowaste processing, while compensating for the total amount of biowaste originating from Food processing.

Finally, looking at the overall system's improvements, when relating the throughput to the stock added to the system it turns out that the system effeciency decreases from 67.0% to 63.5%. However, that method did not account for the waste exported, while in the Trend MFA especially the Slaughterwaste flow is still very large. When also incorporating waste exported to stock added as inefficiency of the system, the Trend MFA efficiency reduces to 43.4%, while Culture-fix efficiency reduces slightly to 60.1%. As such, when also accounting for the waste exported, a diet shift to vegetarism and veganism greatly improves the system.

Yet, Slaughtwaste as a major unrecycled waste flow makes the results more extreme. If this flow were to be recycled with the Mephrec process in both MFAs, the efficiency differences would become smaller. Except from the improvements regarding Slaughterwaste export, the total stock added decreased by only 70.7 t P (1.5% decrease), through the combination decreased soil erosion and deceased animal and increased Biowaste processing. The Trend MFA is initially calculated as more efficiently because in Culture-fix the throughput is reduced by 1,527.6 t P, for which the decreased Slaughterwaste flow is mainly responsible.

As such, vegetarism and veganism do improve the system, but it strongly depends on the efficiency indicator used how great the gain actually is.

7.13.4 Waste recycling

The integrated solutions for the waste treatment subregime in both visions result in large (recycling) improvements compared to the trend. In the Trend MFA, Culture-fix, and Techno-fix the efficiencies of the waste treatment systems are 8.7%, 80.9%, and 66.7%, respectively. Required fertilizer imports decreased by 58.1% for Techno-fix and slightly less by 47.1% in Culture-fix. Losses to surface waters are also slightly lower in Culture-fix (lower in Culture-fix (6.2% decrease) because the vacuum separation toilet system does not lead to effluent release, and because less biowaste applied to urban soils leads to less erosion. Note that the latter erosion reduction is not included in the determination of waste treatment system efficiency.

Yet, overall far less stock is added to the system in Culture-fix, which is mainly due to the unchanged fate and size of Slaughterwaste (1,425.9 t P). In Techno-fix this flow in addition to Deceased livestock and wood wastes are treated, leading to higher landfill stock added as well as a higher total recycling and lower fertilizer imports. The overall efficiency is therefore also lower for Culture-fix. Whereas the vacuum separating toilets present a far superior solution compared to Techno-fix and certainly the trend, its potential is somewhat clouded by the absence of solutions recycling the other waste flows.

As such, vacuum separating toilets in combination with the Mephrec process for the other waste flows would result in the highest efficiency gains, as well as lowest landfill and surface water stock added. The Mephrec process is thus both symbiotic and competitive with vacuum separating toilets.

7.14 Solution integration into the visions

The final MFAs of Techno-fix and Culture-fix, featuring all the previously-mentioned solutions can be viewed in Figures 12 and 13, respectively. The assumptions made for the individual solutions were also applied in the vision MFAs and will therefore not be treated further. Additional choices and assumptions made, as well as the main vision MFA characteristics, are discussed in the following sections.

7.14.1 Techno-fix

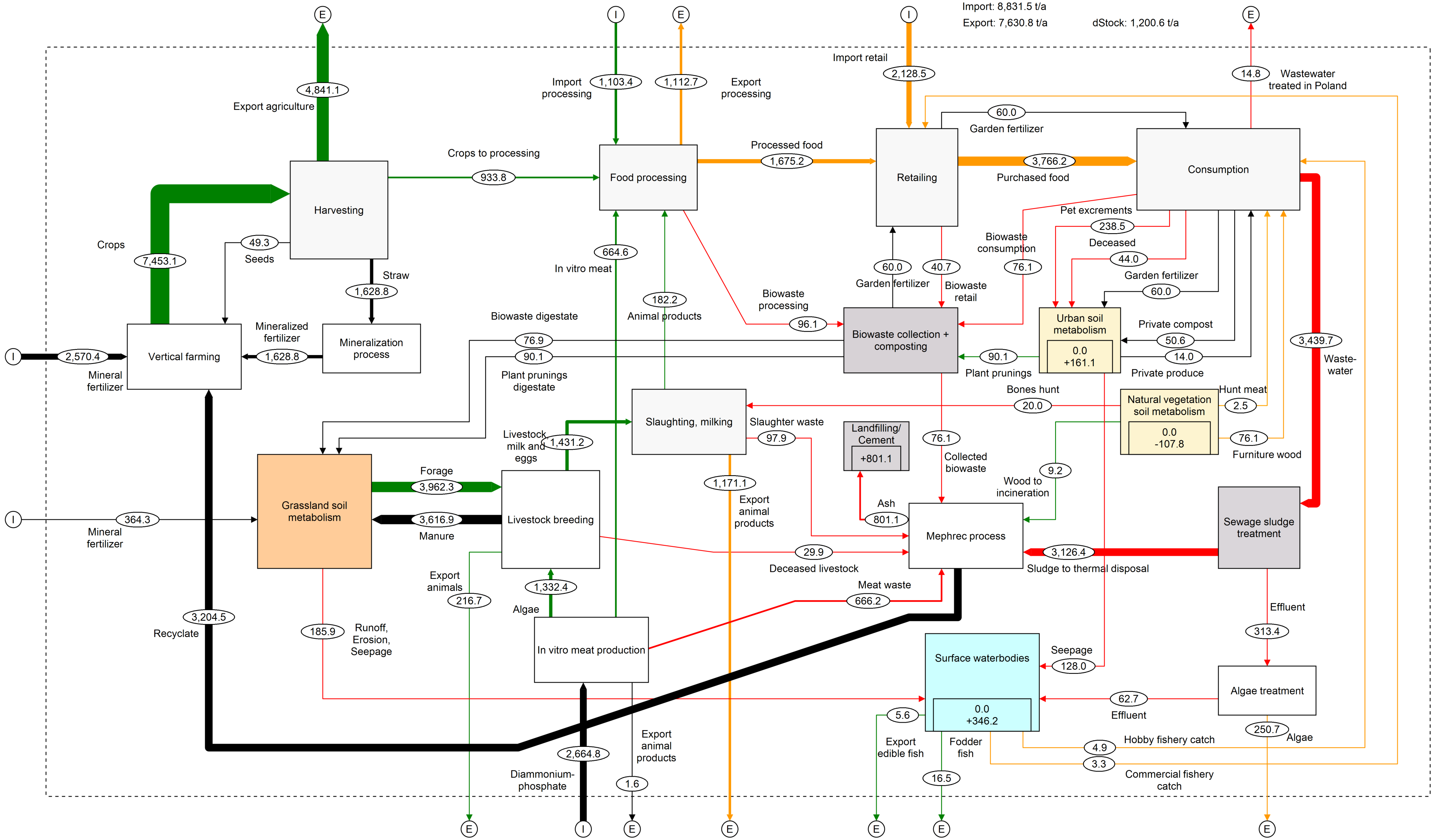
The required fodder for the remaining livestock will be supplied by Forage from the grasslands, which is sufficient (3,962.3 t P). Assuming a linear relationship with the erosion and throughput of the Grassland soil metabolism results in 185.9 t P leaving the soils to the surface waters. As the livestock feeds on the grasslands, their manure will fertilize the soil again. As additional required sources of fertilizer the Plant prunings digestate (90.1 t P) and recycled and digested biowaste from processing and retail was chosen as these flows will have a high carbon content, thereby improving the soil structure. The latter flow amounts to 76.9 t P after substraction of Garden fertilizer (60.0 t P). Closing the process balance, another 364.3 t P will need to be imported as (mineral) fertilizer.

Because livestock fodder requirements have been reduced drastically due to the introduction of in vitro meat production, feed crop production in addition to energy crop production became redundant. The Crops flow, entailing only food crops and related straw, thereby reduced to 7,453.1 t P. In doing so, also the required seeds and related straw was taken into account while assuming a linear relationship between crops + straw and the required seeds. Straw resulting from crop production in Vertical farming (1,628.8 t P) has a high carbon content, and could therefore be applied best to (grassland) soil, but is chosen to be first treated by a Mineralization process and recycled on-site instead. In addition to logistical benefits, the straw would far surpass the fertilizer requirements for the grassland soils.

The flows Slaughterwaste (97.9 t P), Deceased livestock (29.9 t P), Meat waste from in vitro meat production (666.2 t P), wood waste (76.1 t P), wood to incineration (9.2 t P) and Sewage sludge (3,126.4 t P) are all treated by the Mephrec process, resulting in a waste flow of 801.1 t P to Landfilling and a Recyclate flow of 3,204.5 t P. Because the Recyclate is already mineralized it is chosen as input for the Vertical farming process. Through the Algae treatment of Effluent (313.4 t P) the remaining Effluent flow became 62.7 t P and 250.7 t P Algae were produced which could be used as input for non-food production (e.g. bioplastics). The Algae flow is exported and seen as economical flow.

Additional required imported fertilizer became 2,570.4 t P for Vertical farming, 364.3 t P for Grassland soil metabolism, and 2,664.8 t P for In vitro meat production, which adds up to a total of 5,599.5 t P. In interpreting the data it should be taken into account that the Fodder import flow has been made obsolete.

Figure 12: Phosphorus flow chart of the Techno-fix vision.



Finally, because sludge is no longer applied to Urban soils and Natural vegetation soils the stock additions and phosphorus losses from these provesses change. The input to Natural vegetation soils vanishes altogether, and therefore it is assumed that no phosphorus losses take place, and that rather the soil stock becomes depleted. Similarly to the Trend MFA, the stock addition and seepage flow from Urban soils were kept in the same ratio, where both decreased in absolute terms.

7.14.2 Culture-fix

Contrary to Techno-fix, in Culture-fix several solutions affect the supply chain in its entirety. A shift to vegetarism reduced meat consumption and raised milk/egg and plant-based consumption, which was modelled to change food processed and livestock bred accordingly. The elimination of avoidable food waste led to lower Purchased food and Biowaste consumption flows, and was modelled to also reduce food processing and livestock breeding accordingly, while the transition to organic agriculture led to a reduced production of all crops. The throughtput of the Retailing process thereby decreased as a result of the reduced food demand related to the elimination of avoidable food waste, leading to a (linearly) lower Biowaste retail flow. The throughput of Food processing, on the other hand, increased overall; the increase of a higher demand for milk/egg and plant-based food was not offset through reduced meat demand and a reduced overall food demand. The Biowaste processing flow increased accordingly.

The concept of direct marketing was introduced in Culture-fix, which was not treated during the individual solution assessment. Although direct marketing will not improve the phosphorus cycle itself, it is nevertheless seen as an important part of the Culture-fix narrative and therefore included in the final vision MFA. The same holds for urban agriculture, but this concept was not included due to insufficient data availability (e.g. yield, contamination of urban soil, over-fertilization).

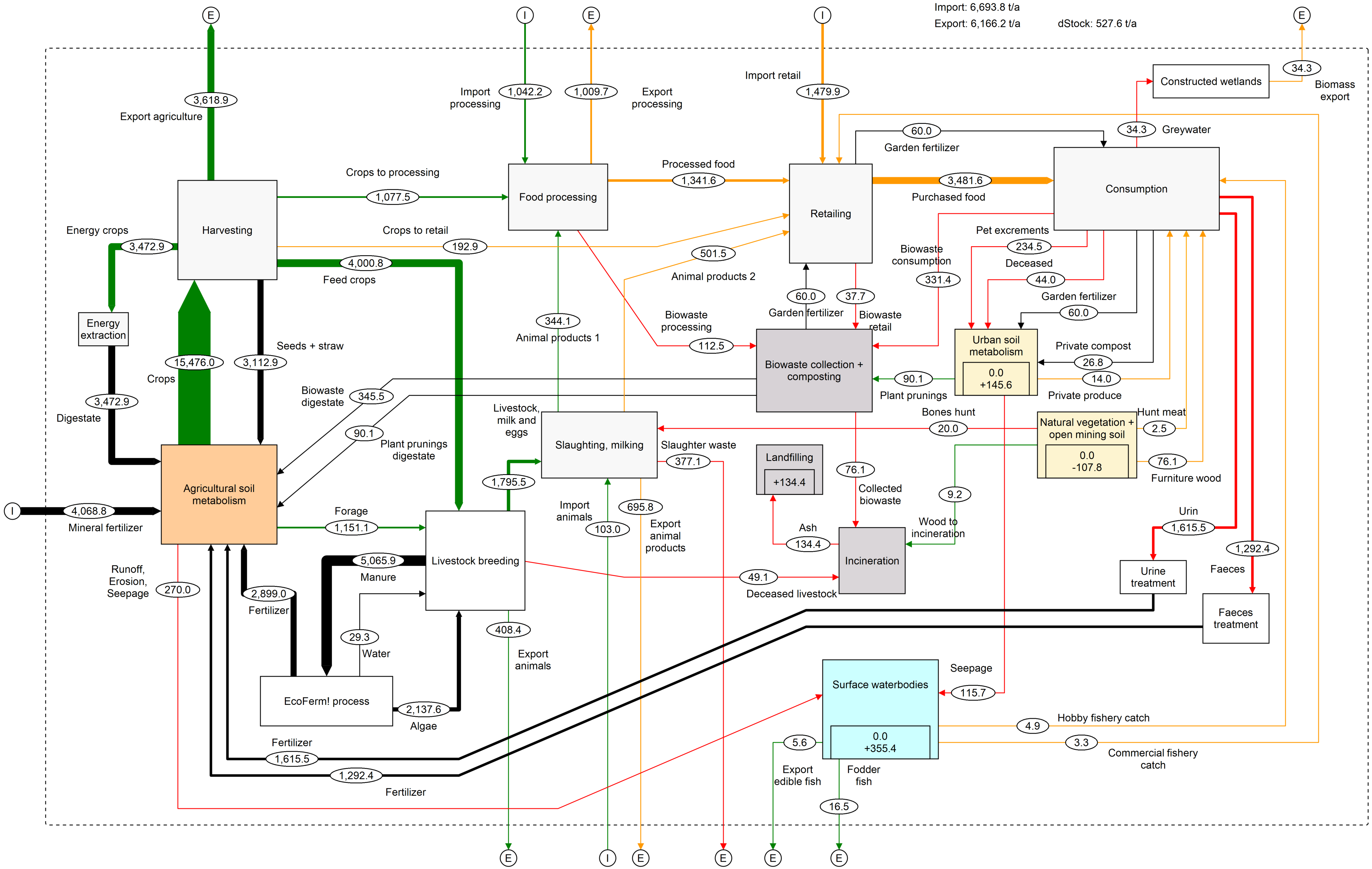
Through the introduction of direct marketing the flows Crops to retail and Animal products 2 were added to the Culture-fix MFA. In doing so, food processed was given priority over direct marketing. Any food produced in Brandenburg that was not processed, yet retailed, was assumed to be directly marketed. The Crops to processing flows mainly consists of potatoes (186 t P), and milk (399 t P) and eggs (101 t P) predominantly make up the Animal products 2 flow. The flows now directly marketed were exported in the Trend MFA, and thereby the Export agriculture and Export animal products are have been reduced further, in addition to the influence of the solutions.

Whereas in Techno-fix the Feed crops flow was eliminated, in Culture-fix it is maintained and the remaining fodder requirements are fulfilled through Forage. The latter flow was thereby reduced to 1,151.1 t P as Algae and Water from the EcoFerm! concept are able to deliver 2,137.6 t P and 29.3 t P to Livestock breeding, respectively. The shift to organic agriculture far reduced Runoff, erosion, and seepage, which was further (linearly) reduced as less Forage flows to Livestock breeding. No solutions were proposed for Culture-fix regarding recycling of Slaughter waste and Deceased livestock, except vegetarism, and therefore these flows have the same fate as in the Trend MFA but have been significantly reduced in size.

Throught the introduction of separating vacuum toilets and subsequent separate treatment of urine, faeces, and greywater, no more effluent flows to the surface waters, while 1,615.6 t P urin and 1,292.4 t P faeces are recycled back to agricultural soil. Reduced biowaste from consumption and retail, together with increased biowaste from processing allow for a total of 345.5 t P to be digested and recycled back to agriculture. Wood waste (76.1 t P) is still incinerated due to its contamination. Together with 2,899.0 t P fertillizer as output of the EcoFerm! process, 90.1 t P Plant prunings digestate, and reduced erosion and crop-related flows, a total of 4,068.8 t P of additional fertilizer is required to balance the Agricultural soil metabolism. Similarly to Techno-fix, also in Culture-fix Fodder imports are no longer necessary.

Finally, the reduction and removal of input to the Urban soils and Natural vegetation soils was approached the same as it was for Culture-fix.

Figure 13: Phosphorus flow chart of the Culture-fix vision.



7.15 Discussion: Vision and trend comparison

The main flow sizes and other characteristics of the Trend MFA and the two visions is displayed in Table 30, which will be used for the discussion. Before making the actual comparison first the waste and recycling definitions, as well as the used efficiency indicators, are discussed and presented in section 7.15.1. After that the trend and visions are compared and discussed in section 7.15.2.

7.15.1 Definitions and indicators

A few issues regarding (efficiency) indicators and definitions were identified when evaluating the systems created in this thesis;

- How are waste and recycling defined?
- What is the right means of determining the system efficiency?
- How to treat negative stock during evaluation?

Regarding the definition of waste, the intermediate waste flows in the system are seen as of minor importance. Rather, the undesired stock additions to the system, in combination with waste flows that are not treated in the system (e.g. Slaughterwaste) are seen as inefficiencies of the system. As such, the final fate of the intermediate waste flow is used to define the nature of the waste flows. All stock additions to the system are seen as wastes. Whereas this is obvious for Landfill, this may not be the case for Urban soil metabolism and Natural vegetation soils. Nevertheless, also the latter two stock additions are seen as undesired as these soils are already (over-)saturated. Particularly phosphorus losses to Surface waters, comprising the unretrievable phosphorus, can be seen as to be of higher relevance than stock additions to Landfilling. The latter stock additions can still be retrieved, whereas leakage to surface waters renders recycling virtually impossible.

Also the term 'recycling' is subject to interpretation. Is manure produced in Livestock breeding a waste that is subsequently recycled? Technically, yes. Yet, a distinction between different kinds of waste seems appropriate. Flows directly recycled back to crop production, such as manure and straw, can be seen as being part of the natural system. These flows are designated as 'Biological recycling'. The other flows, even those originating from animal husbandry (e.g. deceased animals) have become contaminated and have to undergo treatment before these can be used as fertilizer again. These (recycled) waste flows are seen as belonging to the technical system, referred to as 'Technical recycling'. Here also Plant prunings digestate and Garden fertilizer are also counted as being part of technical recycling. Adding the Biological and Technical recycling, the Total recycling [R] is acquired.

For determining the system efficiency, Van der Voet (1996, p. 63) distinghuises three indicators;

1. The amount of virgin materials used [V] in relation to the total internal materials cycle [M], yielding the formula [V/M];
2. The amount of discarded materials [D] in relation to the total internal materials cycle [M], [D/M];
3. In the case of no accumulation, relate the amount of recycled materials [R] to the total of inflows [M], as [1-(R/M)].

Van der Voet (1996, p. 62) states that the internal material cycle [M] comprises the total amount of material consumed. The recycling rate, or inversely the discard rate, in relation to the internal material cycle would then logically yield the efficiency of the system. However, the determination of [M] is problematic for the MFAs created because the consumption and production sides of the system are only very limitedly related to one another. One could state that, apart from actual consumption taking place in the system, also the agricultural (and processing) subregimes use, or consume, resources that are converted and subsequently exported again.

To overcome the difficulties associated with the quantification of the internal material cycle, it is sought to be approached by the sum of imports [V], total recycling [R], and stock deficiency. The latter can be seen as a sort of import originating from within the system, thereby adding to the size of the internal material cycle. Stock deficiency is present in both Techno-fix and Culture-fix, and not in the Trend MFA.

Finally, although deemed invalid by Van der Voet (1996, p. 62), also the discarded materials [D] in relation to imports [V] will be used to determine the efficiency of the system. In a closed (e.g. global) system this indicator will always approximate 100%, giving a false representation of the efficiency. However, in the case of Berlin-Brandenburg the system has a high degree of 'openness', and it is deemed that therefore also [1-(D/V)] can be used as an efficiency indicator in this case.

7.15.2 Comparison

First of all, both visions hugely increased waste recycling from the technical system; +651.7% and +645.6% in Techno-fix and Culture-fix, respectively. Where in the Trend MFA 6,134.2 t P fertilizer was imported, in Techno-fix and Culture-fix this has been reduced to 5,599 t P (-8.7%) and 4,068 t P (-33.7%), respectively. The total reductions in imports is even higher as in the Trend MFA still 4,153.36 t P is imported as fodder, while this is no longer required in both visions. Lookin at the total import reductions, in Techno-fix and Culture-fix 36.6% and 52.0% fewer imports are required.

The stock surplus in Culture-fix (635.4 t P) is more than half as low as in Techno-fix (1,308.4 t P). The main reason for this difference in stock added is that waste recycling through the Mephrec process still induces 20% waste to landfill, amounting to 801 t P. In Culture-fix only 134 t P is added to landfill. Yet, also slaughter waste, deceased animals, and wood waste are being recycled in Techno-fix, and not in Culture-fix. Culture-fix thereby exports 377.1 t P waste, where this is only 14.8 t P in Techno-fix. When viewing the total 'discarded' waste i.e. stock added and waste exported, the difference becomes smaller; 1,323.2 for Techno-fix and 1,012.5 t P for Culture-fix. Of course, if in Culture-fix the exported and landfilled waste flows would also be treated, the difference would be significantly larger.

Turning to stock added to Surface waters as the only unretrievable sink in the system, it can be seen that both visions perform rather equally with +346.2 t P and +355.4 t P for Techno-fix and Culture-fix, respectively. Techno-fix thus performes slightly better, whereas compared to the Trend MFA (+1,684.8 t P) both visions hugely decrease unretrievable phosphorus losses from the cycle.

Although waste recycling as part of the technical system is rather similar for both visions in absolute figures (3,371.5 t P and 3,343.6 t P), Techno-fix still requires 1,530.8 t P more fertilizer imports than Culture-fix. The difference can in part be explained by the fact that in Techno-fix a netto 4,384.2 t P foodstuffs are exported, whereas this is only 3,164.1 t P in Culture-fix. Techno-fix thus creates 1,220.1 t P more foodstuffs than did Culture-fix, for which additional fertilizers are required. The remaining 1,530.8 - 1,220.1 = 310.7 t P can be explained by the fact that Techno-fix adds 673.0 t P more to stock on the one hand, while this is balanced as in Culture-fix 377.1 - 14.8 = 362.3 more waste is exported.

Due to (recycling) solutions implemented, the internal material cycle [M] has been significantly reduced from 31,259.1 t P in the Trend MFA to 17,605.8 t P and 21,689.2 t P in Techno-fix and Culture-fix, respectively. One would think that in Culture-fix the internal material cycle [M] is smaller due to reduced food demand (-284 t P), vegetarism, and the introduction of direct marketing, but this is not the case. Although those solutions have reduced the size of the internal material cycle, in Culture-fix energy crops and feed crops are still produced. And in addition, in Culture-fix still more manure is generated in spite of the vegetarian diets adopted (5,065.9 t P versus 3,616.9 t P), which enlarges the (biological) recycling and thereby the overall throughput.

Finally, the efficiency of the cycles was calculated in three different ways; [R/M], [1-(D/M)], and [1-(D/V)], which produce very different results. Using the first method, [R/M], it seems that Techno-fix has the least efficient cycle, and Culture-fix the most efficient one. This may not be the right way to assess the efficiency, because the [R] is very high in the trend as well as Culture-fix due to maintaining most agriculture-related flows, which are recycled highly efficient. The improvements in Techno-fix are thereby severely masked.

By focussing on the waste generated [D] in relation to the throughput [M], rather than the recycling [R], it seems that a more adequate representation can be given. In doing so, both Techno-fix and Culture-fix can be seen to generate far less waste compared to the decrease in throughput [M], where Culture-fix is the clear winner with an efficiency of 95.3%.

Interestingly, when using the method [1-(D/V)] it turns out that both visions have an equal performance (85.0% and 84.9%), which is far better than the trend (56.6%). It can be stated that both visions present a great improvement to the trend, and that depending on the method, Culture-fix would be the superior vision mainly because its agriculture subregimes have a higher throughput and thereby a higher total recycling rate.

Table 29: Comparison of results found for different configurations subsystems Crop production, Animal production, and Waste recycling.

	Trend [t P]	**Techno-fix [t P]**	**Trend diff. [%]**	**Culture-fix [t P]**	**Trend diff. [%]**	**Vision diff. [%]**
Crop production	Conventional	Vertical farms and grasslands		Organic farming		
Crops	18,280.1	13,961.9	-23.6	15,476.0	-15.3	+10.8
Crops to processing	934.15	934.2	no change	927.9	-0.7	-0.7
Export agriculture	4,841.1	4,841.1	no change	3,961.49	-18.2	-18.2
Forage	4,125.0	4,125.0	no change	3,492.24	-15.3	-15.3
Fodder import	4,153.4	4,153.4	no change	5,511.0	+32.7	+32.7
Total import fertilizer	6,134.2	5,276.6	-14.0	3,131.8	-48.9	-40.6
Erosion (agriculture)	1,051.1	193.5	-81.6	292.3	-72.2	+51.1
Efficiency (production/throughput)	95.5	98.9		98.5		
Meat production	Conventional	In vitro meat		EcoFerm!		
Manure	9,146.4	3,616.9	60.4	9,146.44	same	+152.9
Fodder import	4,153.4	0	-100	241.0	-94.2	$+\infty$
Fertilizer import	6,134.2	9,176.3	+49.6	10,046.5	+63.8	+9.5
Total animal/meat waste	1,530.9	794.0	-48.1	1,530.9	same	+92.8
Efficiency excl. agriculture (production/throughput)	20.6	33.6		20.6		
Efficiency incl. agriculture (production/throughput)	79.8	83.5		79.8		
Waste recycling	Incineration and landfilling	Mephrec process + digestion		Vacuum separating toilets + digestion		
Fertilizer import	6,134.2	2,569.6	-58.1	3,203.3	-47.8	+24.7
Recycled P	456.6	4,271.7	+835.6	3,237.2	+609.0	-24.2
Landfill	+2,617.0	+948.5	-63.8	+190.3	-92.7	-79.9
Surface waterbodies	+1,684.8	+1,211.4	-28.1	+1,136.5	-32.5	-6.2
Unrecycled P excl. soils	2,886.7	1,011.2	-65.0	1616.2	-44.0	+59.9
Efficiency (recycled/waste input excl. soils)	8.7	80.9		66.7		

Table 30: Comparison of the main characteristics of the Trend, Techno-fix, and Culture-fix.

	Trend [t P]	**Techno-fix [t P]**	**Trend diff. [%]**	**Culture-fix [t P]**	**Trend diff. [%]**	**Vision diff. [%]**
Recycling						
Technical recycling	456.5	3,431.5	+651.7	3,403.6	+645.6	-0.9
Biological recycling	16,925.6	5,295.0	-68.7	11,651.7	-31.2	+120.0
Total recycling [R]	17,382.1	8,726.6	-49.8	15,055.4	-13.4	+72.5
Imports and exports						
Fertilizer import	6,134.2	5,599.5	-8.7	4,068.8	-33.7	-27.3
Foodstuffs import	7,802.9	3,231.9	-58.6	2,625.1	-66.4	-18.8
Total import [V]	13,937.0	8,831.5	-36.6	6,693.8	-52.0	-24.2
Foodstuffs export	7,893.8	7,616.1	-3.5	5,789.1	-26.7	-24.0
Waste export	1,438.6	14.8	-99.0	377.1	-73.8	+2,454.9
Total export	9,332.4	7,630.8	-18.2	6,166.2	-33.9	-19.2
Stocks and waste						
Stock surplus	4,604.6	1,308.4	-71.6	635.4	-86.2	
Stock deficiency	0	107.8	$+\infty$	107.8	$+\infty$	
dStock	4,604.6	1,200.6	-73.9	527.6	-88.5	-56.1
Landfill	2,617.0	801.1	69.4	134.4	-94.9	-83.2
Surface waters	1,684.8	346.2	-79.4	355.4	-78.9	+2.7
Waste export	1,438.6	14.8	-99.0	377.1	-73.8	+2448.0
Total waste [D]	6,043.2	1,323.2	-78.1	1,012.5	-83.3	-23.5
Cycle efficiency						
Internal material cycle [M]	31,319.1	17,665.8	-43.6	21,749.2	-30.6	+23.1
Efficiency [R/M]	55.5	49.4		69.2		
Efficiency [1-(D/M)]	80.7	92.5		95.3		
Efficiency [1-(D/V)]	56.6	85.0		84.9		

Chapter 8

Barriers, opportunities, and pathways

8.1 Introduction

The identification of necessary and/or recommended measures will be performed by means of a What-How-Who-analysis as proposed by Quist (2012). Firstly, the overall functioning of the socio-technical system is analysed by means of a Qualitative system analysis (Wiek et al., 2008) in order to identify general barriers and opportunities towards realizing the visions. Then solution-specific barriers and opportunities are derived based on the literature featuring (parts of) the solutions, and own insight. These barriers and opportunities imply What needs to change. Based on the 'What', measures that are necessary and/or recommended to realize the visions are proposed (How) and simultaneously actors that are deemed most suitable to implement the measures are identified (Who).

8.2 Qualitative system analysis

In order to identify general barriers and opportunities influencing the realization of the visions, a Qualitative systems analysis (Wiek et al., 2008) is first carried out. By performing such an analysis the interrelationships between system variables become apparent, which can be used to identify barriers and opportunities towards system improvement. Following Wiek et al. (2008), the present situation is first mapped, followed by mapping the future situation which can be understood as the trend. After that another map is made containing the desired i.e. normative situation. Finally, through assessing the differences between the trend and the normative map, a set of measures is proposed.

Wiek et al. (2008) distinguish four different types of variables that feature in the maps;

- Focus variables are those factors that require optimization such that the system becomes improved, providing the starting point of the analysis. In the present analysis these would encompass factors that directly improve the phosphorus cycle, such as the implementation of new waste treatment facilities capable of phosphorus recycling.
- Target variables are the factors that indicate the 'health' of the system, such as environmental quality and social cohesion. These are mainly public goods. The improvement of these can be seen as the end-goal of the analysis, achieved through optimizing the Focus variables.
- Context variables are additional factors that influence the Focus and Target variables, such as climate change and public perception. As the name already indicates, these form the context as well as interaction between the other variables.
- Action variables can be seen as measures taken to change the interactions between the other variables, steering the system.

8.2.1 Application

Where Wiek et al. (2008) make a total of four different maps with each featuring different types of variables, this is deemed as being too elaborate for this thesis. Instead, the present situation is mapped including landscape factors such that general barriers and opportunities become apparent.

The information input for this analysis is mainly derived from the social system's analysis from Chapter 5 and developments analysis from Chapter 6.

The results of the Qualitative system analysis can be viewed in Figures 14, 15, and 16. Figure 14 comprises the agricultural subregime and its embedment in the Brandenburg society. Figure 15 features the food supply chain including the consumer. Figure 16 shows the waste treatment, policy, and research subregimes. The three figure were created as one large map, but were divided into themes for practical reasons. As part of the large map Figure 14 was situated top left, Figure 15 top right, and Figure 16 bottom left.

All variables except Action variables are used. Regulations and subsidies already in place were seen as Context variables. The Action variables, or measures, will be separately derived in sections 8.7 and 8.8. Within the figures Focus variables were given a purple colour, Target variables a brown colour, and the Context variables a blue colour.

8.2.2 Brandenburg and agriculture

Starting with Figure 14, water quality & availability, soil quality, liveability & social cohesion, and the landscape of Brandenburg were taken as Target variables i.e. common goods. Climate change can be seen to negatively impact the water and soil quality (see section 6.6.2. However, the impact climate change has on the land and surface water is partly determined by the agricultural practises employed, where conventional monocultural practises are seen to be more out of balance with the environment than organic agricultural practises. Higher irrigation demands, reduced access to fresh water, a lower soil quality, and higher fertilizer prices as a result of phosphorus scarcity are all factors negatively affecting the profit margin of the farm. The lower profit margins in combination with the farmers' awareness of future excerbated climate change and phosphorus scarcity will enhance the farmers' willingness to adopt new strategies for crop and animal production. However, as the profit margin of the farmer decreases so does his/her room for investment, creating a lock-in situation.

An additional lock-in mechanism is derived from the processing and retailing industries' demand for high volumes of food. Counter to organic agriculture, conventional agricultural practises are able to meet this demand, but also affect the (future) profitability of the farmer.

Moving to the Brandenburg society, another negative lock-in mechanism can be detected. The ageing population reduces the amount of available workers which creates a less attractive investment climate for companies. In addition, the Brandenburg infrastructure already has a bad quality which further reduces its attractiveness, both for citizens as well as for companies. Not only does the ageing of the population lead to less workers, in general the social activity in the region decreases. As a result of these influences, mainly younger people leave the country-side for the city, excerbating the problems. As the social structure of Brandenburg deteriorates, so does the social cohesion and liveability of the region.

Energy crop monocultures in particular are very concentrated in some Brandenburg regions. These reduce the landscape quality of the region and restrict the tourist industry in its potential. In turn, the tourist industry could enhance the attractivity of the region through employment opportunities and a stimulus for local activity. Thereby it would have a positive influence on the livability of the region.

8.2.3 Supply chain and household

(Bio-)food production is marked as Focus variable because the agricultural practise employed will determine its efficiency and losses to the environment. The practise determines the soil and water quality, which in turn influence the yield in addition to the practise itself. Although Brandenburg's share of organically operated farms is relatively high (10.6% of land), the bio-food processing industry appears to be underdeveloped, of which the cause is not entirely clear. Given the population size and character, Berlin should have a relatively large demand for organic food.

Yet, the purchase power of its citizens is generally conceived as low. Whether this changes with the continued attractiveness of Berlin is hard to estimate. On the one hand the rents rise fast, leaving people less to spend. On the other hand one could argue that more affluent people, able to buy bio-

Figure 14: Main developments and interrelations regarding the agriculture subregime and Brandenburg.

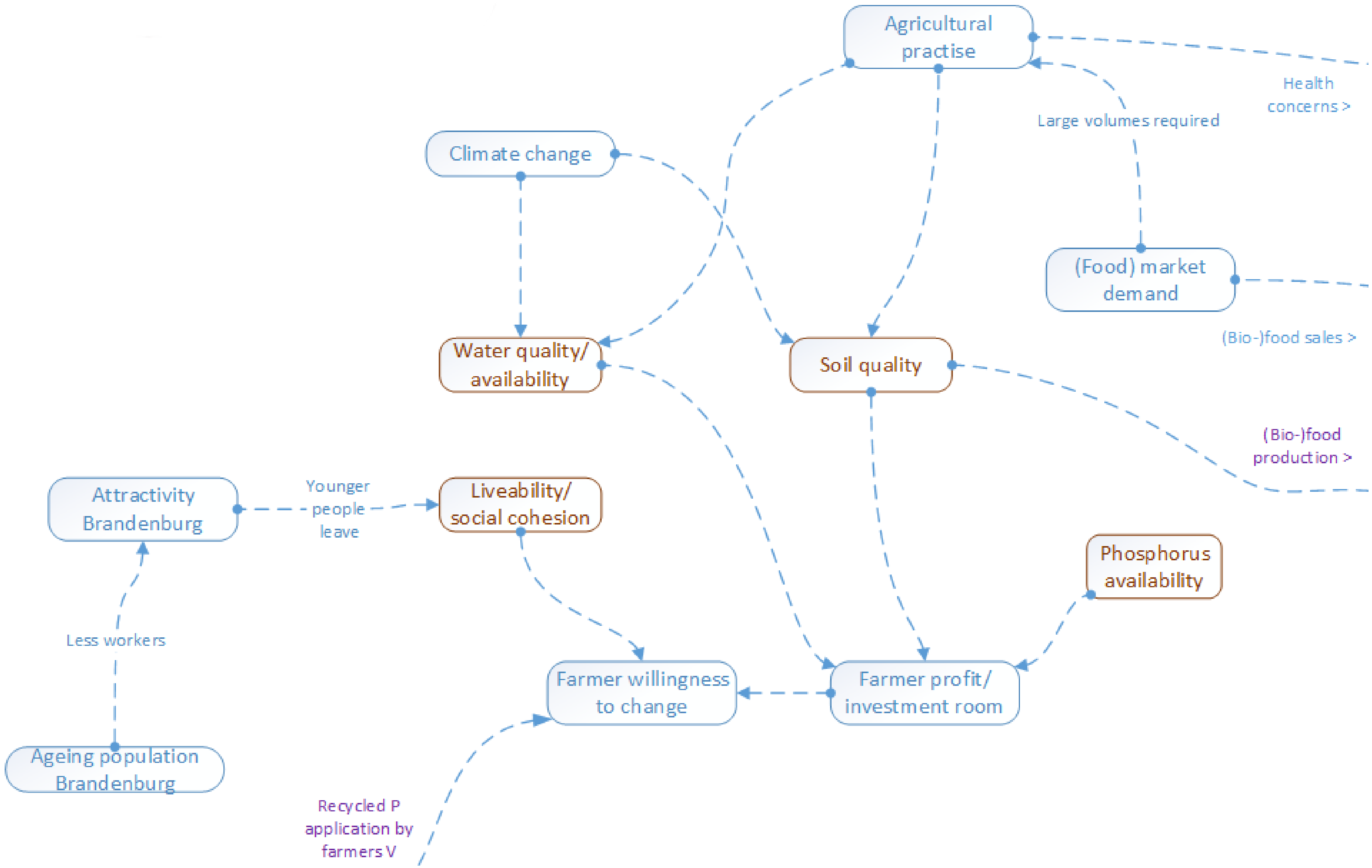


Figure 15: Main developments and interrelations regarding supply chain subregimes and consumption subregime.

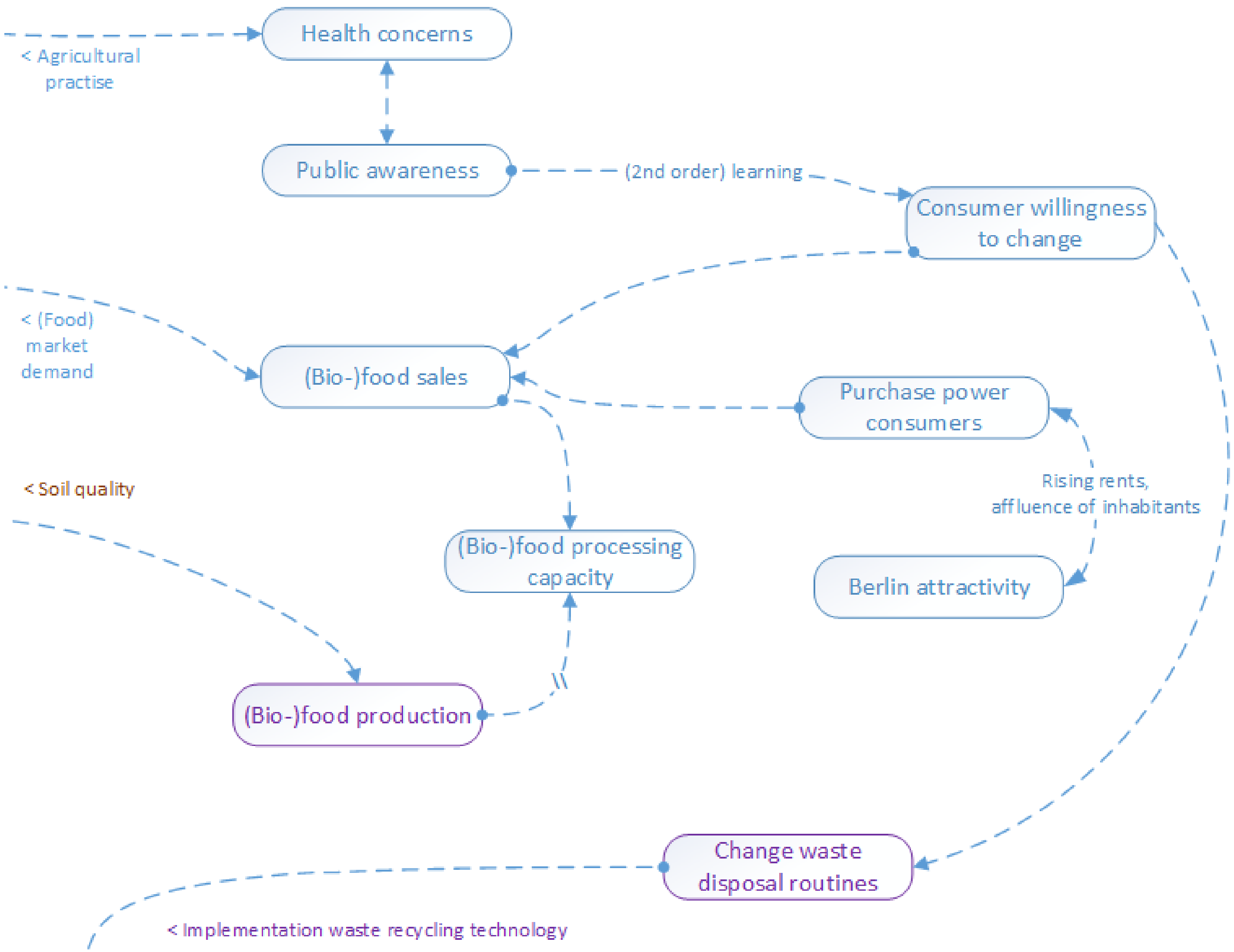
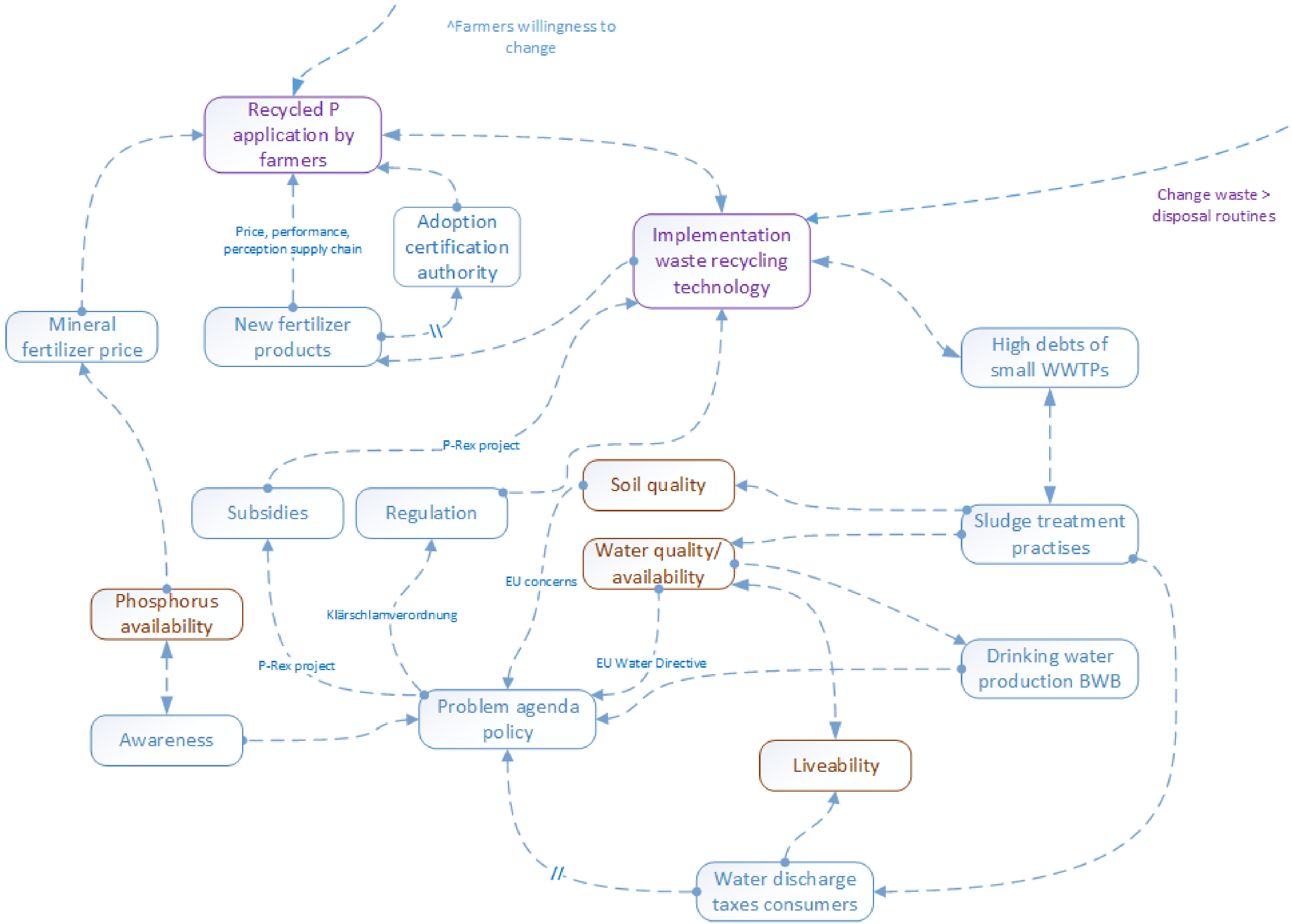


Figure 16: Main developments and interrelations regarding the waste treatment, policy, and research subregimes.



food, will inhabit these appartments. One reason for the underdeveloped bio-food processing capacity may be a lack of demand. But at the same time, insufficient offers of organic food also limit the market share. Based on these findings one could state that here lies a market opportunity for the bio-food industry.

Bad practises in some cases lead to food scandals, raising health concerns as the public becomes aware. For concentrated animal keeping this may be concerns over antibiotics and hormone-use. But even more so for more organic forms of agriculture, which have a good image, a scandal can be fatal. Particularly when recycling sludge (e.g. MAP) or household biowaste, which are perceived as polluted streams, the public perception may disfavour the practises applying these recyclates. In turn, the processing and retailing industry may avert produce grown from recyclates. This forms a barrier not only for the farmers willing to adopt the recyclate, but also for the feasibility of the new waste recycling technology.

More public awareness about food scadals and unsustainabilities induces learning, of which some may be second order. In such a case the consumer may reorientate his/her values towards a desired food production system, leading to higher food sales of produce from that system. Similarly, first and second order learning may also result favouring one waste disposal system over the other, as well as altered waste (disposal) routines (e.g. less food to waste, separation of biowaste). Finally, waste routines may enable or oppose the implementation of alternative waste treatment and recycling technologies.

8.2.4 Waste management

The farmers' adoption of recyclates will for an important part depend on the price of both mineral and recyclate fertilizers. Although mineral fertilizer price can be expected to rise as the phosphorus availability decreases, the recyclate should still atleast be equally expensive. The importance to price will increase as climate change increasingly affects the profitability of the farmers. In addition, processing and retailing industry demand, resulting from public perception, will also influence the farmers' choice. Additonally, in organic agriculture the recyclate also has to be approved of by the certification authority, which approval may be hard given the public opinion. Lastly, a new fertilizer product also has to be approved by the EU, which was granted in the case of MAP.

Related to water quality problems, it is not entirely clear if the related problem agenda is intrinsically or politically motivated. The EU certainly seems to play an important role in this respect by issuing the new Water Directive. This likely motivated the local policy actors to issue stricter fertilizer allowances, as well as (foreseen) stricter sewage sludge application allowances. In addition, the problems related to drinking water production reported by the BWB will also be an important motivation for stricter regulation (e.g. obligatory 4th cleaning step sewage).

Currently the debt-ridden smaller WWTPs bring a share of the sludge (363.2 t P) to agricultural land, as well as to lower quality non-crop land (517.3 t P). This provides the WWTP a cost-efficient way to purify the sludge further, but it also deprives the (agricultural) soil and water quality. Although most cost-efficient, also this method bears significant cost related to the transport of the sludge. Yet, the smaller WWTPs are strongly debted and do not have room to invest in new sewage treatment technologies. This hampers the implementation of sewage recycling technology, and burdens the local inhabitants with high connection costs. The latter creates a disincentive to live in the area, although it does not seem to be on the problem agenda of (higher) regional policy actors. Sewage treatment operators can be seen to face an additional problem as peak river discharges likely lead to higher effluent releases, reducing the quality of the surface waters further.

Phosphorus scarcity seems to be on the problem agenda of both regional, national, and EU policy actors. With regards to erosion, the EU became aware that Brandenburg soil is indeed eroding rapidly, and put the matter on the problem agenda of local political actors. Furthermore, to stimulate sewage treatment recycling technology development the EU funded the P-Rex project in which many technologies are being tested, including the Mephrec process featuring in Techno-fix. Although the research efforts on phoshorus recycling from wastewater seem promising, it has to be kept in mind that the feasibility also depends on the successful adoption of recyclates by farmers. For some waste treatment solutions (e.g. macerator, vacuum toilets) also altered consumer routines are necessary.

8.3 Barriers and opportunities: Techno-fix solutions

8.3.1 Vertical farming and grasslands

Firstly, as vertical farms employ artifical light as energy source for the crops electricity will need to be cheap and abundantly available to be able to compete with open-field farming. As artificial light seeks to replace the sun as an energy as well as an information source for the plant, its properties face high demands; the light spectrum and light intensity have to be optimal and variable (Darko et al., 2014), mimicking natural circumstances. To this end LEDs seem to be the perfect candidate. These are able to deliver 80 to 100% of the light wave length used for photosynthesis (i.e. PAR efficiency), have a low operating temperature, can be manufactured in small sizes, which charcteristics enable the lighting to be applied close to the canopy (Darko et al., 2014). Additionally, LEDs have a long lifetime and can be used all-year round (Darko et al., 2014).

Next to the lighting demand, plants grown in greenhouses require constant water circulation providing nutrients in the right amounts. As the plants are grown in a closed system, pathogens present in the nutrient solution can easily multiply and pass from plant to plant, causing crop losses. There exist many ways to prevent pathogen outbreaks, of which most treat the nutrient solution at a certain point in time and kill most of the pathogens (e.g. ozone treatment, UV radiation, heating, filtering). However, these 'spot-desinfectation' methods seem not to be able to deliver a 100% pathogen elimination, kill the microorganisms beneficial for plant growth (e.g. rhizobia), and are often costly (Ehret et al., 2001). Ehret et al. (2001) therefore conclude there is no obvious 'best' solution. Yet these authors do state that more 'microorganism-friendly' methods provides the best potential for the future, such as microbial inoculation into the nutrient solution. In that case a the microbial culture would form and reach an equilibrium with its environment, minimizing pathogen growth through strong competition with the inoculant.

Although technological development takes place for optimizing closed-loop greenhouse system, it should be noted that to date no actual vertical greenhouse has been built yet (Despommier, 2011). Perhaps needless to state, the concept should first be extensively tested, and therefore built, before it can actually invoke an agricultural transition.

From the solution assessment it became clear that the implementation of vertical greenhouses faces severe misalignments with the current system regarding phosphorus recycling. Current phosphorus recycling takes the form of compost, manure, MAP, and sludge application on agricultural soil, which fertilizer sources are not suitable for closed-greenhouse systems. Either these sources have to be treated (i.e. mineralized) first which induces extra costs, or the vertical farm has to wait for the emergence of matching phosphorus recycling technologies and recyclates. In addition, straw produced along with the crops also needs to be mineralized if it is to be used as fertilizer for vertical greenhouse crop production again.

8.3.2 In vitro meat production

In vitro meat production may sound like science-fiction, but has left this realm as the first in vitro hamburger was made and eaten in 2013 (NY-Times, 2013). According to one of the testers, Josh Schonwald, the bite was similar to meat but tasted "like an animal-protein cake". In addition, the production costs for the one hamburger were 325,000 dollar. As such, the production process of in vitro meat should greatly improve in terms of cost reduction, and more research is needed with regards to taste of the meat. Yet, while no vertical farm has been built yet, in vitro meat had its first success already. For actual full-scale use of this technology the meat will most likely also have to withstand elaborate tests regarding human health.

8.3.3 Mephrec, macerators, algae treatment

The Mephrec process forms the core component of Techno-fix waste recycling technology. Although the process is currently being tested in the P-Rex project, its significant installation costs form a main hurdle for implementation (Kabbe, 2014b, pers. comm.). With the initial costs being so high, the realization of several Mephrec facilities also in Brandenburg seems unlikely given the financial limitations, at least in the short- to mid-term. A better option could be to install one facility close to Berlin, and install smaller sludge dewatering facities near the smaller WWTPs. This way briquettes, necessary input for the Mephrec process, would be produced on-site and transported by truck, train, or boat to the Mephrec facility. This way the transport weight would be reduced significantly, an no elaborate sludge transport network (i.e. piping) would be necessary.

Biowaste diverting macerators would also have to be installed at food consumption places (e.g. restaurants, offices and people's homes). This adaptation to the kitchen is deemed relatively small, although one or more actors will have to pay or subsidize it. On the other hand, the waste treatment operators do no longer need to treat the biowaste, which may alleviate or compensate the costs. Furthermore Kabbe (2014a) pointed out that biowaste transported via the sewage network may create pests (e.g. rats). It should therefore be ensured the installed macerators are good enough. Lastly, the addition of biowaste to sludge will alter the properties of the mixture, and its affect on the sewage treatment process is not known. For now it is assumed that the process feasibility remains the same.

The initial wastewater treatment process is not changed in Techno-fix, and therefore no extra costs will be created in this respect. But for the treatment of effluent with algae extra space for algae baths will be necessary, and hence costs. Although effluent algae treatment seems not to be a mainsteam application, its experimentation and application date back 50 years already (Hoffmann, 1998). Particularly in the light of current case area problems related to the water quality, this concept could prove to be a cost-efficient way to reduce the (future) burden on surface water quality, as well as retrieve nutrients.

8.4 Barriers and opportunities: Culture-fix solutions

8.4.1 Organic farming and the bio-food supply chain

Organic farming in Brandenburg already has a relatively large share of 10.6% of the crop land, which share has been steadily growing since 1992. It is therefore plausible that conversion to organic agriculture will continue, provided that the existing additional subsidies for organic farming are maintained. As organic farms are generally smaller and more labour-intensive than conventional ones, also more people willing to start and operate a farm will be necessary. This may present an obstacle as already convincing local people to take over the conventional farm proves difficult in Brandenburg. In addition, younger people are trading the country-side for the city, which phenomenon can be expected to become stronger as the region ages.

To make organic farming practises more attractive and feasible an improved bio-food supply chain would be of great support. This would allow the farmers to be less dependent on exports, and probably the costs of the produce (e.g. transport) is also reduced. Increased direct marketing by farmers (e.g. weekly markets, on-farm sales) allows these to take a higher profit margin, and it may also potentially reduce the price of organic food further. Social cohesion may be strenghtened as the (public) food market becomes the center of public life once again.

Furthermore, although the current regional demand for organic food is estimated as being relatively high, extra supply in the form of processed food would probably stimulate demand further given its perceived underdevelopment. A halt to rising rents in Berlin and the implementation of minimum wages as recently adopted in the German national coalition treaty, would allow people to have a budget capable of affording organic food. Finally, organic food demand becomes stronger as people become aware and undergo first and second order learning (e.g. awareness on- , and attitude to organic food).

8.4.2 EcoFerm!

The EcoFerm! working concept has been successfully tested in the Netherlands. However, the restricted access to nitrogen of algae still limits algae growth, and causes the phosphorus to be converted insufficienly. The algae water then has to be refreshed (more) often, and the P-rich water treated additionally to avoid phosphorus losses. However, in some cases is might be possible to sell the water to other farmers as combination of irrigation water and fertilizer. Another issue is the phosphorus extraction from the digestate which is not efficient yet (e.g. 40 %), although the rest can be sold as fertilizer.

A regulative hurdle may be posed for feeding cattle with algae grown from their manure. However, a review (Van Liere et al., 2011) showed that at least in the Netherlands no legal restrictions seem to be in place, except the permission to certify algae as fodder source.

Finally, for the actual widespread application the animal farmers should become convinced that the EcoFerm! is a good investment. Calculations by Van Liere et al. (2011) showed that the EcoFerm! for pig farms in size up to 30,000 L manure/yr result in 4% lower results over a ten year timeframe compared to a similar conventional farm. The 30,000+ variation, on the other hand, was calculated to have a return on investment 13% over ten years. Additionally, increasing fodder prices related to foreseen mineral fertilizer and irrigation water (and oil) price rises (and demand) may be reduced through the replacement by algae. Still, even is the cost-benefit picture is favourable, an initial investment needs to be made, which may be a barrier for farmers with little room for investment.

8.4.3 Vegetarism and veganism

Here the most obvious barrier is the mainstream set of normative and cognitive rules of consumers, where the current prices of meat, milk and eggs is sufficiently low to enable mass-consumption. Although a rise in meat, milk, and egg prices would likely discourage some people from consumption, it also creates dissatisfaction or even anger amongst people having the right to eat animal products as a normative rule. Therefore, the route of 2nd order learning, as implicated in the name 'Culture-fix', is preferred.

8.4.4 Separating vacuum toilets and biowaste composting

The application of separating vacuum toilets in households, offices, and restaurants implicates an adaptation to the toilet and its drainage system. The toilet itself should be replaced and a compressor and related technology has to be installed. As urine, faeces, and greywater is separatedly collected, the local piping system also requires adjustment. Once flushed, the urine and faeces have to be collected, stored, and treated. This requires space as well as investment. Space requirements may especially pose a problem for the constructed wetlands treating the greywater. All-in-all, it is clear that the implementation of separating toilets is more feasible if it is planned into the (re-)design of urban space. Nevertheless, also in Berlin the existing basements, attics, court yards, parks, or even roofs may provide the required space. Furthermore, the greywater could be drained together with rain water using the existing sewage piping system, after which it can be diverted to the wetlands outside the city.

Technical specifications aside, the initial costs of such a renovation are likely high, in addition to required changed toiletting routines of people. Alhtough the renovation and installation costs are high, there can be several opportunities for system-wide cost-reduction be discovered;

- Firstly, biogas can be produced from digestion of faeces, which could direclty flow back to the building, or enter the gas network. No significant adaptation to the gas network would probably be necessary.
- Secondly, as WWTPs no longer require to treat the sludge, significant cost reductions can be made. Not in the last place, also the surface water quality would improve significantly. Yet, in the case use is still made of the existing sewage treatment network, the maintaince and replacement costs thereof could lead to higher costs.
- Thirdly, the fertilizers produced can be sold back to the farmers.
- Lastly, possibly also useful crops (e.g. energy crops) can be harvested from the constructed wetlands, and sold for processing. Human or animal consumption from these crops will probably not be allowed (e.g. risk of harmful substances in greywater).

Biowaste from processing, retail, and consumption is assumed to be still collected and treated by the local waste treatment operator. Digestion of plant prunings and separated biowaste is already common-place in Berlin-Brandenburg. A higher separation efficiency would likely lead to economies of scale and reduce the operating costs. Yet, particularly in Brandenburg not enough possibilities for separation of biowaste are absent or insufficient. This can be concluded from the relatively small amount of biowaste produced in Brandenburg (5,900 t/a) compared to Berlin (62,000 t/a). Yet, the main barrier towards more biowaste composting exists in the current waste disposal routines of people. In Berlin, for instance, the volume of biowaste in regular household waste (to be incinerated) was circa 350,000 t in 2011 (Nogueira, 2013, pers. comm.); almost six times as high as the volume of separated biowaste.

8.5 Implications Techno-fix

8.5.1 Technical implications

In comparing the 2011 MFA and the Techno-fix MFA several observations can be made with respect to changes in the system. Firstly, or course, the Techno-fix solutions become implemented. A transition towards vertical farming and in vitro meat production will mean that most current farms will be replaced by highly centralized food production facilities. Not only do most of the current farms disappear, also the material flow and linkages of the food supply chain will change. The food processing industry likely faces least adaptations; the vertical farms are assumed to produce the same crops. Concerning the meat production and processing sector, some animals (i.e. cows and laying hens) still have to be kept and slaughted, but this does not apply to the majority of the meat produced (i.e. in vitro meat). Yet, also in vitro meat still has to be processed before it can be consumed (e.g. packaging, removal of bad quality pieces). As in Techno-fix food is delivered by drones, also the structure of the retailing subregime will be significantly different, where mainstream supermarkts will disappear.

At least more than the supply-side of the system, the demand/recycling side of the system will face limited adaptation to the infrastructure. Macerators have to installed in households and restaurants, an a Mephrec facility and algae basins have to be constructed. The solid waste treatment subregime will shrink as the biowaste from consumption will no longer have to be picked up. This does not apply to processing and retail biowaste. Although the wastewater treatment subregime will have to deal with a higher solid fraction in the wastewater, and therefore a higher wastewater volume, no significant changes to the wastewater treatment plant and its piping are foreseen. In addition to the waterwater treatment plant, in the vision also a dewatering installation, Mephrec facility, and algae bath have to be operated. This could be done by the current actors, as well as new actors. As by far most biowaste becomes recycled, the incineration plant will have to be replaced with a far smaller one.

Finally, given the high technological level of Techno-fix, research activities related to the solutions will have to be refocussed and intensified. Additionally, the safety of the new food production techniques has to be thoroughly tested and ensured.

8.5.2 Socio-economic implications

The introduction of vertical greenhouse, in vitro meat production facilities, and novel modes of food retailing (e.g. drones), constituting the supply side of the system, can most likely come about through the market mechanism itself, supported by landscape pressures. Yet, to speed up the transition sufficiently, adequate subsidies and other regulatory instruments do have to be put into place. Most likely, less people in comparison with 2011 will be needed to produce similar amounts of food using vertical farms and in vitro meat facilities. Whether the same agricultural actors operate and control these facilities is doubtful as because the technology and knowledge demands are very high and divergent from current practises. Stronger and better organized actors such as the Industrials will have more chance of success, whereas the old farmers could potentially work in such a facility, or operate a solar panel field.

Contrary to the supply side of the system, the demand/recycling side of the system (e.g. macerators, Mephrec facility, algae basins) can be seen as limitedly subject to the market mechanism (e.g. public ownership, subsidies). Here the policy arena, motivated by landscape pressures (e.g. P scarcity, environmental quality, ageing), will have to play a more pro-active role in bringing about the necessary changes.

Given the important role of farming in the Brandenburg society, the socio-economic implications will be profound. Agriculture and the related processing industry are an important source of employment in the region, and thereby an important component of the economy and thereby social cohesion. In Techno-fix the new destination of the land will mainly be devoted to solar panels, which can provide a new source of income for the region. This will require an elaborate plan to stimulate solar panel production in the first place, but to also the provide the region a feasible way of dealing with the obsolete employment, activity, and rising health-care demand for elderly people. A related topic explained in Chapter 6 is the diverging trend of economic growth versus employment opportunities created. As can be predicted from the agricultural solutions for Techno-fix, also these technological advances will enable society to produce the same levels of food with less people. Based on the information stated in Chapter 6, certainly for Techno-fix, not only agriculture but throughout society unemployment will continue to rise as labour becomes automated. Obviously, this is a national, and even European future problem, and the institutional measures taken will largely determine future of the region.

8.6 Implications Culture-fix

A major difference between Techno-fix and Culture-fix, is that in the latter the citizens themselves allow or restrict the implementation of the solutions. Although mindset changes may take place as society develops through time, it will likely be necessary to influence and stimulate second order learning at citizens, as the basis of the implementation plan.

As mindset changes take hold, the population share of vegetarians and vegans as well as the demand for organic food will grow. For the consumers to actually buy the organic food, its price will have to drop and/or the affluence of the people needs to increase. Increasing landscape pressures on the current agricultural subregime will favour the organic food sector as its efficiency with regards to input flows (e.g. fertilizer, water) is generally higher. To stimulate demand further the strenghtening of the bio-food processing sector is also required, which may be achieved through the market mechanism itself. In addition, in order to successfully convert the agricultural practises new farmers as well as converting ones require first order learning.

A larger share of vegetarism and veganism will lead the animal production sector to decrease significantly. In terms of phosphorus flow throughput, 73% less meat will be bought compared to the trend scenario, while milk/egg and plant consumption will increase with 10.5% and 26%, respectively. This will impact the size of the related agricultural sector accordingly. The number of people required, and hence employment provision, for organic farming, animal husbandry, and processing and retailing sectors in Culture-fix is largely choice-dependent. In the vision crops will be harvested through robotic aid, which is used to balance the generally conceived higher labour requirements for organic agriculture. Also a larger share of the food will be directly marketed, leading to a decrease of traditional supermarkets, but to an increase in directly marketing people required. Although organic agricultural practises are generally conceived as being more labour-intensive, for Culture-fix it is assumed that robots take over a large share of the work, giving the people operating the farm a more supervising role as well as more leisure time. More cognitive robots will also reduce the increasing labour-requirements related to ageing of the population. Significant research in robotic as well as in hydrogen/biofuel-related technology, should therefore be done to realize Culture-fix.

Lastly, although not assessed, urban agriculture will also be a mainstream practise in Culture-fix. Also rooftops will be converted to food production systems, as well as energy producers. To avoid over-application of fertilizer, and the use of bad quality water for irrigation, people have to undergo first order learning.

8.7 Measures: Techno-fix

8.7.1 Research and development

The development stages of the technologies featuring in Techno-fix are summarized in Table 31, from which it can be derived when the solutions can be introduced, and how much support is still needed.

Table 31: Development stages and required research focus for technologies applied to Techno-fix.

Technology	**Development stage**	**Research focus**
Vertical farms	Concept, part of technology mainstream and experimental (e.g. greenhouses, hydroponics)	Pathogen control, solar cells & nanotechnology integration and production, LED development and application, climate control, automization, recyclate in nutrient solution
In vitro meat production	Proof of concept	Production process, taste, human health
Macerator	Developed	none
Biowaste digestion	Developed	none
Mephrec process	Demonstration (final)	none after P-Rex
Dewatering process	Developed	none
Effluent algae treatment	Demonstration/Developed	unknown

Whereas the Techno-fix waste treatment technologies require no more research, vertical farms, nanotechnology, solar cells, and in vitro meat production still require extensive research efforts. Given the high technological level, relatively low stage of development, and the potentially enormous societal advantages, it is deemed that research efforts should be coordinated European-wide in TRP projects. For solar cells and graphene such projects are already being done, where the latter also enjoys significant support from market actors (e.g. Samsung). This budget for those technologies needs to be maintained, while additionaly TRP projects by the EU should be started featuring closed-loop growing systems, and in vitro meat production. The physical construction and testing of the vertical greenhouse could already be done by students Despommier (2011); the national government should initiate and stimulate such projects at universities.

8.7.2 Implementation

As can be seen from the previous section, the waste treatment technologies are far more developed than the supply-side technologies. In addition, these technologies, and the Mephrec process in particular, also result in the largest benefits regarding phosphorus recycling. Furthermore, there seems to be a growing support amongst researchers related to the local wastewater treatment sectors, as well as politians (e.g. SenStadt), for the recycling of sewage sludge. These technologies should therefore be implemented first.

Although fertilizers produced by the Mephrec process are reported to be relatively pure, its effect on the local agricultural soil should first be thoroughly tested. This should be done in the short-term, using the Mephrec facility featured in the P-Rex project, and test the fertilizer produced in a follow-up of the ELaN project. In the current ELaN project only the recycled fertilizer MAP is being tested on soils. Similar to ELaN currently, also the follow-up could be funded by the German state. By doing so, the farmers can become convinced that the new fertilizer does not pose a threat to the soil and the quality of the produce. It will make the certification of the recyclate at the EU as well as state level more likely. Also the chance of negative media attention (e.g. scandals) for the recyclates will thereby be greatly reduced, making the processing industry more prone to buy the produce from the farmers. As current mineral fertilizer price are still relatively low, the recyclate should be subsidized initially. This could be done by either the state, national, or supra-national policy actors.

8.7.3 Finance

Whereas the Techno-fix solutions at the supply-side of the system will be the result of market competition, the demand/recycling side of the system will require public funding. First an extentive region-wide cost-benefit analysis should be made to assess the implentation and operating costs versus the alleviated costs (e.g. no more sludge application on land, reduction of incineration, easier purification of drinking water), thereby taking into account effects from climate change, as well as expected changes in fertilizer prices. Here it can be expected that the Mephrec process + macerators will become more cost-efficient as fertilizer price rise, given the huge recycling potential it has. Then, viewed over a time period of decades, the average netto annual costs should be reflected in taxes to be paid by the consumer. Households in Brandenburg, which already have to pay premium fees, may even witness a reduction in discharge taxes.

The initial costs will be high, but improvements will be made throughout the system. It is therefore estimated that over a long period of time, the burden on the consumer will be slightly higher than is currently the case. Because the average (Berlin) citizen is already relatively poor, the costs should be mitigated as much as possible. Here the rising groundprices, providing the state (and landlords) with additional income, should either be halted or be used to compensate the discharge tax rises.

8.7.4 First order learning

Apart from research efforts, respective actors and employees have to learn how to build and operate the new facilities (e.g. Mephrec, vertical greenhouses). Knowledge transfer between researchers and technicians of construction companies and waste treatment operators should therefore be a part of the EU-wide research projects.

First order learning about using a macerator by consumers can be done through an explanation of an employee from the installing company, or the landlord.

8.7.5 Mitigating adverse impacts

As the function of the Brandenburg (agricultural) land changes, so will its socio-economic relations. If farmers can obtain similar income compared to the previous situation, this may not pose a problem. Because cheap, abundant electricity is a requirement for vertical farms, stimulating farmers/land owners to shift towards operating 'solar/wind farms' is paramount. This is probably best accomplished by first further stimulating renewable energy technologies, making these more cost-efficient, and then after circa two decades a stimulation/subsidy program can be introduced. Given the past success of the Feed-in tarif law in Germany, a similar law at the national level should be issued again.

As explained in section 6.5.3, increasing automation processes may render a significant part of society unemployed by the time the vision is reached. Also for operating the solar farms, one can easily image a robot performing panel cleaning tasks, while technicians may still be necessary in case of malfunction or to (re-)program the robots. While this may not pose a problem for the owner(s) of the solar parks, it is for the majority of the work force. It is deemed that the only way to overcome this problem is to introduce a basic income for everyone, which currently still highly controverial. Therefore, as a first step, a public debate about this matter should invoked, by action groups/NGOs, researchers, or even politicians/political parties. Once consensus is reached about its necessity, experiments assessing societal impacts of the basic income should be conducted, funded by the national government. In the 1980s, this was already done in Canada where inhabitants of several small cities were given such a basic income. Overall, it turned out that people indeed did continue working, younger people studied more/longer, and health-care costs decreased. Unfortunately the experiment was stopped after several years when a right-winged party got elected. Once small-scale effects are successfully assessed and evaluated, the concept can be slowly introduced on a national scale for which the national government should be responsible.

8.8 Measures: Culture-fix

8.8.1 Research and development

Whereas in Techno-fix waste treatment technologies were already highly developed, and the food production technologies highly underdeveloped, for Culture-fix the technologies have developed further (see Table 32, and the technological complexity is lower. The technological complexity of Culture-fix solutions will be sufficiently low such that a regional innovation network can be develop the solutions towards implementation.

Organic farming is an estiblished practise, but here more experimentation and understanding of eco-system interactions will likely improve yields and reduce labour-input. Also the integration of recyclates into organic farming practises will have receive little attention given the novelty of the recyclates. Given the site-dependency of Brandenburg agriculture, this should be done by the local agriculture institutes ATB, ZALF, and the WiSoLa department of Humboldt Universität. Rather than extra funding, a reorientation of the research focus, stimulated by the umbrella organization Leipniz Gemeinschaft, will probably be sufficient.

Table 32: Development stages and required research focus for technologies applied to Culture-fix.

Technology	Development stage	Research focus
Organic farming	Developed	Beneficial eco-system interactions, labour-intensity, application of recyclates
EcoFerm!	Experimentation	algae conversion efficiency, P extraction
Vacuum toilets & infrastructure	Pilot/demonstration	Site-specific implementation issues, fertilizer conversion process,
Constructed wetlands	Developed	Added benefits (e.g. energy crops)
Biowaste digestion	Developed	none

Vacuum separation toilets and related infrastructure have already been successfully tested in Berlin, with the exception of faeces separation which could not be tested within the project's time scope. Its effect on soil has nevertheless been successfully tested. Because the concept was tested in existing offices and newly-built dwellings, it implementation in the existing Berlin as well as Brandenburg infrastructure still requires research efforts. Also the application of the recyclates to agricultural soils will need to be more thoroughly investigated, if is to serve as food source for humans. Researchers from the Kompetenzzentrum Wasser Berlin in collaboration with the Humboldt Universitä already carried out a previous separation toilet experiment, and are therefore most suitable to carried out the additional research. Whereas that project was funded by the EU, it is also possible to nationally, or even regionally fund and coordinate the project. (Furthermore, also the quality control regarding local fertilizer production (e.g. paint to toilet) deserves attention.)

The EcoFerm! can be considered as the least developed technology in Culture-fix, as experiments are only being performed in two distinct animal farms in the Netherlands. Yet, the EcoFerm! is part of the Dutch InnovatiePlatform and will likely receive continued adequate funding. Also its two main inefficiencies (i.e. algae nutrient uptake and P extraction) can be expected to not pose a major technological hurdle given the medium technological level. Furthermore, cost-benefit analyses already showed that for contemporary (Dutch) pig farms of 30,000+ liter of manure per year, the concept is already cost-efficient. After the EcoFerm! concept has been developed sufficiently, collaboration with the InnovatiePlatform should be sought by the LBV (farmer organization) to successfully adopt the technology.

Constructed wetlands and biowaste digestion do not need to be researched further.

8.8.2 Second order learning/routine change

The definitions of Culture-fix, decentrality and citizen involvement, can not only be applied to solutions but also to the other facets of a system; Politics, economics, social structure. It is believed that the decentralization of society and social cohesion are highly interrelated; as people feel more part of their community, the feeling of responsibility towards it will increase. When then providing people with proper 'sustainability' information, the willingness of people to change routines for the common good is assumed to be sufficient.

One main measure to attain increased social cohesion is to stimulate urban agriculture, and other community-based initiates. Particularly rooftops can serve as a garden for people living in the flats/appartments. This way people come into contact, and more community dynamic builds up. People attain a stronger feeling of responsibility, which will lead to a better biowaste separation rate. To this end rooftops should be strenghtened and made soil/plant-proof, and stairs to the roofs have to be built as well as fences to prevent people from falling off. Landlords should on the one hand be provided with subsidies to lower the costs for implementation, and on the other hand a law should be put into place forcing landlords to make the necessary changes if the inhabitants desire such a roof. Not only do green roofs provide a way to produce extra food in the city itself, but it is also an important measure to adapt to future climate change (e.g. peak water loads to sewage treatment, extreme heat events).

An important lesson learned from a recent public debate about an obliged vegetarian day for public institutions (e.g. schools), sparked by Die Grünen, is that forcing people to commit to a certain habit or mindset leads to widespread civil resistance. A more fruitful approach may be provided by the Brittish DEFRA 4E-model used by Jones and De Meyere (2009, p 144, cited in) to propose strategies for behavioural change; Engage, enable, exemplify, encourage. The behavioural changes that should take place, with the measures taken related to each can be seen in Table 33.

Table 33: Required behavioural changes in Culture-fix, proposed measures, and actors that can implement the measures.

Aim	Measure (4E)	Who involved
Diet change	Provide information of the impact of meat/dairy consumption (encourage)	Government/ NGO/researchers
	Internalization of external costs (engage)	Researchers (data) and national government (law)
Purchase organic food	Internalization of external costs (engage)	Researchers (data) and national government (law)
	Only organic food catering in governmental buildings (exemplify)	Government
Adoption vacuum toilets	Installation of vacuum separating toilets in governmental buildings (exemplify)	Government
	Use the biogas produced in local dwellings (encourage)	Landlords
100% separation of biowaste	Reflect the separation rate in household taxes to be paid (encourage)	Waste treatment actors (data), provincial state (law)
	Provision of proper digestion bags for biowaste (enable)	Solid waste treatment actors
	Redistribute the fertilizer produced to local urban agricultural projects, households (engage)	Solid waste treatment actors

8.8.3 Finance

Solutions related to the supply side of the system are assumed to come about through the market mechanism. Here the creation of demand at the consumer level is highly important. Learning processes will increase demand, but further increases in purchase power may be necessary. One way to achieve this is to, like in Techno-fix, halt the rise of ground- and rentprices by stating a maximum 'Mietspiegel'. Furthermore, as people, stimulated by urban agricultural projects, organize themselves more locally the costs for living will decrease significantly (e.g. enhanced local repairing of broken electronics).

With regards to the waste/recycling side of the system, it was calculated by Peter-Frohlich et al. (2007) that the introduction separating toilets will be cheaper in the long run (i.e. 40 years) than the conventional system. In their calculations these authors did not even include the benefits from local biogas production, which will further enhance feasibility in the long run, certainly when fossil fuel prices rise further. Similarly to the Techno-fix recycling solutions, all costs and benefits should be assessed over several decades such that high initial costs are spread out over a long period of time. When doing this, the household costs regarding wastewater charges will likely decrease, rather than increase.

8.8.4 Implementation

Conversion to organic farming practises will likely continue provided current subsidies remain in place. The share of organic farming area has been steadily increasing since 1992 to 10.6% in 2012, by which growth rate a 100% conversion will not be reached. However, as landscape developments will increasingly pressure the existing subregime, the competiveness of organic farming will increase. Once having sufficient momentum, the transition will accelerate and replace the existing subregime (Rotmans et al., 2001). Additional support from research activities, together with an increase in organic food demand, will then further strenghten the organic farming niche. This, in turn, will create (more) market incentives to enlarge to bio-food processing industry.

The vacuum separating toilets should first be installed at places where economies of scale can be achieved, to enhance the feasibility; Offices, public buildings, public space (e.g. uriniors). Offices will be most suitable as pioneers for separating toilets, because economies of scale can be achieved while people will be probably more prone to use the toilet correctly compared to public buildings. Once this is done, more experiences with installation of separating toilets and continued technological advancement will make the implementation in households more feasible. Here it is important that the inhabitants are actively involved in the process, and that it is communicated well why exactly these toilets are a necessary adjustment to the household. The landlords and/or local municipal departments will be most suited for this task.

8.8.5 Mitigating adverse impacts

Whereas in Techno-fix technology is assumed to m ake most labour redundant, creating a societal problem, this is not assumed to apply to Culture-fix. Due to people's mindset changes (i.e. 2nd order learning) consumption levels will decrease, people will need to work less, and more free time will be devoted to volunteering work. This way the city, as well as country-side, becomes more independent from the global system. One example people growing more of their own food, another is people locally repairing devices and products of others (e.g. repair workshops).

Many animal farmers will be made redudant as the population becomes more vegetarian. These people can convert to organic crop farming, after having received the necessary support and education.

8.9 Pathways

8.9.1 Parameters

One pathway for each of the two visions will be constructed. As a basis for this the typologies of (transition) pathways from Geels and Schot (2007) will be used, whom apply the nature and timing of relationships between niche-regime and regime-landscape as determinants of their typologies. This is treated in more detail in section 2.5.3. Additionally the development of a transition in four phases, as proposed by Rotmans et al. (2001), are used to as a timing-mechanism. The analysis of the three levels comprising the multi-level perspective (Geels, 2002) can be seen as performed in the Chapters; 4 (regime), 5 (regime) 6 (landscape), and 7 (niche).

The following 'transition mechanisms' are foreseen to affect the pathway taken:

1. Relationship niche-regime (e.g. symbiotic or competitive);

2. Relationship regime-landscape (e.g. reinforcing or disruptive);
3. The development stages of the niches;
4. Landscape pressure intensity on subregimes through time.

8.9.2 Pathway variation

One of the criteria for the solutions implemented in the visions is the degree of centrality, which was not only applied for the selection of solutions, but also to shape the social, economic, and political contexts of the visions. Related to this is also the second vision criterium, the degree of activity/passivity of the consumer. In Techno-fix the consumer is passive and the system highly centrally organizated, and as such the agency will mainly originate from central, powerful actors such as large corporations and the EU and national government which govern the system in a top-down manner. The opposite holds for Culture-fix where citizens are the main actors to exert agency, steering the system towards realization of the vision (e.g. altered purchasing behaviour, political pressure).

In drawing pathways to both visions the landscape developments are used as the source of variation, in addition to the vision criteria. In Techno-fix the disruptive landscape developments (e.g. climate change, scarcity) are assumed to be relatively mild, such that the necessary technologies (e.g. renewable electricity) have sufficient time to mature. Yet, also before that time the regimes will be (moderately) influenced by landscape developments. In Culture-fix the disruptive landscape developments are assumed to intensify faster. One can imagine that such developments not only have an influence on the case area, but globally. Strong commodity price rises, amongst others, can be expected. In Culture-fix the regime will be forced to respond to the pressures a more independent, decentralized, and local way.

8.9.3 Solution pathways: Techno-fix

As discussed in section 8.8.1, the Mephrec process is close to (technological) maturation, and the macerators, and algae effluent treatment arte already mature technologies, all part of the waste system. The agricultural solutions on the other hand, still require extensive research and hence time to be developed. In addition, it was discussed that vertical farms also require cheap and abundant renewable electricity, for which other technological advances are required first.

Future phosphorus scarcity is already on the problem agenda of local policy, agriculture, and waste treatment actors, where the largest potential is seen to lie in sewage sludge recycling. For local policy actors stricter EU surface water quality requirements in 2015 will be an extra motivation to change the sewage treatment subregime. Effluent releases to the environment and Natural vegetation soil losses as a result of sludge application both degrade the surface water quality, adding 334.82 t P and 276.81 t P to the surface waters in 2011, respectively. Also sludge application to Urban soils may enhance runoff, but this is not certain. Therefore mainly the Mephrec procsess (i.e. abandonment of sludge application), but also algae effluent treatment, are assumed to be planned in the short term.

Given that the Techno-fix solutions for waste treatment have a symbiotic relationship with the regime, the regime will respond to the (landscape) pressures by adding the Mephrec process to the existing infrastructure, following the Reconfiguration pathway (4). This triggers further adjustments in the structure of the regime (e.g. macerators, additional Mephrec facilities). After that the regime reproduces itself (0).

Although landscape pressures are mild, by mid-term the agriculture subregime is expected to face increasing hardships. A large and sudden landscape pressure (e.g. prolonged drought, fertilizer unavailability) is presented, inducing increasing regime problems causing embedded actors to lose faith. With no clear solution available, the subregime follows the De-alignment/re-alignment pathway (2) as no clear substitutes are available (yet). Consequently, space is created for the emergence of multiple co-existing niches (e.g. greenhouses, permaculture, non-food land use, EcoFerm!) in the de-alignment phase. Due to market forces, vertical farms in combination with solar panels applied to (former) agricultural land becomes the core of the new regime (re-alignment).

Up to long term grasslands continue to exist, providing affordable fodder to animal farmers. However, imported fodder prices become more expensive, while vertical farms cannot produce feed crops at sufficienctly low prices. As in vitro meat production matures in the period 2041-2060, its product becomes increasingly competitive and gradually replaces the dominant regime, following the Technological substitution pathway (3).

After introduciton of the macerators the solid waste subregime will treat less (bio)waste. This will leave the architecture of the subregime intact, following a Transformation pathway (1) in adapting to the changes (e.g. smaller facility).

8.9.4 Solution pathways: Culture-fix

Solutions in Culture-fix are all relatively developed, and could therefore be start planning and implementation in the short term. In Culture-fix strong (disruptive) landscape developments, inducing significant regime stress increasingly take effect in the short- to mid-term.

Strong landscape pressure manifest as disruptions in the global food supply system, causing increasingly fluctuating food prices. Citizens increasingly lose faith in the global food regime and engage more in urban agriculture and direct marketing. This is assumed to lead to increased social cohesion. As landscape developments increasingly manifest in every-day life, people also gain knowledge about unsustainabilities of the system. The enhanced social cohesion and (first order) learning combined are assumed to enable a mentality shift as a landscape development.

Organic agriculture, being competitive with the regime for agricultural land, gradually becomes more feasible, with farmers becoming convinced that conversion of the farm yields a more feasible future. This can be seen as the Technological substitution pathway (3). EcoFerm!, on the other hand, is symbiotic with the regime and follows the Reconfiguration pathway (4) to solve local problems (e.g. increasing fodder prices). The mentality shift further stimulates the organic farming niche through increased organic food demand.

As a result of the enforcing relationship with the mental shift landscape development, vegetarian and vegan diets increasingly replace regular diets, and direct marketing practise gain (retailing and processing) market share. One could state that these 'niches' partly replace the dominant regime (i.e. supermarkets, meat in diet), following the Technological substitution pathway (3) as a result the enforcing relation with the mental shift landscape development. Rather than technological substitution, it can be seen as social, or cultural substitution.

The adoption of urban agriculture in the short term, more than direct marketing and diet shifts, is subject to constraints other than the mindset of the people themselves. Land, or surface, within the city has to be available. Berlin's public space is seen as relatively large, and in addition many housing walls remain 'vacant' as a result of WWII destruction. These could serve as initial development spaces for the urban agriculture niche. Urban farming on roofs, and to lesser extend walls, will present more of a challenge as significant investment is required. Whereas the niche has a relatively symbiotic relationship with public space, it can be seen to have a more competitive relationship with built environment regarding roofs, and also and walls.

Separating vacuum toilets, like urban agriculture, also can be seen to be more feasible in some parts of the infrastructure, and less feasible in other parts. In offices and other large buildings, particularly those still be built, vacuum toilets are deemed most feasible due to economies of scale and avoidance of renovation costs. Also in newly built dwellings vacuum toilets can be taken into the design, but due to necessary organizational changes in the waste treatment subregime (e.g. collection and maintainance of a separating system) it is probable that more powerful actors implement the technology first.

Although separating vacuum toilets compete with the dominant regime, the relationship is also symbiotic in the sense that the two technologies can exist beside one another. For the pathway it is deemed that the niche is even desirable as the dominant regime is forced to discharge effluent more often, compromising the water quality. Phosphorus discharge will be reduced as buildings feature separating toilets, storing excrements in a closed environment. The more frequent occurence of effluent releases is thereby barely affected as strong rain events are most often the cause; only the effluent itself is made less harmful to the environment. For also minimizing these discharges, green roofs are assumed to provide the solution, with especially sedum roofs being applied more than roofs for urban agriculture as the former require (far) less investment.

The sewage treatment and built environment subregimes will therefore follow the Reconfiguration pathway (4), adding green roofs and separating vacuum toilets to the existing infrastructure which enables the embedded actors to deal with landscape developments disrupting the regime, as well as the mental shift landscape development reenforcing the niches (e.g. consumer willingness). These regimes thereby undergo continuous adjustments to its architecture. Sedum roofs may be further converted to roofs fit for urban agriculture, and the fertilizer produced from the separating toiletting system may again be used in urban agricultural practises.

As for Techno-fix, changes imposed on the solid waste subregime take the form of a Transformation pathway (1), where the subregime adjusts along with the new reality.

8.10 Storylines

In this section a storyline towards each vision is presented, in which the measures become implemented and pathways are followed as decribed in section 8.9. The roadmap towards 2060 is divided in three; short-term: 2014-2025, mid-term: 2026-2040, and long term: 2041-2060.

8.10.1 Techno-fix short term: 2014-2025

Halfway the year 2015 the P-Rex project will be finished (Kabbe, 2013a), of which the conclusions were that the Mephrec process proved to be one of most promising technologies, being able to recycle relatively efficient at relatively low operational costs. In 2016 a follow-up project is funded by the EU, in which most promising sewage recycling technologies are brought to the next development stage, and the price/performance of the recyclates of the different technologies is tested. Research actors from the ELaN project (e.g ZALF, ATB), during which the performance of MAP was already tested in Brandenburg, become involved in the follow-up project and test a wider variety of recyclates.

Halfway 2016, the Brandenburg state updates the Klärschlammverordnung in response to the EU Water Directive, by which new standards several smaller WWTPs may no longer apply sludge to the land in 2018. After extensive deliberations between the Berlin and Brandenburg states, the sewage treatment operators, and the Kompetenzzentrum Wasser Berlin, it is decided that for the longer term a mono-incinerating recycling process, to be operated by the BWB near Berlin, holds most potential for phosphorus recycling itself as well as to tackle the environmental problems. The result is thereafter communicated to the DWA and BDE, which will seek to lobby for subsidies. Besides the agreement, the Brandenburg state urges that first sludge to land applications of the most polluting WWTPs should stop such that the EU Water Directive can be honoured. It is decided that the best course of action is first install dewatering facilities at the most polluting WWTPs, after which these bring the sludge to one of the several landfilling sites in the province for the short term. Once a centralize recycling technology is implemented, the sludge can be retrieved from the landfill again. Given the financial problems of the smaller WWTPs, the funding for the facilities is partly funded by the Brandenburg state, and partly by the WWTPs themselves.

After lobbying by the DWA and BDE, the EU presents a subsidy for the implementation of the most promising P-Rex technologies in 2018. The regional actor network reacts by applying for the subsidy after having chosen the Mephrec process as sludge recycling technology. After elaborate planning construction near Berlin starts in 2023, and the project is planned to be finished in 2028.

The architecture of the agriculture subregime is largely maintained. The regional energy crop sector shrinks slightly as the Industrials sell the land again; 2D materials seem to be the most promising market to invest in. Advised by the LBV, the vacant land is mainly taken over by a group of organic farmers, whom wish to collectively expand their production capacity to realize larger volumes of organically produced food. These can then be sold by contract on the national food market, thereby securing the longer-term feasibility of the farm.

Furthermore, by 2021 the P-Rex follow-up project in which recyclates were tested is evaluated, and it is concluded that most processes, amongst which the Mephrec process are able to produce safe, high-performance fertilizers at a relatively low cost. This is welcomed by the farmers and the LBV, whom experience slightly increasing mineral fertilizers prices, affecting the profitability of the farmers. Actors in the food processing and retailing subregimes, however, express their concerns with regards to consumer acceptance. Also the organic food certification authorities are skeptical.

With the support of the national government, the Deutschen Phosphorplatform (DPP) thereafter initiates are more elaborate testing of of recyclate purity, and its effects on crops and human health. In doing so, it invites the main actors along the food supply chain, as well as medical experts. In 2025 the project is evaluated, concluding that the recyclates pose no significant side effects. Yet, as a precaution, it is agreed upon that annual biological tests mandatory for the recyclates produced.

Also the EU foresees (global) energy, material, land, and water scarcity, and initiates a TRP project featuring food production in a closed environment, and funding for solar cell, robotics, and 2D materials are maintained.

8.10.2 Techno-fix medium term: 2026-2040

In 2026 the EU announces a new Water Directive in which quality requirements of the surface waters becoming more stringent, taking effect in 2029. In response, the Berlin and Brandenburg states, amongst others, issues a new Klärschlammverordnung through which sludge application to land becomes forbidden. With the stimulation and financial aid of the Berlin and Brandenburg state authorities, all WWTPs in the region add dewatering process to their facilities. When the Mephrec facilities becomes operational in 2028 the Berlin WWTPs and those in close proximity of Berlin start delivering their dewatered sludge to the facility. Due to limited capacity, the more remote WWTPs keep landfilling the dried sludge. The produced recyclate is sold below international fertilizer prices to ensure sales. This does not lead to large profits, but it gives the shareholders of the Mephrec facility, de BWB, provincial states and several smaller WWTPs more financial room.

From the 2030s onwards, the sustainability linkages increasingly reinforce one another, inducing higher fertilizer prices and worsening climate conditions. Shareholders of the Mephrec facility thereby raise the price of the recyclate to realize a faster return on investment. Although the shareholders benefit, it also severely affects the feasibility of the farms. In response to this shock to the subregime, many farmers seek alternative means of using their land. While some convert to permacultures, others view greenhouses as more feasible for the future. Yet others abandon agriculture altogether and install increasingly cheaper and efficient solar panels on their land. The LBV views these developments as troublesome and urges the waste treatment and policy subregimes to recycle more phosphorus from urban streams, and make the recyclate available against a lower price.

The problems encountered by the LBV are also present in the rest of Germany, as well as large parts of Europe. In 2031 the German government instructs the Deutschen Phosphorplatform (DPP) to broaden their research scope and also investigate the potential of other phosphorus-rich streams. Also farmers' associations have to become more involved in the network. Furthermore, a law is introduced by which regional recyclate use is stimulated, and its price kept below a maximum in order to calm down the agricultural sector.

As climate conditions aggrevate, the surface waters evaporate increasingly high volumes of water. This lowers the surface water quality below the requirements set by the EU Water Directive, after which the authorities are given an offical warning by the EU. In response, the state authorities issue a new Klärschlammverordnung coming into effect in 2033, which poses further requirements on effluent releases to the environment. The sewage treatment operators, many whom are still in debt, are thereby obliged to install an additional (effluent) treatment stap to their facilities.

Inspired by the DPP, actors from the agriculture, waste treatment, and policy subregimes in 2032 deem that the best way forward is to install additional smaller Mephrec facilities in Brandenburg, which are also to recycle slaughter waste, deceased animals, and wood waste, thereby providing more affordable fertilizers to the farmers. It is thereafter agreed upon that funds gained from recyclate sales, as well as EU subsidies, will be used to subsize several smaller Mephrec facilities in other parts of Brandenburg, as well as algae basins to treat the effluent. Continuous operation, and a steady affordable recyclate price, is guaranteed; insufficient input quantities can be compensated by the large amount of dried sludge in landfills, while past experiences with the Mephrec process are used to make it more (cost-)efficient.

In addition, macerators tested within the DPP also proved to hold signficant recycling potential in combination with the Mephrec process. Their household tests also indicate that consumers appreciate the new kitchen item, as it reduces the effort to dispose of biowaste. Stimulated by the LBV, the provincial states lauch a public campain in 2037 to promote the macerator, highlighting its benefits. The state offers the macerators for free to enable a quick adoption, with the idea that the increased phosphorus recycling will bring sufficient returns on investment.

Over the years also the meat price has increased, as a result of higher fertilizer prices with led to higher fodder prices. Yet, the animal husbandry sector remains unaffected; people still demand a piece of meat and are prepared to pay a higher price for it. Nevertheless, the animal farmers have concerns for the future. Stimulated by the EU, several Industrial actors have started piloting in vitro meat facilities after 2035. Their trials indicate that the in vitro meat produced could be competitive as soon as the year 2045, and that a large part of testing consumers find the taste acceptable.

By the late 2030s electronic applications with 2D materials start to slowly become available to the public. Also the integration with solar cells strongly enhances the efficiency at a moderate increase in cost. This causes an increasing number of farmers view electricity production as a more viable means of utilizing the land, whom devote an increasing share of the agricultural land to electricty production. Also (cognitive) robots start to enter more an more business segments by 2038. One main potential is seen to be in the elderly nursing sector, where experiments are performed with the goal of revolutionizing the ever costlier (health) care sector.

8.10.3 Techno-fix long term: 2041-2060

During the early 2040s highly efficient solar cells become mass-produced, and more than half of the land is projected to be covered with solar cells by 2045. This strains the sales of the regional recyclates as more and more farmers move away from crop farmer. Recyclate prices drop due to the reduced demand, and at times recyclate supply is higher than demand. It is thereafter decided by the provincial states to delay the introduction of the macerators.

In the light of these developments the Industrials see a major business opportunity arising in indoor crop production. Using the knowledge acquired from EU TRP research projects featuring indoor crop production, the Industrials start piloting vertical farms. After successful having completed trials in 2047, the Industrials expand their production capacity while contracting a part of the PV field operators, the former farmers.

The success of the Industrials favours recyclate sales in the late 1940s, and together with increasing market penetration of in vitro meat, the regional fertilizer market becomes attractive again. From 2050 onwards the macerators becomes common practise. As global climate conditions aggrevate further, the conventional agricultural subregime faces increasing pressures due to failing crop harvests. Also the Industrial actors, opering vertical farmers and in vitro meat production facilities, expand their activities and are able to offer a wider range of produce against lower prices, forcing the farmers to convert the land for non-agricultural use, and even to bankruptcy. Scientists warn the political elite for future mass unemployment, but after a brief moment of media attention the matter fades to the background and is left unattended.

The food supply chain structure changes drastically vertical farm and in vitro meat Industrials join an alliance with Google and Facebook. A new retailing product, the free food delivery by drones to any coordinate within Berlin-Brandenburg, is received warmly online by the consumer and gains rapid market share.

By the late 1950s vertical farms, vitro meat production and automated food processing and drone delivery have become mainstream food supply chain technologies. Only milk- and egg-producing farmers were able to survive the fierce competition; artificial production thereof is still out of technological reach, but is subject to increasing interest from the scientific community. Nevertheless animal farmers joined the alliance due to mutual interests.

As automation spreads through society, more and more people become unemployed, social and economical struggles increase. The Industrials seeking to maximize the profit margins, lobby successful at the national government and EU to keep corporate taxes low. As societal dissatisfaction intensifies, graduated students unable to find a source of income, grab the momentum to occupy the vertical farms and in vitro meat production facilities. Nothing less than a minimum permanent allowance all people is demanded. After three months of struggles during which several facilities became severely damaged, the demands are honoured and the public satisfied.

8.10.4 Culture-fix short term: 2014-2025

The organic farming niche continues to grow moderately, and the farmers and LBV continue to work together and experiment with climate change-resistant measures, such as perennial crops and natural wind breaks. In addition, in 2018 a EU-sponsored research project is launched, where experiments with a range of recyclates (e.g. Mephrec fertilizer, struvite, faeces digestate) are performed. Both the LBV and local universities and institutes (e.g. ZALF, ATB) are involved. Not only is the performance of these recyclates tested, but also the safety of the food produced. The results show that some modifications in urin and faeces treatment are necessary, but that the recyclates do not pose a threat to human health.

During the years 2019 and 2020 prolonged droughts in combination with extreme heat events not only affects Berlin-Brandenburg farmers, but also those in other parts of Europe as well as the USA. Due to strong surface water evaporation resulting from the droughts, the state raised the fresh water taxes to safeguard fresh water reserves. Especially the conventional farms required large amounts of irrigation water, which these farmers were not able to afford throughout the drought periods, leading to crop losses and significant costs related to irrigation water application. Organic farmers and those experimenting with perennial crops also suffered far lower losses. This did not go unnoticed by the conventional farmers, of which a share starts to consider alternative agricultural practises.

Due to the large size of the disruptive global climate events these cause fluctuating food (and fodder) prices, sparking a national debate about the sustainability of the food system. Scientists related to agriculture, transition dynamics, and the phosphorus cycle take a proactive role and lead the debate, educating the public about unsustainabilities within the system. Learning takes place, with a minor share of it being second order. As a result, organic farming certification authorities give support to recyclates as fertilizers.

As people get inspired and the legitimacy of the global food regime starts to erode, bottom-up action increases. Some people install solar panels on their roofs, while others become involved in urban agricultural activities or even start an organic farm. Supported by the municipalities, more vacant plots are converted to community gardens. These gain a role as local social hotspot, where people meet, learn, and become inspired. This further stimulates people to reduce meat consumption and to purchase organic food, of which some bought directly from the farmer. As people learn and get inspired, the dominant institutional system remains in place, although people increasingly question its credibility by 2025.

8.10.5 Culture-fix mid term: 2026-2040

In 2026 Die Grünen win the national election convincingly, after having presented an inspiring vision of the future featuring a more regionalized economy, greener cities, and a transition of the phosphorus cycle.

Before the 2026 election it was already clear that current sewage treatment operators are facing increasing difficulties as a result of heavy rainfall events and peak river discharges. Separating toilets in combination with green roofs are viewed as the main solution by the experts within the political party, which was subsequently adopted in the national coalition treaty. The government asks the Deutschen Phosphorplatform (DPP) to further test the effect of various recyclates on crop quality and human health, working closely with producers of separating toiletting systems. Four years later, based on strict separating system and recyclate requirements posed by the DPP, several of these systems are licenced.

The government realizes that these adjustments to the infrastructure also require new organizational arrangements regarding maintenance, responsibilities, and fertilizer sales. The national government instructs the states to take charge of the implementation, for which each state is granted a subsidy that can be spent based on own insight.

The Berlin and Brandenburg states deem that large public buildings and offices hold most potential for succesful implementation of both green roofs and separating toiletting systems. The states ask various regional actors, both private and public, if these are interested in pioneering the implementation. Several powerful actors, after having made future prognoses regarding fertilizer and energy prices, are willing to participate. The states then organize a project together with these actors, as well as actors from the waste treatment, research and agriculture subregimes in which an implementation plan is formulated and funds are allocated. The solid waste operators are assigned a coordinating role, organizing separating system maintenance and fertilizer collection, as well as the sales of the fertilizers to the farmers. In addition, through a bidding green (sedum) roof constructors are contracted to install and maintain the new roofs for a 10-year period.

Between 2030-2035 international fertilizer prices spike after workers of a phosphate mine in Marocco strike for gaining better working conditions, and international fossil fuel prices increase signficantly. Recyclates thereby become highly competitive with mineral fertilizers, and local farmers order large volumes of recyclate from the regional solid waste treatment operators. Conventional farmers, being affected most by the price rises, become convinced that more organic farming practises hold most potential for the future. Being member of the LBV, the farming organization helps these farmers in converting their practises by sharing their knowledge. Also a part of the animal farmers, whom see fodder prices rise and demand fall, face bankruptcy or are bankrupt already. The LBV decides to aid these farmers and searches for a solution. The most promising potential is regarded to be the Dutch EcoFerm!, which is reaching mainstream application in the Netherlands. In collaboration with the Dutch InnovatiePlatform, the technology is brought to Brandenburg. With the help of a EU subsidy, the animal farmers implement the EcoFerm! and become competitive with their Dutch neighbours again.

The strike at the mine and its effects on food prices and availability are strongly perceived by the citizen. More and more people start demanding (organic) food produced from recyclates, which is in many cases purchased from the farm itself and via weekly markets. For some food categories, local organic food grown with recyclates becomes competitive with conventionally grown food, although the prices of both food types remain relatively high.

As the economy decentralizes and people become more rooted in their community, the institutional system undergoes a transition. More power is transferred to the states and municipalities, where people can exert more influence. Also the amount of weekly working hours reduces gradually, allowing people to spend more time on other activities, such as trips to Brandenburg, community projects, and taking care of the growing amount of elderly people.

8.10.6 Culture-fix long term: 2041-2060

During the early 2040s heat events, particularly in the urban areas, greatly increases energy demands for cooling and there even a few mortal accidents due to dehydration. In response, the national government obliges the presence of a green roof on every building, for which subsidies are provided. As the green roof sector has been gradually growing over the past years, its implementation has become more affordable and expertise has been built up. Using the subsidy, current sedum roofs are also being converted to roofs capable of supporting more plant growth, which provide further potential for reducing the heat island effect.

Also innovative market actors grasp the opportunity offer landlords a green roof with (vacuum) separating toilet system against relatively low costs. On the green roof vegetables and fruit are grown which are fertilized by the locally produced fertilizer, and the food is provided to the residents as well as the local market. The new business concept appeals the citizens and becomes commonplace by 2060. As much of the greywater produced is treated with local constructed wetlands, and used again on the green roofs, the extensive central sewage piping network becomes an unnecessary burden. Gradually it becomes replaced with a less elaborate water drainage system, connecting the constructed wetlands to farmers' irrigation networks. During droughts the system can be used by the farmers to irrigate the land, and in cases of excess the water is released to the surface waters.

As the economic continues to decentralize and dematerialize, people increasingly engage in arts, sports, and personal development. Self-sufficient communities in Brandenburg arise where people make most decisions themselves and use local currencies. National governments have dissolved in a federation of European (provinicial) states, where citizens influence main politcal choices directly through stating and modifying their preferences on the internet.

Conclusions

The main research question "To what extent is a closed phosphorus cycle for the Berlin-Brandenburg region possible in the long term?" addresses both the current potential within the system, as well as to what extend this potential can be exploited. Conclusions derived from the present technical and social systems with regards to cycle optimization are therefore first presented. After that conclusions about the capability and feasibility of the future visions are formulated.

Technical system: Present situation

The conclusions from the 2011 MFA of Berlin-Brandenburg were already drawn in section 4.9, and will be briefly recapped. The main conclusions drawn were:

- The recycling of wastewater offers by far the greatest recycling potential (3,675.3 t P), followed by slaughter waste (1,426.6 t P), agriculture losses to the environment (1,051.1 t P), collected biowaste (680.5 t P), and deceased animals (105.1 t P);
- Apart from adding processes to the system that recycle these flows, improving sewage treatment, food consumption (e.g. reduce food waste, vegetarism), and agricultural practises will likely enhance the efficiency of the regional cycle;
- The elimination of phosphorus in detergents (612.6 t P) would reduce the phosphorus load in waste water by one sixth;
- A total of 1,434.1 t P was netto extracted from Brandenburg soil, thereby depleting the soil phosphorus stock;
- Urban soils as well as natural vegetation soils receive far more phosphorus than is extracted, leading to soil stock additions and losses to the environment;
- Limited recycling from internal waste flows already takes place in the form of sludge application to agricultural soil (363.2 t P), MAP recycling (17.2 t P), and digestate from plant prunings (90.1 t P); a total of 470.5 t P.

Social system: Present situation

At present actors in the waste treatment, agriculture, research, and policy subregimes of Berlin-Brandenburg view recycling of sewage sludge as the main opportunity for improving the phosphorus cycle, which notion can be confirmed from the MFA of Berlin-Brandenburg. As such, both the awareness on phosphorus scarcity and need for action are recognized, providing a promising first step towards closing the regional phosphorus cycle. However, no evidence of their existence in the food processing, retailing, and consumption subregimes was found. Although the latter three subregimes only offer limited potential regarding system-wide efficiency, the cooperation of the embedded actors is nevertheless crucial in several ways:

- The consumer demand for food in combination with the mode of shopping impose selection pressures on the processing and retailing subregimes;
- In turn, processing industry and retailing actors impose demands on the volumes of and types of food bought from the farmer, thereby providing selection pressures to the agriculture subregime;

- Due to these selection pressures on the agriculture subregime, the farmers may be reluctant to adopt recycled fertilizers from the waste treatment subregimes.

Whereas the will in the actor-network exists to improve waste recycling to agriculture, its realization can be seen to be mainly hampered by present economic system (e.g. debts of sludge operators and states, low profitability farmers), which finds part of the naturally unfavourable environmental system as well as the configuration of the technical system.

The provincial states of Brandenburg and Berlin in particular, are heavily debted as due reconstruction after the Cold War. Brandenburg sewage operators are also strongly debted. Whereas the origin of those debts were not found, it is clear that the current practises (i.e. sludge application on land) bring significant operational costs, in addition to phosphorus losses to the environment.

The farmers also have little room for investment due to the low fertility of the land (i.e. low harvests) and the low prices these gain for their produce on the food stock market. Climate change and phosphorus scarcity are likely to increasingly impose stress on the agriculture and sewage treatment subregimes (e.g. peak river discharges, higher irrigation demand), making the current practises increasingly unfeasible. The agriculture, sewage treatment, and policy subregimes can be seen to be positioned in a locked-in situation, which lock will further strain over time. It can therefore be concluded that it is unlikely that a transition will take place solely from within these subregimes (i.e. policy, agriculture, and sewage treatment), and that external (e.g. technology, higher policy levels) aid is required.

Potential of the visions

To assess the possibilities towards enhancing the efficiency of the Berlin-Brandenburg phosphorus cycle, two distinct visions were created. In the vision Techno-fix centralized solutions are featured; vertical farms, in vitro meat production, and the Mephrec recycling process in combination with macerators and algae effluent treatment. The Culture-fix vision has a decentralized character, integrating organic farming, EcoFerm! manure to fodder, and vacuum separating toilets. Contrary to Techno-fix, in Culture-fix behavioural changes largely determine the implementation of the technologies, while increased vegetarism and avoidance of food waste further enhance the efficiency of the Culture-fix.

The socio-economic contexts of Techno-fix and Culture-fix are highly diverse, yet both seem feasible futures; the preference for either vision will strongly depend on the observer. Conceptually seen, in Culture-fix the society seeks to refind its balance with the environment by slowing down its pace, and by treating the available resources more effectively. In Techno-fix the food production levels and consumer routines are maintained, while seeking to alleviate environmental pressures through strong technological development.

The trend and vision cycle efficiencies were determined using the internal material cycle [M] in relation to discaded waste [D]; [1-(D/M)]. The trend reached an efficiency of 80.7%, while Techno-fix and Culture-fix showed large improvements with 92.5% and 95.3%, respectively. Thus a phosphorus atom cycles an average 5.2 times before discarding in the trend, in Techno-fix this is elevated to 13.3 times and in Culture-fix even to 21.3 times. In this sense, Culture-fix is clearly the most sustainable vision. Yet, while in Techno-fix food production levels are maintained, those in Culture-fix decreased by 15.3%. In addition, the unretrievable losses to surface waters are highly similar for both visions, with Techno-fix leaking 346.2 t P and Culture-fix 355.4 t P. Both visions thereby pose a large improvement to that of the trend; 1,684.8 t P. The visions score differently on each of the three matters (i.e. cycle efficiency, unretrievable losses, food production), and without weighting no clear favorite can be appointed.

Rather, a merger between the two visions leads to the highest score on all fronts. A combination of vertical farms and separating vacuum toilets would lead to the the lowest unretrievable losses, as well as the highest yields. Any produced animal, meat and wood wastes should be recycled, for example through implementing Mephrec facilities without connection to the sewage system. In addition, the reduction of avoidable food waste and full waste separation, and a diet shift to vegetarism in combination with in vitro meat production for meat would further increase the efficiency of the system. Finally, although the EcoFerm! does not lead to efficiency gains within the system, it could be installed on milk and egg producing farms to increase the (future) feasibility.

Implications of the visions

Particularly the high-end technological solutions, the vertical farms and in vitro meat production, are strongly dependent on future technological advances. Whereas the mainstream application of these solutions may well hold the ultimate solution for a growing global population, its realization will surely take decades, in which time landscape pressures may have rendered the technical system unfeasible already. In this sense, Culture-fix solutions in combination with the Mephrec process offer the safest future pathway.

The societal effect of such strong technological development in Techno-fix will probably be the (partial) obsolescence of routine-based labour, on which the majority of the present-day population still depends. Therefore, in Techno-fix institutional adjustments that seem impossible at present, may have to be made to avert future societal crises. Whereas in Culture-fix the institutional system changes gradually as people's mindsets change, in Techno-fix the institutional system will find itself more and more out of balance with the economical system, which balance may only be restored by force from the bottom-up.

Finally, the visions were based on the two seemingly opposing poles that have existed since ancient times; the material versus the immaterial, nature versus culture, the technological versus the social. Although the poles represent two extremes, these are also strongly intervowen and mutually dependent in our society. By performing the research it became possible to imagine two future societies where one of the poles was expressed far more profound than the other. Rather than presenting a choice between the two futures, it was shown what is possible and which implications this could have. The way food is grown and consumed seems to reflect the societal attitude towards food, and thereby the character of society itself. In this sense, the message stated in the beginning of the thesis is deeper than one may think initially. Eine andere Welt ist pflanzbar.

Reflections

Theoretical

The initial theory treated could only be applied partially. Particularly for the analysis of the socio-economic system, the methodological theory from Binder (2007) had to be adjusted. The distinction into four different types of rules, following Giddens social structuration theory, is deemed unnecessarily complicated.

A rules distinction between regulative and internal rules proved to be sufficient for the research, which was nevertheless inspired by Giddens social structuration theory, as well as Geels (2004) paper about rules, actors, and (material) system. In addition an analysis of actors could by made based on insights from MLP theory (Geels, 2002).

Also no adequate example of a MFA-SAA analysis was provided in the paper from Binder (2007). The theory of a quantitative system's analysis by Wiek et al. (2008) in combination with an example of a strongly related methodology (Spoerri et al., 2009) enabled the creation of a holistic qualitative system's analysis, as performed in Chapter 8. This, in turn, enabled the identification of main barriers and opportunities towards reaching the vision, part of the backcasting framework.

The initial theory from Van der Voet (1996) was certainly sufficient to carry out the 2011 MFA. During the modification of the MFA for vision assessment and vision evaluation the theory from Van der Voet (1996) was again useful, yet some additionally required theory could not be found. Advise from the supervisor made it possible to carry out the assessments, but a source integrating all the theoretical and methodological aspects of the MFA procedure (e.g. a handbook) would have been helpful.

Finally, whereas the theory on transitions was not entirely used, it did provide the necessary theoretical context to distill the pathways. The paper by Geels and Schot (2007) proved highly useful in imaging transitions and the relations and timing between the three MLP levels, complemented by papers by Smith et al. (2005) and Rotmans et al. (2001). Whereas the theory is clearly focussed on technological transitions, it was nevertheless possible to also imagine how a more social or cultural transition (e.g. direct marketing, vegetarism, urban agriculture) would take place by using the nature and timing of interactions.

Methodological

In general the methodology as stated in Chapter 3, structured by the backcasting framework, provided a well-capable means of performing the research. The elements considered (i.e. social, technical system and developments) were sufficient to understand the workings of the system, and make recommendations towards improving it. A quantification of the (regional) economic system, related to costs of the adjustments to the system, could certainly improve the quality of the results. In addition, the current and future relationships of phosphorus streams with other material and energy streams would have given a far more holistic perspective on the regional cycle. This, of course, would have required significant additional efforts , which was not possible within the (time) scope of the thesis.

Data collection: MFA

Data about the quantity of flows was sufficiently available for use in the MFA. For flows related to waste, crop production, and food processing provincial reports proved very useful. The yearbook of the

BMELV (2013) allowed for determining the amounts of purchased food. Combining the information with the national biowaste study by Kranert et al. (2012) enabled the creation of the MFA. The latter source was particularly helpful because this way the processing, retailing, and consumption biowastes could be related to one another, providing access to information that in large could not or barely be found using regional sources. Finally, the MONERIS model was able to identify the erosion flows for the various types of soils, which in turn enabled the quantification of agricultural soil stock change.

Unfortunately, very limited information about food(stuffs) imports and exports could be found; these flows had to be derived from the various process balances while making certain assumptions. Although the sizes of these flows will be the most uncertain ones, they are also the least important and a sufficient analysis could still be made.

Whereas information about the quantity of flows could be found with relative ease, data concerning the (phosphorus) quality of the flows was generally hard to find. An exception existed for food- and crop-related phosphorus concentrations, for which the databases from Kirchhoff (2014) and Von Wulffen et al. (2008) proved highly valuable. Many sources were found with regards to the various components and types of livestock and fish, but these most often only provided very limited information that could be used. In the end, many bits of information had to be integrated as a whole, which took significant effort and many assumptions had to be made. A database about general phosphorus concentrations of the various parts of different livestock and fish categories, would have been helpful.

Modelling: MFA

The waste flows were related to the Biowaste consumption flow, which was in turn derived from the Consumption process balance. As such, all processing-, retailing-, and consumption-related flows were calculated in relation to one another. As a result, when one specific (sub)flow changed, the calculations had to be rechecked, and adjustments to the MFA model, and in some cases the report itself, had to be made. This led to (unnecessary) loss of time. A more tight integration with STAN software and an Excell-like program, perhaps even online, could partly smooth this process.

Whereas first Umberto software was opted as MFA modelling system, STAN software proved to be far more simplistic and straightforward to use for MFAs on elemental materials. The only drawback of STAN found was that the software is not able to locate an error, but rather only mentions there is an error. This, in some cases, made the task time-intensive.

Data collection: Social system and current developments

Interviewing experts for the social and current developments analysis proved to be an elaborate, yet valuable means of data collection. Particularly for the agriculture and waste subregimes information was aqcuired that would have been hard or impossible to find on the internet. In that case it did not only save time, but also increased the quality of the research. The interview held with LBV (2014) about the agriculture subregime also helped in determining the fate of flows in the MFA, making it particularly valuable. No interviewees for the analysis of the food processing, retailing, and consumption subregimes could be found unfortunately. Actors approached for the former two subregimes were unwilling to participate, of which one of the reasons was secrecy related to competitiveness. Furthermore, no proper expert related to the consumption subregime was found, which is likely due to the heterogeneity of this subregime. Yet, although the interviews consumed considerable time into prepare, some of which in vain, it was cerainly worthwhile.

Regarding food processing, retailing, consumption and policy subregimes it is deemed that through own insight, and the complementation of reports and papers, sufficient information could still be found. Also through the previously-mentioned interviews not only information about the respective subregimes was found, but also about the regional food supply-chain and local policy. Furthermore, the regional social science research, performed by Dr. Nölting in particular, provided a very rich data source regarding the organic food supply chain, as well as actors and rules related to sewage sludge recycling.

Landscape developments and visions

Forecasts and solution-specific information was abundantly available on the internet. Given the fictional nature of landscape developments, as well as solutions, the treated material was relatively choice dependent. This is a unavoidable drawback with regards to accuracy and credibility of the results, but it also enables the researcher to deliver a unique piece of work and provoke the reader. Especially the latter aspect can be seen as an important result of backcasting.

The data regarding economic, social, and political developments is open for interpretation. Often only the problems and issues related to the landscape developments could be identified, where the documentaries of Tegenlicht were very helpful. From those insights it was possible imagine certain future pathways, but the creation of a reliable forecasts was seen as impossible and therefore in most cases not made.

Finally, for solution characteristics the necessary information could be extracted from papers. Yet, in order to make a thorough vision MFA analysis, more detailed information would be required. This mainly holds for algae effluent treatment, vertical farming, vacuum separating toilets, and particularly for in vitro meat production. Nevertheless, the solution and vision results found are certainly seen as valuable as no other attemps in this direction have been witnessed in the literature.

Barriers, opportunities, pathways

The identification of barriers and opportunities was solely based on analyses done in the previous chapters. Those insights provided a rich context in which the various system characteristics could be related to one another. This was done with the help of a brainstorming excercise and inspiration from Wiek and Iwaniec (2013), which proved sufficient. With the necessary knowledge gained through the solution and vision analyses, additional barriers and opportunities towards implementation of the solutions and visions could be identified. The identification of measures and actors to carry out the measures followed straightforward from the previous analysis.

The creation of vision pathways entailed a rather iterative procedure. The identification of development stages of the niches, and their relationships with the regime and landscape levels, greatly helped imagining the system's change. From there it was realized that Techno-fix solutions for the agricultural sector would surely require decades, and that therefore the timing of landscape development intensity (e.g. climate change) could be used as the means of pathway variation. Based on the pathway typologies and information found on (landscape) developments, sufficient imagination for writing storylines was acquired.

Organizational

Performing the research in the study area was an endeavour with many surprises, negative and positive. If anything, it did enable a close cooperation with partner T. Theobald, which is seen as highly successful. Not only could far more information for the 2011 MFA be found and integrated, also a more thorough understanding of the agriculture and sewage treatment subregimes themselves was attained through the cooperation.

Next to that, also interviews could carried out locally, which provided (more) valuable information to the research. Also learning the German language through everyday interaction helped in understanding many of the German sources used, as well as in conducting the interviews. Additionally Google translate also acted as an easy tool to overcome the language barrier.

Finally, with the help T. Theobald and his supervisor a workshop presentation was given at the ATB institute about phosphorus waste recycling to agriculture, where the (intermediate) thesis results could be shared with the participants. The slides of my presentation can be viewed in Appendix C

Recommendations

It was concluded that particularly the technologically advanced options, vertical farms and in vitro meat production, may well hold be the ultimate solutions for a growing population. However, these options will surely take decades to develop towards mainstream application, during which time long-term developments may have rendered the current mode of food production unfeasible already. In this sense, Culture-fix solutions in combination with the Mephrec process offer the safest future pathway.

Based on these statements, recommendations to actors and directions for future research are the following.

Recommendations to the LBV and the farmers

- Stimulate cooperation amongst organic farmers, such that their crop production efforts become coordinated. This should enable sales on the national food market, and thereby overcome an important growth-limiting barrier.
- Continue or intensify experiments with perennial crops and other measures to become more resistant to longer droughts, heavier rainfall events, and stronger winds.
- Seek cooperation with the Dutch InnovatiePlatform to test the EcoFerm! in Brandenburg. This may not only provide a viable means of organically certified fodder production, but also protect the animal husbandry sector against expected higher fodder import prices in the future.

Recommendations to regional policy actors

- Together with actors from the agriculture and waste treatment subregimes, and in consultation with higher policy actors, devise an implementation plan for recycling urban phosphorus streams. This can be done once the effect of various recyclates is sufficiently tested. Whereas for Berlin and nearby cities a more centralized solution seems most realistic (e.g. Mephrec), in the rest of Brandenburg a more decentralized infrastructure seems more appropriate.
- Provide subsidies for greenroof applications, and provide vacant land to urban agricultural pioneers.
- Examplication by public actors can be a powerful means to convince people. This could, for example, entail installment of separating systems and green roofs in and on public buildings, or the provision of organic food to schools.

Recommendations to higher level policy actors

- Maintain subsidies for both organic and conventional farming practises; without these many farmers will probably face bankruptcy, and the social activity in Brandenburg will further degrade.
- Expand the ELaN/P-Rex projects to investigate the effect of additional recyclates (i.e. other than MAP) on crop production and soil quality. The Deutschen Phosphorplatform (DPP) could be assigned a coordinating role. In addition to actors from agriculture and waste treatment subregimes, also actors in food processing, retailing, and healthcare subregimes should become involved to increase acceptance of crops grown with recyclates within the actor-network.

- When the recyclates prove to be safe, introduce a subsidy that lowers the recyclates price below mineral fertilizer prices to allow for application of the recyclate.
- To minimize the occurrence of food scandals, which may undermine efforts to close the phosphorus cycle, introduce a mandatory (biological) test for the recyclates.
- Create more public awareness on sustainability issues in general, as well as conceptual solutions. An excellent means may be to introduce this broad topic already in highschool education programmes. Thereby more public acceptance, for phosphorus recycling as well as other measures necessary for a sustainable future, will likely be the result.
- Provide financial support to aid the transition of the sewage treatment subregime, potentially via the DPP. Without this support a transition in the waste treatment subregime unlikely takes place. The support will likely be most effective if it features an implementation plan coordinated by the regional actor-network itself. Contrary to the installment of solar panels for example, the installment of vacuum toilets and Mephrec facility requires coordination with the policy, waste treatment, and agriculture subregimes.
- Further stimulate and coordinate research in indoor food production (e.g. vertical farms, in vitro meat production), as well as 2D materials, renewable energy technologies, and robotics.
- Finally, available data regarding the quality of waste flows is inaccurate, and the quantity and fate of food flows largely lacking. Qualitative as well as quantitative data was even lacking for slaughterwaste and deceased animals, which are very phosphorus-rich waste streams. Respective actors governing these streams (e.g. food processors, retailers, waste treatment operators) should be obliged to monitor and report these flows to the national and regional statistics bureaus.

Directions for future research

- A qualitative socio-economic analysis as performed in this research already revealed important barriers and opportunities towards phosphorus recycling. However, a quantification of the economic factors in relation to the (future) sustainability linkages should be able to provide a far more accurate picture of the feasibility of the various solutions proposed.
- Also the creation of a more encompassing and complex computer model, integrating various methodologies (e.g. MFA, LCA), could serve as a stronger basis for policy advise as well as for monitoring the performance of cities and regions. In this regard the scientific field of Agent-based modelling (ABM), in combination with Backcasting, seems very promising.
- Although phosphorus is the element related to food production that will probably be first subject to scarcity, it is important to keep in mind that the recycling of many more (trace) elements is necessary for a sustainable food system. Technologies able to recycle also these these elements should therefore be higher on the research agenda than technologies only able to recycle a few elements, such as MAP recycling technologies.
- Highly concentrated indoor food production, in combinating with renewable energy technologies, seem a requirement for long-term continued thriving of the global population, and should be a focal point for future research.
- Finally, if routine-based labour is to become obsolete, the societal implications will be profound. More research into this (new) topic should be done, including societal experiments testing alternative institutional and economic arrangements.

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Appendix A

Additional tables

Table 34: Options that will be assessed on their potential to improve the regional phosphorus cycle.

Regime	Potential solutions
Agriculture	precision agriculture, organic agriculture, mixed crops and cattle, permaculture, closed-loop greenhouse systems
Distribution	direct trade between farmer and consumer, minimizing and re-using supermarket/catering food waste
Consumption	vegetarian/vegan diet, minimized food waste, plant-based meat replacers
Waste treatment (solid waste)	composting and recycling of organic waste, use of bone meal
Waste treatment (wastewater)	application of struvite, seperate collection and treatment of urine and faeces

Table 35: Calculated turnover, amounts, and phosphorus contents of different petfoods purchased in Berlin-Brandenburg.

Petfood category	Turnover in Germany [mil. euro]	Average price per amount [euro/kg]	Consumption in case area [t]	Phosphorus concentration [mg/gram]	Phosphorus quantity [t]
Dogfood: wet	362	3.63	7,579.2	3.49	26.5
Dogfood: dry	411	3.43	8,130.1	10.57	86.0
Dogfood: snack	373	18.09	1,483.3	10.57	15.7
Catfood: wet	971	3.14	8,245.8	3.49	28.8
Catfood: dry	318	8.47	7,283.6	10.57	77.0
Catfood: snack	197	34.84	406.8	10.57	4.3
Birdfood	49	1.88	1,866.2	10.57	19.7
Fishfood	64	96.18	47.9	10.57	0.5
Other petfood	121	21.21	410.4	10.57	4.3
Total					**262.8**

Appendix B

Interview questions

Interview questions for Dr. K. Lorenz of the LBV (German)

1. Wer sind Sie? Wass ist die Rolle von Ihre Organization?
2. Wird (zukünftigen) Phosphor-Verfügbarkeit in der Landwirtschaft als ein Problem gesehen?
3. Wenn ja, wass wird am Moment in der Landwirtschaft getan um Phosphor effizienter zu nutzen?
4. Welche anderen wichtigen Entwicklungen und 'Problemen' finden statt in der Brandenburger Landwirtschaft?
5. Was sind die wichtigsten Akteure relatiert zu der Landwirtschaft? Wer sind wichtig um Phosphat zu recyclen? Wie sind sie miteinander verwandt?
6. Wie sehen sich diese Akteure ihre Aufgaben und Pflichten? (Nach welchen Prinzipien versuchen diese Akteure (die Nachhaltigkeit) der Brandenburger Landwirtschaft zu verbessern?)
7. Welche Lsungen / Maßnahmen zur (Phosphor) Nachhaltigkeit werden von Ihrer Organisation begünstigt? Was muss geschehen, bevor sie umgesetzt werden können?
8. Was halten Sie von meinem Lösungen nachzudenken? Wass ist von jeden die machbarkeit?
9. Welche bestehenden Vorschriften / Gesetze / Subventionen behindern und ermglichen die Umsetzung dieser Lösungen?

Interview questions for Dr. K. Lorenz of the LBV (English)

1. Is (future) phosphorus availability seen as a problem within the regime?
2. If so, what is currently being done to use phosphorus more efficiently?
3. Which other main developments are currently taking place in the regime?
4. What are the most important actors in the regime? How are they related to each other?
5. How do these regime actors view their responsibilities, rights and duties? (normative rules)
6. According to which principles do these regime actors seek to improve (the sustainability of) the regime? (cognitive rules)
7. Which solutions/measures towards (phosphorus) sustainability are favoured by you/your organization? What needs to happen before they can be implemented?
8. What do you think of my solutions? Why or why not are these solutions feasible?
9. Which existing rules/laws/subsidies may hinder and enable the implementation of these solutions? (regulative rules)

Interview questions for Dr. A. Ochs of the BVE (German)

1. Wer sind Sie? Wass ist die Rolle von Ihre Organization?
2. Wird (zukünftigen) Phosphor-Verfügbarkeit in der Entsorgungssektor als ein Problem gesehen?

3. Wenn ja, wass wird derzeit getan in der Entsorgungssektor um Phosphor zu recyclen?
4. Welche anderen wichtigen Entwicklungen und 'Problemen' finden statt in der Berlin-Brandenburger Entsorgungssektor?
5. Welche (wichtige) Akteuren sind aktiv in der (Berlin-Brandenburger) Entsorgungssektor? Wie sind sie miteinander verwandt?
6. Wass ist der wichtigste Regeln relatiert zu Biomüll/Klärschlammen und Massnamen zur Phosphorrecycling?
7. Wie sehen sich diese Akteure ihre Aufgaben und Pflichten? (Nach welchen Prinzipen versuchen diese Akteure (die Nachhaltigkeit) der Brandenburger Landwirtschaft zu verbessern?)
8. Welche Lösungen / Maßnahmen zur (Phosphor) Nachhaltigkeit werden von Ihrer Organisation begünstigt? Was muss geschehen, bevor sie umgesetzt werden können?
9. Was halten Sie von meinem Lösungen nachzudenken? Wass ist von jeden die machbarkeit?
10. Welche bestehenden Vorschriften / Gesetze / Subventionen behindern und ermöglichen die Umsetzung dieser Lösungen?

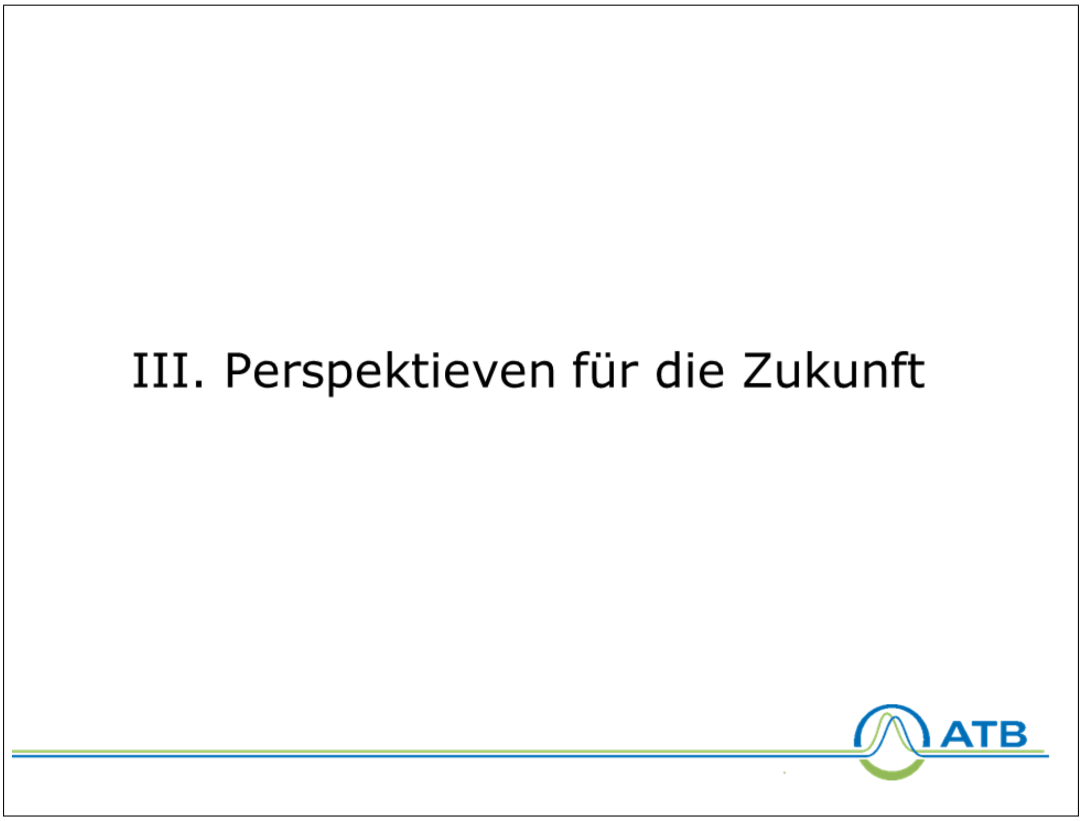
Interview questions for Dr. E. Hoffmann of the IÖW (German)

1. Wer sind Sie, was its Ihre Rolle bei das IÖW?
2. Womit ist das IÖW beschäftigt und welche Rolle spielt das IÖW in Berlin-Brandenburg?
3. Wie kann man der Konsument als Ernährungsverbraucher betrachten?
4. Welche wichtigen Entwicklungen finden statt in dem Konsumentenbereich (in Berlin-Brandenburg)?
5. Und (wie) ändert sich derzeit die Verbindung zwischen Bund-Land, Land-Burger, Konsument-Supermarkt, Konsument-Bauern, Konsument-Entsorgungswirtschaft?
6. Considering the 'solutions' below, how would peoples routines need to be changed, and how could these be changed? Which actor(s) should take the lead?

   - Vertical farming
   - Permaculture/Organic farming
   - Vegetarianism/Veganism
   - Decentralized/seperating sanitation
   - Full separation of biowaste from other wastes (also mascerator)
   - Cycling nutrients i.e. excrements, slaughterwaste, and biowaste back to agriculture

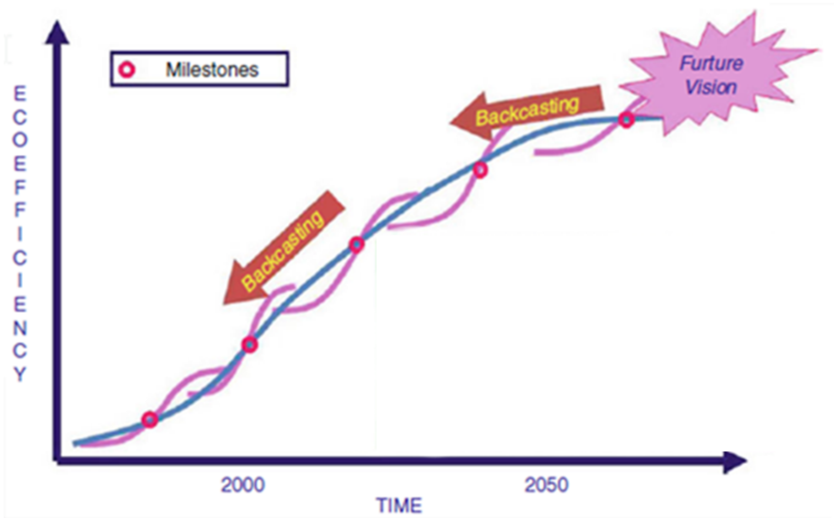
Appendix C

ATB presentation slides



Methodologie

Strömenanalyse in Kombination mit Backcasting.

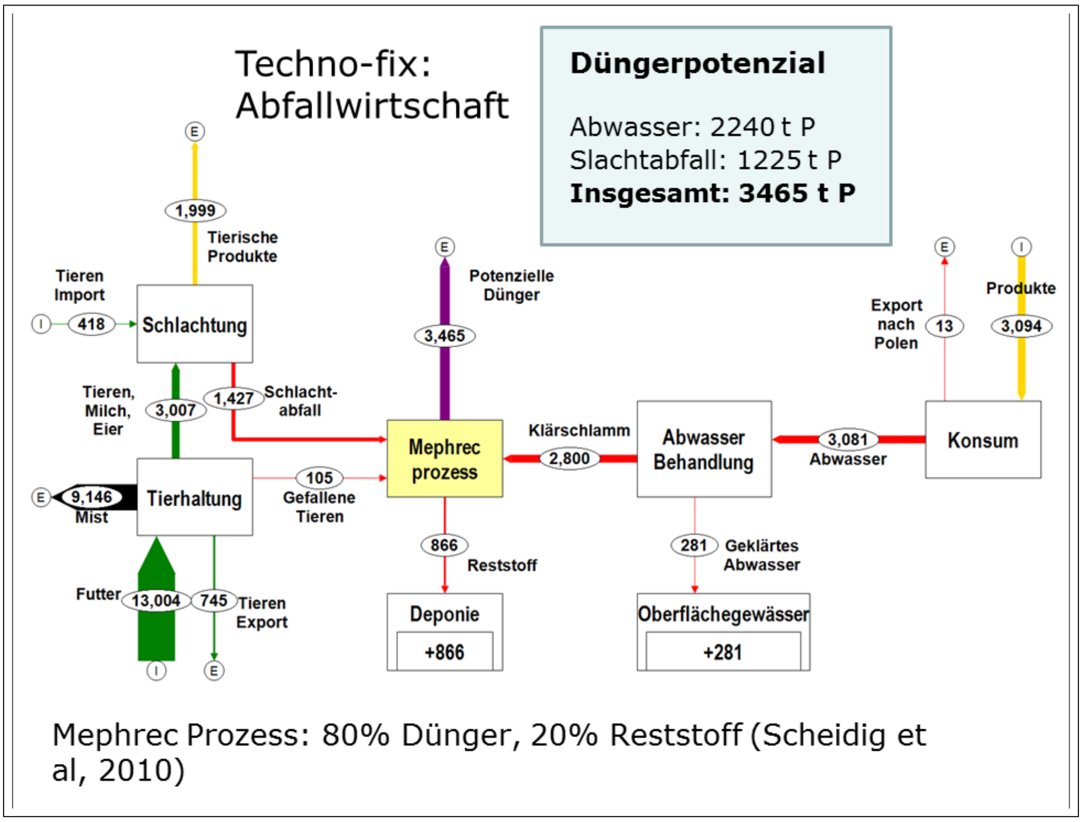


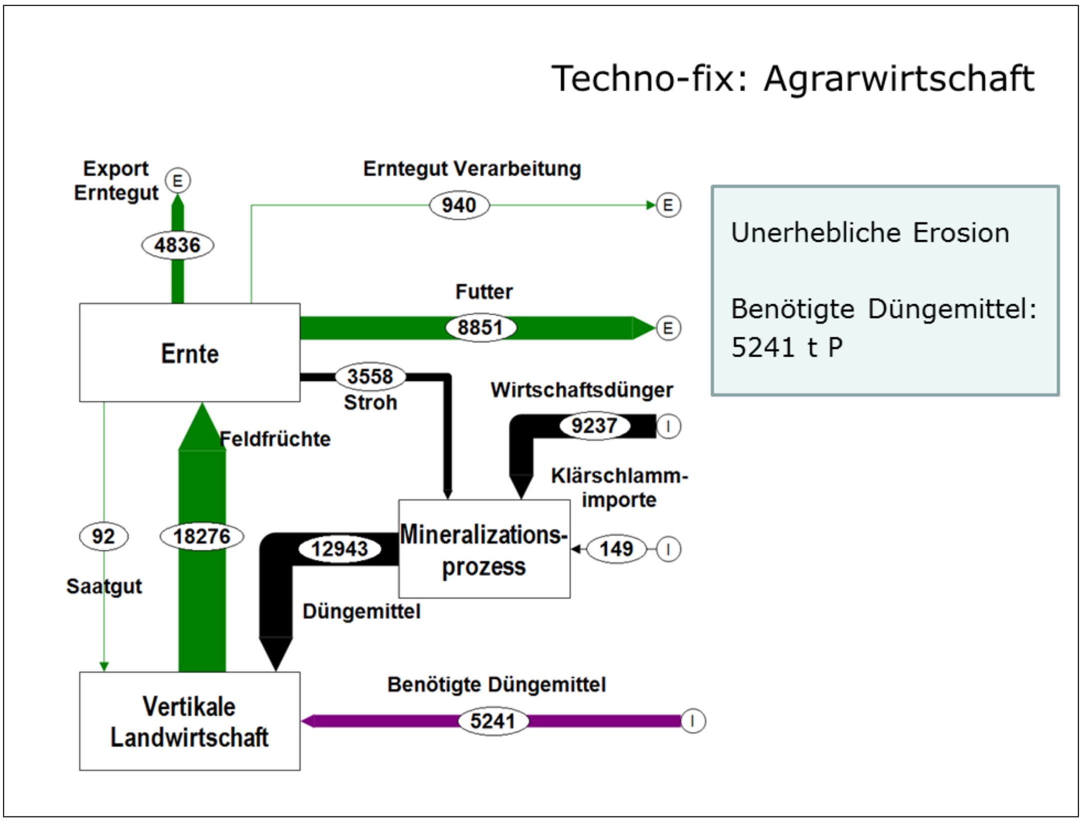
Techno-fix

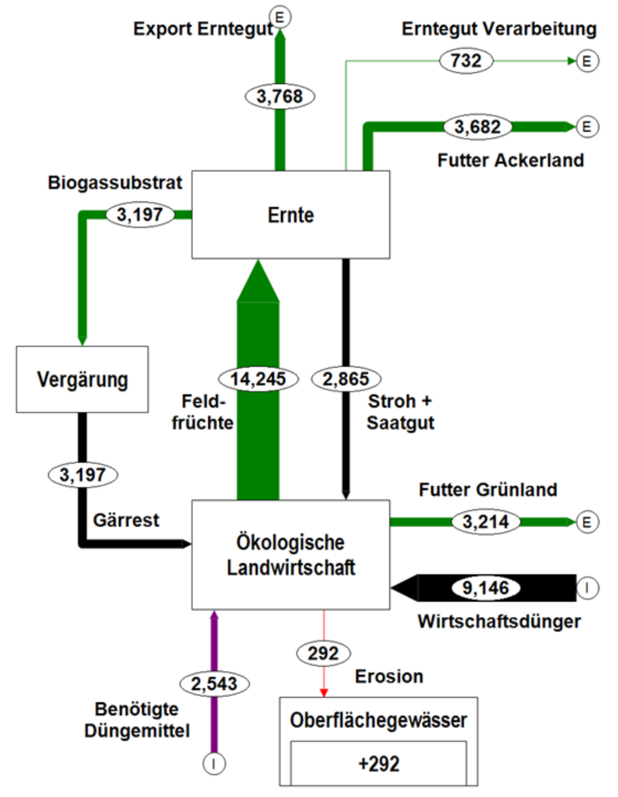
- Zentralisierte Technologien
- Der Mensch spielt eine *passieve* Rolle

Annahmen für das Jahr 2060

- Bevölkerung Berlin-Brandenburg wächst mit 0,45% zwischen 2011 und 2060.
- Phosphatfreie Reinigungsmittel:
  minus 613 t Phosphor in Abwasser
- Bodendefizit wird aufgedüngt mit Mineraldünger.


Techno-fix: Abfallwirtschaft
Düngerpotenzial
Abwasser: 2240 t P
Slachtabfall: 1225 t P
Insgesamt: 3465 t P
1,999
Tierische Produkte
Tieren Import
418
Schlachtung
Tieren, Milch, Eier
3,007
1,427
Schlacht-abfall
9,146
Mist
Tierhaltung
105
Gefallene Tieren
Futter
13,004
745
Tieren Export
Potenzielle Dünger
3,465
Mephrec prozess
866
Reststoff
Deponie
+866
Klärschlamm
2,800
Abwasser Behandlung
281
Geklärtes Abwasser
Oberflächegewässer
+281
3,081
Abwasser
Konsum
Export nach Polen
13
Produkte
3,094
Mephrec Prozess: 80% Dünger, 20% Reststoff (Scheidig et al, 2010)


Techno-fix: Agrarwirtschaft
Export Erntegut
4836
Erntegut Verarbeitung
940
Futter
8851
Ernte
3558
Stroh
Wirtschaftsdünger
9237
Feldfrüchte
Klärschlamm-importe
92
Saatgut
18276
12943
Mineralizations-prozess
149
Düngemittel
Benötigte Düngemittel
5241
Vertikale Landwirtschaft
Unerhebliche Erosion
Benötigte Düngemittel: 5241 t P



Culture-fix: Agrarwirtschaft

Annahmen
Ernte: -24.06% (Rodale trial)
Erosion: -74.4% (Reganold, 1987)
Öko-Landbau in BB: 10.6% (Wimmer et al., 2012)

Benötigte Düngemittel: 2543 t P

Vergleichung und Zusammenfassung

	Trend	Techno-fix	Culture-fix
Land-wirtschaft	Ëtwa 90% konventionelle Landwirtschaft, 10% Ökologisch	100% Vertikale Landwirtschaft	100% Ökologische Landwirtschaft
Abfall-wirtschaft	Verbrennung und Deponie, Recycling: MAP und teilweise Klärschlamm	Mephrec Prozess; Klärschlamm und Schlachtabfall	Grau-, Gelb- und Braunwasser Trennung + Macerator
Benötigte extra Düngung	5911	5241	2543
Recycling Potenzial	----	3465	3021

Vielen Dank für Ihre Aufmerksamkeit!