University of Natural Resources and Life Sciences

Potential of fly larvae from biogenous waste as a source of protein to replace soybean in Austria

Master Thesis

Submitted by: Verena Baumann
Matriculation Number: 0921682
Email: verena.baumann@ymail.com

1st Supervisor: Univ.Prof. Dipl.-Ing. Dr. Erwin Schmid

Department of Economics and Social Sciences
Institute for Sustainable Economic Development

2nd Supervisor: Dipl.-Ing. Mag. Dr. Martin Schönhart

Department of Economics and Social Sciences
Institute for Sustainable Economic Development

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Zusammenfassung

Österreich sieht sich mit der Situation konfrontiert, zwar sehr viel Protein in Form von Futtermitteln für die Haltung von Nutztieren zu benötigen, aber nur einen geringen Anteil davon im Land produzieren zu können. Um den Proteinbedarf dennoch zu decken, wird Soja importiert, überwiegend aus USA, Brasilien und Argentinien. Mithilfe von Insektenmehl aus biogenen Abfällen könnte sich Österreich unabhängiger von Futtermittelimporten machen. Gleichzeitig kann Insektenmehl aus biogenen Abfällen ein ökologisch vorteilhaftes Futtermittel sein: Es gibt keinen Flächenverbrauch, keinen zusätzlichen Einsatz von Pflanzenschutzmitteln und nur sehr geringe Treibhausgas-Emissionen. Diese Masterarbeit untersucht, welche Mengen an importiertem Soja in Österreich durch auf Abfällen gezüchtete Fliegenlarven ersetzt werden könnten und unter welchen Bedingungen die Produktion von Fliegenlarvenmehl aus biogenen Abfällen in Österreich rentabel ist. Aufbauend auf einer umfassenden Literaturrecherche sowie zahlreichen Interviews wurde eine Investitionsrechnung durchgeführt. Die Ergebnisse zeigen, dass die Produktion von Fliegenlarvenmehl in Österreich unter bestimmten Voraussetzungen sehr rentabel sein kann. Vor allem Transportkosten, Konvertierungsraten zwischen Insektenfutter und erzeugtem Protein und der Sojapreis sind ausschlaggebend für den Erfolg einer Fliegenlarvenmehlproduktionsanlage. Allein bei Verwendung von biogenen Abfällen als Substrat könnten jährlich 50.610 Tonnen Rohprotein hergestellt werden. Das entspräche einer Substitution von 24 % der jährlichen Sojaimporte. Das Potential von Fliegenlarven in der Ernährung von Schwein und Geflügel in Österreich ist daher beachtlich. Bis zur Zulassung als Futtermittel in der EU ist es jedoch noch ein weiter Weg. Abfälle in den Nahrungskreislauf zu bringen ist nicht frei von Gefahren. Es ist daher dringend notwendig, neue Methoden und Prozesse für die Substrataufbereitung und die Fliegenlarvenmehlproduktion zu entwickeln, um Substratkontaminationen und Übertragungen von Krankheiten vorzubeugen.

Abstract

Austria cannot cover its livestock feed protein demand by its own. In order to cover the protein demand, thus, significant quantities of soybeans are imported from countries like USA, Brazil, and Argentina. Using Black Soldier Fly (BSF) larvae meal instead of soybean meal would allow Austria to become independent from feed imports. BSF larvae meal from biogenous waste can be ecologically sustainable: Land and water use is marginal, chemical plant protection is not needed and green-house-gas emission levels are very low. This thesis analyses the potential of BSF larvae meal as feed for livestock in Austria and, thus, shows how much of the soybean imports could be substituted by domestic BSF larvae meal production. Additionally, the conditions of successful BSF larvae meal production are revealed. Built on an extensive literature research, congress meetings and numerous interviews, a profit comparison calculation was carried out. The main finding is that BSF larvae meal production can be cost effective under certain conditions in Austria. Transport costs, conversion ratio, and soybean price have a particularly high impact on the profitability of a fly rearing facility. Based on biogenous waste alone, 50,610 t of crude protein can be produced, which equals a substitution of 24 % of the soybean imports. Thus, the potential of BSF fly larvae as a source of protein in the diets of swine and poultry is considerable. However, in order to be permitted as a feedstuff in European Legislation, BSF larvae meal needs to be safe. Hence, efforts should go into the development of new processes and methodologies

of waste treatment, substrate preparation and fly rearing in order to guarantee valuable protein sources without the risk of contamination or pest transmission.

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List of abbreviations

AGES	Österreichische Agentur für Gesundheit und Ernährungssicherheit GmbH (Austrian Agency for Health and Food Safety)
ARGE	Arbeitsgemeinschaft (Working Group)
BAV	Bezirksabfallverband (district waste association)
BMLFUW	Bundesministerium für Land- und Forstwirtschaft, Umwelt und Wasserwirtschaft (Federal Ministries for Agriculture and Forestry, the Environment and Water Resources)
BSE	Bovine spongiform encephalopathy
BSF	Black soldier fly
CO_2	Carbon dioxid
CCM	Cost comparison method
DM	Dry matter
EC	European Commission
EFSA	European Food Safety Authority
EU	European Union
FIBL	Research Institute of Organic Agriculture
FRF	Fly rearing facility
GMO	Genetically modified organisms
GWP	Global warming potential
ICF	Investment cost factor
LCA	Life cycle analysis
PAP	Processed animal protein
PCM	Profit comparison method
PC	Profitability calculation
t	tonnes
TSE	Transmissible spongiforme Enzephalopathie
WIFO	Österreichisches Institut für Wirtschaftsforschung (Austrian Institute of Economic Research)

1. Introduction

1.1. Global patterns in food supply and demand

According to the UN the world's population currently grows by 78 million people per year. In the year 2050 approximately 10 billion people will inhabit this world (United Nations, 2015). The UN Food and Agricultural Organization therefore estimates that 70 % more food has to be produced by 2050 (FAO, 2009). Also, people will increasingly eat more meat in nearly all parts of the world. Rising incomes due to economic growth and rapid urbanization in developing countries, particularly in Asia, are creating shifts in the composition of global food demand (van Huis, 2013). The extent of the increased meat demand is hard to predict, estimates range from 70 % (Oonincx and de Boer, 2012) to 140 % (Veldkamp et al., 2012). On the contrary 795 million people are still chronically undernourished in 2015, caused by continued poverty (Foley et al., 2011; FAO, 2015). Currently food prices are at a 10 year low (FAO, 2015; FAO, 2016a), but it is assumed that they are going to increase in the long term, as they are dependent on energy prices, market speculation, bioenergy crop expansion and climatic disturbances (Foley et al., 2011). The trend of some countries of more environmental protection, for example of less intense production methods and less soil degradation may also shorten supply of agricultural products and lead to rising food prices in the future. In the next chapter the current situation of food, feed and proteins as well as the frequently mentioned "protein gap" will be explained in more detail.

1.2. Current feed protein sources

As global meat demand is expected to rise, so is the demand for protein-rich feed for livestock such as soybeans, wheat and fishmeal. For the production of one kilogram of high-quality animal protein, approximately 6 kg of plant protein are needed (van Huis, 2013). Obviously, feed conversion ratios and thus protein generation is different for chicken, poultry and pig. According to Van Huis (2013), poultry has the best feed conversion ratios (2.5), followed by pig (5) and cattle (10). Currently, the livestock production occupies already about 75 % of all agricultural land, consumes 35 % of the world's grain and produces 14.5 % of anthropogenic greenhouse gas emissions (Oonincx and de Boer, 2012; zu Ermgassen et al., 2016), putting pressure on land availability. Expansion of the area for livestock production leads to deforestation in the tropics. 80 % of new croplands are replacing forests, resulting in biodiversity loss and increased carbon emissions (Van Zanten et al., 2015; Foley et al., 2007; Gibbs et al., 2010). Global agricultural systems are degrading land, water, biodiversity and climate at a considerable rate (Foley et al., 2011). Especially soybean meal has severe ecological and economic consequences that are likely to intensify in decades to come. The global acreage dedicated to the growth of soybeans rose from 57.2 million ha in 1990 to 117.72 million ha in 2014, an increase of 105.8 % in little more than two decades (Pistrich et al., 2014) and it is expected to rise further.

As can be seen in figure 1, the biggest producer states of soybeans are the United States, Brazil and Argentina.

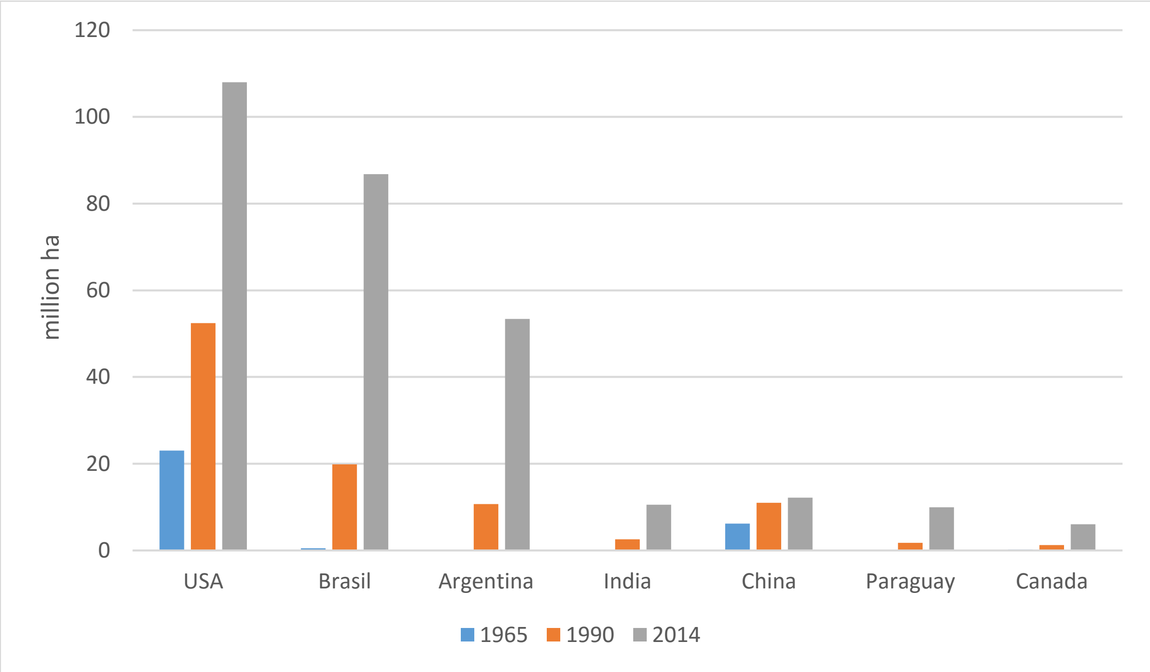

Figure 1 Soybean production areas in selected countries [million ha] (Source: FAO Stat (2016))

The use of soybeans as a source of protein in the diets of pig, poultry and cattle has different consequences: Soybean cultivation is not only made responsible for the clearing of tropical rainforests and subsequent extinction of various plant and animal species, soil erosion and environmental pollution by pesticides (Fearnside, 2001; Barona et al., 2010)), but also increasingly for negative social impacts like health damages. In areas with high and excessive use of agrochemicals, people seem to be more affected by cancer and birth deformations (Rummel, 2015). Even though scientific proof of the causal relationship of agrochemicals use in Argentina or Brazil and the health of the population living nearby agricultural fields is missing, public awareness of the dangers of agrochemicals is growing. According to the WHO driven International Agency for Research on Cancer, glyphosate, which is the world's most widely used herbicide, is probably carcinogenic to humans (Guyton et al., 2015). Legal regulations and, thus, use of agrochemicals is different from country to country, but seems to be especially lax in Argentina and Brazil, the biggest soybean exporting countries. According to Kohl (2016, personal communication) from the Austrian Agency for Health and Food Safety AGES, use of agrochemicals like Glyphosate is very safe and reasonable in Austria and different to the use in Argentina, where agrochemicals are sprayed from airplanes for example. The use of agrochemicals depends on various factors, like location factors (field structures and sizes) as well as legal regulations. However, it is legitimate to criticize western European countries for taking advantage of the lax legislative situation in South America.

A further difficulty of soybeans – at least from an Austrian point of view – is the fact that more than three quarter of the globally cultivated soybeans are based on genetically modified organisms (GMO). Eleven countries used GMO for soybean cultivation in 2012. The countries with the highest acreage dedicated to GMO soybean cultivation are the USA (28.6 million ha), Brazil (23.9 million ha) and Argentina (20.2 million ha) (Pistrich et al., 2014).

Additional pressure on protein availability comes from decreasing yield growth. The rates of yield growth of soybean, as well as of the other three global main crops maize, wheat and rice, were smaller during 1990-2007 than during 1961-1990. This slowdown had been seen in most countries worldwide and was especially distinct in the ten biggest producing countries (Alston et al., 2009).

Beside soybean meal also fishmeal is an important source of protein on a global scale. It is mainly used in aquaculture as feed for carnivorous fish, but is also used as a component in the diets for pig and poultry. Three quarter of the fishmeal is manufactured from wild catch, small marine fish that are not suitable for direct human consumption (National Oceanic and Atmospheric Administration, 2016). Anchoveta is the fish most commonly used from wild catch. Furthermore, fishmeal is gained from bycatch of other fisheries and fish production/processing waste. Approximately one third of the global fish catch is processed to fishmeal (Alder et al., 2008). Sustainability of fishmeal is questionable, as it contributes to overfishing and the exploitation of the oceans. More than three-quarter of the global fish stocks are fully or over-exploited (Deutsch et al., 2007). But protection measurements increasingly turn out to be successful, as fishmeal production has been declining for years. According to the FAO (2014) production peaked in 1994 at 30.2 million t (live weight equivalent). In 2010, it dropped to 14.8 million t owing to reduced catches of anchoveta, increased in 2011 to 19.4 million t and then declined to 16.3 million t in 2012. The decrease of fishmeal from whole fish was only partly offset by fishmeal obtained from fishery by-products. In contrast, global demand of fishmeal continued to grow. The trend of growing few high value fish culture species at large quantities is accelerating the demand for fishmeal and oil (Samuel-Fitwi et al., 2013). The carnivorous fish salmon, prawns and shrimps are good examples thereof: Fishing of salmon has more than tripled between 1990 and 2014 (1990: 1.08 million t; 2014: 3.42 million t) (FAO, 2016b). The same increase of production was reported for prawns and shrimps aquaculture (1990: 2.64 million t; 2014: 8.17 million t) (FAO, 2016c). As a result of lower production volumes but increased demand, prices of fishmeal increased dramatically in the past two decades from 1100 €/t in October 2013 to 2000 €/tonne in 2015 (FAO, 2016a).

A further challenge of high protein demand particularly for livestock breeding in Europe is its low self-sufficiency rate (Pistrich et al. 2014). Austria, as well as many other European countries, is struggling with a significant protein supply gap. Domestic production is limited by land resources, soil quality, and climate, thus, most of the protein for livestock feed has to be imported. The vast majority of the imports is soybean. Sunflower, rapeseed, grain peas and field beans are only used in small quantities. This has several reasons. Generally, the protein quality of these alternatives is lower than the one of soybeans. Certain amino acids and other ingredients show negative effects on daily growth rates, which leads to limitations in livestock diets. Future plant breeding prospects are often poor too. Especially for grain peas, field beans and sunflower prospects regarding new and more resistant or less demanding plant species are not promising (Pistrich et al., 2014). Thus, Austria has constantly been importing more than 80 % of the soybeans that are needed for feeding: In 2012, 503,000 t out of 608,000 t were imported. Various problems arise with the import of soybeans: First, Austria is in a position of dependency and thus vulnerable to international market price fluctuations. Second, most of the foreign soybean origins from the United States, Canada, Brazil and Argentina (AGES, 2014). Those countries grow to nearly 100 % genetically modified soybean (exception Brazil: 35 %). Thus, genetically modified soybeans are imported to Austria, even though there is a distinct public rejection of genetic engineering (Umweltbundesamt, 2014). Livestock products in Austrian supermarkets that are not labeled as GMO-free most probably originate from animals fed with genetically modified soybeans. Third, environmental protection is lax in South America. Hence, there is a strong link between deforestation of tropical forests, biodiversity loss and health problems probably caused by inappropriate pesticide use in Argentina and the meat consumption in Austria. However, if more soybeans are produced within Austria, leakage effects most probably occur. Increasing soybean cultivation reduces cultivation of other crops and will likely lead to land use change elsewhere.

1.3. Waste overflow and manure concentration

The Earth and its human population are facing increasing volumes of biogenous waste streams (Veldkamp et al., 2012). There are significant amounts of organic waste from households, the hotel and restaurant sector and the vegetable production as well as manure that currently end in thermal treatment, anaerobic digestion and as farm fertilizer. Due to stricter waste separation policies volumes of biogenous waste are increasing all over Austria. On the one hand, this is a positive development, as the volumes of residual waste are decreasing and less material has to be burnt in waste incineration plants. On the other hand an additional collection system has been built up, resulting in twice as much driven kilometers and emissions. The collected biogenous waste is mainly treated in composting facilities, and the generated compost is currently predominantly used by farmers as natural fertilizer. However, the situation is different when it comes to manure: Volumes of pig and cattle manure are not increasing, they are decreasing. Highest pig and cattle stocks have been reported for Austria in 1985 and are decreasing ever since (Statistik Austria, 2015). Only poultry stocks are currently increasing. Thus, volumes of manure will not pose a major, future challenge in Austria. However, important is the exact location of generation of the manure. As a consequence of specialization and the trend to large scale farms, intensive livestock farming is increasing in whole of Europe. Especially in northern Germany, the Netherlands or Denmark herd sizes are increasingly decoupled from local crop cultivation due to imported feed. As a consequence, transport of feed and manure are increasing in scale and intensity, but the nutrient fluxes are often unclear. In Lower Saxony 34 million t of manure were traded in 2015, resulting in off-farm manure disposal (Rohwetter, 2016). As can be seen in figure 2, pig farming is also very concentrated in some parts of Austria.

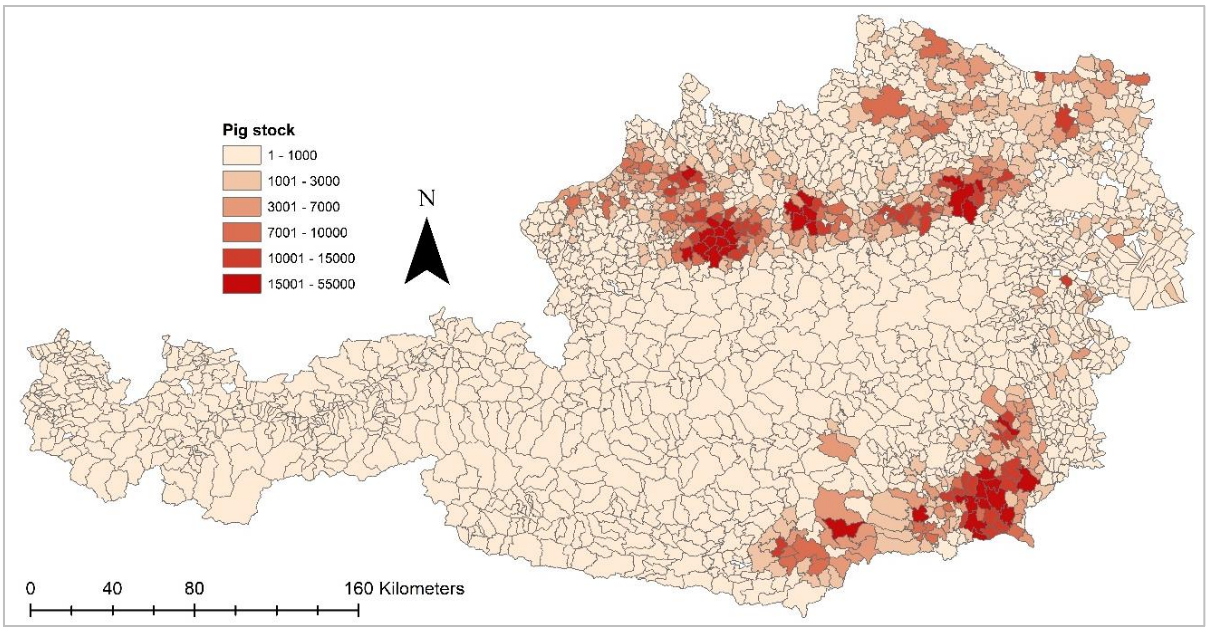

Figure 2 Pig stock densities (livestock numbers) in Austrian municipalities (2015) (Source: Own map, data from Statistik Austria (2015))

Poultry farming is more spread across the country (see figure 3). But intensive poultry farming often takes place in regions with intensive pig farming, resulting in especially high manure amounts (in parts of Upper Austria, Lower Austria and Styria).

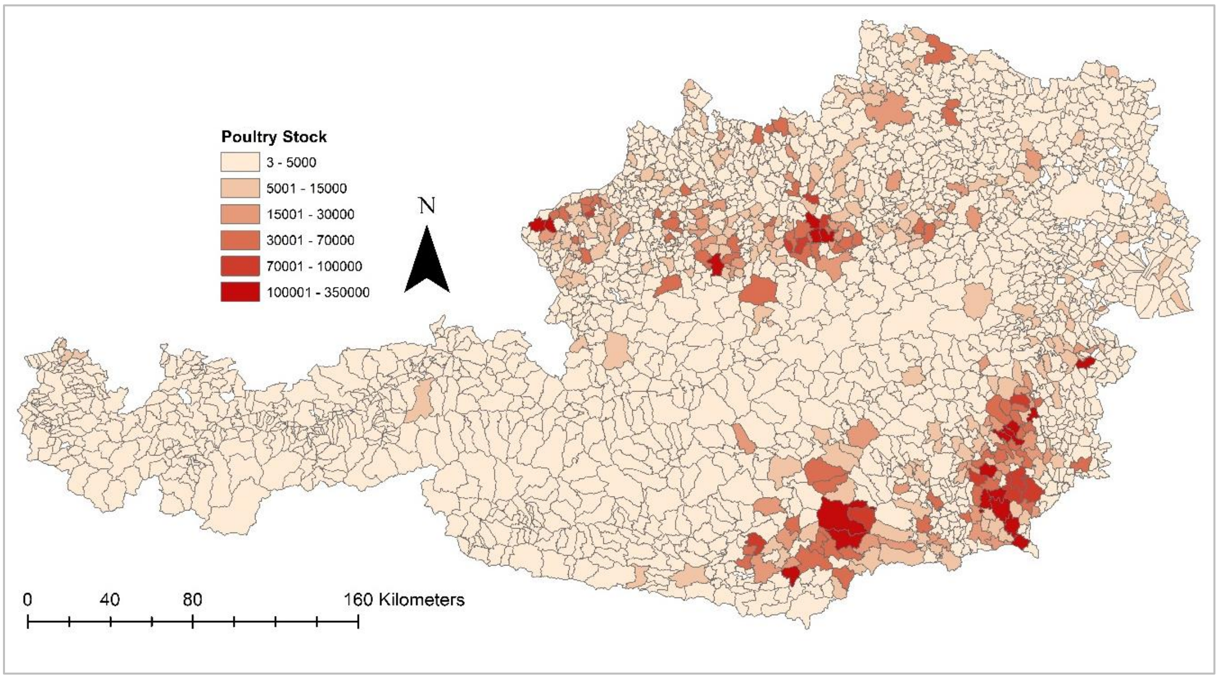

Figure 3 Poultry stock densities (livestock numbers) in Austrian municipalities (2015) (Source: Own map, data from Statistik Austria (2015))

As can be seen, in many regions of Austria, off-farm manure disposal is not necessary, but in others stock densities are too high to allow the spreading on local fields and contracts on off-farm manure disposal are required to meet the Austrian Nitrate Action Program standards. Nevertheless, according to Knöbl (2016) manure trading is not very distinct in Austria yet. At least no records are made.

Insects can serve as missing link between the rising demand of protein, deteriorating ecosystems, increasing levels of biogenous waste and the concentrated levels of manure, as they close the loop and recycle the nutrients that would be used inferiorly otherwise. Studies have shown that insects can be reared on different sorts of waste like biogenous waste from households, slaughterhouse waste or manure, managing mass reductions of about 50%, with even greater reductions in nitrogen and phosphorus mass (Newton et al., 2005a). The insect larvae are dried, milled and processed to protein feed. The dietary composition of many insect larvae seems to be very suitable to livestock such as poultry, pig and fish. This is not surprising, as insects are part of the natural diet of poultry, pig and fish. Additionally, insects have the ability of reducing the microbial load of some pathogens substantially (Čičková et al., 2015). Especially in developing countries, these concepts seem promising. Furthermore, insects are the chance to treat waste in a superior way. The production of protein feed is more valuable than the utilization of the waste as fertilizers or in composting or biogas facilities. Additionally, it is noteworthy that the use for protein production does not per se eliminate further use, as the waste residuals after insect rearing are well suited for the generation of electricity in biogas facilities or as fertilizer on fields.

There is a wide range of insects that are suitable as a component in livestock feed (Makkar et al., 2014). In this thesis, all calculations will be based on the feed conversion rate of the black soldier fly (BSF). This is mainly, because the two largest companies in the field of insect rearing (Agriprotein and Enterra) are using BSF too and it is suggested that they have reasons for doing so. Additionally the BSF has a lot of benefits compared to other insects. These benefits are described in chapter 3 in more detail.

1.4. Aim of thesis and research questions

The aim of this thesis is to estimate the amount of imported soybeans in Austria that can be substituted by using BSF larvae meal (grinded and defatted BSF larvae) as a feed ingredient in the diet of poultry and pig. More precisely, the thesis aims on describing the necessary conditions for a profitable production of BSF larvae meal as a feed ingredient in Austria. The following research questions structured and guided the work on this thesis:

1. What is the state of the art in insect rearing, who are the involved companies and researchers, what are their results and what are the constraints of insect rearing in Europe?
2. On what substrates can the BSF be reared generally and what substrates are particularly suitable? What are the conversion ratios for the different substrates, i.e. how much feed is needed to produce one kg of larvae?
3. Which quantities/volumes by location of appropriate substrates that are considered as waste are available in Austria?
4. What are the conditions for a profitable production of BSF larvae in Austria?
5. How much imported soybeans can be reduced in Austria by using fly larvae in the livestock production of poultry and pig?

In order to answer these questions different methods were used. Figure 4 gives an overview about the process of fly rearing and its input and output streams (note: the actual larvae production process is within the orange borders).

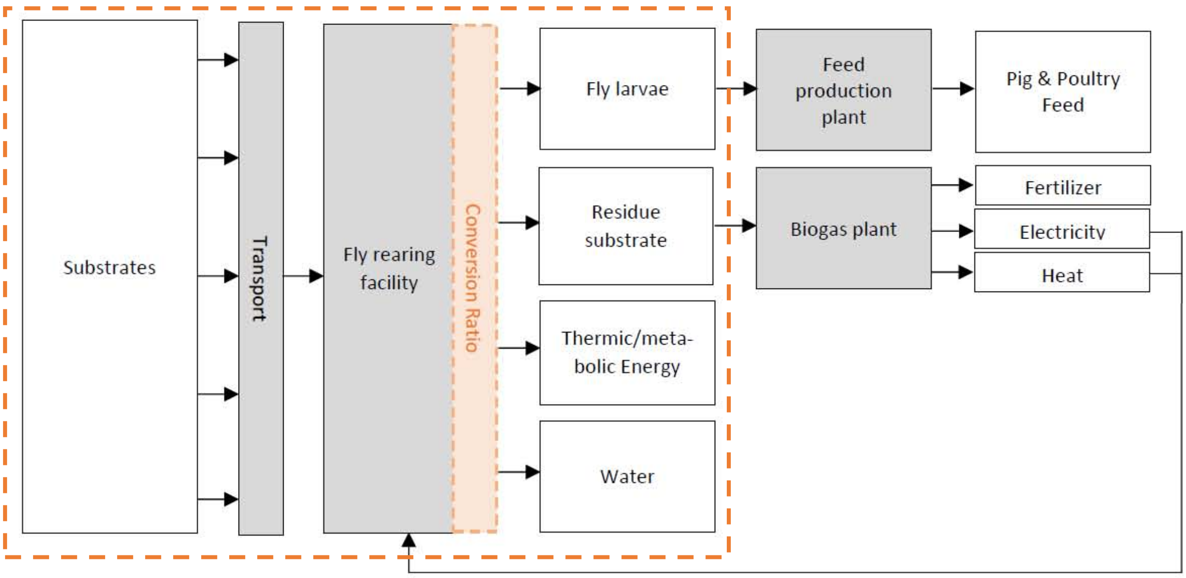

Figure 4 Input - Output diagram of BSF larvae meal production (Source: Own diagram)

The suitable substrates for BSF larvae meal production are transported to fly rearing facilities where they are fed to fly larvae. At the end of the larval stadium the larvae are collected and processed to protein feed. The left-overs of the larvae can be composted and sold as fertilizers. A further, perhaps more ecological possibility is the use of the leftovers in biogas plants. Energy and heat that is generated in the biogas plant can be used for the production process of the larvae.

In order to answer research question four, it is most crucial to determine those variables that impact the profitability of a fly rearing facility. The following questions arise: What are common substrate, substrate transport, and production costs? What are the thresholds for investment and variable costs as well as soybean prices to guarantee profitability in fly rearing? Figure 5 summarises all the important variables and parameters.

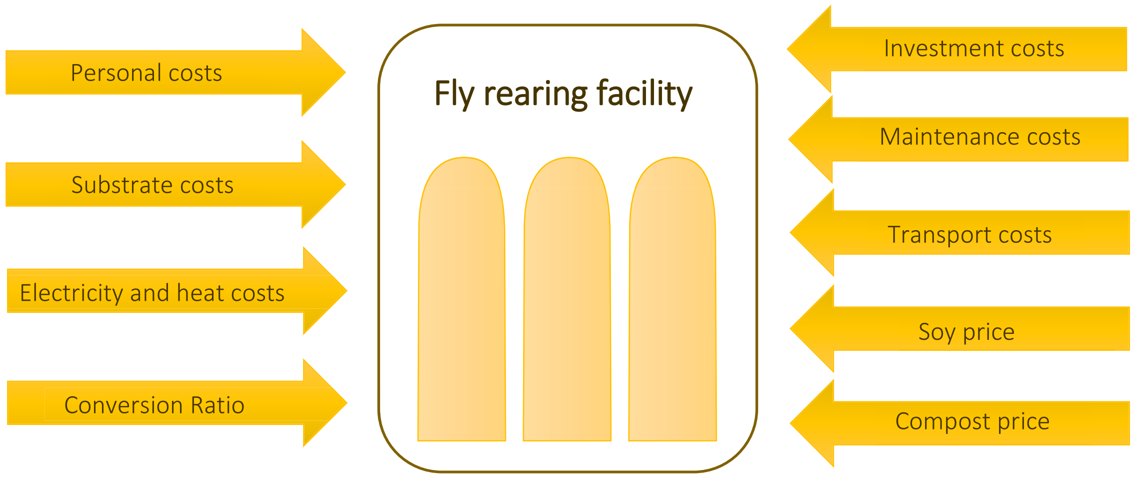

Figure 5 Variables influencing profitability of a fly rearing facility (Source: Own diagram)

Different methods of capital budgeting were used to compare the effects of different capacities for a BSF rearing facility, different soybean prices, energy costs, transport costs, maintenance costs, conversion ratios or personal costs. Different scenarios were developed to address the uncertainty of many variables. Additionally a sensitivity analysis was performed. The potential of BSF larvae in Austria was estimated based on these findings.

This thesis is structured as follows: Chapter 2 describes the state of the art of BSF rearing, the benefits of BSF larvae meal, its potential as a protein feed and its legal constraints. Chapter 3 starts with an explanation of the methods used in this thesis and continues with an overview of all scenarios and scenario combinations. The second part of Chapter 3 contains a precise description of the data used and the scenarios generated. Finally, all results are presented in chapter 4. They are classified regarding the effects of certain parameters. In chapter 5 discussion, the results are compared, the limits of the thesis and the strengths and weaknesses of the used methodologies are named. In the last chapter conclusion the main findings are synthesized and future research potential is outlined.

2. Insects as a source of protein

In order to find out more about insects as a source of protein, a comprehensive literature research was conducted. Relevant journals like Waste Management, Journal of Cleaner Production, Journal of Medical Entomology and Aquaculture were screened in order to learn more about the state of the art of insect rearing, the techniques of insect rearing, the different substrates in use and their suitability. Information from websites and publications of insect rearing companies as well as press articles complements scientific literature. A central part in gaining new knowledge about insect rearing and its potential as a feed ingredient played expert interviews. More detailed information about the methodology used and the way the expert interviews have been performed can be found in the chapter methodology.

2.1. Benefits of insects instead of soybeans in the diet of pig and poultry

Livestock feed based on insects that have been reared on waste substrates seems to have considerable advantages compared to conventional protein sources. First, there is the land saving potential. Assuming that the insects are reared on waste products without alternative use, land use is – apart from the land the insect rearing facility is built on – almost zero. The area needed for the construction of the facility is negligible. The insect rearing company Enterra is using about one hectare of land for their facility. The same might be true for water use. Even though concrete information concerning the production process is not available, it is assumed that only little additional water will be needed. The larvae are fed on some sort of slurry (shredded substrate, if necessary mixed with additional water). Thus the water needed is dependent on the water content of the substrate. Fresh biogenous waste is per se very moist. However, additional water will be needed for cleaning.

Compared to the cultivation of soybeans, insects seem to have considerable advantages: In Brazil, soybean yield per hectare was 2.87 t in 2014, thus, an arable land use of 0.35 ha per tonne of soybean meal is required (FAO Stat, 2014). Soil loss was estimated at 8 t of soil per ha of soybean meal and year for Brazil, especially phosphorus is eroded in high quantities (Mattsson et al., 2000). The water demand of soybeans is high too: In Chapagain and Hoekstra (2013) the global average specific water demand for several crops was calculated. For soybeans, it is 1716 m^3 per tonne. However, the high water use of soybean cultivation is not per se a cause of negative environmental effects, crucial is the type of water used (green vs. blue water)[1]. According to Willaarts et al. (2011), the largest fraction of the water needed for the cultivation of soybeans in Brazil is green water (± 99%), since soybeans are mostly cultivated under rain fed conditions. Due to good climatic conditions irrigations is not needed, thus, blue and grey water represent an extremely low fraction (< 1%) (Willaarts et al., 2011). Furthermore, the soybean monocultures in Brazil, Argentina and the USA are threating biodiversity. Protected areas are often grouped so that they cannot interfere with the airplane application of pesticides. But animal and plant species need corridors to move between their habitats, otherwise they are too vulnerable (Mattsson et al., 2000). Further negative environmental impacts and health problems concern – as has been said earlier – particularly the use of agrochemicals.

[1] According to Willaarts et al. (2011), green water is defined as the water derived from rainfall only; blue water is water from irrigation and grey water is polluted water (for example by the use of fertilizers).

However, the actual benefits that could be obtained with a substitution of plant protein by insect protein are based on the feed substrate used. Until now, there are only few scientific publications evaluating the ecological benefits of insects in the diets of pig and poultry compared to soybean meal or fishmeal. Ooincx and de Boer (2012) analysed the global warming potential (GWP) and the energy use of mealworms (*Tenebrio molitor*) in a full life cycle assessment (LCA). They included not only the adverse effects of gas, electricity and water consumption during the rearing process but also the effects of production and transport of the mealworm feed, which consisted of carrots and grains in this study. The GWP of one kg of fresh mealworms was 2.7 kg of CO_2 equivalents, of which 42 % resulted from the production and transport of feed grains, 14 % from the production and transport of carrots, 26 % from gas used for heating and 17 % from the use of electricity. The energy use of one kg of fresh mealworms was 34 MJ, of which 31 % resulted from the emission of production and transport of feed grains, 13 % from the production and transport of carrots, 35 % from gas used for heating and 21 % from the use of electricity. The land use of one tonne of fresh mealworms was 0.36 ha per year, of which 85 % were required to cultivate feed grains and 14 % to produce carrots (Oonincx and de Boer, 2012). Obviously, the cultivation of the insect feed, namely carrots and grain, is the reason for the high land use and the relatively high GWP. Electricity and energy make up only 43 % of the GWP. In case carrots and grain can be substituted by biogenous waste – as intended in this work – the GWP and land use effect can be reduced significantly.

A second study on the benefits of insects was published by Van Zanten et al. (2015). They explored the environmental impacts of using larvae of the common housefly grown on poultry manure and food waste as livestock feed. They found that the production of one dry matter (DM) tonne of larvae meal directly resulted in a GWP of 770 kg CO_2 equivalents, an energy use of 9,329 MJ and a land use of 32 m^2 caused by the use of water, electricity and feed for flies, eggs and larvae. Thus, it can be noticed that the utilization of manure and waste as a substrate results in significantly lower amount of greenhouse gas emissions and a lower GWP as the utilization of carrots and grains. However, it has to be said that the calculations of Van Zanten et al. (2015) are based on food waste that was previously used for the generation of electricity (biogas). Due to the larvae production, less electricity could be produced. The authors included the reduced electricity into their calculations. Assuming that – like in the case of Austria – most of the food waste would be used in composting facilities otherwise, the energy use and related emission of greenhouse gases would be far less. Furthermore, Van Zanten et al. (2015) assumed that industrial processes to acquire housefly larvae meal are still advancing, which also offers potential to reduce energy use and related emissions. Additionally, a lot of opportunities exist to further reduce energy use, e.g., by technical innovations or an increased use of solar or wind energy. Thus, the authors concluded that larvae meal production has potential to reduce the environmental impact of the livestock sector.

In this thesis it is supposed that BSF larvae are reared on waste products only. The environmental costs of the transportation of the biogenous waste cannot be avoided, as the waste needs to be collected and transported to the fly rearing facilities. But environmental costs due to transportation also apply to soybeans. Furthermore, transportation and collection of biogenous waste from households is already happening and, therefore, no additional transport would occur. The only change relates to the utilisation of the biogenous waste. The larvae do not utilize all the provided feed, they only reduce waste volumes.

As the companies Enterra and Agriprotein have shown, the residuals are well suitable for the production of natural fertilizers. However, it is unknown to what extent fertilizers produced out of residuals can reach the levels of former compost production. Furthermore, it is unclear what consequences appear if the farmer's demand of compost cannot be covered anymore. The reduction of the significant, environmental costs caused by the fly rearing facility's electricity and heat demand is possible via a treatment of the residuals in a connected biogas facility. The heat and electricity generated can be used for the production of the larvae in return. But as the topic is so innovative, there is no research focusing on these issues.

The same may be true for larvae reared on manure. Those manure quantities that cannot be brought to the local fields due to limitations according to the Austrian Nitrate Action Program, can be collected and brought to fly rearing facilities. As they have to be carried away anyway, transport costs occur in any case. However, longer transport distances might incur in case manure is brought to fly rearing facilities.

2.2. State of the art of insect rearing for protein feed

Despite the restrictive legislation, there are many contributions in journals, for example: Barroso et al. (2014), Kroeckel et al. (2012), Stamer (2009), Maurer (2015) and St-Hilaire et al. (2007). The Wageningen Institute belongs to the front runners in this field. In May 2013, a report called 'Edible insects: Future prospects for food and feed security' (Van Huis et al., 2013) was published on behalf of the UN Food and Agriculture Organization. There is also one section dealing with insects as feed for farmed animals in the report. On behalf of the Ministry of Economic Affairs, Agriculture and Innovation, the Institute worked on a feasibility study called 'Insects as a sustainable feed ingredient in pig and poultry diets' (Veldkamp et al., 2012). The Swiss Research Institute of Organic Agriculture (FIBL) is dealing with the potential of insects as feed for fish, poultry and pigs. They are analyzing the suitability of various substrates as feed for insects, like for example manure and food waste. In addition, they are making feeding trials with chicken in order to find out how suitable larvae are as a feed component for laying hens.

Probably the first large congress on insects as feed and food in the German speaking region was held in September 2015 in Magdeburg/Germany. In 22 presentations, the 118 participants got an impression on the diversity and scope of research on insects as feed in Europe. The congress is planned to be repeated every year from now on. In May 2016, the Austrian Agency for Health and Food Safety organized a conference especially dealing with the risks of insects concerning human health (e.g. allergies) in cooperation with the Austrian Ministry for Health.

There is little research focusing on the potential of insect protein in and for Austria. The Austrian company Eutema is part of the EU financed research project Proteinsect. Researchers from the Institute for Food Technology of the University of Natural Resources and Life Sciences, Vienna are working on different processes for the extraction of protein and fat from insects. Moreover, there is a growing number of students dealing with the topic of insects as feed and food in their master and doctoral theses.

Despite the unclear European Legislation (see chapter 3.4) two companies, Protix in the Netherlands and Ynsect in France, successfully operate two large scale insect rearing facilities. They use pre-consumer biogenous waste as an input to grow BSF larvae, which are certified as feed ingredient in aquaculture. Agriprotein in South Africa was the first large scale facility in the world. In Canada, the USA and particularly in Asia fly larvae rearing for feed production is becoming more and more popular. Further detailed information about currently operating insect meal production facilities can be found in annex 2. Table 1 provides a short overview about the operating companies.

Table 1 Overview of companies and research institutes dealing with insects in Europe, Africa and North America (Source: Swart (2015, personal communication), Leung (2015, personal communication), Praxmarer (2015), Preyer (2015, personal communication))

Organisation	Country	Scale	Information concerning Construction Costs	Information concerning variable costs	Information concerning production process
Companies					
Agriprotein	South Africa	110 t of waste/day 7 t larvae meal/day 3 t larvae oil/day	6.4 million €	No	No
Protix	Netherlands	NA	No	No	No
Proti-Farm	Netherlands	NA	No	No	No
Enterra	Canada	100 t waste/day -> 5 t meal, 2 t oil, 8 t natural fertilizer	5.23 million €	No	Limited
Hermetia Baruth	Germany	21 t per year	No	Yes	No
Enviroflight	USA	6 t of waste/day	No	No	No
Entomeal	Switzerland	Under Construction	No	No	No
Ynsect	France	NA	No	No	No
Viur	Iceland	NA	No	No	No
Research Organisations					
Ovrsol	USA	NA	No	No	No
Green Waste Technologies	USA	NA	No	No	No
ESR International	USA	NA	No	No	No
FIBL	Switzerland	NA	No	No	No
TU Dresden	Germany	NA	No	No	No
BioFlyTech	Spain	NA	No	No	No
Entomotech	Spain	5 t of larvae/day	No	No	No
Wageningen Institute	Netherlands	NA	No	No	No
ProteInsect	EU	NA	No	No	No

2.3. Black soldier fly and its large scale production process

The BSF (Hermetia illucens) is a fly of the Stratiomyidae family. It is native in tropical, subtropical and warm temperate zones, but occurs in many regions between 45 ° N and 40 ° S (Makkar et al., 2014). In Europe, the fly can be found in parts of Portugal, Spain, France and Italy as well as on the Balkan Peninsula. The white-yellowish larvae can reach a length of 27 mm and 6 mm in width. Depending on the strain, some weight up to 220 mg in their last larval stage (Makkar et al., 2014).

The feed intake depends on a number of factors but can range up to 500 mg of fresh matter/larva/day (Makkar et al., 2014). The larvae feed on a wide range of decaying organic materials, such as rotting fruits and vegetables, coffee bean pulp, distillers grains, fish offal and particularly animal manure and human excreta (van Huis, 2013; Diener et al., 2011). Optimum conditions for rearing BSF include a narrow range of temperature and humidity as well as a range of suitable levels of texture, viscosity and moisture content of the diet. Temperature should be maintained between 29 and 31°C, although larger ranges may be feasible. Relative humidity should range between 50 and 70 % (Makkar et al., 2014). According to Praxmarer (2015), development time of BSF in the BSF rearing facility of Hermetia Baruth GmbH takes 44 days. Table 2 shows the duration of the life cycle stages.

Table 2 Development time of BSF (Source: Praxmarer (2015))

Life cycle stage	Duration
Egg	4 days (= hatching takes place after 4 days)
Young larvae growth	8 days
Larvae growth	12 days
Prepupae	4 days (“final larvae stage”)
Pupae	4 days
Adult	12 days
Total	**44 days (mating and egg laying)**

The larvae are harvested before the “final larvae stage” right before they start turning black due to the lower degree of sclerotisation of the cuticle and the resulting higher digestibility (Maurer et al., 2015). Thus, one production cycle at the Hermethia Baruth GmbH takes 24 days. However, it has to be said that Hermetia Baruth GmbH is rearing the larvae on a mix of coarse rye meal and wheat bran; development time on manure and biogenous waste will be significantly longer (Stamer, 2009). At the end of the larval stage, the larvae empty their digestive tract and migrate in search of a dry and protected pupation site (Diener et al., 2011). That characteristic simplifies the collection of mature larvae, as they independently move out of the wet feeding area and don’t have to be separated mechanically. The adult females mate 2 days after emerging and oviposit into dry cracks. Adults do not feed (they have no functioning mouth parts) but rely on the fats stored from the larval stage (Makkar et al., 2014). Therefore, BSF is not seen as a pest or a vector for diseases. Figure 6 graphically shows the life cycles of BSF larvae.

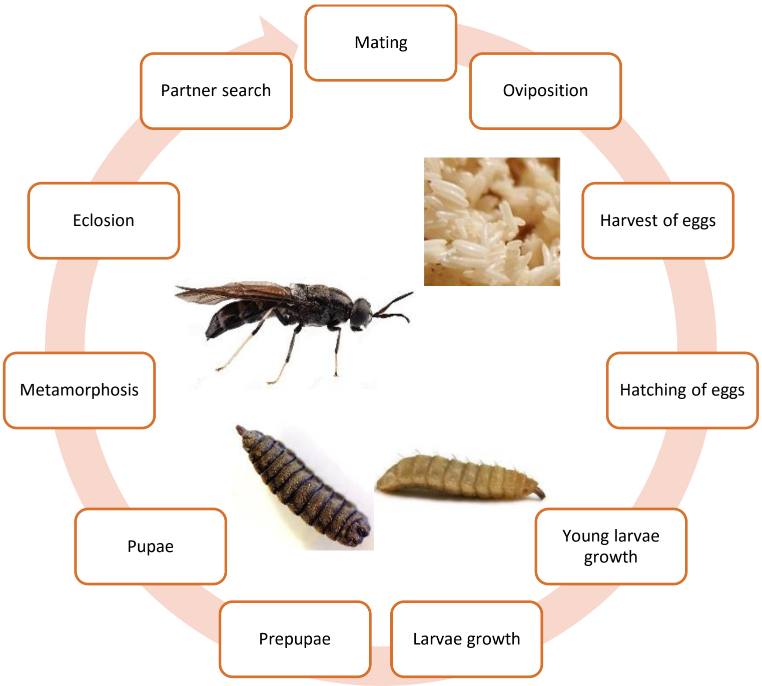

Figure 6 Production cycle of BSF (Source: Praxmarer (2015))

Detailed information on production processes of large scale facilities are not available. The big producing companies do not share their knowledge. "Years of research and a substantial amount of money have gone into reaching this stage. The result of all this hard work is the intellectual property of AgriProtein" and, thus, cannot be shared, says an employee of AgriProtein (Swart, 2015, personal communication). However, Praxmarer (2015) gave insights into the small scale production process of Hermetia Baruth GmbH. Their rearing process is physically separated into different facilities in order to provide optimal conditions for each life stage of the insect. The production facility is divided into spaces for mating, egg deposition, young larvae growth, larvae growth (in so-called bioreactors), and harvesting (Praxmarer, 2015). **Mating** can only take place when enough sunlight is available. This is generally the case in Germany even though the situation can become problematic during short and cloudy winter days. Hence, artificial lighting is necessary in this time. The **oviposition** rate needs to be kept constant at high levels (> 90 %). BSF usually lay their eggs in a dry place next to feed. They do not deposit their eggs directly onto the feed in order to avoid drowning. Thus, in most rearing facilities cardboards are placed next to or onto the substrate. The eggs are then brought into separate facilities, where they hatch after four days and start growing. At the facility of Hermetia Baruth GmbH they are transferred to larger production cages after eight days. In larger facilities, this development phase proceeds in bioreactors. The majority of the larvae are harvested right before they turn black. A small percentage, however, is left to fully mature into adult flies in order to maintain the production process.

2.4. Legal constraints

Due to a lack of safety profiles, insect meal is forbidden as a component in the feed of human food producing animals in the European Union (EU) at the moment. Insects as a protein source are not explicitly mentioned in any relevant EU directive. Therefore, producers claim that they are facing a very unclear and often even conflicting legal situation. EU legislation is not drafted in a way to deal with insects or to support insect production. In the following chapter the legal framework for insect production is explained.

The main obstacle for using insect meal as livestock feed within the EU is that insects are currently classified as livestock in the EU legislation. Insects are, therefore, in the same category like pigs, cattle or poultry. Thus, for rearing, husbandry and slaughtering the same legal requirements apply. Furthermore, regulation EC 999/2001 (TSE[2] regulation) forbids to feed processed animal protein (PAP) to livestock, consequently forbidding the use of insect meal in food producing animals. This legislation came into place after the TSE crisis in 2001 in order to avoid further epidemics. Before 2001, it was allowed to use slaughter house waste as a component in livestock feed. Currently, this waste is burned (high risk waste = category 1 and 2) or used for pet food (low risk waste = category 3). According to Trunk (2015a, personal communication), the European Commission is working on amendments to the TSE regulation. Slaughter house waste from pig and poultry does not pose any risk regarding BSE (Bovine spongiform encephalopathy), as this disease is only transferred by animal products of ruminants. Thus, the renewed approval of animal feed products from pig and poultry slaughter house waste is only a matter of time. Another challenge is that insects must be processed in accordance with the EU Animal By-Products Regulation 1069/2009 (European Commission, 2009). Thus, insects have to be 'slaughtered' and processed according to the same rules as other animals. This is impossible, as insects are mostly killed by freezing, drying or by the addition of carbon dioxide. As a consequence, insects are currently sold alive in the pet food industry.

Additionally, insect producers must follow the EC General Food Law Regulation 178/2002, EC Regulation 854/2004 on food hygiene, EC Regulation 183/2005 on feed hygiene and the Directive EC 2002/32 on Undesirable Substances in Animal Feed (L'Entomofago, 2016). But according to Emmy Koeleman, "compliance of these rules are not the biggest hurdles for insect meal producers" (L'Entomofago, 2016). A further difficulty, however, lies in the fact that in Regulation EC 767/2009 the use of faeces and waste for animal nutritional purposes is prohibited. Consequently, also the use of insects reared on this kind of substrates is banned (EFSA Scientific Committee, 2015).

According to Trunk (2015b), the European Commission (EC) is not opposed to the approval of insects as feed in the EU, as long as all possible risks are eliminated. In order to get an overview of those risks, the EC asked the European Food Safety Authority (EFSA) to assess the microbiological, chemical and environmental risks arising from the production and consumption of insects as food and feed. EFSA presented their report in October 2015 (EFSA Scientific Committee, 2015). Even though the report names all different sorts of microbiological, chemical and environmental risks arising on all different sorts of substrates, the EFSA scientific committee was not able to evaluate the actual danger[3]. The committee stated that the lack of consolidated information, studies and scientific evidence is too big to give any recommendations (EFSA Scientific Committee, 2015). Thus, as long as the uncertainties of

[2] Transmissible spongiform encephalopathy

[3] Danger shall here be defined as the product of risk and exposure. Not every risk automatically is a danger. If, for example, a substrate is contaminated by a fungus, but the fungus is not harmful for BSF larvae, i.e. the fungus cannot be transmitted, there might be no danger.

insects grown on waste products are high, admission appears unlikely in the EU (Trunk, 2015a, personal communication; Trunk, 2015b).

3. Methods, data and scenarios

3.1. Applied methods

A number of different methodologies were used in order to analyse the potential of BSF larvae as a source of protein in livestock feed. Essential basis was an extensive literature research. Relevant journals as well as websites were screened (c.f. chapter 2). Expert interviews and methods of capital budgeting complete the methods framework. They are described in detail in the following paragraphs.

3.1.1. Expert interviews

A central part in gaining new knowledge about insect rearing and its potential as a feed ingredient played expert interviews. According to Froschauer and Lueger (2003) an expert is defined as a person that has been asked qualitative research questions. To gain insights into their expertise, their experience or their view on certain topics it was essential to talk with them. All interviewed persons primarily had practical knowledge. The first interview partner, Prof. Werner Zollitsch, had been chosen upon advice. He shared the contact details of further experts in the field with me, and, just like in the snowball system, the amount of interview partners grew larger. The experts of the Federal Ministry for Agriculture and Forestry, the Environment and Water Resources (BMLFWU) have been interviewed due a tender of the Ministry, where the exposé of this master thesis was submitted. Naturally, not all experts in the field of insect protein have been interviewed, thus, this is only a selection. The conversations were held in the format of semi-structured guided interviews. The sequence of the questions stayed open. In this way it was possible to spontaneously discuss issues that had been arising during the conversation or to deepen several aspects. The questions were chosen dependent on the knowledge and practical background of the interviewed person. Interviews took place between September 2014 and March 2016. Table 3 gives an overview about all interviewed persons.

Table 3 Overview of all personally interviewed persons

Name	Organization
Prof. Werner Zollitsch	University of Natural Resources and Life Sciences
Dr. Franz Sinabell	Wifo
Dr. Wolfgang Koppe	Skretting (feed manufacturer in Norway)
DI Walter Emathinger	Fixkraft (feed manufacturer in Enns/Austria)
Johann Steiner	Chicken farmer in Hochburg-Ach
DI Franz Doppelreiter	AGES
Dr. Bernhard Stürmer	ARGE Kompost und Biogas
Dr. Wolfgang Trunk	European Commission
Alexander Drexler	Owner compost and biogas facility
Paul Zarzer	Provincial Government of Upper Austria
Dr. Christoph Sandrock	FIBL
Anita Epner	BAV Braunau
Rudolf Pichler	BAV Grieskirchen
Mag. Georg Kragl	BAV Freistadt
Walter Köstinger	BAV Schärding

Dr. Susanna Schragner	BMLFUW
Ing. Ignaz Knöbl	BMLFUW
Dr. Matthias Lentsch	BMLFUW

Additionally, a telephone survey was conducted among operators of Upper Austrian biogas facilities situated in municipalities with high pig/poultry stocks. All conversations took place on the same day, the 2nd October 2015. The aim of this survey was to find out to what extent manure is used in biogas facilities and the reasons for not using pig/poultry manure, thus uncovering possible disadvantages of this substrate. Table 4 shows the facilities that have been contacted.

Table 4 Biogas facilities selected for survey (Source of stock densities: Statistik Austria (2015))

	Municipality	Prevailing livestock	Stock density
Nahwärme Atzbach	Atzbach	Poultry	62,000
Zauner Maximilian	Pettenbach	Pig	130,000
Eierhof Ortner GmbH	Roitham	Poultry	29,000
Biogas GmbH Molln	Molln	Poultry	31,000
Bioenergie Gaspoltshofen GmbH	Gaspoltshofen	Poultry	43,000
Bioenergie Esterbauer KG	Hochburg-Ach	Poultry	128,000

Furthermore, at least one email containing several questions concerning production technologies and costs was sent to fly rearing facilities. Agriprotein, Enterra and Protix were contacted several times, as they are the only facilities with large scale operations. The email conversations took place from October 2015 to April 2016. All contacted facilities are listed below:

- Agriprotein (South Africa)
- Enviroflight (USA)
- Enterra (Canda)
- Katz Biotech (Germany)
- Ynsect (France)
- Viur (Iceland)
- Entomotech (Spain)
- Bioflytech (Spain)

All the questions of all interviews and surveys can be found in annex 1. Generally, the interviews and surveys only serve for the purpose of achieving a greater understanding on the topic. They have not been transcribed, as the content of most of the interviews has not been used at all and thus does not appear in this thesis. However, some figures, mainly from the E-Mail conversations with employees of Enterra and Agriprotein, have been used for the profit comparison calculations. Every time a personal or E-Mail conversion has been used as a source, this is marked with ‘personal communication’.

3.1.2. Capital budgeting

Different methods of capital budgeting (in German: *Investitionsrechnung*) were used in order to compare the different investment options and scenarios. Basically there are two types of capital budgeting (Perridon and Steiner, 1999; Däumler, 1998):

- static capital budgeting
- dynamic capital budgeting

Static capital budgeting does consider the point of time of costs and revenues. Usually, mean values serve as a basis of calculations. Frequently, the estimates for revenues and costs of the first year of an investment serve as a proxy for the whole lifetime of an investment. On the contrary, dynamic capital budgeting takes the temporal differences via discounting into account (Warnecke et al., 1996; Perridon and Steiner, 1999). Revenues and costs that arise in the first years of an investment are rated with higher values than revenues and costs that arise at the end of the life, as early revenues may generate further revenues, e.g. via new investments. The further into the future revenues or costs go, the stronger the effect of discounting on the cash value. Thus generally dynamic capital budgeting has to be prioritised. Nevertheless, methods of static capital budgeting are still very popular and are – according to (Warnecke et al., 1996) – the first choice in situations:

- where capital budgeting has to be carried out quickly and without bigger efforts;
- where a decision has to be made about an investment that is of little importance and thus of low value;
- where many variables are unknown or very uncertain.

In case of this master thesis the third argument is of major importance. Nearly every variable requires assumptions. As no insect rearing company shared their knowledge on costs and processes, these costs could only be estimated based on thoughtful and rational estimations. Also, for dynamic capital budgeting it is necessary to know the lifetime of fly rearing facilities. This is unclear because no facility has reached this point so far. Thus, it is unclear when the facility is fully depreciated.

There are 4 different static capital budgeting methodologies:

- Cost comparison method (CCM)
- Profit comparison method (PCM)
- Profitability calculation (PC)
- Amortization calculation (AC)

CCM is the first choice in cases where revenues of different investment versions are either the same or not known. In these cases only the costs of different investment cases are compared. In this thesis the revenues of four differently sized fly rearing facilities are known very well, thus PCM will be taken. The profits of different investment alternatives can be compared, as equation 1 is showing (Warnecke et al., 1996):

$$P = (R_1 - C_1) - (R_2 - C_2) \qquad (1)$$

Whereas

P Profit

$R_{1,2}$ Revenues of two differently sized fly rearing facilities

$C_{1,2}$ Costs of two differently sized fly rearing facilities

Usually costs and revenues are simple to determine in CCM. Uncertainties arise in regard to the interest rate of credits and imputed interest rates of free capital (Warnecke et al., 1996). Whether interest rates are included in the PCM depends on the purpose of the calculation (Perridon and Steiner, 1999), i.e. if it is merely a rough estimation or thorough calculation. However, it is important to be consistent in comparisons. Either interest rates are always included, or they are always omitted. In case of the BSF rearing facility it is suggested that the annuities of credits are included; however, possible imputed interest rates should not be included.

Additionally to PCM, a PC ("Return on Investment") was performed. PC is always building on a PCM or a CCM. The aim of the methodology is to determine the profit ratio of an investment. In the literature many different definitions and ways of calculations exist. In this thesis the profit ratio shall be defined according to equation 2 (Warnecke et al., 1996):

$$profit\ ratio\ \% = \frac{\emptyset\ annual\ profit}{\emptyset\ invested\ capital} \qquad (2)$$

In practice, the determination of the averagely invested capital is problematic (Däumler, 1998). Some define it as the total costs of the investment. In most cases this methodology is not reasonable, as it does not represent the interest on average but the interest of the first year of production. Others take half of the investment costs. This is reasonable, when the remaining value is 0 at the end of lifetime and when the value decreases uniformly. The most accurate way of determining the invested capital is by taking the remaining value of every period. The remaining value decreases by every period, at the same time the rate of return increases. Finally, an overall rate of return can be calculated (Däumler, 1998).

3.2. Overview on data & scenarios

In order to compare different facility sizes and explore the economies of scale, four different facility sizes with respect to processing quantities are assumed: 20,000 t, 40,000 t, 80,000 t and 160,000 t of waste per year. These facility sizes were modelled after the sizes of already existing facilities (Enterra, Agriprotein and Hermetia Baruth). Enterra's facility is capable of treating 36,500 t of biogenous waste per year. The theoretical capacity of Agriprotein's facility is 40,150 t of biogenous waste per year. Thus, the second facility size (40,000 t/a) is approximately the same size as already existing ones. The three others should show what scale effects can be expected.

Many variables in this thesis are uncertain with varying degree (e.g. labor demand, maintenance costs) In order to be able to demonstrate possibilities and uncertainties, different scenarios were defined.

Basically, all variables that concern the inner process of the facility, i.e. the production process, were grouped: Personal costs, investment costs and maintenance costs. Three different scenarios were made thereof: realistic, pessimistic and optimistic. Those three scenarios can be regarded as the basic structure (see figure 7). All other scenarios are built upon those three basic scenarios.

Further scenarios were made concerning the conversion ratio. It describes how much BSF larvae meal can be produced out of one tonne waste substrate. There again, three different scenarios were created: A realistic (0.09), pessimistic (0.05) and optimistic one (0.13). On the basis of the inner process production variables scenarios and the conversion ratio scenarios, an analysis of transport costs and sales prices of BSF larvae meal was made. Three and four, respectively, scenarios were developed. Additionally, all calculations were made for four different facility sizes: 20,000 t, 40,000 t, 80,000 t and 160,000 t. Thus, the different variable combinations add up to 432 scenarios, which are depicted in figure 7.

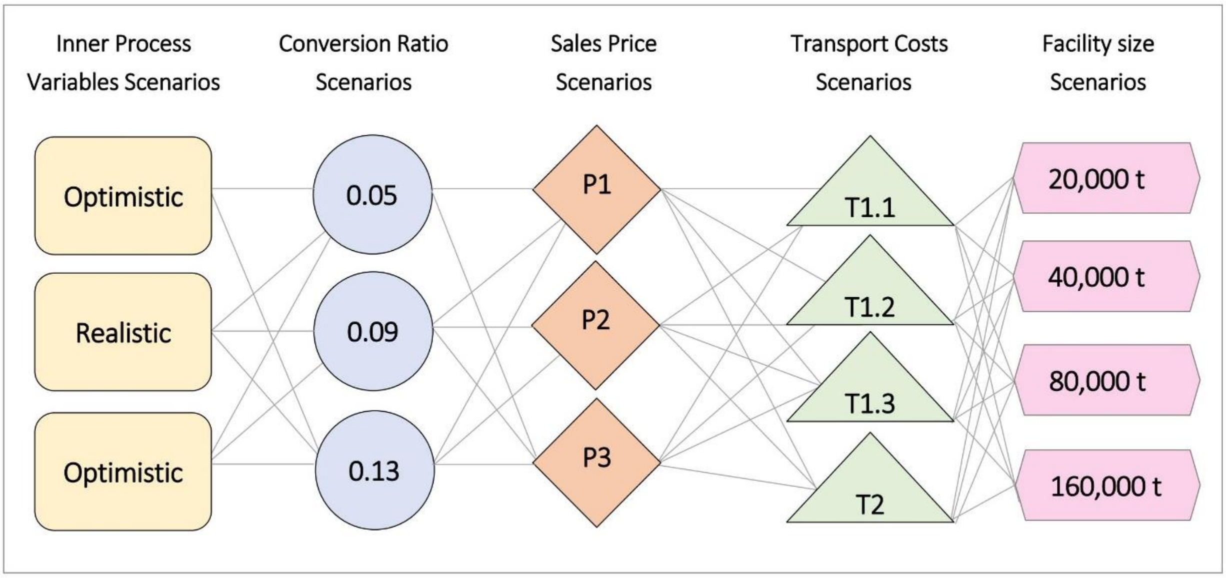

Figure 7 Diagram of variable combinations to develop scenarios (Source: Own diagram)

However, in order to find out which conditions need to be fulfilled to guarantee a cost-effective BSF larvae meal production, it is not necessary to describe all 432 scenario combinations in detail. The focus in the chapter Results will be more on presenting the impacts of certain variables.

3.3. Production variables

3.3.1. Investment costs

Agriprotein and Enterra share their information on investment costs for the construction of the fly rearing facilities: Enterra invested 7.5 million CAD (= 5,230,000 million €) to produce 1,825 t BSF larvae meal per year. Agriprotein invested 8 million USD (=6,399,000 €) and is theoretically capable of producing 2,920 t of BSF larvae meal per year (Leung, 2015, personal communication; Swart, 2015, personal communication). In order to compare those investment costs, an investment cost factor (ICF) is implemented. The ICF is calculated as follows:

$$ICF = \frac{Investment\ Costs}{Substrate\ Capacity} \quad (3)$$

The ICF of the Enterra and Agriprotein can be seen in table 5.

Table 5 Investment cost factor (Source: Own calculation based on Leung (2015, personal communication) and AgriProtein technologies (2014))

	Agriprotein	Enterra
BSF larvae meal production [t/a]	2,555	1,825
Substrate Capacity [t/a]	40,150	36,500
Investment costs [€]	6,399,000	5,230,000
Calculated Investment Cost Factor	**159**	**143**

Considering the different scales of the two facilities, the construction costs are comparable. However, construction cost, especially costs concerning the labour needed for the construction, are very different in South Africa, Canada and Austria. That is why the construction costs of the facilities in Canada and South Africa can only serve as a benchmark. Due to missing literature data, assumptions had been made based on thorough considerations. The assumptions have been changed and corrected several times. Main underlying thought is that the machinery, for example for the drying process, does not have to be doubled or tripled in terms of quantity, but only has to be bigger in size. Thus, it is assumed that significant cost reductions can be archived with higher production quantities. Based on these considerations, the ICFs were estimated for the three different scales as well as for the three scenarios. Table 6 shows the estimates for the ICFs and the corresponding investment costs.

Table 6 Estimated ICFs and investment costs (Source: Own calculations)

	Substrate capacity	20,000	40,000	80,000	160,000
Realistic	Calculated ICF	170	150	120	100
	Investment costs [€]	3,400,000	6,000,000	9,600,000	16,000,000
Optimistic	Calculated ICF	150	130	100	80
	Investment costs [€]	3,000,000	5,200,000	8,000,000	12,800,000
Pessimistic	Calculated ICF	190	170	140	120
	Investment costs [€]	3,800,000	6,800,000	11,200,000	19,200,000

The expected useful life is estimated to be 15 years. After 15 years the production facility will not have lost all its value. Considering the fact that the property, the production hall and also parts of the machinery will be able to be reused, the terminal value is estimated to be 1/5 of the investment costs.

It is assumed that the investment is financed by credit. According to an employee of a local bank (Raiffeisen Bank Hochburg-Ach), an interest rate of 2.75 % seems to be reasonable (March 2016), although interest rates for credits are currently slightly below this value (Esterbauer, 2016, personal communication). But in the case of a new fly rearing facility, the risk for the bank seems to be quite high.

The interest rate does not change with the amount of the credit (Esterbauer, 2016, personal communication). The annuity is calculated according to equation 4. This value represents the sum of capital depreciation and capital costs.

$$R = (S_0 - \frac{T_n}{(1+i)^n}) * \frac{(1+i)^n * i}{(1+i)^n - 1} \qquad (4)$$

Whereas

R	Annuity [€]
S_0	Credit sum [€]
T_n	Terminal value
i	interest rate [%]
n	maturity [years]

Table 7 shows the annuities for the realistic scenario.

Table 7 Estimates on investment costs for different facility sizes (Source: Own Estimations)

	Facility sizes [t/a]			
	20,000	**40,000**	**80,000**	**160,000**
Investment costs [€]	3,400,000	6,000,000	9,600,000	16,000,000
Expected useful life [years]	15	15	15	15
Terminal value	680,000	1,120,000	1,280,000	1,620,000
Annual Interest rate [%]	2.75	2.75	2.75	2.75
Annuity [€]	**242,445**	**427,844**	**684,550**	**1,140,917**

3.3.2. Costs for maintenance and insurance

The costs for maintenance and insurance were estimated based on the Method Handbook of the German Biomass Research Center (Thrän and Pfeiffer, 2015). In cases with high uncertainties regarding production process and technology, Thrän and Pfeiffer (2015) suggest to express maintenance and insurance costs as a percentage of the investment costs per year. They are estimated to be between 1 % and 5 % of the annual labour costs and between 1 % and 6 % of the annual material costs, thus in total between 2-11 % of the annual investment costs. Due to the absence of annual material costs in this thesis, the insurance and maintenance costs shall here be estimated based on a percentage value of the annuity. Considering the high levels of uncertainty, three scenarios were made for the maintenance costs: realistic (6 %), optimistic (2 %) and pessimistic (11 %). These are part of the Inner Process Variables Scenarios. No scenarios were made for the insurance costs. They are estimated to be constant at 1 % of the annuity.

3.3.3. Water Costs

All following variable costs are based on assumptions. The only secured source of data concerning variable costs for the production of BSF is the small scale fly rearing facility Hermetia Baruth GmbH. The production system of the facility is well explained in Praxmarer (2015). He applied a SWOT analysis and a value chain analysis in order to give recommendations for the advancement of the industry.

Hermetia Baruth GmbH uses 6,430 l of water for the production of 1 t BSF larvae meal (DM). The water is mixed with 2,570 kg of coarse rye meal and 260 kg of wheat bran, some sort of slurry is produced. Biogenous waste per se has a higher moisture content than wheat or rye. The need of additional water in the production process is assumed to be dependent on the water content of the waste. In the CIRP-Project (CO_2 neutral Insect born Raw material Production Project) at Technical University Dresden, where BSF rearing is also based on biogenous waste, no additional water is needed for the production process. On the contrary, for the production of 120 t of BSF larvae meal 55 t of water are released. Thus, it is assumed that there is no need to include additional water to variable production costs. Therefore, the water costs are estimated with 0 €/t BSF larvae meal.

3.3.4. Energy Costs

For the production of one tonne dry matter BSF larvae the production facility of Hermetia Baruth GmbH consumes a total of 589 kWh of electricity and 1,594 MJ of thermal energy per year. Given the fact that no other currently operating company shares details to their energy costs, no comparison can be made. With an annual production of 21 t of BSF larvae meal Hermetia Baruth GmbH is a small scale operating plant. In this thesis calculations are made on the basis of higher production capacities. Thus, economies of scale are expected. Again, as no literature had been available serving for comparisons, these reduction levels had been estimated based on thorough considerations. As an example, it is assumed that drying takes place in vessels that function in an equal manner as grain drying plants. With an increasing waste treatment capacity, it is assumed that bigger vessels are needed. Consequently, the energy demand of the vessel is rising. But it is assumed that the energy demand is not rising in the same magnitude as the substrate capacity, as one bigger vessel consumes less energy as two small vessels. This is assumed to be true for all BSF rearing methods and machinery.

In order to express those scale effects, the energy demand from Hermetia Baruth GmbH minus 15 %, 20 %, 30 % or 40 % for an annual production capacity of 20,000 t, 40,000 t, 80,000 t or 160,000 t are assumed. In a sensitivity analysis, the influence of the energy costs will be evaluated.

It is assumed that the energy costs are dependent on the scale of the production facility specified in tonnes of substrate that can be treated. Thus, the better the conversion ratio and the larger the output, the lower are the energy costs per tonne of BSF larvae meal.

The calculation of the electricity costs is based on data from E-Control (E-Control, 2015). The agency publishes industry prices twice a year. The median electricity price for industrial users in July 2015 was 4.65 cent/kWh. This is only the negotiable part of the electricity price. Taxes and duties have to be added additionally: 1.5589 cent/kWh grid utilisation charge, 1.5 cent/kWh electricity duty and 37.11 % of the grid utilisation for the Green Electricity Promotion Contribution (in German: Ökostromförderbeitrag) (Ökostromförderbeitragsverordnung 2016, 2015; Elektrizitätsabgabegesetz, 1996; E-Control, 2016). Based on these prices and the outlined assumptions the electricity costs can be seen in table 8.

Table 8 Electricity price calculations for different facility sizes at a conversion ratio of 0.05 (Con0.05) (Source: Praxmarer (2015), E-Control (2015), E-Control (2016), Ökostromförderbeitragsverordnung (2016), Elektrizitätsabgabegesetz (1996))

	facility size (t/a)			
	20,000	40,000	80,000	160,000
Production capacity at a 0.05 conversion ratio [t]	1,000	2,000	4,000	8,000
electricity need according to (Praxmarer, 2015) [kWh/t BSF larvae meal]	589	589	589	589
assumed reductions due to scale effects [%]	15	20	30	40
estimated electricity need [kWh/t]	500.7	471.2	412.3	353.4
Electricity costs at a 0.05 conversion ratio [€/t BSF larvae meal]	**50.8**	**47.8**	**41.8**	**35.8**
Total annual electricity costs [€]	**50,801**	**95,577**	**167,222**	**286,605**

It should be noted, that the electricity costs per tonne BSF larvae meal decrease with an increasing conversation ratio, as the electricity costs are assumed based on the substrate treated.

Heat costs

Like the costs of electricity, also the costs of heat are based on the Hermetia Baruth GmbH. Praxmarer (2015) reported that 1,594 MJ of thermal energy are consumed for the production of one tonne of dry matter BSF larvae meal. Again scale effects have to be expected and therefore, heat cost reductions of 15 %, 20 %, 30 % and 40 % are assumed.

For the price of heat, the price of district heating was chosen. As mentioned above, the most ecologically worthwhile solution would be the use of larvae plant leftovers for the generation of electricity in a biogas plant. There, waste heat is generated in considerable volumes. This heat can be re-used for the larvae meal production. The pilot project in Dresden works in that way. The district heating facility has an installed power of 100 kW (Gutzeit, 2015, personal communication), which is enough to generate the amount of electricity and heat that is needed for the larvae production. Hermetia Baruth GmbH also uses district heating.

In table 9, the heat prices of five different providers of district heating are shown and a mean is calculated (district heating Graz, Klagenfurt, Linz, Wels and Salzburg).

Table 9 Comparison of heat prices of different providers of district heating; prices excl. taxes [€] (Source: Energie Graz (2015), Salzburg AG (2015), Linz AG (2014), eww Wärme (2016), Stadtwerke Klagenfurt (2014))

Providers district heating	**Heat costs [€/mWh]**
Energie Graz	58.80
Salzburg AG	66.75
Linz AG	41.20
Stadtwerke Klagenfurt	59.38
eww Wels	59.52
Mean	**57.13**

Based on those prices, the heat costs for 4 different sizes of the BSF facilities were calculated. They are summarised in table 10.

Table 10 Heat price calculations for different facility sizes at a conversion ratio of 0.05 (Con0.05) (Source: Own calculations based on: Energie Graz (2015), Salzburg AG (2015), Linz AG (2014), eww Wärme (2016), Stadtwerke Klagenfurt (2014))

	facilty sizes [t]			
	20,000	40,000	80,000	160,000
annual production capacity at a conversion ratio of 0.05 [t]	1,000	2,000	3,000	4,000
heat need per tonne BSF larvae meal according to (Praxmarer, 2015) [MJ/t]	1,594	1,594	1,594	1,594
estimated reductions [%]	15	20	30	40
estimated heat need per tonne BSF larvae meal [MJ/t]	1354.9	1275.2	1115.8	956.4
Heating costs [€/t BSF larvae meal]	**21.50**	**20.24**	**17.71**	**15.18**
Total annual eating costs [€]	**21,502**	**40,474**	**70,829**	**121,422**

The basic fee of both, electricity and heat are not included in the energy costs. This fee is dependent on the amount of installed power of the machinery. Without knowing the detailed production process, the fee is difficult to estimate. Grain drying facilities could have approximately the same installed power as fly larvae drying facilities, but size, exact function and eventually installed power of the reactor, in which the larvae are grown, are completely unknown. However, it is assumed that those costs are the smallest part of the energy costs and therefore are neglected.

3.3.5. Labour Costs

The amount of labour required needs to be estimated, as the detailed process of insect rearing in the assumed scale of 20,000 t, 40,000 t, 80,000 t and 160,000 t is unknown. Furthermore, it is unclear whether day and night operation is needed or how many employees are needed for handling the reactors or for packaging. The amount of labour needed depends on the level of automation. A high level of automation and, thus, higher investment costs lead to lower labour costs and vice versa. Agriprotein does not publish data on labour demand but Enterra does: For the production of 5 t of BSF larvae meal/day (1825 t/a) Enterra occupies 20 persons in full-time positions (Leung, 2015, personal communication). Praxmarer (2015) indicates that Hermetia Baruth GmbH has labour costs of 200 €/t of BSF larvae meal. Hermetia Baruth GmbH's level of automation and the production capacity are low; thus, Hermetia Baruth GmbH's production figures are not the most suitable base for estimations. In the following calculations it is assumed that no night operation is required. However, plant drivers are needed from Monday to Sunday from 6 am to 10 pm, which corresponds to a 2-shift-operation. It is estimated that a minimum of 3 plant drivers are needed for letting the system work, not considering holidays and sick leaves and based on a 37,5h week. With a minimum production of approximately 5 t/day, it is assumed that at least 2 plant drivers need to be present at the same time. The manager and the administration and sales personnel work on basis of a common 5-day-week. The gross salaries including extra payments for shift work were estimated based on the collective agreements of metalworkers and office administrators of the year 2015. In table 11, the estimates for the realistic, optimistic and pessimistic scenario can be seen.

Table 11 Salary of BSF facility personal in a pessimistic, optimistic and realistic scenario (Source: Estimations based on jobs.at (2016))[4]

	Pessimistic scenario		Optimistic scenario		Realistic scenario	
	Gross Salary [€/month]	Total annual employer's costs [€/a]	Gross Salary [€/month]	Total annual employer's costs [€/a]	Gross Salary [€/month]	Total annual employer's costs [€/a]
Plant manager	6500	114,184	3500	64,091	5000	91,195
Administration personnel	2300	42,143	1900	34,814	2100	38,478
Sales personnel	3400	62,298	3000	54,969	3200	58,634
Plant drivers	2800	51,304	2400	43,975	2600	47,640

Finally, table 12 gives an overview of the estimated labour force requirement and exemplary shows the total labour cost for the annual treatment capacity of 40,000 t.

Table 12 Labour force requirement in the realistic scenario (Source: Own calculations)

Scenario	Realistic	Optimistic	Pessimistic
Annual treatment capacity [t]	40,000	40,000	40,000
Plant manager [person]	1	1	1
Administration [person]	1	1	1
Sales [person]	1	1	1
plant drivers [person]	10	8	13
Full time positons [person]	13	11	16
Total labour costs [€]	**664,705**	**505,676**	**885,582**

The total labour costs remain the same for all conversion ratio scenarios, thus, they are assumed to be dependent on the scale of the facility which is defined by its annual biogenous waste treatment capacity and not by the production capacity of BSF larvae meal. Hence, the labour costs are decreasing with increasing conversion ratios.

3.3.6. Transport costs of biogenous waste

There are three possible alternatives for the calculation of transport costs. **At first,** the existing costs for the garbage removal systems could be taken as a basis of the calculation. Biogenous waste collection takes place in nearly every Austrian municipality – it is not necessary to invent or install a second collection system for fly larvae facilities. According to the provincial law on waste management, the collection of biogenous waste lies in the responsibility of the municipalities (Landesgesetz über die Abfallwirtschaft im Land Oberösterreich, 2009) but many municipalities delegate their duties to the

[4] Each scenario has been given its colour: green (optimistic), red (pessimistic) or yellow (realistic scenario). The colours will stay the same in the following tables and figures.

district waste association (*Bezirksabfallverband* (BAV)). As a consequence, the collection system is carried out completely differently in the districts of Upper Austria. A survey was conducted for Upper Austria – exemplarily for whole of Austria – in order to gather representative values for transportation costs (see Annex 3). Table 13 summarises the information of the districts and gives an overview of the transport costs of biogenous waste in Upper Austria.

Table 13 Costs of biogenous waste collection in Upper Austria either per t or per emptied container [€] (Source: Bezirksabfallverband Braunau (2015, personal communication), Bezirksabfallverband Eferding (2016, personal communication), Bezirksabfallverband Freistadt (2016, personal communication), Bezirksabfallverband Grieskirchen (2016, personal communication), Bezirksabfallverband Kirchdorf (2016, personal communication), Bezirksabfallverband Perg (2016, personal communication), Bezirksabfallverband Rohrbach (2016, personal communication), Bezirksabfallverband Schärding (2016a, personal communication), Bezirksabfallverband Urfahr (2016, personal communication), Bezirksabfallverband Wels (2015, personal communication))

District	Transport costs per t [€]	Transport costs per emptied container [€]
Braunau	111 (Tour 4) 87 (Tour 7) 51 (Tour 6)	3 (120 l, but contains also composting costs)
Wels		1.43
Urfahr	-	-
Kirchdorf	-	-
Schärding		0.77 (for 14 l bags, weekly collection)
Freistadt	50 (municipality Tragwein) 143 (municipality Lasberg)	0.77 (for 23 l/47 l buckets, weekly collection)
Linz	-	3.19 (120 l, contains composting costs)
Eferding		1.54 (120 l excl. composting)
Grieskirchen	53 (average) 80 (most expensive collection of district) 33 (cheapest collection of district)	1.23 (120 l, municipality Neukirchen)
Perg	56 - 150 (23 l buckets) 94 - 200 (120 l cans)	0.6-1.2 € (23 l bucket) 1.0-1.6 € (120 l can)
Rohrbach	Prices of 8 composting facilities A 56.46 B 106.49 C 82.46 D 96.78 E 125.64 F 50.96 G 101.07 H 146.80	

For further calculations it is necessary to know the transport costs per kilometre and tonne. It would be possible to estimate the costs per tonne based on the information of the emptying costs per can, bag or bucket. But there are three difficulties for making a reliable estimation: First, the filling levels of the cans/bags/buckets are unknown. Second, the weight of biogenous waste in one can/bag/bucket is unknown, as it depends on the disposed substance (e.g. green cuttings, kitchen waste). Third, the number of emptyings per year are not always known. Thus, only the information on transport costs per tonne will serve as a basis for further calculation. As can be seen, the district of Grieskirchen has the lowest transport costs per tonne of biogenous waste (33 €). In the district of Perg, the highest transport costs were reported: 200 €/t, this, however, represents an extreme value. The information of the routes in the district of Braunau corresponds to densely/sparsely/medium densely populated areas and, therefore, it is a good base. The costs of the districts of Freistadt, Perg and Rohrbach are similar. The lowest values are always around 50 €/t, medium values are around 80-90 € and the highest values are around 150 €. Thus, for the calculations of this thesis the following scenarios are made: In Scenario T1.1, it is assumed that fly rearing facilities are only built next to cities and in regions that are densely populated and, consequently, transportation costs are at a minimum. Hence, the transport costs of one tonne of biogenous waste are 45 € in Scenario T1.1. In Scenario T1.2, it is assumed that biogenous waste of agglomerations, its surroundings and all densely and medium densely populated areas is used. Thus, the price of transportation in T1.2 is approximately the average of T1.1 and medium densely populated areas (85 €/t): 65 €. In T1.3, all biogenous waste that is currently collected in Upper Austria is used. Thus, T 1.3 is approximately the average of T 1.1, T 1.2 and sparsely populated areas (130 €/t): 87 €.

The scenarios T1.1, T1.2 and T1.3 based on prices of the BAVs, contain a profit margin from composting and biogas facilities as well as waste collection companies. **A second way** to estimate the transport costs would be by calculating them based on the annual depreciation of a garbage collection truck, the working hours and the fuel consumption. However, these components are difficult to estimate too because of the mix of collection time and pure transportation time. Thus, the calculation based on the annual depreciation of a garbage collection truck will not be considered in this thesis. **A third alternative** would be the complete exclusion of the transport costs in the model. Currently, composting facilities represent the majority of biogenous waste processors, whereas biogas facilities play a minor role in Upper Austria (Zarzer, 2015, personal communication). The composting and biogas facilities do not pay for the waste transport to their facilities. On the contrary, they are paid for every tonne of waste that is deposited at their facility. The households where the waste incurs have to bear the cost of collection, transportation and composting. The supply of biogenous waste for fly rearing facilities could work in an equal manner. The waste is brought to the fly rearing facilities instead of the composting facilities. As a result, the transport costs in scenario T2 are 0 €. However, the difficulty in the long run is that currently the producers of biogenous waste do not pay the real costs for the collection of their biogenous waste. If this situation changes, the waste separation behaviour of the population will possibly change too and lower amounts of biogenous waste are collected subsequently. According to the guideline of the government of Upper Austria, some municipalities offer the collection of the biogenous waste for free at present. The aim is to decrease the amount of residual waste as a consequence of stricter separation. The question whether the free collection is a successful tool for the reduction of residual waste is not content of this thesis. At the moment, the costs of the biogenous waste collection are – as reported –

often shared among all households using the residual waste collection system. Hence, scenario T2 is only realistic as long as the situation stays as it currently is.

3.3.7. Revenues from the treatment of biogenous waste

Waste collection enterprises have to pay for the deposition of biogenous waste at composting or biogas facilities. The ARGE Kompost und Biogas regularly publishes guidance values for this payment. According to Zarzer (2016, personal communication) from the Upper Austrian Government, Department Environment Protection, composting facilities should currently receive 51.54 €/t of biogenous waste (excl. taxes). This guidance value is principally met, even though, there are regions in Upper Austria where composting facilities are paid less or more respectively. The prices charged are always based on negotiations between the composing facilities and the BAV or the municipalities. There is no collective agreement (Zarzer, 2016, personal communication). Thus it is assumed that future fly rearing facilities receive 51.54 €/t biogenous waste they are treating.

3.3.8. Revenues from sales of residues

It is assumed that the residues, i.e. the larvae's leftovers, will be composted and sold as fertilizers to farmers afterwards. The construction and operation of a composting facility is not very capital intensive. Both the costs of construction and the personnel costs of the operation of the composting facility are assumed to be included in the construction costs of the fly rearing facility and the overall personnel costs. Agriprotein and Enterra also treat the residues in their own composting facility subsequently to the rearing of BSF larvae. These companies promote and sell the residues as fertilizers. A composting and biogas facility in St. Peter, Upper Austria sells compost to farmers for 8 €/t (Drexler, 2015). Compost for households is more expensive with 30 €/t, as it takes far more time to serve these costumers. In the scenarios it is assumed that compost is only sold to farmers at a price of 8 €/t.

3.3.9. Conversion Ratios

The conversion ratio describes how much substrate is needed to produce a certain amount of the BSF larvae meal. It is assumed that the conversion ratio is one of the factors influencing economic efficiency the most. In this work, the conversion ratio is defined according to equation (5):

$$Conversion\ ratio = \frac{dried\ and\ defatted\ BSF\ larvae\ meal\ [kg]}{fresh\ substrate\ [kg]} \quad (5)$$

As there is no standard defining the calculation methodology of this ratio, it is impossible to compare the results of scientific articles, companies or research groups. A crucial part of the calculation is the water content of the substrate and the larvae. Very often, there is no information on the DM content of the substrate. The DM content of biogenous waste from households is not known either. However, the following paragraph is summarising the results of the research on conversion ratios.

Conversion ratios out of the scientific literature

Among others Stamer (2009), Barry (2004), Newton et al. (2005b), Gobbi et al. (2013), Myers et al. (2008), Zhou et al. (2013), Oonincx et al. (2015), Kalová and Borkovcová (2013) and Diener et al. (2009) have published results of their experiments with BSF reared on diverse substrates. None of these articles used biogenous waste as substrate, therefore, their findings are only of limited value in this work.

Additionally, their conclusions are often contradictory and, therefore, difficult to compare, but they show the following:

- The daily feeding rate is crucial. In many publications no information is given on the daily feeding rate, even though it is clear that the daily feeding rate determines growth the most.
- Even the same substrate (e.g. cattle manure) can have different properties and lead to different results. For example, larvae grew worse on manure that was once dried (important for evaluating DM content) and liquefied subsequently, than on manure that has never been dried (Oonincx et al.,2015). Additionally, substrates like "green cuttings", "compost" or "biogenous waste" cannot be clearly defined. Furthermore, their compositions may also vary substantially.
- Growth is dependent on humidity and temperature. Experiments without indications on humidity and temperature are impossible to compare.
- Flies of different strains have different properties, for example, some have higher capabilities in terms of waste reductions, some grow faster. For making comparisons the exact source of the population is needed.

In the following the methodologies and results of the mentioned scientific articles are summarized:

Diener et al. (2009) focused on establishing optimal feeding rates for the conversion of organic material by the BSF. These authors used chicken feed to rear BSF. The main finding is that the growth rate strongly correlates with the daily feeding rate. Diener et al. (2009) used 5 different daily feeding rates: 12.5 mg, 25 mg, 50 mg, 100 mg and 200 mg. The larvae with the daily feeding rate of 100 mg showed the best conversion ratio in terms of waste reduction. The experiment showed that between 17.1 % (class 200) and 32.6 % (class 50) of the material fed to the larvae was metabolized. 55.9 to 76.9 % was left as residual matter, which had either passed through the gut of the larvae or had not been ingested at all. Only a small fraction (6 % to 16.1 %) was transformed into prepupal biomass. The conversion ratio in terms of weight gain is as follows: 12.5 mg of food supply resulted in a 16.1 % conversion ratio, 25 mg of food supply in 12.6 %, 50 mg of food supply in 11.5 %, 100 mg of food supply in 9.6 % and 200 mg food supply in 6 %. The development time depends on the food supply: With a food supply of 200 mg the larvae needed 15.9 days to reach their full development, whereas, larvae fed with 100 mg showed a development time of 16.6 days. Thus, from a lifecycle viewpoint, the feeding rate of 100 mg of food per larva and day marks the threshold where additional daily food supply does no longer accelerate larval development time. In case of a food shortage, the larvae are capable of prolonging their development time. This biological trait may simplify the operation of a waste management system, as larvae can cope with varying food supply (Diener et al., 2009).

A different approach was pursued by Oonincx et al. (2015), who focused on the development time of BSF larvae on chicken, pig and cattle manure and their different compositions regarding nitrogen and phosphorus. They concluded that development time on manure was much longer than on the control diet (144-215 days vs 20 days). This result was surprising, as in other experiments development time on manure was much shorter. It is presumed that the drying of the manure has decreased its nutritional value due to the destruction of microorganisms and heat-labile vitamins. Oonincx et al. (2015) suggest that a production system using fresh manure could result in a considerably shorter development time and increased conversion efficiency. Table 14 summarises the findings of Oonincx et al. (2015).

Table 14 Larvae growth on different substrates (Source: Oonincx et al. (2015)

Manure	Survival rate (%)	Development time (days)	Yield (g fresh weight)
Chicken	82.2±13.50	144.0±33.12	5.68±1.603
Pig	97.0±4.73	144.0±52.80	6.90±1.400
Cow	87.8±5.00	214.5±21.56	7.43±1.414

However, the publication does not contain any information on how much substrate is needed to grow a certain amount of larvae.

Newton at al. (2005b) summarized the results of their experiments in a report for the Animal and Poultry Waste Management Centre of the North Carolina State University. A small scale system for digesting pig manure solids, harvested by a belt beneath a slatted floor holding pigs, was installed and tested. Their results can be seen in table 15.

Table 15 Weight of final larvae, ingested manure and residues, expressed in fresh and dry matter [kg] (Source: Newton et al. (2005b))

	fresh matter [kg]	dry matter [kg]
manure	169	67,8
larvae	26,2	
residue		41,6

A feed conversion ratio of 0.15 on fresh matter basis can be calculated based on the findings presented in table 15. Manure mass was reduced by 56 %. The nutrient analyses and feeding studies of Newton et al. (2005b) indicate that dried BSF prepupae grown on pig manure solids are valuable feedstuff, particularly for aquaculture.

Gobbi et al. (2013) studied the effects of larval diet on adult life-history traits of BSF. They analysed the effects of three different feed: hen feed, meat meal and a mixture of hen feed and meat meal. They focused on development, size, mortality and duration of the larval and pupal stages. It took significantly less time to complete the life cycle on hen feed diet (31 days) than on the meat meal diet (52 days). However, the quantitative analysis of the residues of each type of diet demonstrated that larvae reared on meat meal ingested an average of 167.60 g of the diet, whereas, those reared on hen feed ingested 354.80 g and those reared on the mixture ingested 290.60 g. This indicates that meat meal could not be ingested and digested in the same way as hen feed. Gobbi et al. (2013) supposed that the texture of the meat meal was unsuitable and, additionally, the feed dried out easily (Gobbi et al., 2013). Yet, no information was given on conversion ratios.

Myers et al. (2008) focused on the development of BSF larvae fed with dairy manure. They analysed 4 different feeding rates: 27 g, 40 g, 54 g und 70 g per day. The feeding rates affected larval and adult development to the following extent: The larvae fed 27 g/day weighed 0.143 g at the end of their larval period and those fed 70 g/day weighed 0.179 g. Additionally, those larvae provided with the least amount of dairy manure took longer to develop to the prepupal stage. However, they needed less time to reach the adult stage. Mortality did not differ significantly within the varying feeding rates. Larvae fed 27 g of dairy manure per day reduced manure dry matter mass by 58 %, whereas, those fed 70 g daily reduced dry matter by 33 %. The manure's moisture content was 70 % on average (Myers et al., 2008). However, no conversion ratio was mentioned and can also not be calculated based on the published data either.

Zhou et al. (2013) followed a very different approach. They analysed the developmental and waste reduction plasticity of three different BSF fly strains. They saw that the colonies used for research in the last 20 years had predominantly been established from eggs or larvae received from a colony originated from Texas, USA and found that this fact might have distorting effects on the estimation of the suitability of BSF larvae for various purposes. Consequently, little was known about the phenotypic plasticity across strains from different regions. Their main finding was that eggs, larvae as well as prepupae of the US colony developed much more slowly than those of the two Chinese colonies. The larval development of flies from the Wuhan strain was 5-6 days less than the Texas strain and 3-4 days less than the Guangzhou strain. Significant differences could also be determined regarding the final weight of the larvae: The ones from the US strain weighed 0.107 g on average, whereas, the larvae from the two Chinese strains weighed 0.170 g and 0.146 g. In the second part of the publication, the growth rates on three different substrates were shown: pig, poultry and cattle manure. Larvae reared on poultry manure weighed twice as much as larvae reared on cattle manure. Larvae reared on pig manure grew nearly as well as on poultry manure. This was true for every strain, as can be seen in table 16:

Table 16 Final larval dry weight and protein content of three different BSF strains reared on pig, chicken and dairy manure (Source: Zhou et al. (2013))

Strains	Pig Manure		Chicken Manure		Dairy manure	
	larvae DM (g)	Protein (%)	larvae DM (g)	Protein (%)	larvae DM (g)	Protein (%)
Texas	53.66	32.27	69.17	34.60	22.43	33.53
Guangzhou	59.03	33.16	73.20	34.23	31.30	34.77
Wuhan	65.47	33.03	76.63	34.80	31.20	34.13

Interestingly, in terms of waste reduction a different pattern could be observed: Larvae from the US strain, which performed worst in terms of development and weight gain, reduced dry matter more than the Guangzhou strain. The Wuhan strain was superior in reducing manure dry matter than the other two strains (Zhou et al., 2013). These results lead to three interesting conclusions: First, BSF rearing on dairy manure is least efficient. Second, the weight gains of larvae of different strains are significantly different. Third, larvae that perform well regarding development and weight gain are not necessarily good waste reducers. This is particularly interesting for companies rearing BSF. However, no information was given concerning the conversion ratio. Based on the published data it is not feasible to calculate the ratio either.

Kalová and Borkovová (2013) analysed the waste reduction potential of BSF on different substrates: Plant waste tissue, garden waste, cattle and poultry manure, biodegradable municipal waste, catering waste and food scraps. The highest weight reduction of waste material (by 66.53 % of the original mass) was reached in waste plant tissues. Weight reduction for food scraps was calculated by 46.04 %, for high quality biodegradable municipal waste reduction was at 44.75 % and for catering wastes reduction was at 45.89 %. The worst results were achieved with compost tea from garden waste – larvae reduced the initial amount of waste by only 8.47 % (Kalová and Borkovcová, 2013). Yet again, the authors did not provide information regarding conversion ratios.

Conversion ratios from further research projects

Most recently, the **Technical University in Dresden** has finalised an insect rearing facility based on biogenous waste from households together with corporate partners. In the connected biogas facility, the residues of the larvae production are used to generate electricity. In return, the waste heat of the biogas facility supplies the larvae production with the necessary thermal energy. The scale of the pilot project and the annual capacity are unknown to the public. The facility produces 120 kg fresh larvae out of 300 kg of fresh waste, equalling a 0.4 fresh matter conversion ratio, which represents extraordinary figures. As there is no information available concerning DM and fat content, the following calculations were made: Assuming a DM content of 43 %, 51.6 kg of dried larvae meal is produced. The dried BSF larvae meal still contains approximately 35 % fat (Sheppard et al., 2002, St-Hilaire et al., 2007). For feed production, most of the fatty fraction has to be excluded. As already mentioned above, the suitable fat content in the meal is around 10 %. Thus, out of 300 kg of fresh biogenous waste 38.7 kg of dried BSF larvae meal with a fat content of 10 % can be produced. This equals a DM conversion ratio of 0.129, which is extraordinarily high compared to the DM conversion ratios of Agriprotein (0.064) and Enterra (0.05). However, the project manager Prof. Herwig Gutzeit stated that this conversion ratio is only valid for small scale production (max. input: 300 kg biomass). "Industrial, large scale production faces technical and biological barriers, which are most often not subject of discussion. So far it has not been possible to control a stable large scale production for a longer period of time" (Gutzeit, 2015, personal communication).

The research institute of organic agriculture in Switzerland (FIBL) has been analysing the growth of the larvae on different substrates as well as the suitability of fly larvae in the feed of fish, pig and poultry (Stamer et al., 2007; Stamer, 2009; Sandrock, 2015, personal communication; Maurer et al., 2015). In a series of standardized tests, the growth of BSF on different substrates (manure of pig, manure of cattle, manure of poultry, bread waste and compost out of tomato plants) was analysed. The results were compared with the growth of BSF on a reference substrate, namely mineralized cereal flour. The development rates on cereal flour were the highest. As can be seen in figure 8, BSF on chicken manure showed almost the same development rates, although the biomass building proceeded at lower pace. BSF larvae reared on green cuttings reached the same rates of biomass building like with chicken manure but the development took much longer. In comparison, all other substrates performed badly: slow development rates, low biomass building and high mortality rates. The experiment lasted for 28 days, therefore, no conclusion can be made on the time needed until the full development of the larvae. The protein content of the larvae reared on different substrates varied slightly, they reached around 40 % and, therefore, were below values from the literature (Stamer, 2009).

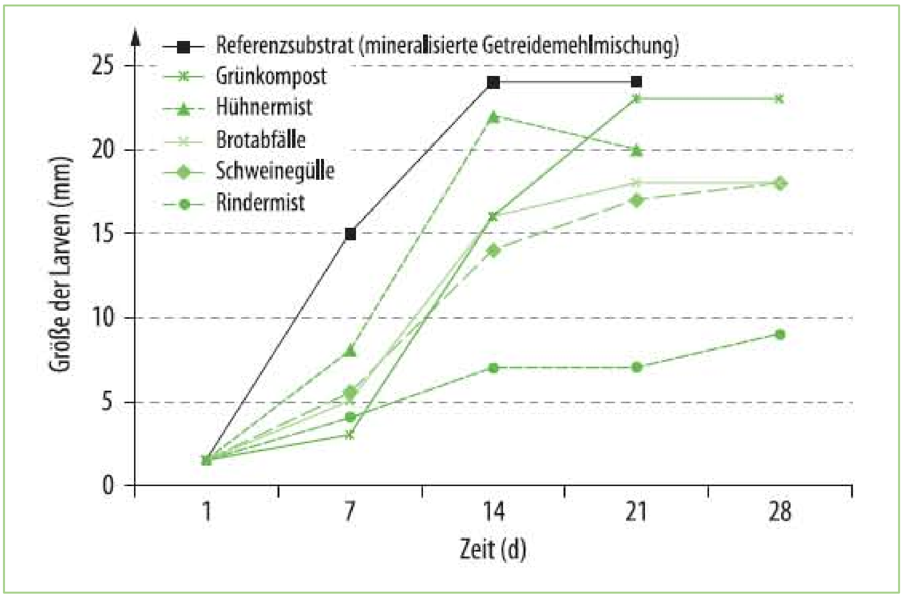

Figure 8 Larvae Growth on different substrates (Source: Stamer (2009:31)

ESR International, a research and development company in Dallas also published data on production efficiency and conversion ratios. It must, however, be taken into consideration that production methodology of ESR International is very different compared to the ones of the TU Dresden, Agriprotein or Enterra. The aim of ESR International research was to develop small container systems targeted for the reduction of biogenous waste that is produced by single households and small gastronomic businesses. The larvae in those small containers are capable to convert up to 30 kg of waste per day. 6 kg of fresh larvae can be produced that way which equals a 0.20 fresh matter ratio with biogenous waste and a 0.0645 DM ratio excluding oil. Those ratios correspond to Agriprotein's values (ESR International, 2015).

CR from companies

The archived conversion ratios are known from Enterra, Agriprotein and Hermetia Baruth GmbH. Enterra is transforming 100 t of waste per day into 5 t of dried BSF larvae meal, 2 t of oil and 8 t of natural fertilizer (Leung, 2015, personal communication). This equals a fresh matter conversion ratio of 0.0116. The conversion ratio regarding fresh waste but dried, defatted BSF larvae meal is 0.05. Until now, Agriprotein was not able to start large scale production at their new facility near Capetown. The intended production capacity is 7 t of MagMeal, 3 t of MagOil and 20 t of MagSoil out of 110 t of fresh waste per day (Swart, 2015, personal communication). The conversion ratio regarding fresh waste and dried, defatted BSF larvae meal would be 0.064. Hermetia Baruth GmbH uses 2,570 kg of coarse rye meal and 260 kg of wheat bran (in total 2,830 kg cereals) as well as 6,430 l of water for the production of one tonne DM BSF larvae meal (Praxmarer, 2015). This corresponds to a DM conversion ratio (=dried grains and dried BSF larvae meal) of 0.353. In order to allow comparisons with fresh biogenous waste, the water has been included into the calculations of the conversion ratio and, therefore, the conversion ratio is 0.108. It has to be considered that the conversion ratio of Hermetia Baruth GmbH is only of little use in this work, as the larvae were reared on cereals and not on biogenous waste. Table 17 depicts an overview of the conversion ratios of the three companies.

Table 17 Conversion ratios of three BSF rearing companies (Source: Praxmarer (2015), Swart (2015, personal communication), Leung (2015, personal communication))

Company	Enterra	Agriprotein	Hermetia Baruth GmbH
Conversion ratio (fresh substrate - dried larvae)	0.05	0.064	0.108

Scenarios for conversion ratios

Based on the values from the literature and the publications of Enterra, Agriprotein, Hermetia and the Technical University of Dresden, three different scenarios were made: A realistic one, an optimistic one and a pessimistic one. The extraordinary high conversation ratio of the TU Dresden is the base for the optimistic ratio (C3 = 0.13), as it is more than twice as high as the state-of-the-art ratios of the existing largescale facilities. The conversion ratio in the pessimistic scenario (C1) is 0.05 and, thus, little lower as Enterra's conversation ratios. A realistic ratio (C2) is assumed to be 0.09, which represents a value in between both extremes. Not all of the substrate absorbed by the larvae is converted into larvae growth. Part of the substrate is needed for their metabolism or converted into thermal energy. The TU Dresden observed that 22 % of the substrate is "lost" that way. In C1 and C2 less larvae are produced than in C3. Consequently, it is assumed that in C1 and C2 less substrate is needed for metabolism and thermal energy. The same is assumed to be true for water generation: The TU Dresden observed that at a substrate input of 300 kg, 55 kg water is generated. Irrespective the fact that the share is highly dependent on the water content of the used substrate, it is assumed that the less larvae are living and growing in the substrate the less movement there is and, hence, the less water is generated.

A considerable part of the substrate is left over by the larvae. This amount of residuals is – again – highly dependent on the conversion ratio. The higher the production volumes of larvae, the less residuals remain. In the research project of the TU Dresden, 1/5 of the substrate was left. The shares of the substrate devoted to the generation of larval biomass, the larval metabolism as well as the shares devoted to the generation of water and the generation of the remaining residuals were calculated for all three conversion ratio scenarios based on the findings of the research project of the TU and Dresden. They are presented in figure 9. It can be seen that the lower the share of the produced fresh larval biomass, the higher is the amount of residuals.

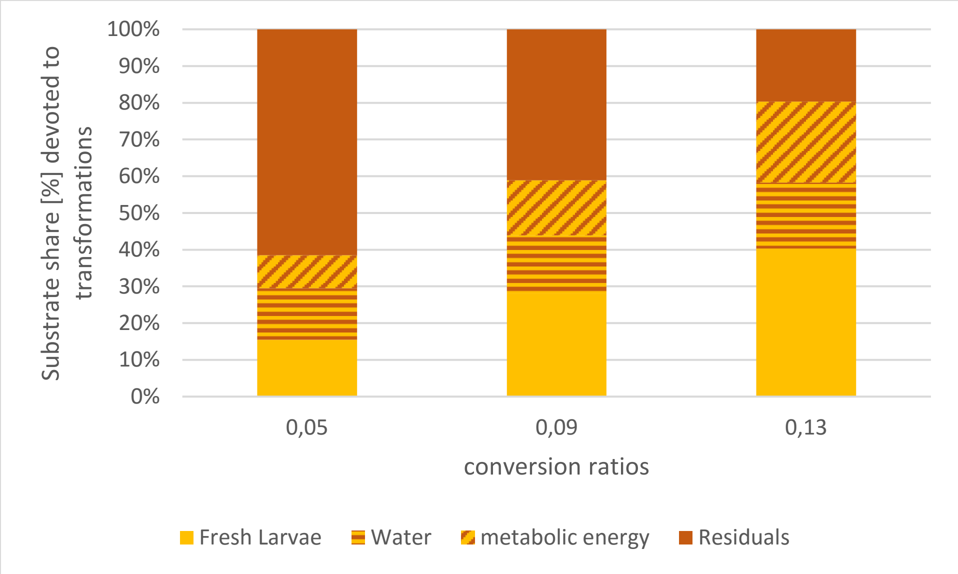

Figure 9 Shares of the substrate use for three conversion ratios (0.05, 0.09, 0.13) (Source: Own calculations)

In order to process the fresh larvae to protein feed for livestock, the water and fat fraction needs to be extracted. Newton (1977) reported a DM content of 43 %, which is confirmed by more recent studies (St-Hilaire et al., 2007, Maurer et al., 2015). The fat content of dried BSF larvae is around 35 % (St-Hilaire et al., 2007). Table 18 shows how much t of BSF larvae meal is left after the extraction of water and fat.

Furthermore, it is necessary to calculate the amount of compost that can be produced out of the residues. In a conventional biogenous waste composting facility, an amount of 300 kg of high quality compost can be produced out of 1,000 kg of biogenous waste (Drexler, 2015, personal communication). This equals a composting ratio of 0.3. However, the larvae have already done a big part of the rotting. Therefore, it is assumed that the composting ratio of larvae residuals is higher: 0.7. Table 18 shows how much compost is estimated to be generated during the production of one tonne of BSF larvae meal DM.

Table 18 Scenario parameter estimates for compost production dependent on different conversion ratios (Source: Own calculations based on AgriProtein technologies (2014), Leung (2014, personal communication) and Gutzeit (2015, personal communication)

	Conversion ratios		
	0.05	0.09	0.13
Production capacity [t/a]	40,000	40,000	40,000
Conversion ratio Larvae [fresh matter]	0.16	0.28	0.40
Amount of fresh larvae produced [t]	6,202	11,163	16,124
Amount BSF larvae meal DM [t]	**2,000**	**3,600**	**5,200**
Conversion ratio Residuals [fresh matter]	0.61	0.41	0.2
Amount of biogenous waste needed [kg]	24,400	16,400	8,000

Conversion ratio compost production	0.7	0.7	0.7
Compost Production [kg]	**17,080**	**11,480**	**5,600**

3.4. Sales prices of BSF larvae meal

The price that can be achieved for one tonne of BSF larvae meal mainly depends on the substituted product (e.g. soybean meal). If BSF larvae meal would be more expensive than soybean meal, feed manufacturers would eventually not use BSF. The price of Agriprotein can serve as guidance values. The sales price of Agriprotein's MagMeal is around 13,000 Rand/t for a 50 % protein meal (Swart, 2016, personal communication). The exchange rate of the South African Rand to Euro is currently at 16.96 (09.03.2016) (finanzen.at, 2016a). Therefore, the price of one tonne of MagMeal is at 768 € at present. As Agriprotein's processing plant is not fully operational yet, this price is only a target price. According to Agriprotein's employee (Swart, 2016, personal communication), the market price can be determined once the final product specifications are known. The price of Enterra's Enterra Meal is not made public.

As BSF larvae meal is supposed to replace soybean meal and to a lesser amount also fish meal, the prices of those two commodities are relevant. As can be seen in figure 10, the commodity market price of soybean meal has been quite volatile. The price of soybean meal is currently at a five-year-low:

Figure 10 Price of soybean meal [$/t]; Chicago Board of Trade, Chicago Soybean Meal Futures (first contract forward), minimum 48 percent protein, (finanzen.at, 2016b)

In contrast, the price of fishmeal has been increasing since 2005. As illustrated in figure 11, the current price is more than double as in 2005. In 2015, fishmeal was even three times higher than in 2005 and nearly reached 2000 €/t.

Figure 11 Price of Fishmeal (Peru, pellets, CIF, protein content 65 %) [€/t] (indexmundi.com, 2016)

Fishmeal is predominantly used in aquaculture and to a lesser extent also in pig and poultry feed in Austria. Due to the high prices and the possibility of substitution its use in pig and poultry feed has declined in last years (Emathinger, 2014, personal communiation). Thus, according to Lentsch (2016, personal communication), the use of BSF larvae meal as fish feed is becoming increasingly interesting, also in Austria, due to the high prices of fishmeal. However, the focus is on the substitution of soybean meal in poultry and pig rearing in this thesis, whereas, aquaculture is not considered at all. Thus, fishmeal has a inferior role in this thesis and will be excluded from further considerations or calculations. For additional comparisons, the soybean meal price will be used. In order to obtain a meaningful price that is representative for a longer period of time, the mean of the soybean meal prices of the last five years was calculated: 386.26 $/t (finanzen.at, 2016b). In order to express the price in Euros, the mean of the exchange rates of the last five years was calculated (0.799) (oanda.com, 2016). Hence, the average soybean meal price over the last five years is 308.96 €/t. Whether a direct substitution is possible also depends on the composition of BSF though, i.e. its crude protein content and on the composition of amino acids. In general, the protein content of hermetia illucens depends on the stage of its development (larvae or prepupae), the protein content in the feed of the larvae and the amount of feed served (Elissen et al., 2015, Diener et al., 2009). Therefore, results on the protein content are varying and difficult to compare, because rearing methods differ widely. Stamer et al. (2007) and Sheppard et al. (1994) measured high protein contents of 42-43 %, considerably lower protein contents of 37 % are reported by Sánchez-Muros et al. (2014). The compositions of BSF prepupae, Enterra Meal, Mag Meal and soybean meal can be seen in table 19.

Table 19 Composition of BSF larvae meal and soybean meal according to different studies [%] (Source: See below)

	BSF Prepupae (Sheppard et al., 2002, St-Hilaire et al., 2007)	BSF larvae (Maurer et al., 2015)	Enterra Meal (Enterra, 2015b)	Mag Meal (AgriProtein technologies, 2014)	Soybean Meal (St-Hilaire et al., 2007)	Soybean cake (WIFO, 2013)
Crude Protein [%]	43.6 (42)	59	62	50	54.4	53.3
Crude Fat [%]	33.1 (35)	11	10	8	3.7	-
Moisture [%]	8.4 (-)	4,1	10	10	12	-
Ash [%]	15.5 (-)	-	8	-	7.4	-

As can be seen, BSF prepupae contain less protein but much more fat than soybean meal. Therefore, a direct substitution is not possible, as the high fat content would have adverse effects on pig and poultry health (Zollitsch, 2014, personal communication). Enterra and Agriprotein degrease the prepupae, resulting in fat contents lower than 10 %, which is less than in soybean meal. As a consequence of degreasing, the share of the protein rises: MagMeal contains 50 % of crude protein and Enterra Meal even 62 %. In this thesis, it is assumed that the produced BSF larvae meal has a protein content of 60 %. This is 6.7 % higher than the protein content of soybean cake which should be replaced. Furthermore, the amino acid profile has to be taken into consideration. If the amino acid profile is not balanced, artificial amino acids need to be added to the feed. Hence, the cost of poultry or pig feed would be higher, depending on the price of the artificial amino acids. Generally, the amino acid profile varies depending on the substrate the larvae have been reared on. Comparing the findings of different feeding experiments, Maurer et al. (2015) state that “the nutritional value of insect meal is unquestioned”. Thus, it can be assumed that no artificial amino acids are required. The higher protein content of BSF larvae meal, however, leads to higher sales prices: It is assumed that BSF larvae meal can be sold for the price of soybean meal (€ 308.96) + 7 % due to the higher protein degree. In scenario P1 therefore, the price of BSF larvae meal is 330 €.

In scenario P2, it is assumed that the price of soybean meal increases sharply due to several reasons: First, meat consumption is increasing globally, especially in India and China people are switching to a diet containing more meat than in the past. In order to satisfy this demand, more protein feed, mainly soybeans, is needed. However, the demand of soybean meal cannot be covered by additional production and, consequently, prices will rise. Second, plants get increasingly resistant to many herbicides and pesticides and as no new plant protection products have been approved yet due to stricter approval procedures (the precautionary principle is state of the art worldwide), the yields of soybeans decrease, especially in countries of South America and the USA. Third, the extension of the area devoted to the cultivation of soybeans in countries like Brazil, Argentina and Indonesia has stopped as a consequence of finally successful certification schemes. The clearance of rainforests and other areas with high environmental value for the purpose of soybean cultivation is strictly prohibited. Consequently, the areas devoted to the cultivation of soybeans approximately remain unchanged on a world wide scale. In scenario P2, the price of soybean meal is nearly twice as high as the 5-year price:

550 €/t. Therefore, the BSF larvae meal can be sold for 550 €/t too, as no cheaper alternative is on the market.

In scenario P3, it is assumed that around 70 % of the end consumers in Austria prefer – due to a trend of more sustainability – the meat of animals that have been grown with feed based on the BSF larvae meal instead of soybean meal. Meat products that are labelled "Soy free" can be sold at higher prices. As the costs of pig and poultry feed are not the most important factor determining the price of the end product (meat and meat products), the BSF larvae meal can be sold for 700 €/t in P3.

3.5. Soybeans in Austria

In order to be able to answer the final research question on how much soybean meal can be substituted by BSF larvae meal, it is necessary to know which amount of soybean meal is currently produced as well as used for feeding purposes in Austria.

3.5.1. Production of soybeans in Austria

Records of the soybean cultivation in Austria started in 1990. Before 1990 field and soybeans were recorded collectively. As can be seen in figure 12, the production increased sharply in the first years of the separate recordings. In 1993, production was more than six times higher compared to 1990. From 1995 until 2008, production volumes approximately stayed the same. Since 2009, production volumes have increased again. Austria produced 118,132 t of soybeans in 2015 and 43,832 ha were cultivated. The full cultivation potential in Austria is estimated to around 70,000 ha. Austria is the fourth-biggest producer of soybeans in the EU. Concerning the share of the acreage a country devotes for the cultivation of soybeans, Austria is even ranked first (Statistik Austria, 2016a, Statistik Austria, 2016b) (Pistrich et al., 2014).

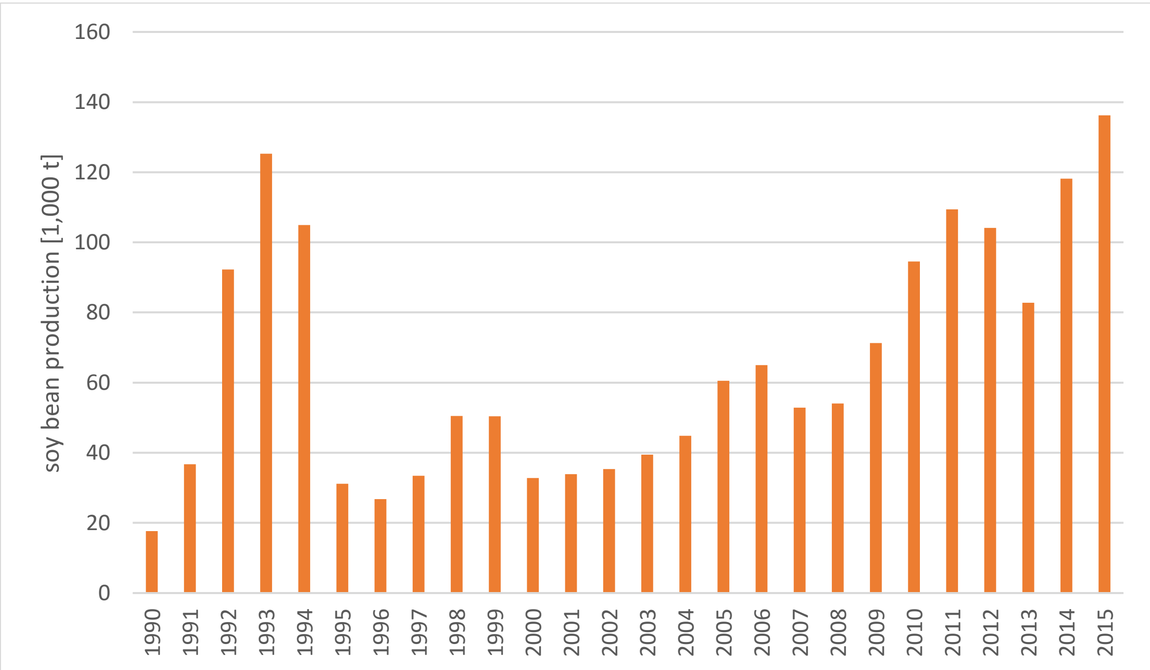

Figure 12 Soybean production in Austria (1990-2015) [1,000 t] (Source: Statistik Austria (2016b))

Soybean production is concentrated on three provinces: Burgenland, Lower Austria and Upper Austria. Figure 13 gives an overview of the production volumes of the provinces of Austria:

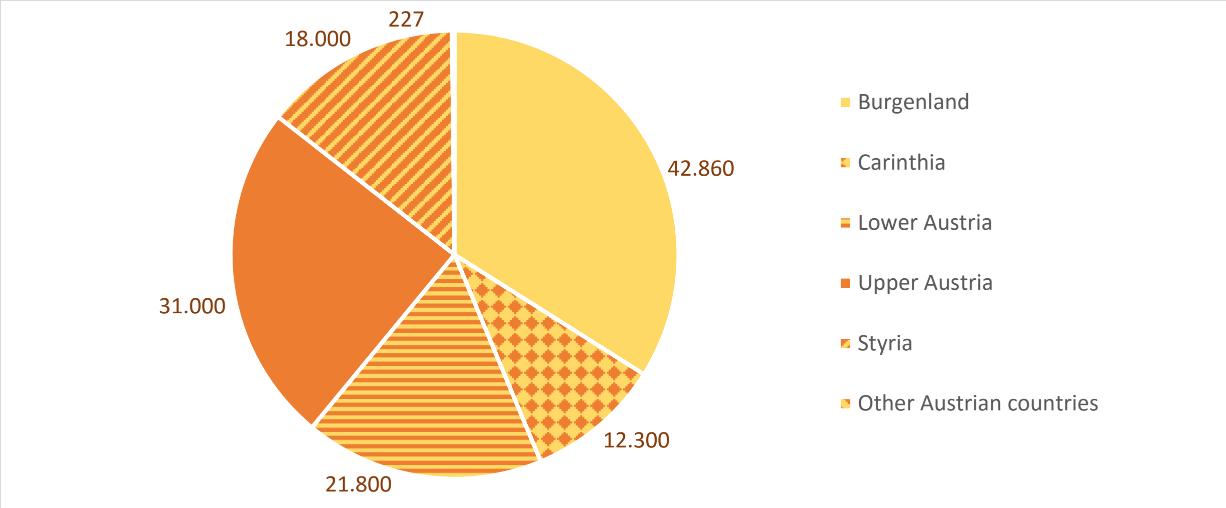

Figure 13 Soybean harvest of the federal provinces of Austria [t] (Source: Statistik Austria (2016b))

In total, 136,195 t of soybeans were harvested in Austria in 2015, thereof 31,000 t in Upper Austria (35,018 t in 2014; 31.002 t in 2013). 136,200 ha were under cultivation in Austria (14,000 ha in Upper Austria). The different yields in the different provinces are noticeable: In Lower and Upper Austria yields are significantly lower (~ 22 t/ha) than in Carinthia (31 t/ha), Salzburg (36 t/ha) or Styria (36 t/ha).

3.5.2. Soybean use and imports in Austria

According to data of the Austrian Institute of Economic Research, 429,622 t of soybean cake and 75,926 t of whole soybeans were fed to livestock in 2009/2010 (WIFO, 2013). Using a conversion factor of 0.787 according to Pistrich (2014), this amount corresponds to 622,000 t soybean equivalents. As can be seen in figure 14, the amount of soybeans used for livestock feed has been increasing slightly in Austria since 1988:

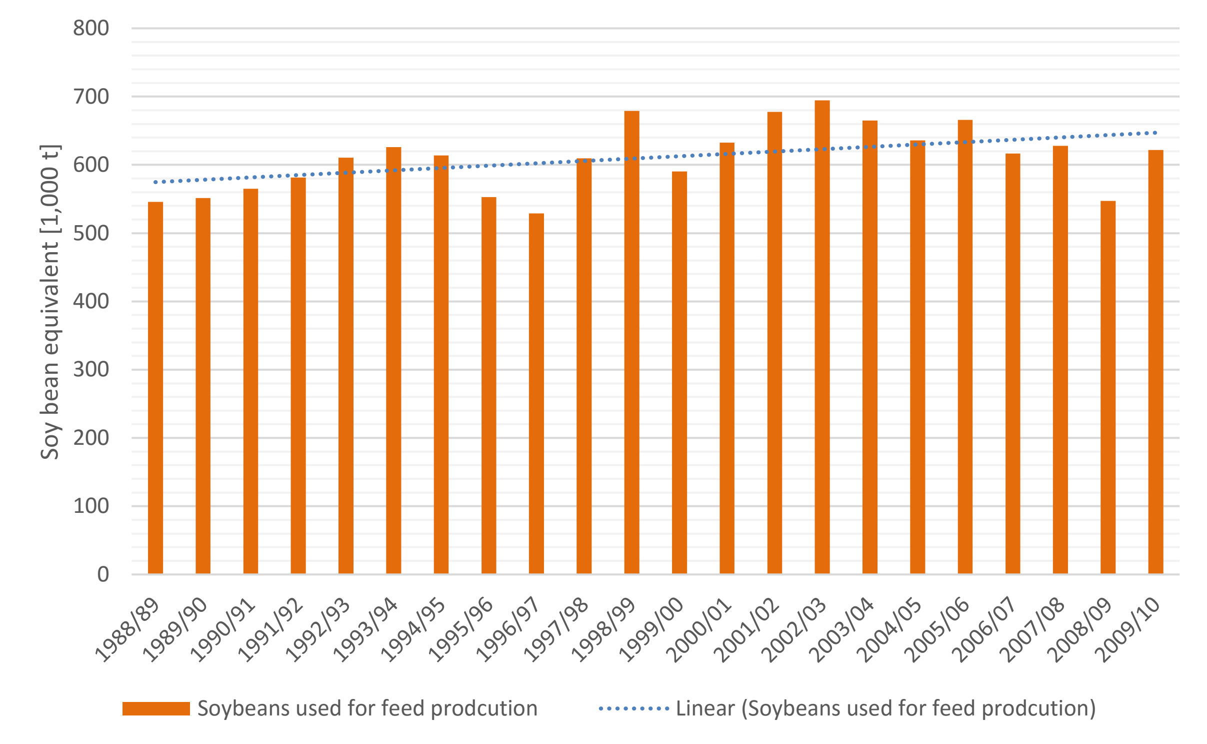

Figure 14 Soybeans fed to livestock in Austria from 1988-2009 [1,000 t soybean equivalent] (Source: WIFO (2013))

The majority of the soybeans are fed to pigs (48 %), 28 % of the soybeans are fed to cattle, thereof 9 % to dairy cows. Roughly one quarter (23 %) is fed to poultry. The remainder is fed to goats, sheep or other animals.

In addition, a considerable amount of soybeans is needed for the production of food and beverages. Approximately 35,000 t were used by the Austrian food industry in 2008. However, this demand is increasing considerably due to changing diets or lactose intolerance in recent times. Food based on soybeans is regarded as very healthy by the public. New, unconventional food is on trend. In 2009 the potential for soybeans needed for food was estimated to be around 45,000 t per year. Nearly all of the soybean needed for food and beverages is covered by the Austrian soybean production in 2009. Hence, more than half of the annual soybean production is used for food and beverages. Unfortunately, there are no current figures available. Only a small part of the Austrian soybeans is used for livestock feed (Pistrich 2014). Table 20 shows the import export balance of soybeans in t DM and in t crude protein for Austria.

Table 20 Import and export balance of soybeans and soybean products in Austria (2012) in DM and crude protein [t] (Source: Own calculations based on WIFO (2013) and Pistrich (2014))

	whole soybeans	soybean meal	soybean cake	soybean cake in soybean equivalents	Total
Crude Protein Content [%]	39.8	54.4	53.3	-	
Imports [t] DM	100,952	739	431,308	548,041	649,731
Exports [t] DM	69,355	16,412	47,697	60,606	146,373
Total [t] DM	**31,597**	**-15,673**	**383,611**	**487,435**	**503,358**

Total [t] crude protein	12,576	-8,526	204,465	-	208,514

649,000 t of soybeans (in equivalents) were imported in 2012. 146,000 t were exported, resulting in an import-export balance of -503,000 t. About 84 % of the imports is soybean cake. Assuming a crude protein content of 39.8 % for soybeans, 54.4 % for soybean meal and 53.3 % for soybean cake, in total 209.000 t of crude protein needed to be imported in 2012 (WIFO, 2013; Pistrich et al., 2014).

3.6. Substrates for BSF larvae rearing

3.6.1. Overview of suitable substrates

According to Makkar et al. (2014) BSF feed on a wide range of decaying organic materials, such as rotting fruits and vegetables, fish offal and particularly animal manure and human excreta. Thus, a list of all possible organic material that is available in Austria has been made, with the limitation that only those regarded as waste are of interest for this thesis. Organic material like wheat or maize are regarded as too valuable to use as a substrate for rearing insects. The Input-Output-Diagram is now extended with all substrates that are assumed to be suitable for BSF rearing in Austria (figure 15):

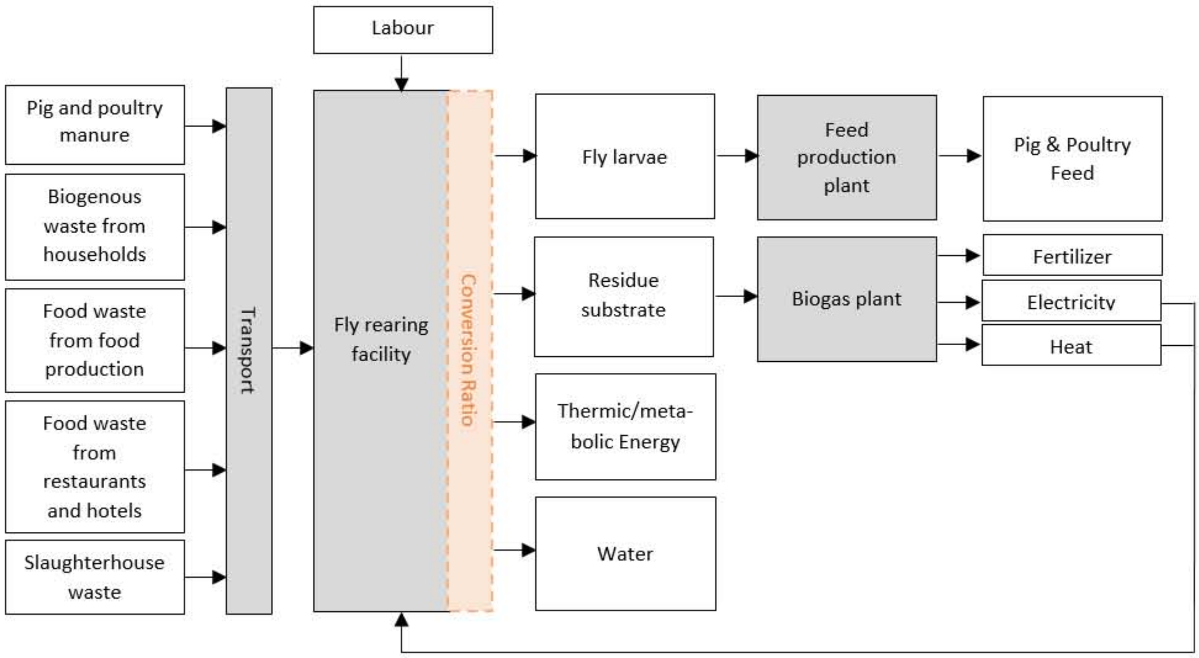

Figure 15 Extended Input- Output- Diagram (Source: Own diagram)

However, one limitation of this master thesis is that despite this variety of possibilities the focus is on biogenous waste. Thus further calculations are based on the volumes of biogenous waste only and do take into consideration the volumes of slaughterhouse waste and pig/poultry manure. Further research is needed to analyse the full potential for Austria.

3.6.2. Biogenous waste volumes

The Federal Ministry for Agriculture and Forestry, Environment and Water publishes an annual status report on the Austrian waste management (BMLFUW, 2015). The report contains data concerning the volumes of all waste categories. According to this report, a total amount of 933,100 t of biogenous waste was generated by the Austrian households in 2014, whereof 524,000 t of biogenous kitchen waste was collected via the biogenous waste collection system and 409,100 t of green cuttings were brought to composting sites by the households themselves. Table 21 shows the amount of biogenous waste that was collected in every single province of Austria.

Table 21 Amount of biogenous waste in the provinces of Austria in 2014 [t] (Source: BMLFUW (2015))

Provinces	Biogenous kitchen waste [t]	Green cuttings [t]	Total [t]	kg/inhabitant
Burgenland	14,400	14,000	28,400	99
Carinthia	11,900	16,500	28,400	51
Lower Austria	161,100	105,200	266,300	163
Upper Austria	71,400	143,200	214,600	150
Salzburg	34,600	19,300	53,900	100
Styria	68,400	43,800	112,200	92
Tyrol	49,700	45,100	94,800	131
Vorarlberg	15,000	10,100	25,100	67
Vienna	97,500	11,900	109,400	61
Austria Total	**524,000**	**409,100**	**933,100**	**109**

Furthermore, the high amount of biogenous waste that is collected in Lower Austria (163 kg/inhabitant) and also in Upper Austria is strongly noticeable. In contrast, it seems as if biogenous waste collection has not been established successfully in Carinthia (51 kg/inhabitant), Vorarlberg (67 kg/inhabitant) or Vienna (61 kg/inhabitant) yet.

Another source of biogenous waste are green cuttings from green area, for example from municipal gardens and parks, from cemeteries and green borders from streets or railways. They are most commonly brought to composting facilities, where they are processed into compost. However, a large part is not collected but rots directly at the place where it was cut.

Another large source of biogenous waste is kitchen waste from catering and hotels. The Status Report of the ministry divided this particular waste category in two subcategories: Those that contain animal products and those that do not contain animal products. In total, 270,500 t of biogenous waste were collected in Austrian kitchens in 2014. The exact distribution can be seen in table 22.

Table 22 Categories of kitchen waste [t/a] (Source: BMLFUW (2015))

Category	Amount [t/a]
Kitchen waste without animal products	104,700
Kitchen waste with animal products	145,200
Fat and Oils	20,600
Total	**270,500**

The kitchen waste has to be treated in special aerob or anarob facilities (composting as well as biogas). It has to be mentioned that the composition of the biogenous waste from kitchens without animal products is depended on the collection system, the consumption behavior, the geographical location of generation and the time of the year. Therefore, compositions can hardly be compared. A considerable amount of 337,700 t biogenous waste is created by Austrian dairies in 2014. Finally, the category of food industry residues remains. Table 23 gives an overview about available waste categories and amounts for BSF rearing:

Table 23 Biogenous wastes from the food industry assumed to be suitable for BSF rearing [t/a] (Source: BMLFWU (2015))

Waste category	Amount [t/a]
Food that was stored too long	65,200
husks	196,000
residues from condiments production	1,100
dough	21,000
Residues from tinned and frozen food production (fruits, vegetables and mushrooms)	2,100
Luxury food that was stored too long	19,000
residues and waste from juice production	34,300
Total	**338,700**

It has to be mentioned that the status report names much more residues from the food industry (in total 1,257,000 t) but not all are of importance for this thesis. Pomace, slop and marc from beer or wine production, molasses, residues from sugar beet processing as well as residues from oil seeds, maize and potatoes starch production have been excluded, as they are already directly used as a feed ingredient for livestock feed. Thus, taking those volumes away from feed production and use them as a substrate for BSF rearing instead is not advisable. Furthermore, it is questionable whether husks are suitable for BSF rearing. It has not been possible to find any scientific research paper focusing on this question yet. Thus for the moment, husks are not assumed to be a suitable substrate for BSF rearing and, therefore, excluded. Concluding, 142,700 t of waste from the food processing industry are assumed to be available and suitable for BSF rearing.

Figure 16 gives an overview about all mentioned biogenous waste categories and shows their distribution in Austria. It can be seen, that the food industry has the highest share with 39 %, followed by households (29 %), green cuttings from municipal areas (14 %), dairy wastes *(=Molkereiabfälle)* (10 %) and kitchen waste (8 %). It has to be mentioned that the volumes of biogenous waste composted by the households at their own home compositing facilities are not included.

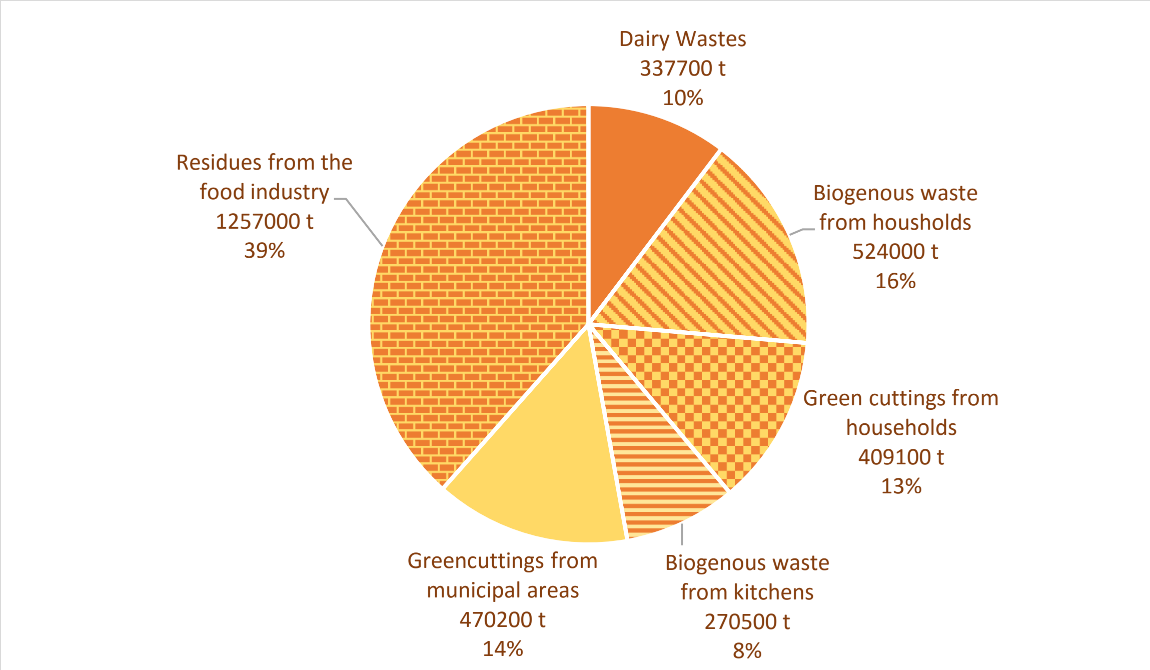

Figure 16 Volumes of biogenous waste in Austria [t] (Source: BMLFUW (2015))

Total biogenous waste from households and kitchens as well as parts of the residues from the food industry (142,700 t from 1,257,000 t, i.e. 11.4 %) are supposed to be most suitable for rearing BSF. A total of 937,200 t of biogenous waste can thus be used for BSF production in Austria.

4. Results

The aim of this chapter is to show what conditions need to be fulfilled in order to guarantee a profitable BSF larvae meal production. As 432 different combinations of scenarios were created, it is not useful to present all results in this chapter individually. Thus, selected scenario combinations will be presented showing the effects of the different variables. Chapter 5.1. for instance shows the effects of different assumptions regarding the inner production costs of a facility. In that case the other variables remain unchanged (e.g. transport costs and sales price), but the production costs vary. That approach permits to show all main results by using a selection of scenario combinations only while maintaining significance and clarity of results.

4.1. Effects of inner production process variables

At first the difference between the realistic, optimistic and pessimistic scenarios concerning the inner production process variables (labour, maintenance, energy and investment costs) will be shown. The operating results have been calculated according to the PCM, a methodology which is explained in the chapter methods.

In table 24 the operating results of a BSF facility are shown, dependent on different assumptions concerning the inner process variables (either realistic, optimistic, or pessimistic). The calculations are based on

- → an average waste treatment capacity of 40,000 t;
- → a low conversion ratio of 0.05;
- → a realistic sales price of 330 € (P1);
- → and low transport costs of 45 € per km and t (T1.1).

Table 24 Operating results per year of production [€] - comparison of different inner process variables scenarios; calculations are based on a pessimistic conversion ratio of 0.05, a sales price of 330 € (P1), transport costs of 45 € per t and km and an average waste treatment capacity of 40,000 (Source: Own Calculations)

	Scenarios		
	realistic	optimistic	pessimistic
Expenses [€]	3,058,549	2,815,148	3,368,361
Revenues [€]	2,796,640	2,796,640	2,796,640
Operating result [€]	**-261,909**	**-18,508**	**-571,721**

As can be seen in table 24 none of the three scenarios shows a positive outcome. However, the differences are significant. The operating result in the optimistic scenario is 553,000 € higher than in the pessimistic one. This is mainly caused by lower labour costs, as can be seen in figure 17:

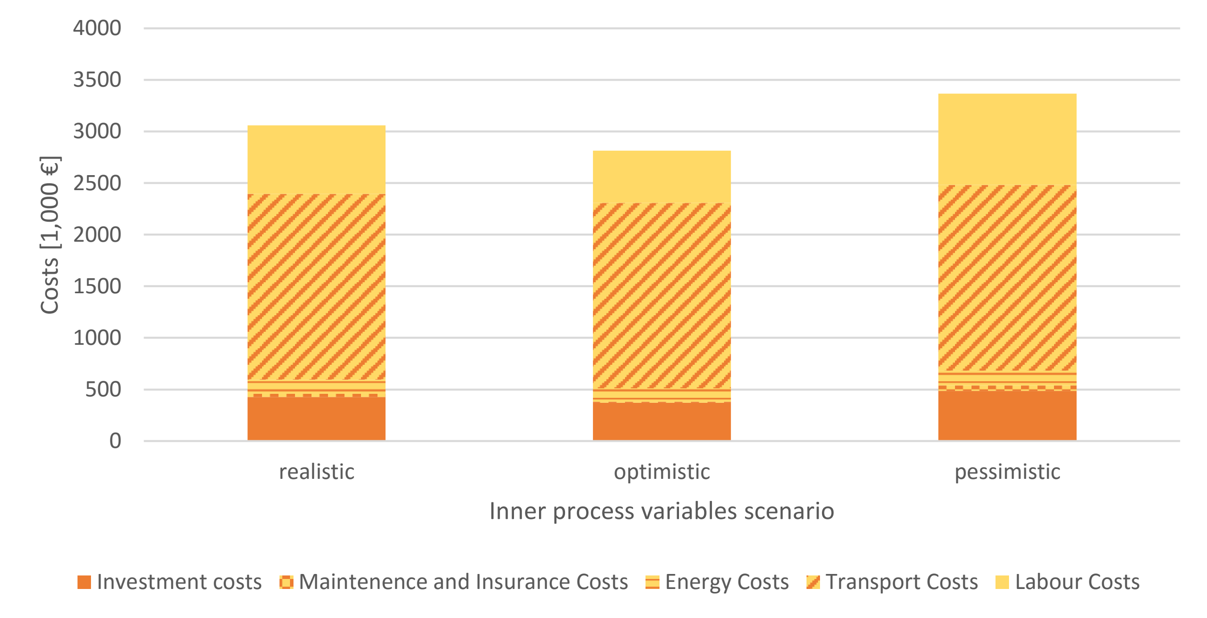

Figure 17 Comparison of costs per year of production [1,000 €] – effects of different estimates concerning the inner process variables; calculations are based on a pessimistic conversion ratio of 0.05, a sales price of 330 € (P1), transport costs of 45 € per t and km and an average waste treatment capacity of 40,000 (Source: Own Figure)

Most astonishing is the fact that under the given assumptions, transport costs for biogenous waste have the highest share on the total costs (58.9 % in the realistic, 63.9 % in the optimistic and 53.4 % in the pessimistic scenario). Energy and maintenance costs only play a minor role. Their share on the total costs is only 4.9 % in the optimistic scenario (5.4 % in the realistic, 5.9 % in the pessimistic scenario). Thus, also changes in the height of the energy and maintenance costs have an insignificant impact on the total costs. The share of the labour costs on the total costs is higher (17.8 % in the optimistic, 21.7 % in the realistic and 26.3 % in the pessimistic scenario) and, therefore, also changes in labour costs have a higher impact of the total costs.

4.2. Scale effects for different facility sizes

This chapter presents the effects of the facility size. Four different sizes were assumed: 20,000 t, 40,000 t, 80,000 t and 160,000 t. Table 25 shows the operating results for

→ the realistic scenario for labour, investment and maintenance costs;
→ a pessimistic conversion ratio of 0.05;
→ a sales price of 330 € (P1);
→ and transport costs of 45 € per t and km.

Table 25 Operating results per year of production [€] - scale effects for different facility sizes assuming a realistic inner process production scenario, a conversion ratio of 0.05, a BSF larvae meal sales price of 330 € per year (P1) and transport costs of 45 € per km and tonne (T1.1) (Source: Own table)

	Scenarios on facility size [t/a]			
	20,000	40,000	80,000	160,000
Expenses [€]	1,801,144	3,058,549	5,368,983	9,770,191
Income [€]	1,398,320	2,796,640	5,593,280	11,186,560
Operating result – realistic scenario [€]	**-402,824**	**-261,909**	**224,297**	**1,416,369**

It can be seen that a facility in the size of Enterra or Agriprotein is not profitable under the assumed circumstances. Due to significant economies of scale, only facilities with production capacities two or four times higher turn profitable. Figure 18 shows the share of the investment, maintenance, insurance, energy, transport and labour costs on the total costs.

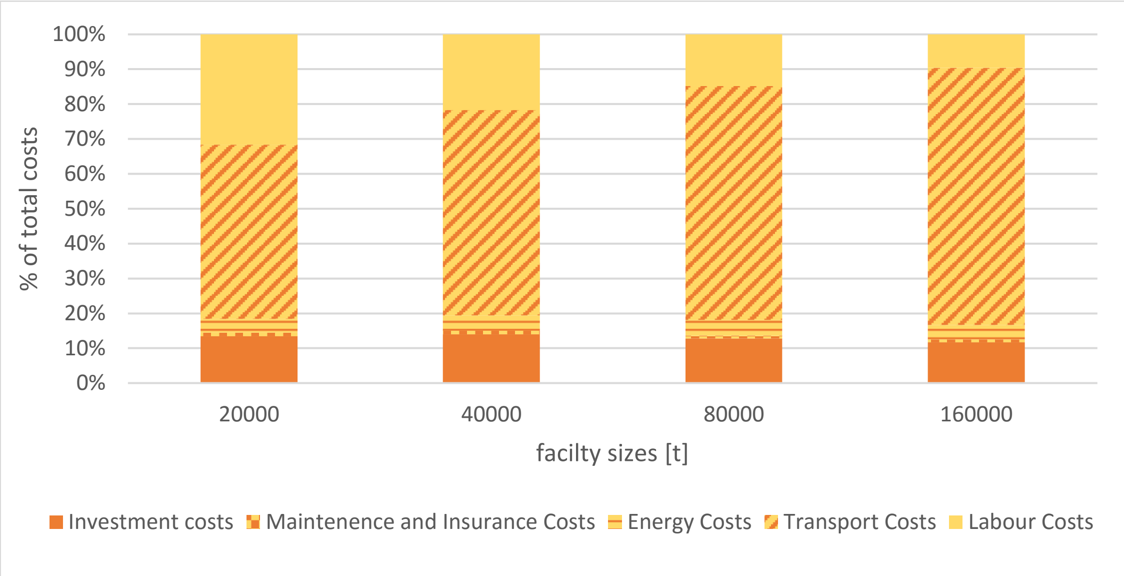

Figure 18 Comparison of costs per year of production [%] - scale effects for different facility sizes; calculations are based on a realistic inner process production scenario, a conversion ratio of 0.05, a BSF larvae meal sales price of 330 € per year (P1) and transport costs of 45 € per km and tonne (T1.1) (Source: Own diagram)

Again, the substrate transport costs have the highest share on the total costs. The share is growing with an increasing facility size. The highest scale benefits can be made regarding labour costs: The share of the labour costs decreases significantly from 31.6 % to 9.6 %. The share of the investment costs decreases only to a smaller extent: from 13.5 % to 11.7 %.

Concerning the revenues, it is most surprising that the BSF larvae meal revenues are not the most important source of income. BSF larvae meal revenues contribute with only 23.6 % to the total revenues. Under the given circumstances substrate revenues have a far more important role: They contribute with 71.5 % to the total revenues in all scenarios. The shares are the same for all facility capacities, as the relations of substrate use and BSF larvae meal production are the same.

4.3. Effects of conversion ratios

The calculation model of this thesis is built in a way that a change in the conversion ratio does have impacts on the revenues but not on the costs. If the biogenous waste treatment capacity of the facility stays the same, it is assumed that the costs also do not change. But with increasing conversion levels the revenues increase, as more of the substrate is converted to BSF larvae meal and BSF larvae meal can be sold at higher prices as the leftovers. As can be seen in table 26, the production costs stay the same, but the revenues are increasing. Calculations in table 26 are based on

→ a realistic scenario;

→ a biogenous waste treatment capacity of 40,000 t per year;

→ a BSF larvae meal sales price of 330 € (P1) and

→ transport cost of 45 € per km and t (T1.1).

Table 26 Operating results per year of production [€] – effects of different conversion ratios assuming a realistic inner process production scenario, a biogenous waste treatment capacity of 40,000 per year, a BSF larvae meal sales price of 330 € per year (P1) and transport costs of 45 € per km and tonne (T1.1) (Source: Own table)

	Conversion ratio scenarios		
	0.05	0.09	0.13
Expenses [€]	3,058,549	3,058,549	3,058,549
Income [€]	2,796,640	3,279,840	3,760,800
Operating result – realistic scenario [€]	-261,909	221,291	702,251

Figure 19 demonstrates that the share of BSF larvae meal revenues is increasing with rising conversion ratios. The share of substrate revenues decreases, even if it is the most important part of the revenues (with a 0.05 conversion ratio 71.5 %, with a 0.09 conversion ratio 61.0 % and with a 0.13 conversion ratio 53.2 %). The substrate revenues are constant at 2,000,000 €. The revenues from residuals have a minor part and only contribute with 1.2 % to the total revenues at a 0.13 conversion ratio (4.9 % at a conversion ratio of 0.05, 2.8 % at a 0.09 conversion ratio).

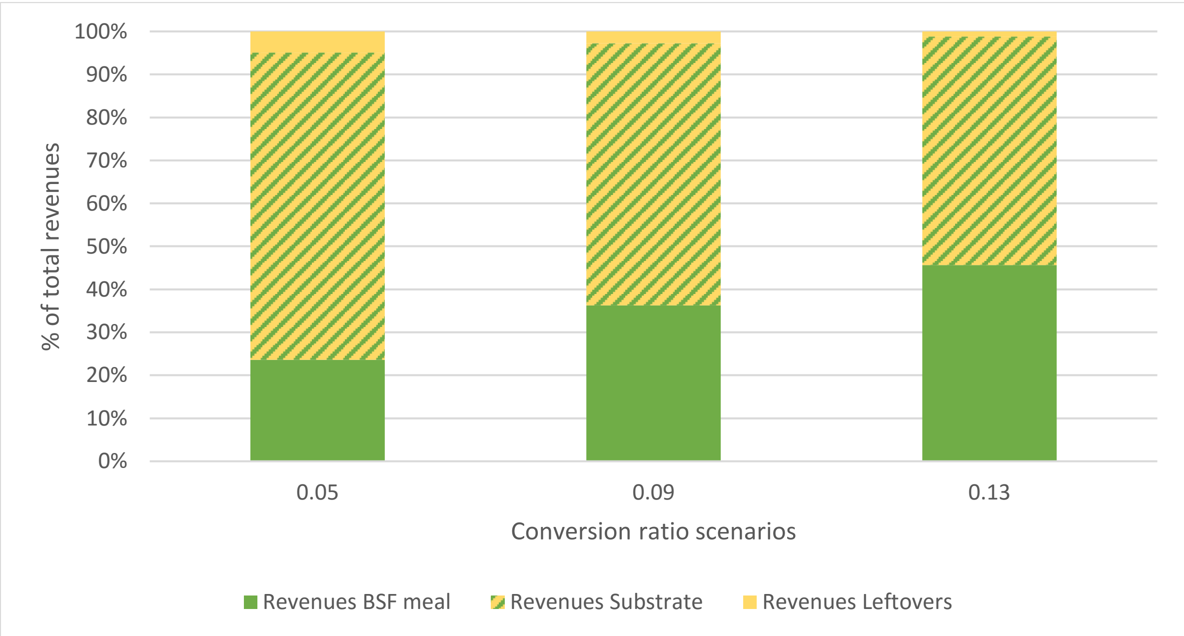

Figure 19 Comparison of annual revenues at a 0.05, 0.09 and 0.13 conversion ratio [%], assuming a realistic inner process production scenario, a biogenous waste treatment capacity of 40,000 per year, a BSF larvae meal sales price of 330 € per year (P1) and transport costs of 45 € per km and tonne (T1.1) (Source: Own diagram)

4.4. Effects of transport costs

Four different scenarios were created reflecting assumptions regarding transport costs. T1.1, T1.2 and T1.3 are based on revealed costs of the biogenous waste collection in Upper Austria and take into consideration different settlement structures, densely and sparsely populated areas and thus different transport distances. In T2 it is assumed that the fly rearing facility does not have to pay the transport costs, as they have to be paid by the generators of the waste - the households. Table 27 shows the operating results for all transport scenarios assuming

- realistic inner production variables scenario;
- a 0.5 conversion ratio;
- a biogenous waste treatment capacity of 40,000 t per year;
- and a BSF larvae meal sales price of 330 € (P1):

Table 27 Comparison of operating results per year of production [€] - effects of transport costs, assuming a realistic inner process variables scenario, a conversion ratio of 0.05, a BSF larvae meal sales price of 330 € per year (P1) and a biogenous waste treatment capacity of 40,000 t per year (Source: Own calculations)

	Transport cost scenarios			
	T1.1	**T1.2**	**T1.3**	**T2**
Transport costs per km and t [€]	45	65	87	0
Expenses [€]	3,058,549	3,858,549	4,738,549	1,258,549
Income [€]	2,796,640	2,796,640	2,796,640	2,796,640
Operating result [€]	-261,909	-1,061,909	-1,941,909	1,538,091

It can be seen that transport costs have a considerable impact on the profitability of a fly rearing facility. If the facility does not have to pay for transportation of the substrate, a considerable profit of 1.5 million € can be generated. But even with the cheapest way of biogenous waste collection (transport costs of 45 € per tonne and km), already a deficit of approximately 262.000 € per year was calculated. Figure 20 shows the significance of the transport costs compared to the other cost components.

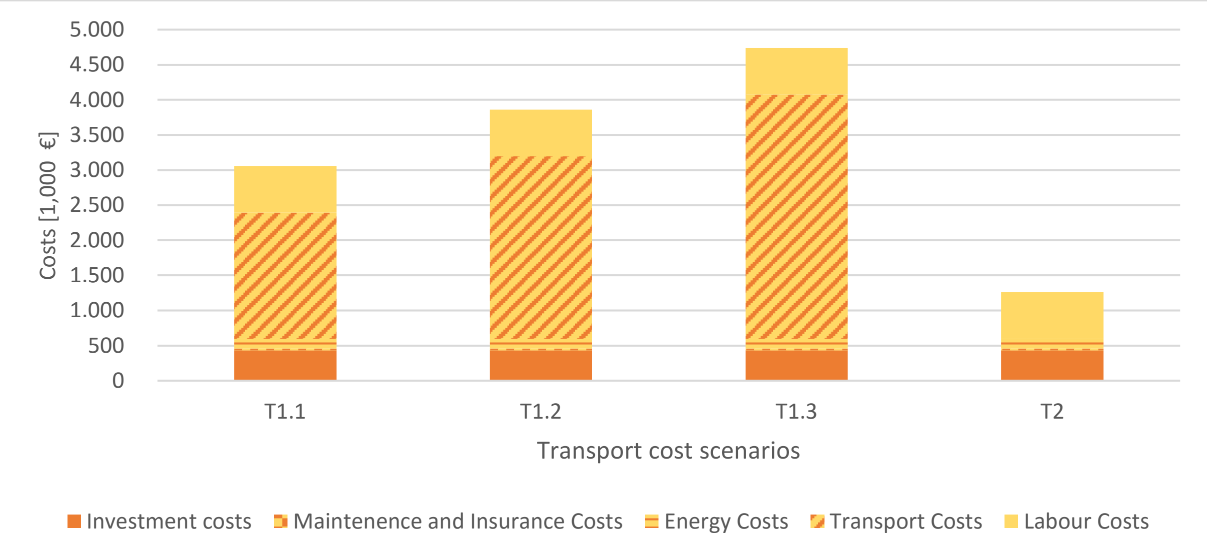

Figure 20 Comparison of costs per year of production [1,000 €] – effects of transport costs, assuming a realistic inner process variables scenario, a conversion ratio of 0.05, a BSF larvae meal sales price of 330 € per year (P1) and a biogenous waste treatment capacity of 40,000 t per year (Source: Own diagram)

In table 28 the share of the transport cost on the overall costs is shown for all transport cost scenarios and all facility sizes.

Table 28 Share of annual transport costs on annual overall costs in different transport cost scenarios [%], assuming a realistic inner process variables scenario, a conversion ratio of 0.05, a BSF larvae meal sales price of 330 € per year (P1) and a biogenous waste treatment capacity of 40,000 t per year (Source: Own calculations

Facility size	**Transport cost scenarios**			
	T1.1	**T1.2**	**T1.3**	**T2**
20,000 t	50.0	59.1	65.9	0
40,000 t	58.9	67.4	73.4	0
80,000 t	67.1	74.6	79.7	0
160,000 t	73.7	80.2	84.4	0

It can be seen that the share of transport costs is generally much higher in larger facilities, but it is increasing less rapidly with increasing facility sizes.

4.5. Effects of BSF larvae meal sales prices

Until now all calculations have been based on a sales price of 330 € (P1), which corresponds to the 5-year-mean of the soybean meal commodity market price (+ 6.7 % for the higher protein content). Table 29 shows the operating results also of the scenarios P2 and P3 assuming

- realistic inner production variables scenario;
- a 0.5 conversion ratio;
- a biogenous waste treatment capacity of 40,000 t per year;
- and transport costs of 45 € per km and t (T1.1):

Table 29 Operating result per year of production [€] - effects of different BSF sales prices, assuming a realistic inner production process variables scenario, a 0.5 conversion ratio, a biogenous waste treatment capacity of 40,000 t per year and transport costs of 45 € per tonne and km (T1.1) (Source: Own calculations)

	BSF sales price scenarios		
	P1	**P2**	**P3**
Sales price BSF larvae meal [€]	330	550	700
Expenses [€]	3,058,549	3,058,549	3,058,549
Income [€]	2,796,640	3,136,640	3,536,640
Operating result [€]	**-261,909**	**78,091**	**478,091**

It does not come as a surprise that the operating result turns positive. Naturally, the impact of a higher sales prices is even more distinct with higher BSF larvae meal production volumes (=better conversion ratios). However, as can be seen in figure 21, revenues from substrate sales stay the most important source of revenues.

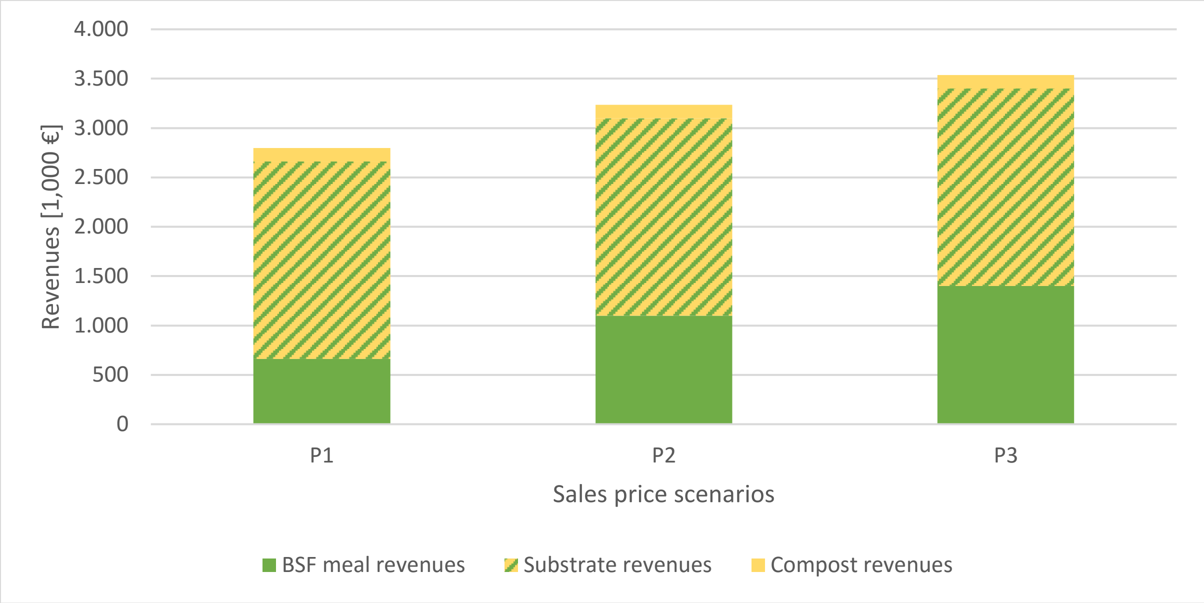

Figure 21 Comparison of annual revenues [1,000 €] - effects of different BSF sales prices, assuming a realistic inner production process variables scenario, a 0.5 conversion ratio, a biogenous waste treatment capacity of 40,000 t per year and transport costs of 45 € per tonne and km (T1.1) (Source: Own diagram)

In P3 substrate revenues still contribute with 56.6 % to the total revenues (P1: 71.5 %, P2: 61.8 %), whereas the BSF larvae meal revenues only add 39.6 % (P1: 23.6 %, P2: 34.0 %).

4.6. Theoretical potential of soybean meal substitution in Austria

In order to calculate the protein amount that can be substituted, it is necessary to know how many tonnes of BSF larvae can be produced in Austria. As has been stated in the chapter biogenous waste volumes, 937,200 t of biogenous waste are suitable for BSF production and available in Austria. Assuming a conversion ratio of 0.09, **84,350 t of BSF larvae meal DM can be produced annually based on biogenous waste streams in Austria.** Assuming a crude protein content of 60 %, **50,610 t of crude protein can be generated, which equals 24 % of the imported soybean protein in 2012.**

5. Discussion

BSF larvae meal is not used as an ingredient in pig or poultry feed in Austria (yet) (Emathinger, 2014, personal communication). As a consequence of missing legal frameworks at European level, companies that are investing in insect production are rare: In Europa there are only Protix in the Netherlands, Hermetia Baruth in Germany and Ynsect in France. Enterra (Canada) and AgriProtein (South Africa) are leading producers on a global scale. However, many research organisations and universities are active in the field of insect rearing. Their analysis focus on the suitability of different substrates, insect rearing methods, insect meal production methods and potential risks of insect meal as a feed ingredient. The Austrian company eutema has been involved in the European research project PROteINSECT, and a couple of Austrian students are writing their final thesis on the issue (Praxmarer, 2015).

The main focus of this thesis is to explore the conditions of a profitable production of BSF larvae in Austria. The big uncertainties have been a major challenge. As there are only few companies in the field of BSF larvae production, there are many uncertainties concerning the production process and the technology and, consequently, concerning the investment, personal, maintenance and energy costs. Therefore, various assumptions had to be made. In order to cover the uncertainties, different scenarios have been defined. The critical parameters with the highest impact on profitability are the transport costs, the conversion ratio and the substrate as well as the BSF larvae meal revenues. Only a slight increase in transport costs has considerable negative impacts on the profitability of the facility. Labour and investment costs are important too but changing them did not have the same impact as changes in the assumptions of the transport costs. An interesting fact is that the revenues of BSF larvae meal sales are not the most important source of income. Revenues derived out of substrate treatment have the highest share on the total revenues throughout all scenarios. In case of a conversion ratio of 0.05, 72.6 % of the revenues are revenues out of substrate treatment.

Diverse scenario combinations are presented in the chapter results – but which one is the most realistic? What are realistic assumptions for BSF rearing in Austria? Concerning the **conversion ratio**, 0.09 seems to be a realistic value, as it is already met by Agriprotein and Enterra. Even if Agriprotein is still struggling with the full scale production and even if Prof. Gutzeit from the TU Dresden/Germany stated that the biology of a large scale facility is very difficult to manage, large scale insect rearing will be subject to further investments in technological development and thus, 0.09 likely is feasible within the next years. Concerning the **transport costs,** it is more tedious to come to a decision. Four different scenarios were made, three of them describe costs based on existing collection prices in Upper Austria (T1.1, T1.2. and T1.3). One scenario is not including transport costs at all (T2), as it is assumed that the costs are borne by the generators of the waste and are not transferred to those treating or collecting the waste. The difficulty of the first three transport costs scenarios is the realistic estimation of the transport costs of each waste category for every district of Austria. Unfortunately, information on the exact location of the waste is not available in most cases. For biogenous waste from households, the data is available on district level only. Generally, it would be possible to estimate the biogenous waste levels on municipality level, based on data on district level and the population per municipality. However, data from the district waste associations have shown that collection does not happen in all municipalities. And even in those municipalities that offer biogenous waste collection, not every household is connected. In most cases collection only happens in areas that are densely populated (e.g. villages). Hence, it is incorrect to assume that rural districts like Ried or Perg have high costs, whereas densely populated districts have low costs. Such distortions have to be taken into consideration for estimations. Additionally, it has to be noticed that the transport distances to BSF rearing facilities will be longer as those to current composting or biogas facilities. Taking Upper Austria as an example, 152 composting facilities and 26 biogas facilities are treating biogenous waste from the collection system in 2016, which are spread all over the country. Thus, the waste usually stays within a district. It does not have to be transported over long distances and, in many cases, the waste is treated in a neighbouring municipality. Assuming a facility size of 40,000 t, only 5 facilities would be needed to treat all the biogenous waste of households and companies in Upper Austria. Practically, there would be one in each Upper Austrian quarter (Innviertel, Mühlviertel, Hausruckviertel and Traunviertel) and one in the central region (region between the cities Linz, Wels, Enns, Eferding and Steyr). Supposing a facility size of 20,000 t, ten facilities would be necessary. Ten facilities could be spread more than five, nevertheless, the transport distances would be much longer than with the current biogenous waste collection system. Thus, the current transport costs cannot be used without modifications. This is true for all other regions of Austria. In most cases, transport distances will even be longer than in Upper Austria (except Lower Austria), as all other provinces are collecting less biogenous waste per inhabitant. Concerning the biogenous waste from kitchens, the volumes are only known at country-level. Estimations at municipality level are therefore impossible. It is however questionable, whether the approach of T1.1-T1.3, i.e. the different estimates for transport cost, is realistic at all. Even if it could be managed to estimate the transport costs for biogenous waste from households as well as for kitchens and the food industry, it is assumed that T2, i.e. the assumption that the transport cost stay with the households, is the more realistic scenario. It seems to be very unlikely that people do not have to pay for the collection and the treatment of the waste they produce any more. Thus, it is also realistic that fly rearing facilities will not have to pay for the transportation of the substrate to their facility.

However, a more conservative approach has been chosen concerning the **sales prices of BSF larvae meal**. Currently, it seems unlikely that BSF larvae meal can be sold for much more than the price of Austrian, GMO-free soybean meal. Therefore a price of 330 € seems to be realistic.

Based on these assumptions, already the smallest facility scale is highly profitable: A 20,000 t facility has an operating result of 761,000 €. The profits increase with the size of the facility: 2,021,000 € with a 40,000 t facility, 4,791,000 € with a 80,000 t facility and 10,549,000 € with a 160,000 t facility. According to these results, BSF rearing seems to be a lucrative business. A comparison with literature values cannot be made, as similar analyses on the potential of BSF larvae as a feed ingredient for poultry and pigs are not known, neither for Austria nor for other countries. Veldkamp et al. (2012) analysed the feasibility of insects as a sustainable feed ingredient in pig and poultry diets and estimated that large scale rearing for insects will be feasible by 2017 in the Netherlands. However, the authors did not provide estimates regarding production costs or the amount of soybeans that could be substituted by insect meal.

Assuming that all biogenous waste that is collected from households, kitchens and companies is used for BSF rearing (937,200 t), nearly ¼ of the soybean imports could be substituted by BSF larvae meal. Furthermore, it is assumed that considerable amounts of BSF larvae could be produced from slaughterhouse waste, provided that appropriate methods for a safe production are available. Currently slaughterhouse waste treatment is concentrated on few locations in Austria. For example, in Upper Austria all slaughterhouse waste that is not directly sold to processing industries like the pet food industry or tanneries, is brought to Regau. A large potential also exists for manure: Currently, manure is used as a natural fertilizer in agriculture. Especially in regions with high stock densities, where manure production is too high to allow the spreading on local fields, alternatives need to be found. Despite lower conversion ratios compared to biogenous waste, rearing of BSF larvae on manure is possible and - according to Newton et al. (2005a) and Oonincx et al. (2015) - a valuable tool in both, manure reduction and protein generation. Thus, BSF larvae meal can additionally serve as a tool to reduce nitrate surpluses. In summary therefore, it can be assumed that the quantities of waste needed for BSF larvae meal production are available for Austria. However, one limitation of this thesis is that the profitably and the potential have been calculated for BSF larvae on biogenous waste only. Doing the same with all suitable substrates (slaughterhouse wastes and pig and poultry manure) would have been beyond the scope of this thesis. Thus, the last research question on substitutable soybean imports in Austria has only been answered partly. In order to get a comprehensive picture about the potential of BSF larvae meal in Austria, it is recommended to consider those substrates in further research projects.

Due to a lack of safety profiles, insect meal is currently forbidden as a component in the feed of human food producing animals in the European Union (EU). EU legislation is not drafted in a way to deal with insects or to support insect production. The main obstacle for using insect meal as livestock feed within the EU is that insects are currently classified as livestock in the EU legislation. Thus, for rearing, husbandry and slaughtering the same legal requirements apply. Furthermore, regulation EC 999/2001 (TSE regulation) forbids to feed processed animal protein to livestock, consequently forbidding the use of insect meal in food producing animals. However, due to the focus on the profitability of fly rearing facilities, no in-depth analysis of the legal situation in Europe has been made. The most essential frameworks have been named in the chapter 'Legal Constraints', more wide-ranging analyses can be found in Van Huis et al. (2013) and in EFSA Scientific Committee (2015). Moreover, this thesis does not deal with questions on ethics in insects rearing for feed production or on the well-being of insects, even though these issues are most critical. Do insects feel pain? What are painless methods of killing? What are natural stock densities, how many fly larvae should be allowed per square meter? Is it legitimate, to kill thousands of larvae for only one kg of protein? According to PROteINSECT (2016), 1 kg dry weight of housefly meal contains approximately 200,000 housefly larvae. Some of these questions are picked up by Erens et al. (2012), but generally, not much light has been shed on these issues yet. Research so far has focused more on production methods enabling large scale rearing and are more interested in the potential of insects as a feed ingredient.

Moreover, it sometimes might be unclear why certain values are only available for Upper Austria and not for Austria as a whole (e.g. transport costs for the collection of biogenous waste). This is due to the fact that as a consequence of new findings, the research goal, methodology, the scope and thus the needed data and information changed several times during the formation of this thesis. At the beginning it was planned to reveal the most suitable locations for insect rearing in Austria. The research question was: "How many fly rearing facilities can be built economically, what capacity should they have and where should they be built so that a maximum amount of insect protein can be produced?" It was intended to create a location optimization model. However, one of the main obstacles was that there is no information available on how much waste is generated by every single municipality. Moreover, it became clear that the question of the possible locations was not the most urgent one. In the present state it is not so important where exactly the fly rearing facilities can be built. A far more interesting proposition was to analyse the conditions that are necessary for a successful and economic operation of fly rearing facilities. This research process determined the choice of interview partners, the questions that have been asked, the sort of data that has been collected and the geographical scope of the thesis. Originally it was intended to analyse the potential of BSF larvae meal for the whole of Austria. The scope very quickly shifted to Upper Austria, as a location optimization model was aimed to be performed. As this methodology was replaced by a profitability analysis soon, the geographical scope changed back to Austria again. However, in all those cases the findings of Upper Austria are assumed to be true for Austria as a whole and therefore no further inquiries were made.

Due to the uncertainties in the variables and the time frame of one year, methods of static capital budgeting were chosen instead of dynamic capital budgeting. Even if the reason for taking static capital budgeting have been reasonable, its main weakness remains: Costs and revenues are estimated without reference to time. Thus, in the case of this thesis, the profitability of a fly rearing facility was analysed for an average year only. As the lifetime of a BSF rearing facility is expected to be at least 15 years with varying revenues and costs, a dynamic analysis of the profitably for the entire lifetime of the investment would have been interesting and eventually more meaningful. Nevertheless, taking the annuity as a proxy for the investment costs – as it has been done in this thesis – is assumed to be a good solution.

The different scenarios serve two functions simultaneously: They try to depict the reality by representing all imaginable possibilities of parameter values. But at the same time they are a sensitivity analysis, as they show which variables have high or low impacts on total costs and revenues. Taking energy need as an example: Three different scenarios were created, representing optimistic, pessimistic and realistic assumptions regarding the electricity and heat need of a BSF rearing facility. The scenarios showed that energy costs only have a small share on the overall costs, consequently also the scenarios only had an insignificant impact on the overall costs. On the opposite, the different scenarios of the transport costs had a high impact on the overall costs. Changing the parameters of the transport costs only slightly already lead to significantly different operating results. The scenarios are thus both, an illustration of the possibilities as well as a sensitivity analysis.

6. Conclusion

The aim of this master thesis was to analyse the potential of BSF larvae meal as a source of protein for pig and poultry. Therefore, at first investigations have been made about the state of the art of insect rearing and the substrates, technologies and methods used by successful fly rearing companies. Biogenous waste, manure and slaughter house wastes have been identified as suitable substrates for BSF rearing. However, one limitation of this study is that the potential for Austria was calculated based on biogenous waste only. The main finding of this thesis is that protein feed based on BSF larvae reared on biogenous waste streams have a high potential for reducing the volumes of soybean imports. Nearly ¼ of the imports could be substituted. But also the results of the profitability study are promising: Assuming that fly rearing companies do not have to pay for the transport of the biogenous waste, the majority of the scenario combinations showed positive operating results. Transport costs, conversion ratio and BSF larvae revenues have been identified as those variables influencing the operating result the most.

In combination with the mentioned environmental benefits, the waste reduction potential and the effect this new protein source could have on soybean imports, one might ask why BSF rearing is not more popular yet. There are a number of reasons: First, there are significant risks when waste streams enter the food chain. It has to be ensured that pathogens, heavy metals, etc. are not transferred to pig, poultry, fish or cattle. However, it was not able to proof yet, that BSF reared on waste do not pose any harm. But lacking such proof, the European Commission will not adapt its policies but continues prohibiting BSF as a feed ingredient. Second, the biology of BSF rearing does not work properly on a large scale yet. The new facility of the South African company Agriprotein for example is struggling heavily, current production is below 20 % of its intended capacity. Third, there is no financial pressure and consequently, there is no urgent need of finding an alternative to soybean meal in pig and poultry rearing. Soybean meal can still be imported at low prices and in huge quantities. Consequently pig and poultry meat can still be produced and sold at comparatively low prices. A completely different situation can be experienced at the fish market, as this industry is dependent on expensive fish meal. Thus, it is very likely that insect meal will first enter the fish feed market before it enters the market of livestock feed (Veldkamp et al., 2012), which is already true for Norway. Fourth, the knowledge on BSF larvae has not been available for everybody in the past. When interviews for this thesis on the topic of BSF rearing started in autumn 2014, the issue was relatively unknown for nearly everybody in Austria. Now, in summer 2016 almost all of the responsible people in ministries, the industry or in further involved organisations at least heard about BSF as a source of protein. In May 2016, the Ministry for health even organised a conference on the health aspects of insects as food or feed. Scepticism still remains though, as, for example, disgust plays an important role too. Fifth, even if appropriate EU legislation would be implemented and even if BSF rearing would not be a challenge technically anymore and full support from Austrian authorities would be available, it is questionable whether BSF rearing will start right away in Austria. Currently most of the biogenous waste is treated by composting facilities. These companies are dependent on the incomes of the compost treatment. According to a member of the Federal Ministry for Agriculture and Forestry, the Environment and Water Resources, it is unlikely that they will let this business go. In any case, compensation payments for forgone profits appear likely.

What is needed most urgently however is further research in production methods in order to guarantee hygiene and safety standards and to rule out hazards from contaminants in the larvae substrate. Only when all hazards are eliminated, European policy makers can consider BSF larvae as an European feed ingredient. As long as there is no approval, farmers cannot use it. Additionally, it would be helpful if there are more life cycle analysis, proofing the environmental benefits of BSF reared on waste substrates. So far, this potential environmental benefit of waste-fed insects is relatively unknown. Results about direct and indirect environmental impacts are always dependent on the actual situation, but first scientific analyses point in the direction that protein feed based on larvae that have been reared on manure and biogenous waste promises significant reductions in terms of water- and land use, greenhouse gas emissions and further environmental pollution compared to soybean production (Ooincx and de Boer, 2012; Van Zanten et al.,2015)).

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Annex

Annex 1

Questions Prof. Zollitsch

- What is your personal opinion, can the alternative source of protein BSF larvae meal be one of the solutions for guaranteeing food security? Or do you think other ways are more promising (e.g. more intense cultivation of grasslands)?
- What are the things we have to be careful when feeding BSF larvae meal? Especially if BSF larvae meal is fed to ruminants or herbivores? What is the difference between animal and vegetable protein?
- Here is the amino acid profile of BSF larvae meal. What do you think of it? What are advantages/disadvantages?
- In what cases artificial amino acids are used? Can the quality of artificial and natural amino acids be compared? How expensive are artificial amino acids?
- What are examples for rumen-protected proteins?
- One of the dangers of BSF larvae meal is the potential heavy metal pollution. How do poultry/pig absorb heavy metals, what are the concerned organs and what implications does that have?
- I need to find out more about the amino acid profile. What textbooks to animal nutrition can you recommend?
- I'd like to talk to some feed producers and ask them, if they could imagine to try BSF larvae meal in their feed formulars. Do you know which company or employee could be interested in innovation like that?

Questions Fixkraft

- Where does the soybean meal you are using come from? How much soybeans do you import/process every year?
- What type of soy exactly are you using (soybean cake, soybean meal,…)?
- Is the demand of GMO-free soybeans higher than the production volumes?
- What kind of soybeans do you import (whole soybeans/soybean cake/soybean meal)? What is the use of the different soybean products?
- Have you ever heard of insect meal as a source of protein?
- Here can you see the amino acid profile. What is your opinion – is it suitable for chicken and pig feed?
- Would you say it is possible to substitute all soybeans in the different formulations?
- Artificial amino acids: For what purposes are you using them? What is the price of them? Is the price stable?
- Unfortunately I couldn't find any concrete information in the internet. What is the exact composition of several chicken feeds? Do you use fish meal for chicken or poultry feed? How high is the soybean content?

- Currently no animal products are used for feeding (TSE-regulation). When do you think will that situation change again? And if that changes – do you think there is still a market for BSF larvae meal?

Questions Skretting

- Skretting is financing research in insect meal for fish feed. Why is that?
- The BSF larvae meal you used in your trials – did you buy it or did you have your own insect rearing facility?
- You have done feeding trials with salmon already in 2010. What are your results? Do you see a future market for insect meal in aquaculture?
- In the feeding trials you made you used several substrates as well as several different BSF larvae meal ratios. Which substrate and which ratios were best for fish growth?
- Generally, how do you estimate the potential of BSF larvae meal in fish feed? What are the barriers for the use as a fish feed?
- What maximum price can BSF larvae meal have so that you'd still use it as a component in your fish feed?

Questions Interview Steiner Johann

- What amount of manure do your hens produce per year and what do you do with the manure?
- Are you "selling" the manure to biogas facilities?
- Imagine you'd "sell" all your manure. What kind of fertilizers would you use on your fields instead?
- What chicken feed do you currently use? What is important for you?
- To whom do you sell your chickens and the eggs?
- To what degree do purchasers indicate, what kind of feed you are using? Are you deciding what you feed your hens – or are those decisions made by the purchasers of the eggs/chickens.
- Have you ever heard of fly larvae as a source of protein in chicken feed? What do you think of it? Would you use it?

Questions Dr. Franz Sinabell

- You worked in agriculture before you started your career in sciences. What is your personal opinion, can the alternative source of protein BSF larvae meal be one of the solutions for guaranteeing food security? Or do you think other ways are more promising (e.g. more intense cultivation of grasslands)?
- What I hope to receive from your balances is information on how much protein we are currently feeding animals in Austria and where the protein comes from. Do your balances include that information?
- With larvae a lot of acreage that is now dedicated to soybeans/rapeseed/etc. might be "won" back and used differently. But do you think that is promising? Currently rapeseed is predominantly used for oil production, the cake is actually the by product. Additionally, rapeseed and other oil seeds are used in crop rotation and cannot be excluded easily. Do you think fly larvae can change something in that situation?

- Currently no animal products are used for feeding (TSE-regulation). When do you think will that situation change again? And if that changes – do you think there is still a market for BSF larvae meal?

Questions DI Doppelreiter (AGES)

- Current legislation does not allow the use of animal protein as feed for livestock. Do you think that legal situation might change soon and reallow the use of animal protein? Are there debates about TSE legislation and its further usefulness? Who debates about it?
- Do you think the TSE legislation still makes sense?
- Could you imagine that fly larvae will ever be allowed as a feed ingredient? If not, why?
- What are the requirements for the allowance of BSF larvae meal as a feed ingredient?

Questions telephone survey biogas facilities

- I am calling you because you are operating a biogas facility in a municipality with a very high pig/poultry stock. Could you please tell me what you are using as a substrate?
- Are you using pig/poultry manure? If not, what are the reason for not using pig/poultry manure?
- Do you know how the farmers in your area are using the manure?

Questions E-Mail questionnaire BAV

- How is the collection of biogenous waste organised in your district? Do the municipalities organise the collection on their own or do they get assistance from the BAV?
- Who makes the contracts with the collection companies and composting/biogas facilites? The municipalities or the BAV?
- If the BAV is responsible for the whole collection, do the municipalities pay a lump sum or does every municipality pay the real price for collection and composting/biogas treatment?
- Do you have any information on how they pass the costs to the producers of the waste, the households?
- Would it be possible to receive some data concerning those issues? Especially interesting would be to know, how many garbage cans are emptied in your municipality, how many tons (weight) those are and how much their collection and composting/biogas treatment costs.

Questions to Paul Zarzer, federal province of Upper Austria

- Where do the numbers of your waste report originate (119.079 t biogenous waste in 2013)? Could I get access to this data base?
- What is your estimation, how strongly do restaurants and hotels obey the rule concerning the separate collection of kitchen wastes?
- Could you tell me the names of the companies that are authorized to carry out the collection of kitchen waste in Upper Austria?
- Biogenous waste from households: How is it treated in Upper Austria? Only in composting facilities or are there also some biogas facilities that treat biogenous waste?
- Where are biogas facilities located in Upper Austria and what are their capacities?

Questions Alexander Drexler

- Where does the compost that you are treating come from? How much material do you receive per week?
- Is it necessary to mix the biogenous waste with green cuttings in order to guarantee successful composting?
- Could you please explain the composing cycle? What composting ratio do you achieve?
- You're also operating a biogas facility. What is its capacity, how much material can you treat per week?
- Is your biogas facility working well? Or are there any problems due to the "pollution" of the biogenous waste by plastic materials?
- For how much can you sell your compost?
- How much do you receive for one tonne of biogenous waste? Who is paying you – the municipalities or the BAV? With whom are you having contracts?

Questions E-Mail questionnaire BSF larvae meal producing companies

- What is the scale of your production site, how many tons BSF larvae meal are you producing per year?
- How high were your investment costs?
- How many employees do you have?
- Do you have any publications on your production process that you could send me?
- I've read the description of the production process on your website. But could you please tell me in more detail, what plant technology and what machinery you are using?
- How are the larvae kept at your facility, at which stadium do you harvest the larvae and how do you separate them from the biogenous waste you are using as a substrate?
- How do you prepare the substrate?

Questions Dr. Bernhard Stürmer

- Where are biogas and composting facilities located in Austria?
- What are their capacities? What is their actual workload?
- What kind of biogenous waste are they treating? Do you know if anybody in Austria has that information (=exact location of facility, capacity of facility, kind of biogenous waste that is treated in facility)?

Questions Dr. Susanna Schragner

- What is the idea behind respectively the target aimed to reach with the collection of biogenous waste? What concept is used?
- Is the collection of biogenous waste obligatory in whole of Austria?
- Are there any EU guidelines?
- What are the reasons for biogenous waste collection, i.e. the positive effects?
- How is the collection carried out in the provinces of Austria? I've recognized big differences between the districts and municipalities.

- Biogas vs Compost: Which goal is pursued?
- Compost: Assuming that a large portion of the biongeous waste is treated in BSF rearing facilities in the future, what consequences are you expecting in/for the compost industry? Is it problematic if less compost in produced?
- Could you give me up-to-date data concerning biogenous waste collection in the provinces?
- Waste collection companies: Do they have to face controls? Are there guideline concerning the price of biogenous waste the municipalities have to pay to the compost/biogas facilities?
- During the creating of my thesis I've got the impression that this sector is largely unregulated. What is your opinion?

Annex 2

Companies specialized on fly rearing for feed and food

Agriprotein

Agriprotein is the most popular producer of insects for feed in the world. The company is based in South Africa and Gibraltar and is working on fly larvae producing processes suitable for large scale insect rearing since 2009 (AgriProtein technologies, 2014, South Africa Info, 2014). In April 2015 Agriprotein opened its first large scale fly rearing facility near the Airport of Cape Town. Investment costs for this facility were around 8 million USD. An Internal Rate of Return of 30 % is expected (Swart, 2015, personal communication). The planned capacity of the site is a production of 7 t of MagMeal (defatted BSF larvae meal), 3 t of MagOil (fat residues) and 20 t of MagSoil (feed residues of the insects) per day. However, the full capacity has not been reached yet due to start-up problems (Drew, 2015). According to Swart (2015, personal communication) more factories "to a number of locations around the world" are planned to be licensed in 2016.

Initially the company used human faeces and blood as a substrate. According to South Africa Info (2014) readily available organic waste material, including out-of-date and uneaten food, animal manure and abattoir waste are used recently.

Protix

Protix has been operating since 2009, headquarter and parts of its research is based in Dongen in the Netherlands. According to the information on their own website, their production facility in Dongen has been in use since the end of 2015. The facility is fully automated. Unfortunately, no further information concerning production costs and capacity is provided. Protix globally cooperates with various partners, in the following some projects and cooperations (Protix, 2015) (National Institute of Nutrition and Seafood Research, 2014):

- Together with Barentz Group they develop new product propositions. The insect based nutrients will be used for food production or in the pharma and cosmetics industry.
- In Germany, Protix investigates about the components of insects in order to better understand possible future fields of application together with *Deutsches Institut für Lebensmittel*.

- The Research Council of Norway has allocated NOK 13 million to the AquaFly project. Protix plays an important role in this project that aims on investigating the potential of using insects as safe and healthy ingredients of future fish feeds. The Norwegian National Institute of Nutrition and Seafood, Protix and many industrial companies are part of the project.
- In Eastern Europe, Protix is currently building an insect rearing facility capable of converting 100,000 t of waste input. Exact location and project partners are confidential.
- With partners in Chile, Protix has set up a first production site aiming at providing valuable feed for the aquaculture.

Proti-Farm

According to the company's website Proti-Farm is the "world's first fully automated high-tech lesser mealworm production facility to serve the food and pharmaceutical market". In contrary to all other large scale facilities Proti-Farm is not using BSF larvae but the lesser meal larvae for the production of their meal. The headquarter is based in Ermelo, Netherlands. Proti-Farm will start to deliver large quantities of insect products in 2016 and they plan to rapidly expand their facilities worldwide. End products are whole insects, protein powders (isolated, concentrated, hydrolysed) and (refined) lipids. Proti-Farm has its own research and development centre. Further information concerning their production capacity or production costs is not available (protifarm.com, 2016).

Enterra

Enterra's mission is "to secure the future of the world's food supply by solving two major global problems: food waste and nutrient shortage" (Enterra, 2015b). The company is based in Vancouver, Canada and transforming 100 t of organic waste in 5 t of meal, 2 t of oil and 8 t of fertilizer every day (Leung, 2015, personal communication). They are only accepting pre-consumer waste from farmers, grocery stores and food producers. The facility is using about 1 ha of land. Enterra invested about 7.5 Mio CAD in the construction of the facility (Leung, 2015, personal communication). In figure 22 the production process of Enterra's facility can be seen.

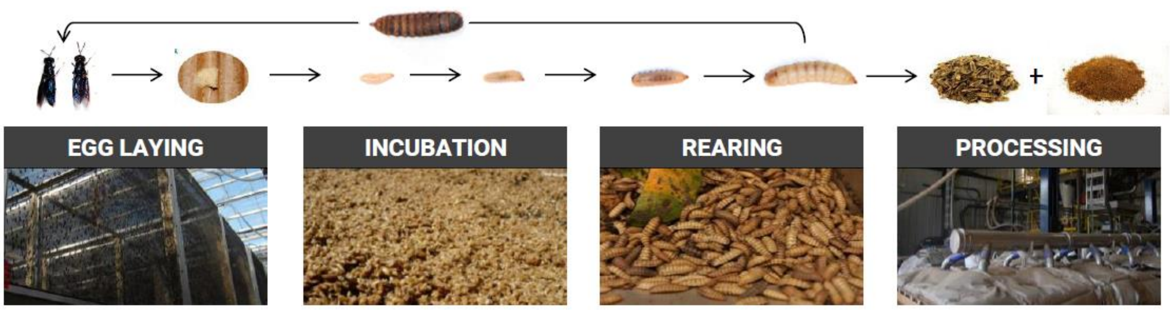

Figure 22: Enterra's process (Source: (Leung, 2015, personal communication))

Hermetia Baruth GmbH

Hermetia Baruth is based in Germany and produces insects for pet food. Every 12 days, 700 kg of fresh larvae can be harvested per bioreactor, resulting in a yearly production of 21 t per bioreactor. Hermetia Baruth is currently building a second production facility, as the company intends a capacity of 1,000 t in 2016. As long as there is a ban on waste products, they use rye flour and wheat bran as a substrate (Katz, 2015, personal communication).

EnviroFlight

According to the self-description on the website of EnviroFlight, this company started research on insects in 2009. In 2012 EnviroFlight started commercial large scale production. The property on which the facility is built has a size of 20,000 square feed (app. 1860 m²). EnviroFlight uses the co-product from breweries, ethanol production and pre-consumer food waste as a feedstock for BSF larvae (Enviroflight, 2014). Enviroflights chief developer Cheryl Preyer stated that Enviroflight is currently using “6 short tons” of pre-consumer waste each day for the production of BSF Larvae. As antiquated on the website EnviroFlight “takes advantage of 35 million t of food waste per year” (Enviroflight, 2014).

Entomeal S.A.

According to a press release on the Enterra Website, Enterra and Entomeal formed a Joint Venture in Switzerland. Entomeal S.A. does not have an own website, but according to Enterra, the new facility will have a capacity to treat 36,000 t of organic waste per year with expansion plans to 54,000 t per year in the second year of operation. Predominantly waste vegetables and fruits from local farming and food processing companies will be used. The insect meal that will be produced has been approved as a feed ingredient for aquaculture in Switzerland. The by-product oil can be used in aquaculture, poultry farming and animal feed preparations (Enterra, 2015a).

Ynsect

The French company Ynsect was created in 2011 and has its office in Evry. In 2014, the company developed a pilot insect biorefinery in Evry. In this pilot facility Ynsect uses insects to bioconvert organic substrates, such as cereal by-products. At the moment, Ynsect is searching for investors to be able to build a large scale insect biorefinery facility. Until the beginning of 2015, the company had already collected 5.5 million € (Ynsect, 2015).

Annex 3

Explanation of the biogenous waste collection system in Upper Austria

According to the BAV Braunau (2015, personal communication) municipalities in the Upper Austrian district of Braunau pay 3,00 € (excl. taxes) for the collection of a 120 l waste container. Both transportation and composting are included in this price. In the district of Braunau, the garbage removal companies collect the garbage in tours, with some of them comprising more than one municipality. Therefore, the municipalities in the district of Braunau have no information on how much biogenous garbage was collected in their own municipality. The collection companies are paid by the BAV based on the driving hours per tour (75 €/hours excl. taxes). The BAV Braunau shared some information on the actual transport costs of some municipalities: In tour 4 (municipalities Hochburg-Ach, Überackern, Schwand, Gilgenberg, Handenberg, St. Georgen, Pischelsdorf, Eggelsberg and Geretsberg), the average costs of the transport for one tonne of biogenous waste was 111 € in the year 2015. For the municipalities of four 6 (Mauerkirchen, Uttendorf, Moosdorf), the collection was significantly cheaper: 51 €/t. The average costs in tour 7 (Mattighofen, Pfaffstätt, Jeging, Schalchen, Auerbach) were 87 €. The BAV calculates the average costs for the whole district and passes these costs on to the municipalities. The price for composting is negotiated and, thus, varies in the district of Braunau (e.g. 53.20 €/t for the municipalities Hochburg and Gilgenberg). It lies within the responsibility of each single municipality whether they pass along the costs to the households connected to the biogenous waste collection system. For example in the municipality of Hochburg-Ach, owners of a biogenous waste container pay 1.65 € for every emptying. The rest of the costs (1.35 € per emptying) are shared among all households connected to the residual waste collection (Bezirksabfallverband Braunau, 2015, personal communication; Municipality Hochburg-Ach, 2016, personal communication).

In the district of Wels Land, the collection price is the same in every municipality (1.43 €/emptied containter excl. taxes) but the price for composting is different depending on the actual amount of biogenous waste collected per municipality. As can be seen in Annex 4, the filling level of the containers is very different in each of the municipalities. In some municipalities the containers are filled twice as much as in other municipalities. Consequently, some municipalities pay twice as much for composting as other municipalities do. The district of Wels used to have the same system as in the district of Braunau. However, the BAV found that it was very unfair and, therefore, started weighing the trucks after the collection in a municipality had been finished. Composting costs are the same all over the district: 50.70 €/t (Bezirksabfallverband Wels, 2015, personal communication).

In the district of Urfahr-Umgebung, the collection of the biogenous waste is managed by the municipalities on their own. The BAV Urfahr does not assist at all. Every municipality that is offering the collection of biogenous waste has its own contracts with composting or biogas facilities. In 8 municipalities, the biogenous waste is collected by the composting facilities themselves, whereas in 6 municipalities the waste is collected by a biogas facility and in one municipality the Linz AG is collecting the waste (Bezirksabfallverband Urfahr, 2016, personal communication).

The same organisation is used in the district of Kirchdorf. Each municipality in the district organises the collection of the biogenous waste on its own. The collection is performed by composting facilities, by biogas facilities as well as by professional waste collection companies (Energie AG) (Bezirksabfallverband Kirchdorf, 2016, personal communication).

A completely different collection system is applied by the district of Schärding. Instead of the usual 120 l containers 14 l bags are used for the collection of biogenous waste. The weekly collection is carried out by the composting companies via car trailers or platform trucks. The BAV Schärding has been organising the collection of the biogenous waste for all 30 municipalities of the district since 1997. The collection is done on a district level, so that’s why there is no data on collected waste/year on municipality level. Thus, also the price is the same for every municipality, as it is based on the average costs of the district. These costs are around 40 € per household per year (=0.77 €/emptying), based on the quantity, the distance driven and hours needed for the collection. According to the BAV Schärding the private collection shows distinct price advantages compared to the conventional truck collection system even if the costs of the bags are considered. In 2015, the BAV changed its way of organisation completely. The BAV is now responsible for the complete waste collection system of 27 out of 30 municipalities in the district, including waste collection of residual waste, all calculations, contracts and payments. Since 2015, all households only pay a single waste collection fee. This fee is divided into two parts: basic charge and quantity charge. The quantity charge depends on the quantity of the waste and the collection interval. The collection is now organised in a transparent and comprehensible manner (Bezirksabfallverband Schärding, 2016b, personal communication).

The system in the district of Freistadt works similar to the system in the district of Schärding. In the district of Freistadt every household in the densely populated areas has the opportunity to connect to the biogenous waste connection system. In the whole district of Freistadt no 120 l or 240 l containers are used but 23 l or 47 l buckets. They are collected every week, even in winter months. The collection is carried out by the composting facilities themselves. In most cases farmers collect the waste with tractors and trailers. Composting is done in 13 different composting facilities for the price of 40 €/t on average (=0.77 €/emptying). The advantage of this collection system mentioned above is the visual control that can be made by every singly bucket. Households which do not obey to the rules of separation can be traced back easily. As a consequence the compost is of very high quality. The share of green cuttings in that collection is low, the buckets are mainly filled with kitchen waste. The green cuttings are directly brought to the composting facilities. The costs of transportation differ in the single municipalities: In densely populated municipalities, transportation costs are low (for example in the municipality of Tragwein 50 € /t transport costs), whereas, in municipalities with greater distances the costs are higher (for example in the municipality of Lasberg 142 €/t transport costs). Accounting is done by every municipality on its own, also the contracts with the composting facilities are made by every singly municipality. However, the BAV Freistadt suggested a guideline value of 40 €/t. The costs are passed on to the consumers via the basic waste charge of 120 €/average household. An average household is calculated with 2.8 persons, households with more or fewer people pay more or less respectively. The basic waste charge does not only include the biogenous waste but also the fee for the local recycling centre where citizens of Freistadt have the possibility to deliver their residual waste in addition to the residual waste collection system. In 2015, a total amount of 2,925 t of biogenous waste was collected in Freistadt (2014: 2,960 t), although this value is estimated due to missing scales at the composting facilities. It is assumed that 1 m³ of biogenous waste weighs 650 kg, not including low filling rates. The correctness of this value is proved approximately twice a year. Additionally, 5,600 t of green cuttings and 3,000 t of hedge cuttings are collected in Freistadt every year (Bezirksabfallverband Freistadt, 2016, personal communication).

In Linz, the collection of biogenous waste is obligatory. 15,000 garbage containers in the usual sizes of 120l and 240 l are installed. The collection is performed by the Linz AG. From March to November the containers are emptied every week, in December, January and February the garbage is collected every 14 days (makes 684375 emptyings per year). In 2015 11,000 t were collected. Biogenous waste collection is generally free of charge, only producers of large amounts of waste, like restaurants or hotels, are asked to pay 3,19 € for extra 120l respectively 4,91 € for extra 240 l containers. The biogenous waste is brought to the rotting tunnel of Linz. Before the rotting process starts, contaminants and materials like plastic bags and aluminium containers is separated mechanically. The rotting process itself takes 14 days, the material is sanitized with water and air. After 14 days the rotting process is not completed, but the material is brought to composting facilities outside of Linz in nearby municipalities. The accrued hummus is used in the agriculture by local farmers. Linz AG could not share their information on collection and composting costs, as Linz AG is disposal company offering their services also in other municipalities (Linz AG, 2016, personal communication).

In the district of Eferding, offsetting of biogenous waste collection is performed by the BAV. One collection company is in charge of the collection of all the biogenous waste of the district. 4,636 120l containers were emptied regularly and 2,404 t of biogenous waste were treated by the composting facilities in 2015. The price of the collection of one 120 l container was 1.54 € (excl. taxes) in 2015. Composting facilities are mainly paid directly by the municipalities, some are paid by the BAV. Composting facilities received 51.54 € per ton, which corresponds to the guideline price of ARGE Kompost & Biogas (Bezirksabfallverband Eferding, 2016, personal communication).

In the district of Grieskirchen, the BAV has a coordinating role, payments are made directly by the municipalities. 5,300 t of biogenous waste were collected in Grieskirchen, 120 l and 240 l containers were in use in 2015. The overall costs of transportation were 280,000 € in 2015. Thus the average costs of collection/t are 53 €. Collection in sparsely populated areas is more expensive than in densely populated areas, as collection trucks need to drive greater distances. However, most municipalities pay around 50 €/t, as collection is only offered in densely populated areas. The municipality with the highest/lowest costs of collection pays 80/33 €/t. According to (Bezirksabfallverband Grieskirchen, 2016) this is extraordinary, because transportation costs are usually higher in Upper Austria. The collection companies are paid per hour: one driving hour costs 64 €. The BAV Grieskirchen has contracts with the waste collection companies, but every municipality has its own contracts with the composting facilities. This is possible, because collection is either done separately for every municipality or because the trucks are weighed after the collection is terminated in one municipality. The weighing of the trucks is no problem in the district of Grieskirchen. Composting costs are the same for every municipality: 51.54 € (Bezirksabfallverband Grieskirchen, 2016, personal communication).

In the district of Perg, two different systems for the collection of the biogenous waste are applied: In some municipalities the composting facilities themselves are collecting the waste. The households connected to that system collect their waste in 23 l buckets. In other municipalities 120 l containers are used. Those are collected by professional waste collection companies. The costs of those two systems vary between 0.60 and 1.20 € for the emptying of a 23 l bucket and between 1.00 and 1.60 € for the emptying of a 120 l container. The containers and buckets are usually collected weekly, in winter months they are collected biweekly (39 emptyings per year). The composting costs are in the range of 45 € and 52 €. 2,420 t of biogenous waste were collected in 2014, of which 1,375 t were collected via 23 l buckets and 1,045 t via 120 l. On average between 312 and 416 kg are collected per household. Thus the transportation costs per tonne are in the range of 56 € and 150 € for buckets (96 € on average) and between 94 € and 200 € for 120 l containers (139 € on average) (Bezirksabfallverband Perg, 2016, personal communication).

In the district of Rohrbach, biogenous waste is collected by eight composting facilities. In total 1224 t of biogenous waste were collected in 2014. The composting facilities use tractors and tractor trailers as well as cars and car trailers for the collection and they are paid on the basis of hours and kilometres driven. Every household gets 52 15l bags every year. The collection costs are significantly different throughout the district: The cheapest collection is done by composting facility F with a price of 50.96 €/t. The most expensive collection is found in the region, where composting facility H collects the waste: 146.80 €. The average collection price of the district is 86.94 €. The BAV includes the costs of biogenous waste collection into the general waste collection fee. The price of composting is € 51.63, which corresponds to the guidance value of *ARGE Kompost & Biogas* (Bezirksabfallverband Rohrbach, 2016, personal communication).

Annex 4

Gemeinden	Einwohner	Gesamt-volumen [l]	Gesamt-gewicht [kg]	Entleerungen /Jahr	Anzahl Biotonnen	kg/Entleerung [kg]	kg/Biotonne /Jahr [kg]	Entleerung /Tonne [€]
Aichkirchen	561	294720	45794	26	96	1761,31	477,02	0,93
Bachmanning	683	353760	54993	26	115	2115,10	478,20	0,93
Bad-Wimsbach	2436	1503360	208620	26	472	8023,85	441,99	0,86
Buchkirchen	4130	3978240	442690	26	1270	17026,54	348,57	0,68
Edt	2036	1494960	236530	26	495	9097,31	477,84	0,93
Fischlham	1324	432480	70900	26	141	2726,92	502,84	0,98
Gunskirchen	5717	3712800	541730	26	1180	20835,77	459,09	0,90
Holzhausen	803	756240	76620	26	253	2946,92	302,85	0,59
Krenglbach	2989	2085600	282580	26	672	10868,46	420,51	0,82
Marchtrenk	12662	8885880	1126600	27	2841	41725,93	396,55	0,74
Neukirchen	887	144360	22513	26	49	865,90	459,46	0,90
Offenhausen	1594	822240	102693	26	268	3949,75	383,18	0,75
Pennewang	894	424200	52987	26	139	2037,94	381,20	0,74
Pichl	2821	791160	130080	26	257	5003,08	506,15	0,99
Schleißheim	1275	1554720	172770	37	347	4669,46	497,90	0,68
Sipbachzell	1876	1285800	133525	26	415	5135,58	321,75	0,63
Steinerkirchen	2360	737040	161380	27	237	5977,04	680,93	1,28
Steinhaus	1940	2124120	235360	38	467	6193,68	503,98	0,67
Thalheim	5499	6311760	542390	39	1248	13907,44	434,61	0,56
Weißkirchen	3243	4208400	471110	37	941	12732,70	500,65	0,69
Gesamt			**5111865**		**11903**	**177600,67**		