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DEVELOPMENT OF A RISK MANAGEMENT CONCEPT FOR GREEN FERTILIZER UPCYCLING FROM MANURE

Master Thesis

by

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To my family

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Last but not least I would like to quote Ralph Waldo Emerson:

"*Life is a journey, not a destination*."

When I started studying I always tried to imagine how it would be like to reach the end of my studies. Being there, let's me realise that not the result is what does count but all the experiences I have faced while trying to reach my goal.

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List of abbreviations

BOD_5	The amount of dissolved oxygen consumed in five days by biological processes breaking down organic matter
EC	Electrical conductivity
EcoManureMine	Project acronym for the 7th framework project “green fertiliser upcycling from manure- technological, economic, and environmental sustainable demonstration
TAN	Total ammonia nitrogen
TKN	Total concentration of organic nitrogen & ammonia
TSS	Total suspended solids
tCOD	Total chemical oxygen demand
VSS	Volatile suspended solids

Abstract

This thesis is part of the of the recently implemented Seventh Framework project "ManureEcoMine" which has the goal of reusing nutrient rich livestock manure as a source for biofertilisers and biogas production while at the same reducing environmental risks being emanated by animal manure. Therefore an experimental plant has been constructed, first in the Netherlands and further in Spain, in order to ascertain various combinations of state of the art technologies in terms of efficiency, economic viability and applicability for the project. As part of the project, this thesis is trying to develop a literature based risk management concept based on the ISO 31000:2009 risk approach, trying to identifying potential risks arising from raw animal manure as well as throughout several process steps. Further, identified risks should be analysed and evaluated on behalf of ISO recommended tools resulting in risk treatment suggestions. Based on that, monitoring measures should be determined in order to guarantee unproblematic functionality of used technologies. In addition, the risk management concept analyses the projects' viability by comparing identified hazards to process scheme state of the art technologies and thereby determining the hazard treatment potential. Therefore a prediction can be made if the used technologies are reasonable or if changes in the project scheme should be considered. Last but not least economic aspects should be analysed in order to investigate the economic potential of the project.

Abstract in german

Diese Arbeit ist Teil des kürzlich implementierten Seventh Framework Projektes „ManureEcoMine" welches das Ziel verfolgt nährstoffreiche Tierausscheidungen als Quelle für Biodünger und Biogas wiederzuverwerten während gleichzeitig vom Ausgangsmaterial ausgehende potentielle Umweltschäden minimiert werden. Im Zuge dessen wurde eine Versuchsanlage in den Niederlanden und später nochmals in Spanien erreichtet um verschiedene Kombinationen von auf dem aktuellen Stand der Technik befindlichen Technologien in Bezug auf Effektivität, Anwendbarkeit und ökonomische Effizienz zu erforschen. Diese Arbeit hat im Zuge des Projektes ein Risiko Management Konzept im Rahmen der ISO 31000: 2009 Richtlinie erstellt um auftretende Risiken sowohl ausgehend vom Ausgangsprodukt als auch während der einzelnen Prozessschritte zu identifizieren, diese dann anhand von ISO empfohlenen Methoden und Techniken zu analysieren und zu bewerten und mögliche Risikobehandlungsmethoden aufzuzeigen. Aufbauend darauf veranschaulicht das Risiko Management Konzept die Effizienz der einzelnen Prozessschritte ausgehend von angenommen Ausgangsrisiko und Effektivität der eingesetzten Technologien. Daraus folgend kann eine Aussage über Sinnhaftigkeit der Versuchsanordnung getroffen werden und falls nötig Verbesserungsvorschläge eingebracht werden. Abschließend wird diese Arbeit noch das ökonomische Potential des Projektes darstellen.

1. Introduction

On the first of November 2013, the European Commission has approved funding for 14 new research projects in the field of resource efficient economy. Across Europe more than 140 partners from research organisations and private companies collaborate in terms of tackling the challenge of recycling waste materials from manufactured products and the agricultural sector to improve the quality of the environment and save money (Europawire, 2014). With a budget of € 3,8 million over 3 years the “ManureEcoMine” projects’ proposal is an integrated approach for the treatment and reuse of animal husbandry waste in nitrate vulnerable and sensitive areas and beyond, by applying the eco-innovative principles of sustainability, resource recovery and energy efficiency.

In the European Union, the annual amount of manure produced by cows and pigs amounts 1.27 billion tons which equals around 500.000 olympic swimming pools. These extractions therefore represent a largely unexploited resource of organic carbon and nutrients. The usage of in this way produced manure as a source for sustainable fertiliser production is the goal of the recently implemented EU project. Additionally the idea is that after having processed the excretions, only water and a slight amount of harmless solids should remain and therefore no harm to the environment should occur (Jülich, 2014).

The direct usage of liquid manure as a fertiliser contains various disadvantages and risks: pathogens and remedy residues which may be attained into the soil can lead among others to ground water exposure or eluviation of nitrates as well as smell pollution. Under the aegis of the University of Gent and in close cooperation with all eleven project partners as well as the industry, scientists and experts built an experimental plant in order to explore and put to test alternative usages of manure as energy and fertiliser supplier. Thereby biogas and other organic additives should be produced through fermentation processes. Further steps include the usage of contents of digested residues as a fertiliser basis. These are: Phosphorus, nitrogen components, potassium as well as other minerals. Technologies of proven efficiency in the field of wastewater treatment will be combined in several process configurations in the treatment of manure at the pilot scales in order to demonstrate their ecological and technical potential. Ammonia stripping, struvite precipitation and partial nitrification / anammox will be the key technologies.

To render the cradle-to-cradle approach complete, the fertiliser and potential trace contaminants effects of recovered nutrients on plant growth and soil health and emissions will be established. Finally safety is going to be managed by a risk management plan, a life cycle analyses will determine the sustainability of the concept and the boundaries of economic viability will be determined.

2. Aim of research

The aim of this thesis is the development of an on literature review based risk management concept regarding to the ISO 3100:2009 risk management frameworks in order to fulfil the following tasks:

- Identifying potential hazardous risks within the livestock manure as well as process risks occurring throughout the process chain
- Analysing identified risks in terms of existing controls, control effectiveness, determination of risk levels as well as potential uncertainties occurring throughout the process
- Evaluating already identified and analysed risks by determining risk tolerance levels and further categorising them
- Identifying and suggesting risk treatment possibilities by deciding which risks need to be treated and which can be tolerated
- Identifying Monitoring and review measures
- Identifying quality assurance measures for produced products
- Determining the viability of the project's used combination of state of the art technologies

This thesis should be used as the basis for a risk management concept which is going to be implemented in the Seventh Framework Project "ManureEcoMine".

3. Risk management

The purpose of risk management is to ensure that adequate measures are taken to protect people, the environment and assets from harmful consequences of the activities being undertaken, as well as balancing different concerns, in particular health, environment, safety and costs. It includes measures both to avoid the occurrence of hazards and reduce their potential harms. Risk management can be seen as an integral aspect of a goal oriented regime which acknowledges that risk cannot be eliminated but must be managed (Vinnem, 2007). Risk management should be part of every project's objectives and should include all possible anticipated risks that possibly may occur (Tularam et al., 2012).

Due to the fact that risk is uncertainty of outcome, good risk management allows having increased confidence in achieving desired outcomes, effectively constraining threats to acceptable levels and taking informed decisions about exploiting opportunities (WHO, 2013).

Successful Risk Management further is needed to ensure that:

– All significant risks are identified

– Identified risks are understood, with both the range of potential consequences they present and the likelihood of values in that range being determined as far as is necessary for decision-making

– Assessment is undertaken of individual risks relative to the other risks to support priority setting and resource allocation

– Strategies for treating the risks take account of opportunities to address more than one risk

– The process itself and the risk treatment strategies are implanted cost-effectively (Brühwiler,2007)

3.1 Overview of widely used risk management standards and guidelines

Risk management strategies generally focus on one or more of the following events:

- Meeting or exceeding an organisations' objectives
- Adhering to control-based objectives, rules and / or controls
- Complying with regulatory requirements (Crickette et al., 2011)

Nevertheless all standards are slightly different – differing in terms of scope of application, method of approach or composition. To show the specialities of different risk management standards, several of the better known standards are illustrated below:

AS / NZS 4360 risk management

Established in 1995, the AS / NZS 4360 was the first generic risk management (RM) standard which integrated RM as part of corporate management. It is the basis for several subsequent risk management standards (e.g. ISO 31000).

OCEG “Red Book“ 2.0:2009

Consisting of two books, the ” Red Book” contains the overview and principles and the “burgundy book” which contains procedures and assessment criteria”, the OCEG “Red Book“ 2.0:2009 focuses mainly on the application of governance, risk management and compliance (GRC) methods (Crickette et al.,2011).

BS 31100:2008

Implemented by the British Standard Institution (BSI), the BSI 31100:2008 RM standard is similar to the ISO 31000 framework but also recognises the knowledge contained in Treasury’s Orange book, a British guidance for Practitioners published by the Office of Government Commerce. It pays particular attention to the benefits of using a risk maturity model to improve an organisation’s risk management capability (Crickette et al., 2011).

COSO:2004

Comprising a variety of professional associations including the American Accounting Association (AAA) or the Institute of Internal Auditors (IIA), COSO is dedicated to guiding executive management and governance entities towards the establishment of more effective, efficient and ethical business operations on a global basis. COSO’s objectives are the improvement of organisational performance through better integration of strategy, risk, control and governance (Crickette et al., 2011).

FERMA: 2002

FERMA 2002 is the risk management standard of the Federation of Risk Management Associations and provides a simplified framework for the risk analysis step, which can be used to organise and categorise risk consequences and their probability of occurrence. Similar to ISO 3100o and COSO: 2004 it highlights the importance of a risk management monitoring as a tool for continuous improvement. Specific to the FERMA standard are the inclusion of regular audits of compliance with risk management (Crickette et al., 2011).

3.2 Environmental risk management

The interdisciplinary approach of environmental risk management and the concomitant devastating consequences if it is fails makes it a complex field of application and therefore needs prescient planning and a circumspect course of action. Risks arising in this field are transmitted through air, water, soil or biological food chains to man. Their causes and characteristics are however very diverse and can be created by man through introduction of new technologies, products or chemicals on the one hand side or could emerge as natural hazards, resulting from natural processes which happen to interact with human activities and settlements on the other hand side. Even though environmental risks diverse in terms of occurrence and effects they still have several similarities. They are being transported through environmental media and cause harm to people who not voluntarily or specifically chosen to suffer their consequences. Therefore regulations on the part of some authority above that on an individual citizen are required which in conclusion leads to environmental risk management (Wiley, 1980).

Environmental risk management covers amongst others the following fields of application:

- Ecological Monitoring (soil degradations, river and sediment discharges…)
- Biosphere (wildlife sampling, pesticide residues....)
- Pollutants (air, water, food...)
- Climate (climate change, glacier mass balance and fluctuations…)
- Natural disasters (flood forecasting, tsunami information...) (Wiley, 1980)

Environmental Risk Management involves the search for the “best route” between social benefit and environmental risks. It balances or is trading off processes in which various combinations of risks are compared and evaluated against particular social and economic gains. Like any other risk management concept the active risk assessment is part of an overall management system (e.g EMS, ISO 14001). Based on Shewhart’s Plan-Do-Check-Act (PDCA) cycle successful environmental management includes a systematic approach for solving problems.

Environmental risk management differs in terms of goal setting, thresholds, environmental impacts and problem solving strategies, they still have one important procedure in common- the Risk Assessment process. Consisting of three components:

- Problem identification - hazard identification
- Exposure characterisation - identification of consequences, and estimation of the magnitude of the consequences
- Risk characterisation - probability of the consequences significance of risk and placing it in a context such as legislative criterion (Christensen et al., 2010)

Successful environmental risk management takes place within the legal policies as well as institutional frameworks are established by individual countries and international agencies. Already in the early 1990’s the Convention on Environmental Impact Assessment in Trans boundary Context (1991) and the Rio Declaration (1992) included transnational declarations for environmental issues which need to be considered when managing environmental risks (Ogola, 2007). On EU basis the European Environment Agency (EEA) publishes Risk policies / initiatives and provides guidance for the usage on national level. National legislations in the field of application additionally have to be considered and are published by governmental institutions (e.g. Bundesministerium für Umwelt, Naturschutz und Reaktorsicherheit in Germany, Bundesministerium für Land- und Forstwirtschaft, Umwelt und Wasserwirtschaft in Austria, Centro de Investigaciones Energeticas Tecnologicas y Medioambientals in Spain) (Christensen et al., 2014). Further investment banks like the World Bank (WB), the European Bank for Reconstruction and Development (EBRD) have environmental safeguards to ensure that financing of projects is not only based on precautionary principle, preventative action rather than curative treatment but sustainable development (WBCSD, 2005).

3.3 Risks in fertiliser production from manure

To obtain a sufficient yield of crops, fertilisation with nitrogen, phosphorus and potassium is necessary. Therefore fertilization from manure is a valuable source of these nutrients.

Manure provides several favourable characteristics as a nutrient source:

- Can serve as a soil conditioner through the addition of organic matter which leads to improvement of physical structure and stability in soils

- Provides a broad profile of macro – and micronutrients

- Contains nutrients in organic and inorganic (crop available) forms (Alberta Environmentally Sustainable Program, 2011)

Nevertheless the usage of manure as fertilisers in agriculture include various risks, which needs to be identified, analysed and abolished, and may occur during usage or production processes. Applications of manure based fertilisers can create risks of contamination to soil, water, and air quality as well as in form of pathogens.

Risks to soil quality:

- Livestock manure can be rich of soluble ion like sodium and potassium due to small detainment of salt in the animal's body. This further leads to saline soil conditions. Also long term build-up of Sodium can have a negative impact on soil structure by reducing soil aggregation (Alberta Environmentally Sustainable Program, 2011)

Risk to Water quality:

- Manure application raise soil nitrate levels in groundwater

- Agricultural runoff can lead to enrichment of surface water bodies by nutrients, particularly N and P. This may lead to increased algae production which further result in significantly deplete oxygen levels (Alberta Environmentally Sustainable Program, 2011)

Risk to Air quality:

- Ammonium in manure converted to ammonia gas can be lost to the atmosphere (Alberta Environmentally Sustainable Program, 2011)

Risk of Pathogens:

- Human pathogens (such as E. coli) are primarily found in the gastrointestinal tract of humans without causing any health problems. When using manure based fertiliser these pathogens can be introduced either to plants either directly by manure or indirectly via contamination or irrigation water, run-off from of flooding from neighbouring fields (FiBl, 2011).

Potential pathogenically loads in animal faeces:

Cattle: E.coli is frequently present in ruminants, especially when concentrate feed rich in carbohydrates, dominates cattle diets. Further calves shed contain high quantities of Enterohaemorrhagic Escherichia coli (EHEC), disease causing strains of E. Coli, Campylobacter and less frequently Salmonella.

Pigs: less frequent carriers of EHEC strains than cattle but are often associated with Salmonella and Campylobacter (FiBl, 2011).

Nutrients are essential for plant growth but excesses are hazardous. Therefore EU and national wide regulations exist to delimitate the amount of nutrients used for fertilisation.

3.4 Regulations in fertilisation processes

The general fertiliser law (Regulation EC 2003 / 2003) set outs detailed technical provisions regarding the scope, declaration, identification and packaging of various fertilisers, control measures and acts as the basis for several Commission Regulations concerning the usage of fertilisers. Nevertheless the fertiliser law just regulates inorganic fertilisers. The current Fertilisers Regulation (EC) No 2003/2003 mentions in its Article 14© that “A type of fertiliser may only be included in Annex 1 if: [...] (c) under normal conditions of use it does not adversely affect human, animal, or plant health, or the environment” but does not indicate how this assessment should be carried out. The safety approach / methodology is not defined (European Commission, 2012).

Agricultural food production is an essential process so supply humans with necessary food. In order to do so, biofertilisers from animal manure and slurries are used to support soils with essential nutrients in order to keep the production rates high. Especially chemical hazards arising from pesticide, fungicides, herbicides, heavy metals and human pathogens (e.g. E Coli O157, Salmonella, Listeria, etc.) and antibiotics used in animal feeding can affect the food quality and further human health. In order to avoid such hazardous impacts along the production chain the Hazard Analysis and Critical Control Points system (HACCP) concept can be used. The HACCP concept is used along the food chain and is a systematic preventive approach to food safety that addresses physical, chemical, and biological hazards as a means of prevention rather than finished product inspection. The key usage is to identify potential food safety hazards, so that actions can be taken in order to reduce or eliminate risks and hazards being realised. HACCP can be applied to the whole food production chain. Therefore it can be applied to the “ManureEcoMine” project because animal manure is used as source for fertiliser production and substances within the fertiliser may be hazardous to soil, crops and subsequently have an impacts on the produced vegetables (Landau, 2011).

4. ISO – International Organisation for Standardisation

4.1 Overview

ISO (International Standard Organisation) is a global network consisting of national standard institutes in more than 160 countries that identifies required international standards for business, government and Society. ISO standards are developed in partnership with experts of the sectors that will put them to use. Even though ISO is a non-governmental organisation, the ISO standards are widely respected and implemented by public and private sectors internationally. The international network is operating on the basis of one member per country, which is the principal standards organisation in the country and has the task of proposing new standards and providing support in collaboration with ISO Central Secretariat. Altogether, more than 50,000 experts are contributing directly to the work of the organisation each year, plus approximately another 300,000 who follow the work and provide input to national “mirror” committees (ISO, 2011).

The story of ISO began in 1906, when the International Electronical Commission (IEC) was established. From 1926 on the international Federation of the National Standardising Associations (ISA) yielded pioneering work on the field of mechanical engineering but was abandoned in the early 1940’s. After the Second World War, in 1946, delegates from 25 countries met in London and decided to create a new international organisation with the objective of facilitating the international coordination and unification of industrial standards. On the 23 February 1947, the new Organisation ISO officially began it operations. Up to now ISO has implemented more than 18 600 standards that provide practical solutions of almost every sector of business, industry and technology. Together they make up a complete offering for all three dimensions of sustainable development- economic, environmental and societal. ISO closely collaborates with its partner in international standardisation, the International Electro technical Commission (IEC) and the International Telecommunication Union (ITU) and has strategic partnerships with the World Trade Organisation (WTO), the United Nations (UN) and several UN sub-organisations. As part of that ISO provides assistance and support to developing countries. Altogether, ISO’s technical committees have formal liaison relations with more than 700 regional and international organisations (ISO, 2011).

4.2 ISO risk management standards

The European Committee for Standardisation (CEN) has identified more than 60 standards in the area of risk management. ISO standards are documents that provide requirements, specifications, guidelines or characteristics that can be used consistently to ensure that materials, products, processes and services are fit for their purpose. The ISO 31000:2009 can be seen as an “umbrella” for all of these standards by acting as a basic module for areas specific risk management. These standards have been aligned with the ISO 31000:2009 standards or are in the process of being aligned in future versions (Vandijck, 2013).

4.3 ISO certifications

ISO certificates give providers of risk management processes the opportunity of getting their methods aligned to an international standard by having their conformity certificated.

By being ISO certified, a risk management system will have been implemented that brings among others following benefits:

- Effective risk management can reduce the chance of incidents occurring as well as the financial loss which is often linked to them

- Becoming officially ISO certified can help to improve stakeholder and costumer confidence by standing out from competitors who are not certified

- Certification enhances a company's reputation by demonstrating commitment to reducing accidents and incidents

- Allows confidential work by having the knowledge that there's a framework in place to assess potential risks and mitigate or avoid them

- Certification can improve health, safety and performance by assessing all risks within an organisation

- ISO certified companies utilize systems that have been accepted for use by over 80 countries as effective means to achieve product quality and environmental stewardship

- Companies producing ISO certified products reduce the need for the buyers to perform audits and reviews to determine if quality systems are in place and being maintained

- A certificate of analysis from an ISO certified company will be supported by documented procedures and records that demonstrate its validity (Cryotech, 2014)

4.4 ISO guideline 31000:2009

4.4.1 Purpose and principles

Over the last decades “Risk management” has become a frequently used catchphrase which has been accompanied by great expectations and many misunderstandings. Therefore, it was about time to clearly define the term “risk management” including all relevant processes. A lot of sectorial respectively branch specific solely refer to certain areas as illustrated in the following enumeration:

- Technical risks (machinery or product safety)
- Financial risks (internal auditing)
- Risk in information technology (IMS Information technology management)
- Work safety (Work safety management)

This task was assumed by the International Standard Organisation (ISO) which implemented a new norm “ISO 31000:2009 Risk Management – Guidelines on principles and implementation of risk management” as a generic guideline for Risk Management which includes all kinds or risks occurring in projects or organisations. In Addition the norm is attended by the likewise newly revised “ISO Guide 73 Risk management – Vocabulary” (Jaecklin, 2007). While people are working in many different forms of risk management, decision makers are uncomfortable about resolving pieces of apparently similar but fundamentally different information, obtained from different processes and with different assumptions, that are described using the same words but have different meanings. Therefore, the International Standard Organisation (ISO) set out to achieve consistency and reliability in risk management by designing a standard that would be applicable to all forms of risk. This contains:

- One Vocabulary
- A set of performance criteria
- One, common overarching process for identifying, analysing, evaluating, and treating risks
- Guidance on how that process should be integrated into the decision- making processes of any organization (Purdy, 2010)

To do so, from 2005 on, through a consensus driven process over four years, through seven drafts, a working group comprising experts nominated from 28 countries had been founded to guide the development of the standard and the associated vocabulary. Through these mirror committees, a network of hundreds or risk management specialists and their customers from around the world have helped create, review, and shape the eventual ISO 31000:2009 and Guide 73. Therefore, these documents represent the views and experience of hundreds of knowledgeable people involve in all aspects of risk management (Purdy, 2010).

The ISO 31000:2009 guideline provides principles and generic guidelines on implementation of risk management and can be applied to any public, private or community enterprise, association, group or individual. Because of that, the ISO guide is generic and not specific to any industry or sector. In Addition ISO 31000:2009 can be applied throughout the life of an organisation, and to a wide range of activities, processes, functions, projects, products or decisions. Even though the International Standards provides generic guidelines, is not intended to impose uniformity of risk management across organisations knowing that design and implementation of risk management depends on varying needs of specific sectors. As stated in the ISO 31000:2009, it therefore intends to harmonize risk management processes and provides a common approach in support of standards dealing with specific risks and /or sectors, and does not try to replace them.

4.4.2 Structure

Successful Risk management consists according to ISO 31000:2009 of three interrelating processes which build upon another and are illustrated in figure 1.

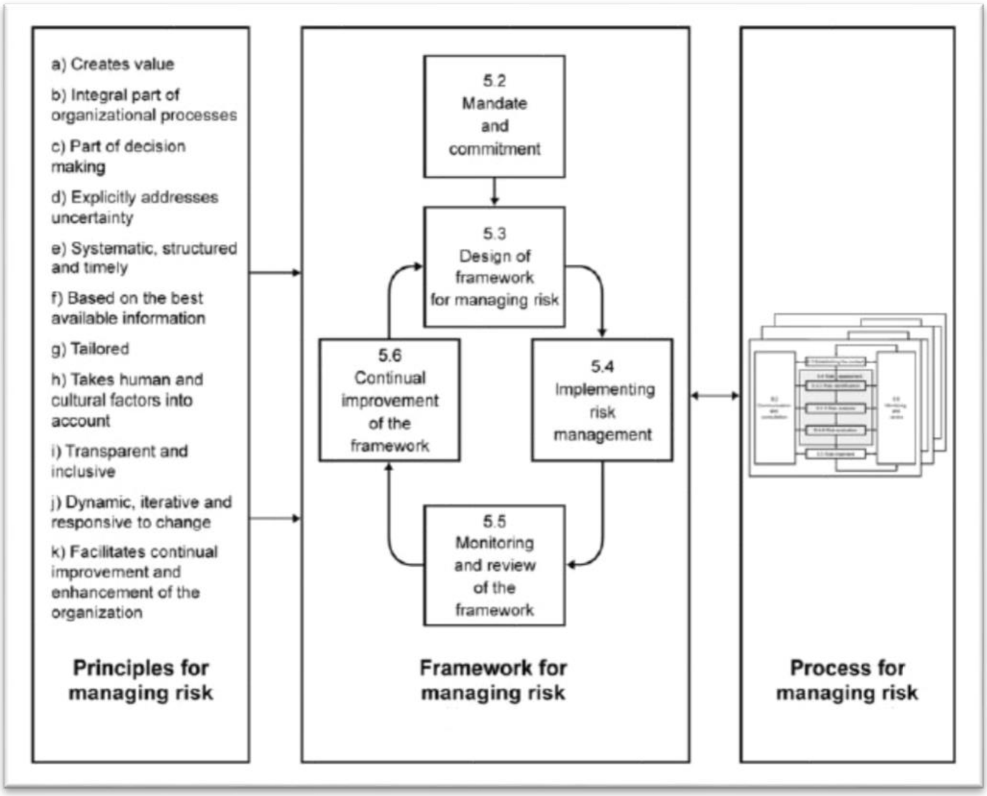

Figure1: Components for a successful Risk Management Process (ISO 31000:2009)

Principles for managing risks have to be determined and should adhere to among others to these principles:

- Risk management has to be seen as an integral part of organisational processes
- Risk management is part of the decision making process
- Risk management is systematic, structured and timely
- Risk management is tailored (ISO 31000:2009)

For successfully implementing a risk managing process is has to function within a risk management framework which provides the foundations and organisational arrangements that will be embed it throughout the organisation at all levels. The framework assists an organisation in managing its risks in an effective way by applying the risk management process.

4.4.3 Framework

The management frameworks task is not to describe a management system, but rather, it assists the organisation to integrate risk management within its overall management system. There the frameworks components have to be adapted to the organisation's specific needs.

As already shown in figure 1 an effective risk management framework consists of five interrelating components and can be defined according to Weis (2009):

- **Mandate and Commitment** acts as an introduction of risk management for ensuring its on-going effectiveness which requires strong and sustained commitment as well as strategic and rigorous planning.

- The **Design of framework for managing risk** is a vital part for the successful implementation and realisation of the risk management system. It takes into account external as well as internal conditions for designing the framework. External conditions especially consist of legal and social determining factors whereas intern conditions consider organisational factors like leadership, management quality or company values / culture. The design further has to elucidate the context of strategy and politics as well as between goals and organisation.

- For the successful **implementation of a risk management** it is necessary to change the perspective from seeing risk management as a discrete tool towards an in all organisational processes integrated instrument. The implementation process takes place on the framework level by defining appropriate timing and strategies for the implementation, application of the risk management as well as on the risk management process level where it ensures that the risk management process is applied properly at all relevant levels and functions of an organisation.

- **Monitoring and review** ascertains that risk management is effective and continues to support organisational performance by periodically establishing performance measures, reviewing whether the risk management policies / plans are still appropriate or by composing drafts on risks.

- Finally **continual improvement of the framework** is necessary to continually compose decisions on how risk management framework, policy and plan can be improved.

As part of risk management implementation process, the risk management process comprises all systematic applications of management strategies, practices and activities. The risk management process supports the decision – making procedure under consideration of uncertainties, the probability of occurrence of future events and their impact on the achieving objectives. On top of that the risk management process is an important condition for monitoring measures and is a communication tool for intern and extern stakeholders (Weis, 2009).

4.4.4 Risk management process

According to ISO 31000, the risk management process includes five activities: communication and consultation, establishing the context, risk assessment, risk treatment, monitoring and review as shown in figure 2.

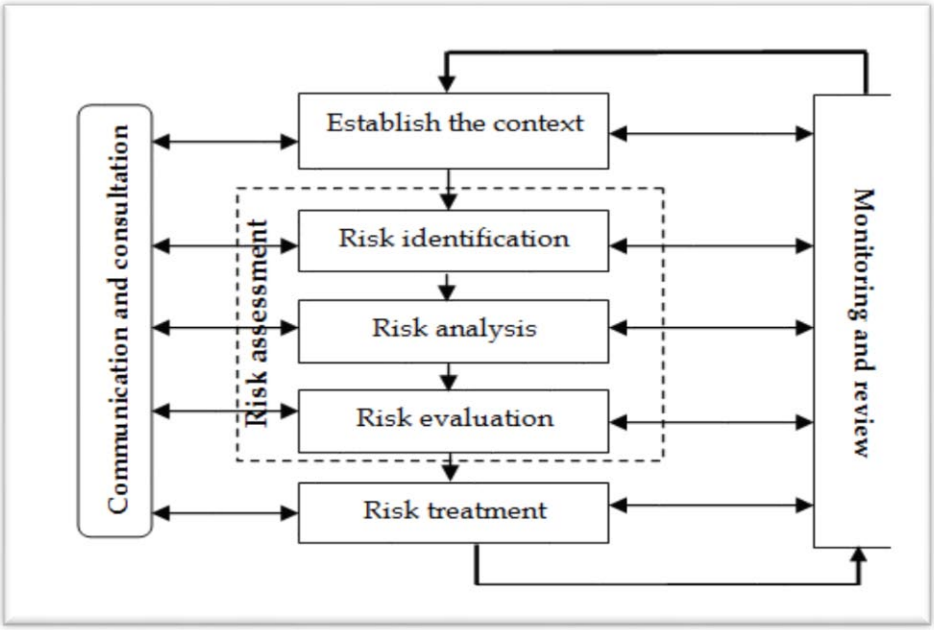

Figure 2: Elements of the risk management process (ISO 31000:2009)

- **Communication and consulting** with internal and external stakeholders as far as necessary should take place at each stage of the risk management process. Therefore a communication plan has to be developed which suits the scope of the examined risks.

- For the risk management process it is necessary to **establish the context** in order to define the scope and the related parameter. Therefore the internal and external conditions need to be considered. The external context includes social-cultural, economic, legal, political and technological factors. Understanding the external context is important to ensure that external stakeholders, their objectives and concerns are considered when developing risk criteria. The internal context on the other hand illustrates the environment in which the organisation seeks to achieve objectives concerning internal organisation strategy, policies, structures as well as internal project and business objectives. In Addition, responsibilities, the scope of the examining unit, the deliberated valuation method, the acceptance criteria, risk criteria together with the method of treatment are going to be defined.

- The **risk assessment** is the overall process of *risk identification, risk analysis* and *risk evaluation* and tinkers with questions like what can happen and why, what are the consequences, how high is the probability of occurrence and what are the consequences for the achieving objections? The purpose of risk assessment is finding evidence based information and analysis methods for profound decision making for specific risk concerning organisations or projects.
  Risk assessment can be conducted on various organisation levels – on sectional / compartment level or on the project level. Further it can assess individual activities or specific risks. The precondition for successful risk assessment is the understanding of risks, their origins and consequences. For successfully conducting risk assessment it

is necessary to know the projects goal and the risk boundaries- therefore the upper and lower threshold have to be defined.

- *Risk identification:* The process of finding, recognising, register and listing of relevant risks. The purpose of risk identification is to recognize what may happen in which particular situation and functions as the basis for the further procedure due to the fact that solely identified risks can be analysed and evaluated. The aim of this process step is to generate a comprehensive list of risks based on those events that might enhance, prevent or degrade the achievement of set objectives. The result of the risk identification process is the creation of a risk catalogue in which risks are getting systematized and documented. As part of that procedure, risks are further divided into internal and external risks to identify their potentials.

- *Risk analysis*: Based on the risk identification the risk analysis provides an input to risk evaluation and to decisions whether risks need to be treated and on the most appropriate risk treatment strategies and methods (ISO 31000). The risk analysis includes the verification risk sources and origins as well as the probability of occurrence. In general it further includes the estimated range of consequences. Used methods can be qualitative, quantitative or semi quantitative. In Addition the understanding of uncertainties is vital and therefore a sensitivity analysis can be used to estimate the impact of individual parameter on their meaning.

- *Risk evaluation:* According to ISO 31000:2009, risk evaluation assists in making decisions, based on the outcomes of risk analysis, about which risks need treatment to prioritize treatment implementation. To do so, a variety of risk evaluation methods exist which can be divided into three groups: *inductive* methods, *deductive* methods and *explorative* methods.

    - *Inductive methods*: Based on known cause, these methods are trying to find the consequences. An example therefore is the failure mode and effects analysis (FMEA).

    - *Deductive methods*: In comparison to inductive methods, deductive methods are trying to identify the problems' origin based on known impact and consequence. A typical example is the fault tree analysis.

    - *Explorative methods*: These approaches are used for systems where neither impacts nor its consequences are known. They especially suit for exploring complex systems which are based on experiences rather than on specific data. Used methods are brainstorming, Delphi technique, checklist method, preliminary hazard analysis (PHA), Hazard and Operability Study, Structured What-If Technique (SWIFT), Scenario Analysis or Root Cause Analysis (RCA).

- After having successfully assessed the risks, the **risk treatment** is the active and aimed regulation / interference of the in context analysed and assessed risk potentials. It involves selecting one or more options for modifying risks, and implementing those options. Risk treatment is a cyclical process of assessing a risk treatment; deciding whether residual risk levels are tolerable or not; if not tolerable generating new risk treatment; and assessing the effect of that treatment until the residual risk reached complies with the organisation's risk criteria (ISO 31000:2009). In order to do so, risk treatment options need to be selected and choices have to be made for the implementation process regarding legal, regulatory, social and environmental aspects. In Addition, risk treatment plans document the efficiency of chosen options. In general various strategy alternatives exist for the appropriate dealing with risk: *Risk avoidance, risk deterioration, risk shifting* and *risk acceptance*.

- **Monitoring and review** has to be planned as part of the risk management and should encompass all aspects of the risk management process for the purpose of ensuring that the risk control and treatment measure are effective in both design and operation, changes are detected in the internal and external context including changes to the risk itself as well as learning lessons from events, changes and trends. The results of monitoring should be recorded and internally and externally and should be used as an input to the review of the risk management framework (ISO 31000:2009).

5. The „ManureEcoMine“ project

5.1 Project overview

Raw livestock manure provides enormous potential as a source for energy production as well as for using it as a biological fertiliser in agriculture but in contrast includes substances which can harm humans, animals and the environment. Therefore the designed experimental plants used in the “ManureEcoMine” project consist of several state of the art technologies in order to use the potential subsequent compounds for product production as well as elimination of potential threats existing in the basic resource and occurring during diverse process steps. Figure 3 shows the first draft of a potential process scheme designed for the Seventh Framework Project.

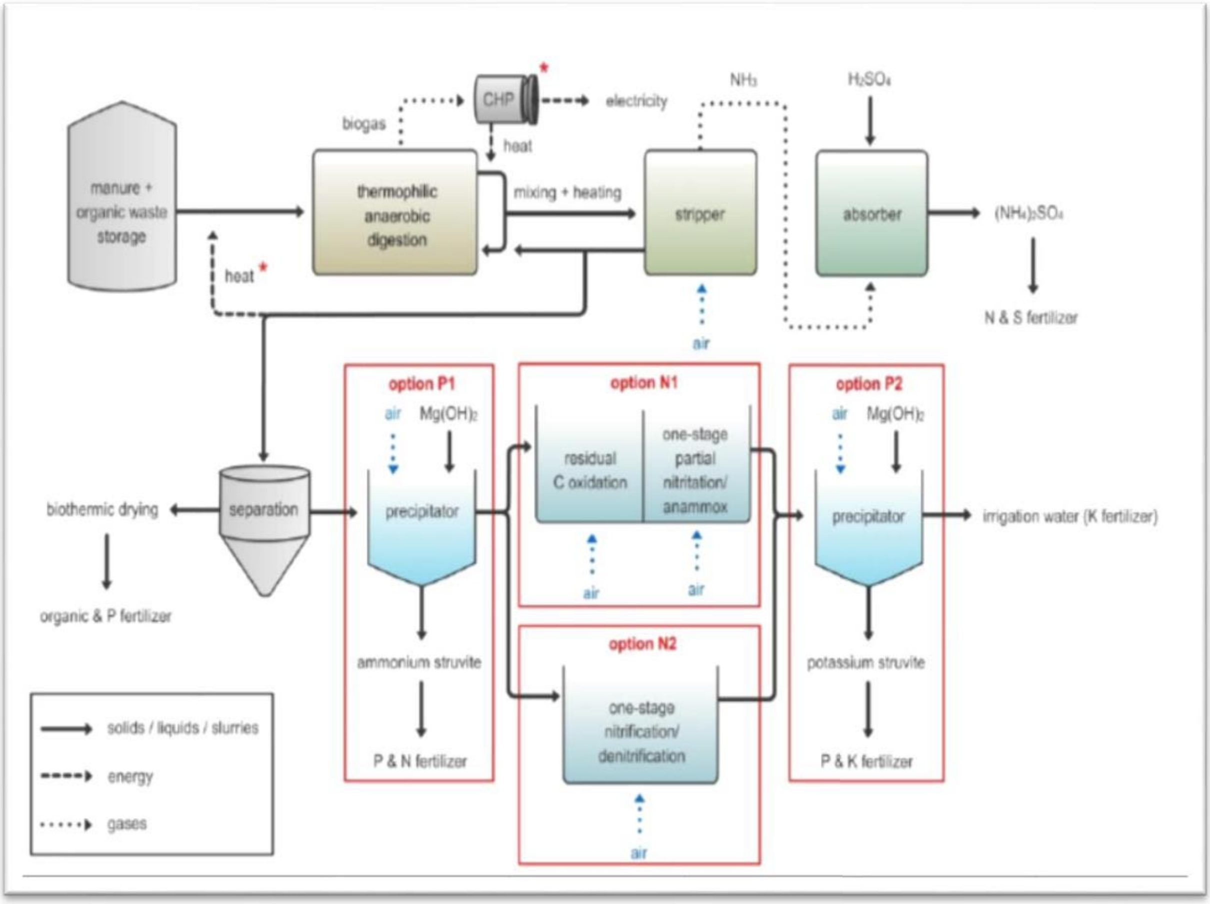

Figure 3: ManureEcoMine project process scheme

Raw animal manure is a mixture of various compounds arising naturally during digestion processes or artificially added during animal husbandry. Dependent on diet, growth stage, species of animals, and the manure collection method, the composition of manure can vary drastically but generally contains nutrients, pathogens, and certain concentrations of heavy metals, odorous elements, hormones, residues of antibiotic treatment, as well as several other typical chemical and physical properties. These natural excrements, explicitly characterised in chapter 5.3.1, therefore build the basis input material for the project.

In order to improve process stability and methane production during anaerobic digestion, co-digestion is done upstream by adding co-substrates to the low carbon content livestock manure. The mixed feedstock is then added to an anaerobic thermophilic digester which reduces environmental hazards, while at the same time producing biogas for energy needs (Ismail et al., 2012). The process is the breakdown of complex organic material by microorganisms in the absence of oxygen, resulting in biogas and stabilized organic matter. Biogas, which consists of 50-75% Methane (CH_4), 25-50% Carbon Dioxide (CO_2), 0-10% Nitrogen (N_2), 0-1% Hydrogen (H_2), 0-3% Hydrogen sulphide (H_2S), and 0-2% Oxygen (O_2), is then directly transferred to a combined heat and power unit (CHP) which uses the gas for producing both, heat and electricity. While the heat is used for the anaerobic digestion process and further digestate handling processes, the electricity can be fed into grid (Wright, 2001).

Beside biogas, anaerobic digestion produces a digestate which differs massively from the feedstocks’ original composition. Nutrients, like Nitrogen (N), Phosphorus (P), and Potassium (K) are not lost or reduced during anaerobic digestion, but are transformed from organic forms to inorganic forms. As a result, the levels of ammonium N inorganic P, and inorganic K increase as in relation to the total N, P, and K-values when compared to raw manure. Moody et al. (2009) compared in their study five different types of anaerobic digesters, and found that relative ammonium concentrations of ammonium N and inorganic phosphorus in digestate increased about 24% and 20% depending on operation conditions. Thermophilic anaerobic digestion leads to a massive reduction of viable pathogenic indicator microorganisms and selected pathogens in the digestate. According to Cote et al. (2006) the reduction rates of Salmonella spp., E. coli, Giardia, and Cryptosporidium spp. pathogens are around 100% during thermophilic anaerobic digestion with incubation times of only a few seconds. Findings of Beneragame et al. (2013) and Kotelko et al. (2013) proved that antibiotics used during livestock farming (e.g. penicillin, tetracycline, tylosine) can be removed partly during thermophilic anaerobic digestion. Further, the reduction of heavy metal concentrations during fermentation processes varies according to Wetzel et al. (1999) between 2-97%.While some elements have relatively high removal rates during anaerobic digestion (e.g. calcium (Ca) 97%, zinc (Zn) 74%, copper (Cu) 60,5%), others are more resistant to the process (lead (Pb) 31%, nickel (Ni) 2%) and remain mostly in the digestate. Also the odorous intensity is reduced by anaerobic digestion due to the fact that volatile organic acids, the primary odour causing compounds, are intermediate fermentation products and therefore are being used during anaerobic digesters. Ammonia and hydrogen sulphide are part of the digestion effluent which results in the presences of odours compounds in the digestion output (Barth et al., 1974). The reduction rate of odours from feedstock is according to Weiland (2010) about 80%. Information about hormones removal is scarce and inconsistent. In addition anaerobic digestion leads to a reduction of other chemical and physical parameters of the influent manure. Biological oxygen demand is reduced by 75% in pig and 55% cattle feedstock whereas chemical oxygen demand is reduced drastically by 50% in pig and 35% in cattle feedstock. Total solid levels and volatile fatty acids levels are reduced by ~35 % and ~ 70%, making no difference what kind of animal feedstock is used.

In the next step of the suggested process the warm anaerobic digestate, heated up by the residual heat of the CHP, is transmitted to ammonia stripping for nitrogen removal. During this process, the digestate is brought into contact with a gas, usually air, so that ammonia can be carried away by the gas. At optimum conditions, up to 98% of the ammonia can be removed by this method. The ammonia gas is then directed to an absorption tower where the ammonia reacts with externally added sulphuric acid and produces ammonium sulphate which can be used as an organic fertiliser. Ammonia stripping also effects heavy metal concentrations which did not get removed completely during anaerobic digestion. According to Ferraz et al. (2012) 70-90% of the existing zinc, iron, and manganese compounds can be removed. No evidence was found that ammonia stripping does effect hormones present in anaerobic digestate. The ammonia stripping effluent, which is still rich in nutrients, is then transmitted to a mechanical solid/ liquid separator which separates the remaining digestate into a nutrient and energy rich, low volume solid fraction and a liquid fraction which is rich in ammonium. The separated solid fraction is then aerobically composted which results in greenhouse gases emissions the one hand side and a phosphorus rich soil improver on the other hand side. The remaining liquid fraction is still rich in nitrogen, phosphorus and potassium and therefore needs to be treated and transformed in a more suitable form for soil application. In addition, the liquid remaining nitrogen concentrations need to be reduced. Therefore, struvite precipitation is used as a method for removing phosphorus from anaerobic digestion effluents by recovering it by using crystallization of phosphorus, magnesium, and nitrogen as struvite granulate, which further can be used as a slow release fertiliser. Even though struvite precipitation is a viable method for phosphorus recovering, is does not have any effect on potential hormones and heavy metal concentration in the digestate. According to Ronteltap (2009) only 2% of hormones are removed during the process and no evidence was found on heavy metal removal. For the final ammonium removal after precipitation two state of the art technologies are compared: conventional combined nitrification/dentrification and partial nitrification / anammox. Both technologies are capable of high nitrogen removal rates of up to 90% of total nitrogen and 98% of ammonium if processed adequately, but differ in terms of operation processes, energy demand, and outputs. As a by-product, both technologies produce N_2O gas, which is has a 300 fold higher greenhouse gas potential than CO_2. Last but not least, the residual effluent water is still rich in potassium and can be used as irrigation water in agriculture. Summarizing, it can be concluded that the process has the potential of producing five main products, which are described more closely in the following chapter.

5.2 Technologies used in the “ManureEcoMine” project

5.2.1 Anaerobic co-digestion processes

Anaerobic co-digestion is defined as a treatment that combines different types of wastes with the aim of increasing biogas yield. The improvement is gained by balancing the nutrient content and reducing the negative effects on the digestion process. In anaerobic digestion processes inhibition process mainly occur due to high ammonia concentrations, pH levels and temperature. Therefore manure should be preferably co-digested with wastes that have high carbon content, so as to improve the carbon to nitrogen (C/N) ratio (Cuetos, et al., 2011).

5.2.2 Anaerobic digestion

Anaerobic digestion is one of the most important and advantageous processes existing in livestock manure waste treatment by offering the opportunity of reducing environmental hazards, while at the same time providing biogas for energy needs (Ismail et al., 2012). The process is the breakdown of complex organic material by microorganisms in the absence of oxygen, resulting in 50-75% methane (CH_4), 25-50% carbon dioxide (CO_2), 0-10% nitrogen (N_2), 0-1% hydrogen (H_2), 0-3% hydrogen sulphide (H_2S), and 0-2% oxygen (O_2), and stabilized organic matter (Wright,2001). Under mesophilic process conditions, anaerobic digestion usually takes 25-30 days and can be divided into four phases:

- Hydrolysis: undissolved biodegradable organic matter gets converted by exoenzymes (celluloses, lipases and proteases) excreted by fermentative bacteria into different compounds (Gonzalez et al, 2012).

- Acidogenesis: Acid bacteria transform the dissolved compounds into fermentation products (volatile fatty acids (VFA), ethanol, lactic acid, hydrogen and carbon dioxide) (Gonzalez et al., 2012).

- Acetogenesis: Fermentation products are oxidized to acetate, carbon dioxide and hydrogen which are the substrates for methanogenic bacteria.

- Methanogenesis: Methane can be produced by two different ways: Hydrogenotrophic methanogenesis (30%), where hydrogen and carbon dioxide are converted into methane and acetoclastic methanogenesis (70%), where acetate is converted into methane and carbon dioxide (Gonzalez et al, 2012).

5.2.3 Combined heat and power (CHP) units

The principle of heat and power units is based on biogas generated during the fermentation of organic material. This material is then collected and used to produce heat and power which is both economical and saves resources. The electricity produced can either be used to supply the operators’ own requirements or can be fed into the national grid. The heat generated while operating the engine can be used by heat exchangers to maintain the temperature of the fermenters at a constant optimal level for the fermentation process.

5.2.4 Ammonia stripping and absorber

Ammonia stripping is a viable method for nitrogen removal from anaerobic digestate by taking advantage of the high ammonium nitrogen values and residual heat of the thermophilic digestion effluents. The process of ammonia stripping is based on ammonium disassociation and ammonia equilibrium between liquid and gas (Jiang, 2009). The stripping takes place in a packed stripping tower where air is pumped through the tower upwards, and further water flows downwards. The intimate contact of air and water permits the transfer of ammonia from water to air; thereby affecting a purification of water (Perez, 2002). The equation shown below illustrates the stoichiometric principle:

$$(NH_4)_2SO_4 + 2OH^- \rightarrow 2NH_3 + SO_4^- + 2H_2O$$

At optimum conditions the process allows an ammonia removal capacity greater than 98% (Perez, 2002). One of the major concerns in applying ammonia stripping to anaerobic digestate is the demand of chemical agents, including both alkali for rising pH prior stripping and acid (e.g. sulphuric acid) for lowering pH after stripping.

Ammonia stripping towers can be directly connected to absorber towers which are quite similar, only using the reverse operation principle instead. Ammonia is absorbed in water and removed from air in order to build ammonium sulphate. The chemical process happens on behalf of the equation shown below and is based on the addition of sulphuric acid to guaranty favourable operation equilibrium:

$$H_2SO_4 + 2 \cdot NH_3 \rightarrow (NH_4)_2SO_4$$

Compared to Ammonia stripping, in absorber towers, the pH level has to be kept low in order to guarantee successful operations (Perez, 2002).

5.2.5 Mechanical solid / liquid separation

Solid-liquid separation in digested manure are well developed processes which normally are operated by drum filters, screw presses, filter belts presses or centrifuges with the aim of getting a nutrient and energy rich low volume solid fraction and a liquid fraction rich in ammonium (Popovic et al., 2013).

5.2.6 Aerobic composting of solid digestate

Composting or biothermic drying consists of two processes: active aerobic composting and curing. During the active aerobic composting process microorganisms consume oxygen (O_2) while feeding on the organic material in manure. Feeding the organisms produces heat, CO_2 and water vapour. During the feeding process most of the easily compostable organic matter is decomposed (Langenberg, 2010). Composting processes are influenced by temperature, carbon / nitrogen ratio, moisture content and pH.

5.2.7 Struvite precipitation

Struvite precipitation is a method for removing phosphorus from anaerobic digestion effluents by recovering it by using crystallization of phosphorus, magnesium, and nitrogen as struvite (magnesium – ammonium - phosphate $MgNH_4PO_4*6H_2O$) which can be used directly in agriculture as a high quality, slow releasing fertiliser. Due to the fact that phosphate and ammonium concentrations are high in anaerobic digestate, magnesium must be added in form of magnesium hydroxide to achieve the required ratio between these elements. The three main components should be kept at a ratio of around 1:1:1 to achieve optimal struvite production based on the chemical equation illustrated below (Li et al., 2012):

$$Mg_2^+ + NH_4^+ + PO_4^{3-} + 6H_2O \rightarrow MgNH_4PO_4 \cdot 6H_2O$$

Struvite production relies on a certain pH level and gets enhanced when the pH value is between 7 and 11. Furthermore the Mg:P ratio plays a vital role in the process because of the limiting factor of Mg. (Burns et al., 2002). Jordan et al. (2010) found that the maximum phosphorus removal rate (80%) can be achieved at pH of 9.0 and at Mg:P ratio of 1.6:1. In addition the scientists stated that purest struvite precipitation was found at pH of 7.5.

5.2.8 Nitrification / denitrification and partial nitrification / anammox

One of the vital aspects of the project is the N removal. Therefore two different technologies are used along the process chain. The combined bioprocess of nitrification-denitrification (NDN) is a usual process for removing nitrogen by the conversion of ammonium (NH_4^+) into innocuous dinitrogen gas (N_2) through nitrate (NO_3^-) as intermediate (Magri et al., 2010). An alternative, which is characterised by significant savings in power requirements for the supplying oxygen during nitrification, considers an alternative nitrogen pathway such as the anaerobic oxidation of ammonia (anammox). The combination of partial nitrification coupled with anammox bacteria has gained a lot of interest as a more sustainable alternative than conventional NDN (Magri et al., 2010).

Conventional nitrification / denitrification

The conventional biological nitrogen removal treatment is done in two process steps which are defined by the complete oxidation of ammonium, under the action of nitrifying bacteria, in addition of sufficient dissolved oxygen, first to nitrite and then to nitrate (nitrification phase). Further, nitrate is reduced to molecular nitrogen in the denitrification phase, with sufficient organic substance, through reduction of nitrate to nitrite and then to N_2 (Progetto, 2011).

Equations for nitrification and denitrification:

Nitrification: $2\ NH_4^+ + 1.5\ O_2 \rightarrow NO_2- + 2H^+ + H_2O$

$NO_2^- + 0.5\ O_2 \rightarrow NO_3^-$

Dentrification: $2NO_3^- + 2NO_2 \rightarrow N_2$

Partial nitrification / anammox

Partial nitrification / anammox (anaerobic ammonium oxidation) are processes for nitrogen removal in ammonium rich wastewaters and consist of two separate processes. First nitrification takes place in which half of the ammonia is converted to nitrite by ammonia oxidizing bacteria according to the following equation:

Partial nitrification: $2NH_4^+ + 1.5\ O_2 \rightarrow NH_4^+ + NO_2^- + 2\ H^+ + H_2O$

Then the resulting ammonium and nitrite are further converted in the anammox process to nitrogen gas as shown below:

ANAMMOX: $NH_4^+ + NO_2^- \rightarrow N_2 + 2\ H_2O$ (simplified equation)

According to Lan et al. (2011), partial nitrification / anammox processes have a potential to remove 85-87% of total nitrogen and around 96% of ammonium bysimultaneous partial nitrification / anammox in a sequential batch reactor. Hao et al.(2004) further found that a total nitrogen removal efficiency of about 90% can be reached partial with nitrification / anammox under stable process conditions. Like conventional nitrification processes, partial nitrifaction is dependent on pH value, dissolved oxygen concentration and temperature. Also the anammox process requires high temperatures for optimal functioning.

When comparing conventional nitrification / denitrification to partial nitrification / anammox processes is has been shown that partial nitrification / anammox provides several advantages and disadvantages.

Advantages:

- During partial nitrification / anammox processes the oxygen demand is greatly reduced due to the fact that only half of the ammonia needs to be oxidised to nitrite instead of the full conversion to nitrate. Further anammox bacteria converts ammonium and nitrite directly to N_2 anaerobically which means that this process does not require aeration and other electron donors (Hu et al., 2013)

- The authothrophic nature of anammox bacteria and ammonia oxidising bacteria guarantee a low sludge production (Hu et al., 2013)

- Costs are reduced up to 60% due to lower energy demand because of only partial nitrification and no denitrifiaction processes (Siegrist et al., 2008)

- No organic carbon source has to be added for denitrification process

- Lower demand of organic substrate (up to 40%)

Disadvantages:

- The disadvantage of Anammox processes is the low bacteria growth rate which can lead to long start – up periods (Malovanyy, 2009)

- Anammox process require high temperatures for optimal functioning (>30°C)

Even though both processes are an effective method for nitrogen removal in wastewaters, both processes produce nitrous oxide (N_2O).

5.3 The “ManureEcoMine” process

In order to depict the processes involved with the “ManureEcoMine” project, this chapter is going to illustrate the general livestock manure characteristics and the products being generated.

5.3.1 Raw input material characteristics

Livestock manure contains a mixture of faeces and urine, and may include wasted feed, bedding and water. Manure characteristics can be affected by diet, growth stage and species of animals, and the manure collection method, including the amount of water added to dilute the waste (Zhang et al., 1997). Animal manures generally contain both, useful compounds that can be further used and compounds which cause threats to human health and the environment. Livestock manures are a good source of nitrogen, potassium, and phosphorus which can be used as a basis for organic fertiliser production. Over applied to soil and water and transformed into other elements these nutrients can cause severe threats to soil, water, air, and humans. In addition manures contain pathogens, antibiotics applied during feeding, hormones and heavy metals which cause risks to the environment and different life-forms. When analysing animal manure, several other factors are illustrated as well in order for better characterisation. Totals solids (TS) concentration , also referred to as dry matter (DM), is necessary information about the amount of solids expressed as a percentage of the overall mass of manure. It is the sum of suspended solids and dissolved solids and can be further comprised of a fix solids portion and volatile solids (VS). For better understanding of what animal manure actually consists of, this chapter is going to give an overview of the mean values found in scientific literatures of different compounds existing in animals manure as well as concentration values already gathered within the “ManureEcoMine” project.

5.3.1.1 Raw input material characteristics based on literature findings

Values found are solely based on literature findings in scientific journals and books and illustrate general animal manure compound compositions and concentrations.

5.3.1.1.1 Nutrients

Feedstock manure is rich in nutrients, which are vital components for crop growth. Around 70-80% of nitrogen (N), 60-85% of phosphorus (P), and 80-90% of the potassium (K) in feeds are excremental in manure and therefore build a basis for sustainable biological fertiliser usage (Herbert et al., 2009). Nitrogen in manure is generally present form of inorganic ammonium-N (NH_4-N) and organic N. Ammonium N is initially present in urine as urea (~50% of total N), whereas organic N must be mineralised to ammonium or converted into nitrate forms first, before it is available to plants. Table 1 shows the mean nutrient contents of various animal sources.

Table 1: Mean nutrient contents of various animal manures (Rosen et al. 2005)

Nutrients					
manure source	**dry matter (%)**	**total Nitrogen [kg/t]**	**NH4-N [kg/t]**	**Phosphorus P_2O_5[kg/t]**	**Potassium K_2O[kg/t]**
swine, no bedding	18	4.5	2.7	4.1	3.6
swine, with bedding	18	2.7	2.3	3.2	3.2
beef, no bedding	52	9.5	3.2	6.35	10.4
beef, with bedding	50	9.5	3.63	8.2	11.8
dairy, no bedding	18	4.1	1.8	1.8	4.4
dairy, with bedding	21	4.1	2.3	1.8	4.5

5.3.1.1.2 Chemical and physical properties

In addition to nutrients, raw animal manure also consist of several chemical and physical properties which are illustrated in table 2.

Table 2: Average characteristics of pig and cattle excrements as percentage of dry matter (Svoboda, 2003)

parameter in % of dry matter	**pig**	**cattle**
organic matter	82	84
suspended matter	86	81
COD	35	40
BOD5	33	20
volatile fatty acids	0.7	0.2

5.3.1.1.3 Pathogens

Livestock manure naturally contains a wide range of bacteria, viruses and protozoa which can be a source of pathogen contamination on crop products intended for human consumption. Most of the bacteria and parasites found in the animal faeces are non-pathogenic and do not pose any threat to humans or animals. Only a small number of animal pathogens in faeces, water and soil have the potential to infect humans and domestic animals. Table 3 illustrates the most relevant pathogens according to their prevalence (Olson, 2001) as percentage of analysed samples.

Table 3: Prevalence of enteric pathogens in cattle and pigs (Olson, 2001)

	cattle (% of tested animals)	**pigs (% of tested animals)**
*Salmonella spp.**	0-13	0-38
*E. coli 0157:H7**	16	0.4
*Campylobacter jejuni**	1	2
*Yersinia enterocolitica**	<1	18
*Giardia lamblia***	10-100	1-20
*Cryptosporidium spp.***	1-100	0-10

*Bacteria, **Protozoa

Pathogen survival durations depend on the pathogen type on the one hand side and on external conditions on the other hand side. Table 4 gives an overview of relevant pathogens and their survival rate in different media and environmental conditions.

Table 4: Survival of animal faecal pathogens in the environment (Olson, 2001)

material	**temp**	**duration of survival**					
		Giardia	***Cryptosporidium***	***Salmonella***	***Campylobacter***	***Yersinia entercolitica***	***E.coli O157: H7***
water	frozen	< 1day	> 1year	> 6months	2-8 weeks	> 1year	> 300 days
	Cold(5 C°)	11 weeks	> 1year	> 6 months	12 days	> 1year	> 300 days

	warm (30C°)	2 weeks	10 weeks	> 6 months	4 days	10 days	84 days
soil	frozen	< 1day	> 1 year	> 12 weeks	2-8 weeks	> 1year	> 300 days
	cold(5C °)	7 weeks	8 weeks	12-28 weeks	2 weeks	> 1year	100 days
	warm (30C°)	2 weeks	4 weeks	4 weeks	1 week	10 days	2 days
cattle feces	frozen	< 1day	> 1year	> 6 months	2-8 weeks	> 1year	> 100 days
	cold(5C °)	1wee k	8 weeks	12-28 weeks	1-3 week	30-100 days	> 10 days
	warm (30C°)	1wee k	4 weeks	4 weeks	1 week	10-30 days	10 days
slurry		1 year	> 1 year	13-75 days	>112 days	12-28 days	10-100 days
compo st		2 weeks	4 weeks	7-14 days	7 days	7 days	7 days
dry surfac es		1 day	1 day	1-7 days	1 day	1 day	1 day

Appendix 2 further gives an even more detailed enumeration of pathogens in terms of bacteria, fungi, protozoa, and helminths. Even though table 4 shows most commonly occurring human pathogens in animal manure, a further determination has to be done in terms of parasitic pathogens such as Giardia and Cryptosporidium, bacterial pathogens like Salmonella, E. Coli, Campylobacter, and Yersinia Enterocolitica.

5.3.1.1.4 Antibiotics

Veterinary antibiotics are used as animal feed supplements in order to promote productivity and animal growth and help counteracting the effects of crowded living conditions and poor hygiene in intense animal agriculture. Around 50- 90% of the added antibiotics are excreted in urine and faeces by the animals because they cannot be utilized by the animals. A large number of these Antibiotics remain potent in the manure for a considerable period and therefore can be deployed into the soil as a result of fertilization. Therefore potential human risk can be associated with consumption of vegetables grown in soil amended with antibiotic laden manures (Sikka, 2011). In Addition systematic large scale usage of antibiotics increases the number antibiotic resistance which leads to even higher rate of bacteria remaining in the manure. Table 5 shows commonly used antibiotics in animal feeding.

Table 5: Most common used veterinary antibiotics according to European Federation of Animal Health (Follet, 2000)

product group	**% share of application**
Penicillins	9
Tetracyclines	66
Macroloides	12
Aminoglycosides	4
Flourchinolones	1
Trimethprim / sulphas	2
Others	6

Appendix 1 further shows explicit antibiotic drugs commonly used in cow and pig livestock farming.

Masse et al. (2014) studied the treatment methods of veterinary antibiotics in animal manure and thereby published potential concentrations in animal manure as shown in table 6.

Table 6: Concentrations of veterinary antibiotics in animal manure (Masse et al. 2014)

antibiotic	**matrix**	**concentration (mg/L^{-1})**
Oxytetracycline	manure	136 (mg/L^{-1})
Chlortetracycline	-,,-	46 (mg/L^{-1})
Tetracycline	swine manure	98 (mg/L^{-1})
Oxytetracycline	-,,-	354 (mg/L^{-1})
Chlortetracycline	-,,-	139 (mg/L^{-1})
Doxycycline	-,,-	37 (mg/L^{-1})
Sulfadiazine	-,,-	7.1 (mg/L^{-1})
Tetracycline	swine manure	30 (mg/kg^{-1} DM)
Sulphonamides	-,,-	2 (mg/kg^{-1} DM)
Tylosin	fresh calf manure	0.11 (mg/kg^{-1})
Oxytetracycline	-,,-	10 (mg/kg^{-1})
Chlortetracycline	beef manure	6.6 (mg/kg^{-1})

Monesin	-,,-	120(mg/kg^{-1})
Tylosin	-,,-	8.1(mg/kg^{-1})
Oxytetracycline	cow manure	0.5-200(mg/L^{-1})
Chlortetracycline	swine manure	764.4(mg/L^{-1})
Chlortetracycline	swine manure storage	1(mg/L^{-1})
Oxytetracycline	lagoon	0.41(mg/L^{-1})

In addition Masse et al. (2014) studied half-life periods of veterinary antibiotics under storage and environmental conditions. These are illustrated in table 7.

Table 7: Half-life periods of veterinary antibiotics und different environmental conditions (Masse et al., 2014)

antibiotic	**medium matrix**	**half-life time in days**
Tetracycline	Biosolids storage	37 to >77
Tetracycline	Stored feedlot manure	17.2
Chlortetracycline	Composted manure	3
Chlortetracycline	Dairy manure	6.8
Chlortetracycline	Stored feedstock manure	13.5
Oxytetracycline	Stockpiled fresh manure	21
Oxytetracycline	Dairy manure	17.7
Oxytetracycline	Stored feedlot manure	31.1
Oxytetracycline	Horse manure	8.4
Tylosin	Aerobic soil-manure slurry	3.3-8.1
Olaquindox	Aerobic soil-manure slurry	5.8-8.8
Metronidazole	Aerobic soil-manure slurry	13.1-26.9
Erythromycin	Storage of pig manure	41
Erythromycin	Biosolids storage	7-17
Roxithromycin	Storage of pig manure	130
Roxithromycin	Storage of pig manure	6

Last but not least table 8 shows the results Masse et al. (2014) gathered while adapting findings from Boxall et al. (2004) in terms of persistence of major classes of antibiotics in manure.

Table 8: Persistence classes of animal manures (Masse et al. 2014)

chemical group	**half-life in days**	**persistence class**
Aminoglycosides	30	Moderately persistent
ß-lactams	5	Slightly persistent
Macrolides	< 2 to 21	Impersistent to slightly persistent
Quinolones	100	Very persistent
Sulphonamides	< 8 to 30	Slightly to moderately persistent
Tetracycline	100	Very persistent

5.3.1.1.5 Hormones

Hormones are naturally synthesized in endocrine systems of all mammals and regulate metabolic activity and development processes. To improve animal growth and meat quality, livestock animals are often treated with additional natural and synthetic exogenous hormones. Table 9 therefore gives an overview of widely used natural and synthetic hormones.

Table 9: Overview of natural and synthetic hormones and their functional purpose (EPA, 2013)

natural hormones		
hormone	**select hormone metabolites**	**purpose**
Estrogens	Estrone, 17ß-estradiol, and estriol	Stimulates and maintains female characteristics
Androgens	Testosterone, Androsterone, Dehroepiandrosterone, 4-Androstenedione	Stimulates and maintains mal characteristics
Progestogens	Progesterone	A metabolic precursor to estrogens
synthetic hormones		

synthetic hormone	mimics the behaviour of which natural hormone metabolite	purpose
Zeranol	17ß-estradiol	Used to improve feed and animal growth
Trenbolone acetate	Testosterone	Used to improve feed and animal growth
Melengestrol acetate	Progesterone	Administered as a feed additive, Used to improve feed efficiency and animal growth

The total amount of hormones excreted by livestock varies by animal type, season, diet, age, gender, breed, health status, reproductive rate, and whether or not the animal is castrated. Therefore table 10 shows the differences of hormone excretions between swine and cattle in terms of hormone excretion compared to total affiliation.

Table 10: Estimated percentages of excreted hormones compared to affiliation amount (EPA, 2013)

animal type	estrogens	androgens	progestogens	total
cattle	92.7%	43.7%	92.0%	91.5%
swine	1.7%	8.0%	8.0%	7.1%

5.3.1.1.6 Heavy metals

Animal excretes contain among others concentrations of heavy metals. Table 11 illustrates the differences in various types of manures and animals.

Table 11: Mean heavy metal concentrations in animal manure measured in (mg/kg dry matter) (Nicholson et al., 1999)

manure type	Zn	Cu	Ni	Pb	Cr	As	Cd
dairy solid manure	145	31.4	2.8	2.24	2.58	1.15	0.42

dairy slurry	176	51	5,5	4.79	5.13	1.09	0.20
beef solid manure	63	15.6	2.1	1.4	1.5	0.71	0.14
beef slurry	132	30.9	3.3	5.8	2.62	0.98	0.22
pig dry manure	387	346	5	2.83	1.87	0.73	0.68
pig slurry	403	364	7.8	1	2.44	1.33	0.3

5.3.1.1.7 Odours

Odour gasses are intermediates or end- products produced by anaerobic microorganisms in manure. A number of volatile (~ over 200) are thought to contribute to odour of animal manures. Volatile compounds can be sub-divided into general groups of volatile amines, sulphides, disulphides, organic acids, phenols, alcohols, carbonyls, nitrogen heterocycles, esters, fixed gases, and mercapants. According to Hobbs et al. (1995), volatile organic compounds are the primary odour causing compounds from farm wastes. These are illustrated in table 12.

Table 12: List of odorous volatile compounds in animal manures (Hobbs et al., 1997)

Acetic acid
Pranoic acid
Butanoic
3-Methyl butanoic acid
Phenol
4-Methyl phenol
Indole
Dimethyl sulphide
Dimethyl disulphide
Dimethyl trisulphide
Hydrogen sulphide

5.3.1.1.8 Volatile organic compounds (VOC‘s)

Volatile organic compounds originate from the degradation of amino acids in the intestines of animals and anaerobic decomposition of manure and can be classified into many different chemical groups including acids, alcohols, aldehydes, amines, hydrocarbons, ketones, indoles, phenols, N-containing compounds, S-containing compounds (Koziel et al.,2010).

5.3.1.1.9 Mycotoxins & pesticides

No evidence of mycotoxins and pesticides was found during literature review. Also testing within the “ManureEcoMine” project did not result in findings of mycotoxins or pesticides. Therefore these trace pollutants have not been considered as relevant throughout the thesis.

5.3.1.2 Recent “ManureEcoMine” raw input material characteristics

Results of already gathered data in the course of the “ManureEcoMine” project

5.3.1.2.1 Nutrients

Samples have been taken over a period of several months in order to determine the amount of nutrients available in raw cow and pig manure. Table 13 & 14 therefore shows gathered results.

Table 13: Nutrient contents of gathered “ManureEcoMine” data (1)

manure	sample	TKN (mg N/L^{-1})	TAN (mg N/L^{-1})	NO_3^- N (mg N/L^{-1})	NO_2^- (mg N/L^{-1})
cow	23/12/13	3422 +/- 50	1328 +/- 172	< d.l.	< d.l.
cow	15/01/14	3356 +/- 138	1079 +/- 160	12.1 +/- 8.3	< d.l.
cow	14/02/14	3265 +/- 18	2099 +/- 107	< d.l.	12.9
cow	25/02/14	4015 +/- 27	2009 +/- 23	19.5	< d.l.
cow	06/03/14	4829 +/- 133	2297 +/- 99	n.d.	n.d.
pig	no. 1	5298 +/- 165	4251 +/- 820	10.8 +/- 4.2	16.9 +/- 5.1
pig	no. 4	6579 +/- 27	4118 +/- 57	9.6 +/- 2.6	15 +/- 2.4

pig	no. 9	3990 +/- 320	2912 +/- 282	< d.l.	14.9 +/- 0.1

n.d.: not determined. <d.l.: below detection limit

Table 14: Nutrient contents of gathered “ManureEcoMine” data (2)

manure	sample	TP (mg N/L^{-1})	PO_4^{3-} N (mg P/L^{-1})	K^+ (mg K^+/L^{-1})
cow	23/12/13	510 +/- 119	226.1 +/- 30.7	4674 +/- 491
cow	15/01/14	494 +/- 231	303.7 +/- 13.1	2087 +/- 55.4
cow	14/02/14	635 +/- 5	n.d.	2186 +/- 31
cow	25/02/14	582 +/- 98	n.d.	2160 +/- 260
cow	06/03/14	459 +/- 4	n.d.	n.d.
pig	no. 1	1497 +/- 160	694.3 +/- 129	4221 +/- 178
pig	No. 4	1374 +/- 430	745.3 +/- 160	4115 +/- 34.7
pig	No. 9		932.6 +/- 15.8	5081 +/- 14.1

n.d.: not determined. <d.l.: below detection limit

5.3.1.2.2 Chemical and physical properties

In addition, chemical and physical properties have been measured which are illustrated in table 15.

Table 15: Chemical and physical properties

manure	sample	tCOD (g O_2/kg^{-1})	$tBOD_5$ (g O_2/kg^{-1})
cow	23/12/13	40 +/- 3	15 +/-1
cow	15/01/14	52 +/- 1	21 +/- 0
cow	14/02/14	41 +/- 2	26 +/- 0
cow	25/02/14	66 +/- 2	23 +/- 0
cow	06/03/14	87 +/- 4	25 +/- 4

pig	no. 1	684 +/- 8	3.4 +/- 1.5
pig	no. 4	67 +/- 3	3.5 +/- 1.6
pig	no. 9	65 +/- 1	5.5 +/- 1.2

5.3.1.2.3 Heavy metals

Table 16 shows heavy metal concentrations already gathered throughout the “ManureEcoMine” project.

Table 16: Heavy metal concentrations of gathered “ManureEcoMine” data

manure	sample	Cr (mg/kg^{-1})	Ni (mg/kg^{-1})	Cu (mg/kg^{-1})	Zi (mg/kg^{-1})	As (mg/kg^{-1})	Ca (mg/kg^{-1})	Pb (mg/kg^{-1})
cow	23/12/13	0.2	0.23	2.9	16.8	0.05	0.01	0.53
cow	15/01/14	0.19	0.22	2.9	16.2	0.05	0.01	0.52
pig	no. 1	0.45	0.53	18.2	74.9	0.08	0.03	0.23
pig	no. 4	0.46	0.55	17.7	71.9	0.08	0.03	0.23
pig	no. 9	0.67	0.81	24.9	105	0.12	0.46	0.27

5.3.1.2.4 Co-substrate composition

In order to identify optimal co-substrate material, the BALSA institute analysed seven co-substrate products:

- Bioiberica fat
- Segragates
- Corn
- Maize silage
- EcoFrit (supermarket mix)

Due to the fact that different co-substrate material change the characteristics of the anaerobic digestion process, the differences of various co-substrates in terms of nutrient contents, chemical and physical characteristics are illustrated in table 17.

Table 17: Co-substrate characteristics by LEQUIA, UGent-LabMET and LVA

co-substrate	TKN (mg N/ kg^{-1})	N-NH_4^+ (mg N/ kg^{-1})	N-NO_3^- (mg N/ kg^{-1})	P-PO_4^{3-} (mg P/ kg^{-1})
bioiberica fat (dry)	29216 +/- 7061	-	-	-
bioiberica fat (moist)	*16413 +/- 1934*	-	*160.6*	-
corn	*6320 +/- 678*	*675 +/- 50*	-	-
segregates	-	*0.9 +/- 0.1*	*1.2 +/- 0.3*	*4.7 +/- 1.1*
maize silage	-	-	*20554.5 +/- 528.9*	-
vegetable waste	-	-	-	*89.1 +/- 9.9*

5.3.2 Comparison of already gathered “ManureEcoMine” data to literature findings

Manure characterisation has been done on behalf of literature findings based on scientific literature, trying to figure out mean values for manure compounds. Based on the fact that the “ManureEcoMine” project has already started first results are available already. A collaboration of scientific institutes including the Laboratory of Chemical Engineering (LEQUIA), the University of Gent Laboratory of Microbial Ecology and Technology (UGent-LabMET), and LVA GmbH aim to characterise various sorts of animal manures as potential input material for the “ManureEcoMine” process as well as optimal co-substrate combinations for anaerobic digestion. By comparing already gathered results with literature findings a general statement about whether used input material equals literature findings or not can be done.

Table 18: Comparison of literature findings and “ManureEcoMine” gathered data (1)

manure	pH	EC (mS/cm^{-1})	Alkanity (g CaCo/L^{-1})	TSS (gTSS/L^{-1})	VSS (g VSS/L^{-1})	source
cow	7.39-7.51	27-28	14.0-14.2	20.3-51.8	19.1-48.8	ManureEcoMine
cow	6.9-7.6	-	8-13	30-126	26-102	Barret et al. (2013)
pig	8.03-8.21	29.9-31.9	28.5-30.7	-	-	ManureEcoMine

pig	6.6-6.9	-	7.6-17	5.2-136	4.2-81	Mondor et al. (2008)
pig	7.24-7.72	22.9-30.9	15.2-20.7	26.6-32.1	17.8-24.5	Chelme-Ayala et al. (2011)

Table 18 shows a variation of raw manure compositions throughout various scientific findings. While pH values of measured cow samples are within a certain range, pig pH values of “ManureEcoMine” gathered samples on the other hand side tend to be higher than literature findings. In addition measured electrical conductivity and alkanity is by trend higher than literature findings by Mondor et al. (2008) and Chelme-Ayala et al. (2011). Comparing measured cow samples it can be concluded that total suspended solids (TTS) and volatile suspended solids (VSS) values are below those found in scientific literature while pH and alcanity tend to be higher than literature findings.

Table 19: Comparison of literature findings and “ManureEcoMine” gathered data (2)

manure	**tCOD (g COD/L^{-1})**	**BOD_5 (g BOD/L^{-1})**	**BOD_u (g BOD/L^{-1})**	**TKN (mg N/L^{-1})**	**TAN^+ (mg N/L^{-1})**	**source**
cow	41-87	23-26	35	3265-4829	2009-2297	ManureEcoMine
cow	71-237	-	-	2600-5300	1500-2100	Barret et al. (2013)
pig	65.3-68.4	3.4-5.5	9.4-10.6	3990-6579	2912-4118	ManureEcoMine
pig	27-194	-	-	2100-3800	400-1800	Mondor et al. (2008)
pig	-	-	-	4580-6740	3710-5540	Chelme-Ayala et al. (2011)

As showed in table 19, the levels of COD, BOD, TKN, and TAN^+ do fit the literature findings.

Table 20: Comparison of literature findings and “ManureEcoMine” gathered data (3)

manure	PO_4^{3-} (mg P/L^{-1})	Mg^{2+} (mg Mg^{2+}/L^{-1})	K^+ (mg K^+/L^{-1})	Ca^{2+} (mg Ca^{2+}/L^{-1})	source
cow	226.1-303.7	468.1-482	2160-2186	931.2-948.1	ManureEcoMine
cow	-	-	2700-3200	-	Barret et al. (2013)
pig	694-933	334-376	4115-5081	377-396	ManureEcoMine
pig	-	-	1600-2200	-	Mondor et al. (2008)
pig	-	-	2130-2610	-	Chelme-Ayala et al. (2011)

Due to lack of information not all in table 20 illustrated compounds can be compared accurately. Nevertheless one major difference has been determined - concentrations of K^+ in “ManureEcoMine” samples are far beyond values found in literature findings.

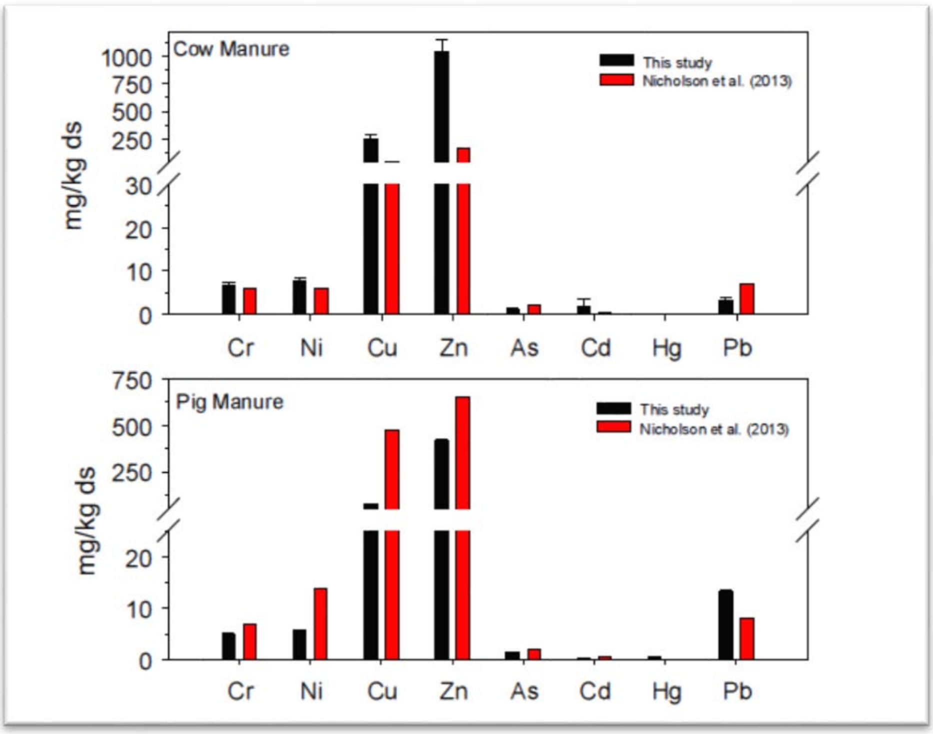

Figure 4: Comparison of heavy metal concentrations of literature findings and “ManureEcoMine” gathered data

Figure 4 illustrates two significant trends within heavy metal concentrations in raw input manure. Heavy metal concentrations in cow manure tend to be higher in “ManureEcoMine” samples while at the same time “ManureEcoMine” pig samples mostly do have lower heavy metal concentrations.

5.4 Product description

Products produced during the “ManureEcoMine” project can be distinguished into bio fertilisers / soil conditioner on the one hand side and biogas on the other hand side.

5.4.1 Organic fertilisers

Potassium struvite ($KMgPO_4·6H_2O$) and ammonium struvite ($NH_4MgPO_4·6H_2O$)

Ammonium struvite ($NH_4MgPO_4·6H_2O$): A bioavailable, slow- release fertiliser which contains of minimum 4% N, 30% P_2O_5, 8% Mg, and has a moisture content of ~ 2-3%. Potassium struvite contains at least 14, 67% potassium, 9-12% magnesium, and 11-62% phosphorus. The major characteristics of struvite fertilisers are its bio-availability which means it can be readily absorbed by the plant, its slow-release function which guarantees a slow but steady nutrient supply, and its high purity which means that struvite contains only little contaminates. Abma et al. (2010) conducted a heavy metal analysis of struvite produced at a pilot plant in Olburgen and found that heavy metal concentrations in struvite are negligible and do not threat any harm to nature. The heavy metal contents were measured in (mg/kg P) and compared to European standards. Table 21 shows measured heavy metal concentrations and comparison to European standards by illustrating measured values relative to allowed values.

Table 21: Heavy metal concentrations in struvite in comparison to european standards (Abma et al., 2010)

	Cd	Cr	Cu	Hg	Ni	Pb	Zn	As
EU Standards (mg/kg P)	31	1875	1875	19	750	2500	7500	375
struvite product (mg/kg P)	0.9	17	42	<0.3	26	6.6	336	<6
relative to allowed value	3%	1%	2%	<2%	3%	0%	4%	<2%

Ammoniumsulfate ($(NH_4)_2SO_4$)

Ammoniumsulfate ($(NH_4)_2SO_4$): Ammoniumsulfate is an odourless white / grey crystal-like soluble, readily available source on nitrogen and sulphur. It contains 21% nitrogen and 24% sulphur. According to EEC Directive 67/548/EEC it is classified as a non-hazardous material (Weiss et al., 2009).

5.4.2 Biogas

Biogas is characterised based on its chemical composition and the physical characteristics which result from it. It consists of 50-75% Methane (CH_4), 25-50% Carbon Dioxide (CO_2), 0-10% Nitrogen (N_2), 0-1% Hydrogen (H_2), 0-3% Hydrogen sulphide (H_2S), as well as 0-2% Oxygen (O_2) and can be fed into the gas grid directly, transformed to bio fuel, or converted into heat and electricity in combined heat and power units.

5.4.3 Composted solid digestate fertiliser

Threshold values concerning potential hazardous like heavy metals or pathogen as well as application rates vary throughout countries and are not standardised throughout all EU member states yet. Even though there already exists a draft for an EU bio waste directive for standardising threshold values etc., it has not been legally implemented yet (Hogg et al., 2002). Nevertheless compost for biological agriculture can be distinguished based on harmful matter (heavy metals concentrations), on hygienic aspects, and on undesired ingredients.

5.4.4 Effluent used as potassium fertiliser

Treated liquid digestate still contains a diverse range of nutrients and can be used as so called “fertigisers”. “Fertigisers” or liquid fertilisers can be applied by using irrigation systems. Fine filtering might be necessary in terms of irrigation application due to potential blockage of feeder pipes. As with a fertiliser containing plant nutrients, liquid digestate should only be used if there exists an agronomic demand, in certain locations and on certain types of soil. In addition, it should only be applied in accordance with good agricultural practice as part of an integrated fertiliser programme (Adkins, 2013).

6. Risk management according to ISO 31000:2009

6.1 Establishing the context

Establishing the context defines the basic parameters for managing risk and sets the scope and criteria for the rest of the process. Therefore internal and external relevant parameters have to be considered and need to be analysed. In addition, the process of establishing the context defines risk assessment objectives, and classification of risk criteria.

6.1.1The external context

Companies but also projects are influenced by external factors that limit and constrain the scope of the project implementation. Therefore a PEEST analysis can be conducted in order to illustrate the boundaries and potential behaviour during project operation. PEEST is an acronym that stands for Political / Legal ,Economic, Environmental, Social, and Technological factors that could affect industries, companies and even single projects.

PEEST analysis

Political / legal aspects: The “ManureEcoMine” is influenced by political and legal issues on two levels. On the on hand side the European Union as well as its member states are encouraged to use the enormous potential of livestock manure for bioenergy as well as for organic fertiliser as an green alternative to existing products. On the other hand side environmental protection in terms of greenhouse gases (EU Climate Policy), soil, water, and health protection (EU Water Framework Directive, Nitrate Directive, Water Quality Act, REACH regulations …) gain more and more interest. More and more EU regulation are being published in order to determine product quality for manure based products (EU fertiliser directive, EU end of waste directive, EU Compost regulations,….) as well as environmental regulations have to be met in terms of national environmental protection goals.

Economic aspects: Biogas production rates from livestock manure have risen massively throughout the last 20 years and have become a viable alternative to fossil resources. In addition, by-products of the biogas production process can be further treated and then used as fertilisers or soil conditioner, meeting the same quality standards as conventional products. Therefore manure possesses the potential to be economic reasonable in terms of producing products for two different market segments and sectors.

Environmental aspects: Livestock manure contains potential hazardous compounds that can threaten the environment as well as life forms. Used technologies have the potential to transform or remove those compounds and therefore reduce the potential impacts that may occur if manure is not treated properly and just used as landfill or simply used untreated. Therefore using potential hazardous input material and producing non-hazardous output materials helps to avoid or at least minimise harmful environmental impacts.

Social aspects: Society has changed drastically since the middle of the 20th century. People now are more aware of how important sustainability is and how human behaviour can help to maintain a healthy environment. Therefore trends can be seen in terms of willingness to use renewable energies; if possible people even produce it themselves. People are further willing to use electricity produced from biogas even if it might by more expensive than atomic energy. In addition, it has become more likely that organic fertilisers which originate from animal manure are used instead of industrial chemical fertilisers.

Technical aspects: Technical innovation during the past decades makes it possible to treat and reuse manures in a way that environment and economy can profit from it. During the “ManureEcoMine” project various state of the art technologies are used to eliminate potential hazardous input material compounds in order to guarantee high quality end products and the lowest possible impact to the environment. Therefore it has to be determined if the combination of used technologies is the best available or if other technologies might lead to an even better outcome.

6.1.2 The internal context

The internal context refers the internal project environment and considers the project objective, the scope, stakeholder interests as well as used strategies. In terms of the “ManureEcoMine” project the scope is to determine if the chosen variation of state of the art technologies is capable of succeeding 3 goals:

- Minimising environmental related risks
- Reaching quality standards for placing produced products on the relevant markets
- Analysing if used procedure is economically reasonable

6.1.3 Definition of risk criteria

Risk criteria need to be defined in order to gain a common understanding of how to evaluate the significance of a risk. Table 22 shows a potential characterisation of risk criteria including the creation of defined consequence and likelihood levels and their combination in a risk matrix for risk evaluation and management.

Table 22: Risk criteria characterisation

risk criteria	used for
consequence levels: the scale you will use to assess consequences of a risk	risk analysis
consequence table: a matrix where consequence levels are described for different types of consequences	risk analysis
likelihood table: the scale you will use to assess the likelihood of a risk	risk analysis

control effectiveness: the scale you will use to assess risk control	risk analysis and evaluation
risk matrix: a technique used to combine consequence and likelihood to determine the level of a risk.	Risk analysis
risk tolerance table: defines your response to risk depending on whether or not you accept or tolerate the risk	risk evaluation

Based on risk assessment techniques listed in ISO 31010, qualitative consequence levels ranging from low to very high and describing potential environmental risks as well as process failure can be applied. Table 23 shows the potential consequence level which can be used for the "ManureEcoMine" project. Consequence types have been divided into two types: Environmental risks and process failure due to the fact that along the process scheme risks can either occur during varies process steps and/or having effects on the environment.

Table 23: Defined consequence types and consequence levels

consequences type	**consequence level**		
	low	**high**	**extreme**
environmental risks	Identified risks are within determined legal value thresholds	Exceeding of defined threshold values, threat to environment is possible	Identified risk levels are far beyond legal thresholds. Catastrophes are probable due to high levels.
process failure	Identified risks do not to affect process performance	Risks affecting processes and lead to decreased performance and potentially process fail but still no harm to the environment arises	Complete system failure combined with resulting environmental disasters.

Based on the same principle a likelihood table has to be established for describing the chance of risks happening. Table 24 illustrates the likelihoods related to the project.

Table 24: Defined likelihood table for the project

likelihood table	
likelihood table	**frequency**
certain	The event is expected to occur every time
almost certain	The event is probably happening most of the times
likely	The event is likely to occur in more than 50% of the times
possible	The event may happen as a summary of coincidences
rare	The event is generally no happening

Further also the effectiveness of existing control measures has to be defined for evaluating the capability of existing control measures in terms of effectiveness. Table 25 therefore shows the control effectiveness table.

Table 25: Defined control effectiveness table for the project

control effectiveness table	
level of effectiveness	**operational effectiveness**
substantially effective	Operational effective controls means that process controls are capable of reducing potential hazardous manure compounds to a legally acceptable level. In addition substantially effective control leads to a function process scheme and minimises potentially process failure.
partially effective	Controls are reducing occurring risks, but not a legally defined level. Control effect is not hundred percent given.
largely ineffective	Control measures are not capable of treating input material properly which leads to infective input material treatment. In addition, hazardous compounds levels have not been reduced properly.

For determining a risk level both, defined consequences and likelihood levels have to be combined by forming a risk matrix. For this study, risks are going to be categorised as low, high, or extreme, and provide information about what kind of action is required. Extreme risks cannot be tolerated and requires immediate treatment not matter how high the costs are. Extreme consequence levels occur if defined legal threshold are highly exceeded. Risks are identified as high if legally defined thresholds are exceeded. Low consequence levels mean that concentrations remain within defined threshold levels. Table 26 shows the defined likelihood / consequence matrix.

Table 26: Determined likelihood / consequence matrix

		consequence		
		low	**high**	**extreme**
likelihood	**certain**	high	high	extreme
	almost certain	low	high	extreme
	likely	low	high	extreme
	possible	low	high	high
	rare	low	low	high

Last but not least, tolerances need to be defined for making adequate decisions about whether risks need to be treated or can be accepted. Table 27 therefore illustrates the defined risk tolerance table.

Table 27: Defined risk tolerance table

risk tolerance table	
action required	Unacceptable risks that cannot be tolerated because their consequences, couples with their likelihood, are unacceptable high. In terms of this study action are required when thresholds are exceeded and required output quality is not given. Reconsideration of existing controls and potential alternatives is required.
potential action	Risks may be tolerate at their current levels if existing control measures do not have the optimal output but alternative state of the art technologies are not available not are not useable in a feasible economic way.
no action required	Risks do not exceed legal threshold. Current control measure reduces risks to a level below risks thresholds.

6.2 Risk assessment

Risk Assessment in the “ManureEcoMine” project is going to be based on three major columns: environmental risks related to the compounds raw manure and their influence on the environment and life-forms, environmental risks, especially emissions, occurring during the production process of organic fertilisers and biogas, and process failure along the process scheme.

6.2.1 Risk identification

The first step, the risk identification, includes the finding, recognising, register and listing of relevant risks. Identified risks can be distinguished into risks occurring from the raw input material compounds reaching the environment, dangerous by-products arising during each process step and the influence of raw manure compounds on these processes. For identifying relevant risks the ISO 31010 guideline provides several potential tools. In this study a HACCP Analysis has been done in order to identify hazards and risks related to the process scheme. Based on the gathered information a risk catalogue has been formed, identifying relevant risks and potential consequences.

6.2.1.1 Risks related to raw manure

Raw livestock manure consists of far more than just animal excrements. It includes valuable nutrients which can be used for agricultural usage but also traces of heavy metals, antibiotics given during livestock farming, human pathogens, natural and synthetic hormones, as well as odours compounds. These substances may face threats to the environment if not treated properly but may also occur alongside the process scheme as drawback compounds resulting in reduced control effects and process failure. Table 28 therefore shows a detailed listing of potential risks occurring from raw livestock manure. In terms of the “ManureEcoMine” project, particular attention is going to be paid on heavy metals and antibiotics concentrations due to their relevance for projects end product

Table 28: Risks related to raw animal manure

nutrients
- N: Nitrogen can be present in various forms and can pollute water, soil, air and also harm humans and animals. o Nitrogen applied to soil gets converted to nitrate by the soil's aerobic environment. Nitrate then percolates into deeper soil layers and contaminates ground water, which is often used as a drinking water source. High nitrate levels in water may also cause human health threats (e.g. methemoglobinemia for infants). o Ammonia volatilisation occurs in manure due to hydrolysing the nitrogen in urea can form airborne nitrate particles which can serious have effects on human health (EPA, 2001). o Under anaerobic conditions, methane (CH_4) can be formed by microbial degradation of organic matter or dinitrogen gas by nitrification / denitrification processes. Also Hydrogen sulphide and other reduced sulphur compounds can be produced when manure decomposes anaerobically .All of them act as air pollutants and can harm nature and humans (EPA, 2001). - P: Excess phosphorus in soils can be converted into water insoluble forms, which are then attached to soil particles and can erode into lakes, streams, and rivers. This can lead to eutrophication, an abnormal growth algae and aquatic weeds which is detrimental to fish populations due to a decline in oxygen levels
pathogens
Pathogens can be transmitted to humans directly through contact with animal and animal's wastes or indirectly through contaminated water of food. Water can be contaminated by runoff either from livestock facilities or from excessive land application of manure. Pathogens can remain in untreated manure and deployed (Spiehs et al, 2007).
antibiotics
Antibiotics remain in livestock manure and may enter, soil, water and further also humans by vegetable consummation. Usage of antibiotics to prevent or treat common production diseases in intensive farming lead to antibiotic-resistance bacteria that colonise farm animals and can be transmitted to people in food through the environment. Infected people therefore can be treated more difficult due to resistance of these bacteria (FAO, 2011).
hormones
Hormones and their metabolites present in manure can enter aquatic ecosystems through runoff from pasture and rangeland used by grazing cattle and cropland fertilised with manure, as well as via leaks / overflow from manure lagoons. Hormones are endocrine disrupting compounds and therefore potentially adverse impacts of aquatic organism exposure to manure. More specific, hormones can affect the reproductive biology, physiology, and fitness of fish and aquatic organisms.
heavy metals
Excessive heavy metal concentrations from animal manures make affect the good functioning of soils by crops contamination and cause health risks to both livestock and humans. Heavy metals can accumulate in soils with repeated fertiliser applications and

contaminate soils or get further transported within agricultural products and enter the human bodies where they can cause serious health issues (Lupascu et al., 2009).
odours
Threats arising from odours compounds can be distinguished into two categories. One the one hand side odorous nuisance leads to aggregation of life quality in the area surrounding livestock farms and manure storage facilities and on the other hand side the effects of individual odorous gases has to be considered. Ammonia for example is not as offensive as some other odours, but if continuously breathed at sufficient concentrations, it can cause serious health effects. Also Hydrogen sulphide concentrations can cause health effects (e.g. lung tissue oedema) (Cromwell, 1998).

6.2.1.2 Process related risks

Along the process scheme several risks possibly arise being either related to the raw input materials affecting process steps or risks occurring through used technologies itself. Described risks do not include storage or transport processes of used materials, assuming that risks can only occur if storage and transport are not done properly.

6.2.1.2.1 Risks related to anaerobic digestion

In addition to risks related to the raw input material there also exist several risks while running the anaerobic digesters. Table 29 therefore shows potential risks potentially occurring throughout the anaerobic digestion process.

Table 29: Risks related to anaerobic digestion

inhibition of anaerobic digestion by ammonia
Ammonia is present in the form of the ammonium ion (NH_4^+) and free ammonia (NH_3), of which the free ammonia (FA) is suspected to be the main cause for inhibition. The free ammonia concentration depends mainly on three parameters: the total ammonia concentration, temperature and pH. Ammonia inhibition is especially distinct when digesting animal manure, especially swine manure, which often contains total ammonia concentrations higher than 4 g/l (Hansen et al., 1998). The process of inhibition is based on the toxicity of ammonia to acetoclastic methanogens, which are essential “biogas generating” organisms. Inhibition of total ammonia can lead to a chronic inhibition which leads to a decrease in methane production between 40-60 % at concentrations of 4g/l to 6g/l. Total concentration of 8-13 g/l can cause 100% inhibition effects (Sung et al., 2003). In addition ammonia inhibition leads to an increase in the volatile fatty acids concentration due to lower methane production. This further leads to in decrease in pH during the anaerobic digestion process (Angelidaki et al., 1993).

inhibition of anaerobic digestion by heavy metals
During anaerobic processes heavy metals can be stimulatory, inhibitory, or even toxic in biochemical reactions depending on their concentrations. A trace level of many heavy metals is required for the activation and for functioning of many enzymes and co-enzymes during anaerobic digestion, mostly due to the chemical binding of heavy metals to enzymes and microorganisms. Based on studies done by Mudhee et al.(2013), copper, nickel, zinc, cadmium, chromium, and lead have been overwhelmingly reported to be inhibitory and under certain conditions toxic, depending on their concentrations. According to Swanswick et al. (1969), heavy metal toxicity is one of the major causes of digester upset or failure. Heavy metals can disrupt enzyme function and structure by binding of metals with protein molecules or by replacing naturally occurring metals in enzyme prosthetic groups. The severity of heavy metal inhibition depends upon factors like metal concentration in soluble, ionic form in the solution, type of metal species, as well as on digester operation parameters. Heavy metals affect acetogenesis and methanogenesis during anaerobic digestion resulting in lower biogas production output. Lin (1992) found that heavy metals, especially chromium, cadmium, lead, copper, zinc, and nickel affect volatile fatty acid degradation during the acetogenesis stage, ranking cadmium and copper the most and lead and nickel the least toxic heavy metals. At dosages > 20mg /l cadmium, inhibited acidogenisis, while Chromium already reduces volatile fatty acids and alcohol generation at values of 5mg/l leading to a severe inhibition on the acidogenesis. Inhibition also occurs during methanogenesis, but not as fast and not as severe as during acitogenesis. Based on studies of Zayed et al. (2000), inhibition takes place at levels of around 160 mg/l zinc, 180 mg/l cadmium,100mg/l chromium 170 mg/l copper, 0,6 mg/l nickel, and 2 mg/ lead.
inhibition of anaerobic digestion by sulphides
In the anaerobic digestion process, sulphate is reduced to sulphide by sulphate reducing bacteria (SRB) (Gerardi, 2003). H_2S as the main part of dissolved sulphide in the liquid phase can easily penetrate the cell membrane and denature native protein within the cytoplasm, producing sulphide and disulphide cross-links between polypeptide chains (Siles et al., 2010). Inhibition thresholds in anaerobic digestion processes are 100-800 mg/l as dissolved sulphide or approximately 50-430mgl/l as undissociated H_2S (Parkin et al., 1990). In addition, it has to be noted that inhibitory effects of sulphides increase as pH declines

inhibition of anaerobic digestion by antibiotics
Studies by Sanz et al. (1996) studied the effects of antibiotics of anaerobic digestion and found that they might have three reactions on the process. He found that some inhibitors, such as the macrolide erythromycin, lack any inhibitory effect on biogas production; some antibiotics, with different specificities, have partial inhibitory effects on anaerobic digestion and decrease methane production by interfering with the activity of propionic-acid- and butyric-acid-degrading bacteria, (e.g. antibiotics that interfere with cell wall synthesis, RNA polymerase activity and protein synthesis, especially the aminoglycosides); the protein synthesis inhibitors chlortetracycline, and chloramphenicol are very powerful inhibitors of anaerobic digestion Lallai et al. (2002) studied the effect of antibiotics on biogas production by using swine manure as feedstock and found that high concentrations of both thiamphenicole and amoxicillin cause inhibitory effects on one or more of the major metabolic bacterial groups active in methane fermenters. They further reported that antibiotics increase the accumulation of volatile fatty acids and so decrease gas production. Also Masse et al. (2000) investigated six antibiotics in thermophiles digestion processes of swine manure and found that manures containing penicillin and tetracycline lead to a decrease in biogas production of 35% and 25%.
volatile fatty acids
Based on research by McCarty (1964), volatile fatty acids can become toxic at a level of 6 g/l if there does not exist an adequate buffer capacity to maintain system pH in the range of 6,6- 7,4 standard units. In addition, scientists found that the main effect of volatile fatty acids is the dropping in pH and have no adverse effect on the biogas process

6.2.1.2.2 Risks related to nitrification / dentrification

Table 30 lists potential threats occurring while nitrification / denitrification processes.

Table 30: Risks related to N_2O emissions from nitrification / denitrification

N_2O emissions from nitrification / denitrification processes
Nitrous oxide (N_2O) can be produced in both process, nitrification and denitrification because it is a known obligatory intermediate in the heterotrophic denitrification pathway and is also produced by autotrophic nitrifying bacteria, mainly ammonia oxidizing bacteria, as a by-product (Kampscheuer et al.,2008). According to Tallec et al. (2006) concentrations vary between 0.4-1% of the oxidised ammonium during nitrification and around 0 to 2% of the reduced nitrate during denitrification. Nitrous oxide is a dangerous greenhouse gas, having a 300-fold stronger effect than carbon dioxide and is also predicted to be the most dominant ozone – depleting substance in the

twenty-first century. In addition N_2O cause short and long term health issues like vitamin B12 deficiency, reproductive side effects, and numbness (Kampscheuer et al., 2008).

6.2.1.2.3 Risks related to partial nitrification / anammox

Similar to nitrification / denitrification also partial nitrification / anammox processes do face several risks which are illustrated in table 31.

Table 31: Risks related to partial nitrification / anammox processes

N_2O emissions partial nitrification / anammox
For a long time it has been believed that anammox activity does not produce any N_2O. Kartal et al. (2004) showed that anammox bacteria produce small amount of nitrous oxide as a result of detoxification of NO which is an intermediate of the anammox process. Nevertheless the major amount of N_2O emissions is produced during the partial nitrification process. Comparing studies from Kampscheuer (2009), Strous (1998), and Joss et al. (2009), found N_2O emissions vary among the scientists. Whereas all studies mentioned above had average emissions between 0.6-1.2 percent of the influent nitrogen concentration, Ekström (2007) found that N_2O emissions may vary between 2-6%.

6.3 Risk analysis

Based on ISO 31010 the risk assessment understands the identified risks and consists of the determination of risk consequences and probabilities for identified risk events as well as taking into account the presence and effectiveness of any existing controls.

Therefore the first step consists of identifying existing controls which minimise or prevent negative consequences, or reduce the likelihood of a potential event.

6.3.1 Existing controls

Control measures in risk management are all processes used to treat already identified risks and further have the potential of treating them completely or at least reducing them to a non-hazardous level. Throughout this thesis controls can be related either to raw input material controls or to the process chain.

6.3.1.1 Controls related to environmental risks occurring from raw livestock manure

Controls related to raw livestock are being controlled by either being destroyed throughout the process scheme or being bound in form of end-products and therefore transforming potential hazardous compounds in a non-hazardous product. Table 32 therefore shows existing controls related to raw manure.

Table 32: Controls related to raw livestock manure

nitrogen
During the project nitrogen removal is processed by three separated processes. Ammonia stripping, nitrification / denitrification processes or partial nitrification / denitrification, and struvite precipitation respectively.
phosphorus
Phosphorus removal is done by struvite precipitation.
pathogens
Pathogenic bacteria, viruses and protozoa existing in livestock manure are treated during thermophilic anaerobic digestion due to the intolerance to high, long lasting temperatures.
heavy Metals
Heavy Metals are difficult to treat biologically due to the fact that they are not biodegradable. According to Wetzel et al. (1999), heavy metals can be partially removed due to anaerobic digestion and ammonia stripping but probably not due to biological depletion but more likely by agitation and process outflow.

hormones
Hormones, present in livestock manure can be partially removed during anaerobic digestion struvite precipitation, as well as during nitrification / denitrification processes & partial nitrification / anammox.
antibiotics
Antibiotics can be removed during anaerobic digestion and composting processes. Removal rates depend on antibiotics characteristics and treatment method and range from 2-98% (Masse et al., 2004).

6.3.1.2 Controls related to inhibition of anaerobic digestion

In order to prevent process failure during anaerobic digestion several controls can be implemented. These are shown in table 33.

Table 33**:** Controls related to anaerobic digestion processes

ammonia
Ammonia inhibition can be controlled by specifying reactor conditions, e.g. the reduction of the pH value during anaerobic treatment. Based on the knowledge that ammonia inhibition appears at levels of 4 g N/l or 3 g N/l, the findings of Angelidaki et al. (1992) and McCarty (1964) is proved that an existing control is to keep the influent level as low as possible. In addition Callaghan et al. (1999) said that a common approach to ammonia inhibition relies on dilution of the manure to a solid level of 0,5-3%. If keeping ammonia levels low is not possible due to high contents in the feedstock material, Hansen et al. (1998) suggest that longer hydraulic retention times (HRT) or a low temperature should be chosen to achieve optimal methane yield. Therefore in terms of thermophilic anaerobic digestion longer HRT could be used to achieve high biogas production rates with low inhibition levels.
heavy metals
Except chromium, heavy metal inhibition and toxicity can be controlled by precipitation with sulphide. Thereby hexavalent chromium is normally reduced to trivalent chromium which under normal anaerobic pH levels is relatively insoluble and not toxic. Approximately 0,5 milligram of sulphide is required to precipitate 1 milligram of heavy metal (Mignone, 2005).
sulphides
Soluble sulphide levels can be controlled either by addition of iron salts or by eliminating the sources of sulphur containing materials (Mignone, 2005).
volatile fatty acids

The increasing concentration of volatile fatty acids indicates some kind of environmental stress in the anaerobic digestion processes. The addition of proper alkaline buffering material allows the process to continue functioning until the reason for the imbalance has been found (Mignone, 2005).
antibiotics
Literature does not show any proven control of antibiotics during anaerobic digestion processes. Antibiotics control has to be done at livestock feeding stage by prevention of disproportionate antibiotics usage.

6.3.1.3 Controls related to N_2O during nitrification / dentrification processes

Table 34 shows existing controls used to prevent N_2O emissions during nitrification / denitrification processes.

Table 34: Control related to nitrification / denitrification

N_2O emissions
So far no scientific solution has been determined in order to control N_2O emissions during nitrification / denitrifaction processes. Only the adaptation of process factors has proved to affect successfully affect N_2O emissions. Nevertheless this control measure is solely able of reducing existing emissions but is not able to prevent emissions completely.

6.3.1.4 Controls related to partial nitrification / anammox

Like for nitrification / denitrification processes there do exist control measures for preventing N_2O emissions which are shown in table 35.

Table 35: Control measures for partial nitrification / anammox

N_2O emissions
Similar to nitrification / denitrification processes the most effective control measure so far is on site piloting by continuously controlling and adjusting process parameters in order to minimise produced emissions.

6.3.2 Effectiveness of existing controls

Identified and described control measures now need to be analysed in order to identify if chosen control measure have the potential of treating identified risks properly.

6.3.2.1 Raw input material

Table 36 shows the effectiveness of in chapter 6.3.1 identified control measures for raw input material.

Table 36: Effectiveness of existing controls for raw input material

nitrogen
Based on research by (Perez, 2002) ammonia stripping is capable of removing ~ 98% of the ammonia nitrogen. Nitrification / denitrification and partial nitrification / denitrification processes have an efficiency of total nitrogen removal of around 90% (85-87% of total nitrogen and 96% of ammonium nitrogen) similar to struvite precipitation processes which are capable of removing around 88% of the existing ammonium nitrogen (Miles et al., 2001).
phosphorus
Struvite precipitation has an efficiency rate of 80% (Jordan et al., 2010).
Pathogens
Thermophilic anaerobic digestion is capable of destroying up to 100% of existing pathogens. Cote et al. (2006) measured the efficiency of pathogen destruction and found that Salmonella spp., Giardia, and Cryptosporidium pathogens were destroyed entirely whereas E. coli destruction efficiency was between 99-100%.
heavy metals
Findings about heavy metal removal efficiency during anaerobic digestion vary between scientists. Wetzel et al. (1999) studied the efficiency of anaerobic digestion processes and found that Calcium (Ca) 97%, Zinc (Zn) 74%, Copper (Cu) 60, 5%), Lead (Pb) 31%, Nickel (Ni) 2% can be removed during the process. Also ammonia stripping is capable of removing several heavy metals, namely between 70- 90% of Zinc, Iron, Manganese concentrations.
hormones
Based on research done by Aga (2010) anaerobic digestion is capable of removing estrogens like 17ß- estradiol by about 40% and testosterones by 90%. Also Ermawati et al. (2007) found that generally anaerobic digestion is capable of removing natural steroid hormones by about 80%. Nitrification / dentrification & partial nitrification / anammox are capable of removing about 80% of steroid estrogens and about 50% of total estrogens

(McAdam et al., 2010). Struvite precipitation has only a little effect on hormones, removing only about 2% of the influent hormone concentration (Ronteltap et al., 2007).

antibiotics

Based on findings of Beneragame et al. (2013) and Kotelko et al. (2013) antibiotics used during livestock farming (e.g. penicillin, tetracycline, tylosin) can be removed during thermophilic anaerobic digestion. In addition Masse et al. (2014) studied the biodegradation of veterinary antibiotics in anaerobic digestion processes and composting.

Table 37: Antibiotics reduction efficiency during anaerobic digestion (Masse et al., 2014)

treatment	**antibiotic**	**concentration**	**observed reduction**
anaerobic digestion			
anaerobic digestion of swine manure (21 days)	chlortetracycline	6.5 mg/L^{-1} 8.3 mg/L^{-1} 5.9 mg/L^{-1}	7% (22°C) 80% (38°C) 98%(55°C)
anaerobic digestion of cattle manure (28 days)	monesin	0.74 mg/L^{-1} 0.36 mg/L^{-1} 0.30 mg/L^{-1}	3% (22°C) 8% (38°C) 27% (55°C)
batch anaerobic digestion	oxytetracycline	20 mg/L^{-1}	55-73% at 37°C
anaerobic sequence batch reactor (ASBR)	tylosin A	5.8 mg/L^{-1}	Decreased to 0.01 mg/ L^{-1} in 48h
composting			
composting (22-35 days)	chlortetracycline monensin tylosin sulfamethazine	1.5 mg/kg^{-1} 11.9 mg/kg $^{-1}$ 3.7 mg/kg $^{-1}$ 10.8 mg/kg^{-1}	99% 54% 54% 76%
composting beef manure (35 days) abiotic removal	oxytetracycline	115 µg/g^{-1}	99% (laboratory) 25% (22°C)

composting	oxytetracycline	20 mg/L^{-1}	85%
	tetracycline		92%
	chlorteteacycline		90%
	levofloxacine		81%
	ciprofloxacine		100% (all removals at 38°C)
	erythromycin		67%
	sulfamonomethoxine		79%
	sulfamthoxazole		95%
	trimethoprim		86%
	carbamazepine		37%

According to scientists biodegradation of antibiotics depends on their chemical properties and manure- related matrix characteristics which modify the antibiotics' reluctance to biodegradation and play a significant role in their removal. Based on studies of Masse et al. (2014) sound conclusions could not be drawn regarding the effect of the biological action temperature on antibiotic removal. They compared mesophilic and thermophilic anaerobic digestion and found that the removal rate mesophilic and thermophilic treatment is capable of higher removals of chlortetracycline than psychrophilic operation but for monesin, both psychrophilic and mesophilic showed low removal rates compared to thermophilic process temperatures. Therefore increased temperature does not automatically lead to higher removal rates. In addition, Masse et al. 2014 found that composting has even higher removal rates than anaerobic digestion due to the additional aerobic bioactivity during these processes.

6.3.2.2 Anaerobic digestion

The effectiveness of proven control measures for determined risks related to anaerobic digestion are shown in table 38.

Table 38: Effectiveness of control measures related to anaerobic digestion

ammonia inhibition
Ammonia inhibition control by pH reduction leads to a low methane (CH_4) yield. Therefore Strick et al. (2005) concluded that that pH based Ammonia inhibition control combined with a satisfying biogas production is not achievable if concentrations are above a certain level. According to Mignone (2005) ammonia inhibition can be prevented by addition of hydrochloric acid in order to keep pH at a level between 7-7.2 at concentrations of 1.5 - 3g

N/l. If the pH exceeds 7.4 and concentration above 3g N/l, Mignone (2005) as well as McCarty (1964) and Sung et al. (2003) found that pH control is useless. Callaghan's et al. (1999) approach to dilute manure to a low amount of total solid is economically unattractive and therefore not reasonable.
heavy metals
The drawback of using sulphide saturation is sulphide toxicity, production of hydrogen sulphide gas or the generation of weak sulphuric acid which will cause corrosion problems (Mignone, 2005).
sulphides
According to literature, sulphide controls are effective under proper process conditions
volatile fatty acids
According to literature, volatile fatty acids controls are effective under proper process conditions
antibiotics
No evidence was found for antibiotics inhibition controls. Therefore no proposition can be made

6.3.2.3 N_2O emissions during nitrification / denitrification

Table 39 illustrates the effectiveness of existing control measures for N_2O emission during nitrification / denitrification processes.

Table 39: Effectiveness of existing controls related to N_2O emissions during nitrification / denitrification

N_2O emissions
In general, N_2O emissions measurements are made directly on site and reflect the output of continuously adjusted process parameters. The exact effectiveness of on-site process adjustments cannot be given due high variation of individual factors affecting this procedure. Effectiveness has to be determined for each plant separately.

6.3.2.4 N_2O emissions during partial nitrification / anammox

Table 40 shows similar to table 39 the effectiveness of existing control measures for N_2O emissions during partial nitrification / anammox processes.

Table 40: Effectiveness of existing controls related to N_2O emissions during partial nitrification / anammox

N_2O emissions
Similar to nitrification and denitrification processes, N_2O emissions control is based on on-site adjustments of process parameters in order to minimise emission. Complete prevention is so far not possible.

6.3.3 Determination of risk levels

Risk levels need to be determined based on the likelihood and consequence of these. Therefore the in the risk management context defined risk matrix is used for categorising the identified risks. Based on this matrix the risk level can range from low, over high up to extreme, depending as already mentioned on the likelihood of the occurrence and the potential consequences.

6.3.3.1 Environmental risks

Table 41 shows determined risk levels for potential environmental risks arising from raw animal manure.

Table 41: Determined environmental risks related to raw animal manure

risk	determined risk level	justification
nutrients	low	Nutrients have the potential to generate negative environmental impacts if not treated properly. Throughout the process scheme nutrients have been transformed into a useful and non-hazardous form. Therefore the determined risk level can be summarized as low.
pathogens	low	Anaerobic digestion processes are capable of reducing pathogens to a level not relevant for end-products. Even though the consequence may be

		medium, the likelihood is *rare* which results in low risk potential
antibiotics	high	Based on the analysis of control measures and findings in literature the risk level has to be determined as high. Removal rates vary from 2-98% and therefore literature review does not give any guarantee if antibiotics levels remain within defined legal thresholds. Due to this uncertainty, the risk level has to be defined as high.
hormones	low	The environmental effects of hormones at the end of the “ManureEcoMine” can be categorised as low due to the fact that several process during the process chain are capable of removing hormones from the used material.
heavy metals	low	Heavy metal removal can be done partially during anaerobic digestion. As the likelihood may be *possible* but the consequence is still *low,* the risk can be determined as low.

6.3.3.2 Process related failure risks

In addition to risks resulting from raw input material, risks that potentially lead to process failure need to be determined. Therefore table 42 illustrates determined risk levels of risks related to process failure.

Table 42: Determined process related failure risks

risk	**determined risk level**	**justification**
ammonia inhibition during anaerobic digestion processes	high	Livestock manure contains high concentrations of nitrogen which is transformed to ammonia nitrogen during anaerobic digestion. Limits of inhibition are therefore quickly reached and a loss of up to 60% of methane production is possible. At high concentrations inhibition is even certain and leads to total process failure. Therefore the likelihood has been determined as *likely* and the consequence as *high*. Ammonia inhibition risks when using cattle manure is higher than when using swine manure due to higher level of nitrogen in the raw input material.

heavy metal inhibition during anaerobic digestion	high	Also in terms of heavy metal inhibition it has to be differentiated between swine and cattle manure feedstock for anaerobic digestion. The levels of zinc and copper in raw swine are massively higher than in cattle manure which increases the likelihood of heavy metal inhibition when using swine manure. Due to the fact that the consequences are medium in cases of both input materials but the likelihood is *likely* for swine manure and just *possible* for cattle manure it results in a *high* risk level for cattle manure and a *high* risk level for swine manure. Any effect that potentially affects the process has to be categorised as a high risk.
antibiotics inhibition during anaerobic digestion	high	Literature showed that some antibiotics are very powerful inhibitors during anaerobic digestions processes. In addition antibiotics are capable of reducing biogas production up to 35%. The risk level has been determined as moderate due to a likelihood which is categorised as *possible* and a consequence which can be defined as *high.*
inhibition by volatile fatty acids during anaerobic digestion	low	Volatile fatty acids inhibition levels and not easily reached during anaerobic digestion levels and occurs to process parameter failure and as a result of accumulation of other substances important to the process. Therefore the risk can be defined as low.

6.3.3.3 Risks related to by-products during processes

Alongside the process scheme risks arising by by-products are N_2O emission during nitrification / dentrification processes as well as during partial nitrification / anammox and composting. Risks resulting in by-products during composting processes can be neglected throughout this study due to their low levels and their climate relevance. Table 43 shows determined risk level for nitrification / denitrification & partial nitrification denitrification processes.

Table 43: Determined risks related to nitrification / denitrification & partial nitrification denitrification processes

risk	determined risk level	justification
N_2O emissions from nitrification / denitrification & partial nitrification denitrification processes	high	Likelihood of N_2O emissions can be categorised as certain even though the amount of emitted gases is only max 2% of the nitrogen influent concentration, the high threat of this gas requires a risk consequence classification of serious.

6.3.3.4 Determined risk levels if existing controls fail

The above determined risks tables consider that all identified control measure function properly. Talking about risk management, it is also vital to consider the fact that controls may fail. Therefore also risk levels have been determined for the case that control measures fail to treat risks properly.

6.3.3.4.1 Risks related to raw compounds reaching the environment

All categorised risks have been defined as high risks in case of control failure due to the exceeding of determined threshold levels as well as due to their potential threat to the environment. Table 44 therefore illustrates the environmental risks in case defined control measure fail.

Table 44: Environmental risk levels in case control measures do not work properly

risk	determined risk level
nutrients (nitrate / nitrite leakage, ammonia volatilisation, methane and hydrogen sulphide emissions, and eutrophication processes)	high
pathogens	high
antibiotics	high
hormones	high
heavy metals	high

6.3.3.4.2 Process related risks

Process related risks have either been determined as low risks in case of no process performance affection or high in case risks lead to process failure and major process efficiency reduction as illustrated in table 45.

Table 45: Process related risks in terms of control failure

risk	determined risk level
ammonia inhibition during Anaerobic digestion processes	high
heavy Metal inhibition during anaerobic digestion	high
antibiotics inhibition during anaerobic digestion	high
inhibition by volatile fatty acids during anaerobic digestion	low
inhibition by sulphides during anaerobic digestion	low

6.3.3.4.3 Risks related to by-products during processes

Besides process failure, several process steps do emit by-products resulting in risks for the environment. Table 46 therefore illustrates potential by-products for the case that determined control measures fail.

Table 46: Determined by-products risks in case of control failure

Risk	determined risk level
N_2O emissions from nitrification / denitrification & partial nitrification denitrification processes	high

6.3.4 Uncertainties in risk analysis

Due to the fact that risk analysis processes comprise inherent uncertainties, it is important that uncertainties need to be identified and documented. Most of the risks related to the "ManureEcoMine" project occur due to high concentrations of manure compounds that may cause a threat in their original forms, threat risks based on transformations during process steps or on behalf of their amount occurring. A major uncertainty is the composition of raw manure. Livestock feeding processes, animal growth stage, species of animals, and the manure collection method effect the composition and therefore the whole process. Even though the analysed risks may occur along the process chain, the consequences and likelihood may change due to the change of raw input material.

6.4 Risk evaluation

Risk evaluation is the process of deciding which risks require further treatment and in what order. It is based on the outcomes of risk analysis and involves the determination of particular risks, after existing controls are applied, and compares with the level of risk your agency is prepared to accept or tolerate. Based on that, a decision about further treatment has to be done. Therefore the identified risks have to be compared to the tolerance of risks for deciding if potential risk levels are acceptable and can be neglected or if risk needs to be treated. The risk tolerances can be categorised into three levels (action required, potential action, and no action required) as shown in the risk tolerance table defined in the project context.

6.4.1 Risk tolerances

6.4.1.1 Tolerances related to environmental risks of livestock manure compounds

Raw input materials contain dangerous compounds which have the potential to harm the environment and life forms. Therefore, based on the risk analysis of existing control measures, each risk has to be evaluated in terms of the remaining concentrations in the products leaving the process scheme. Therefore it has to be determined if they are acceptable according to national and international standards or still face threats and need further treatment. To do so only tolerances of risks need to be considered which cannot been treated by existing control measures. Table 47 therefore lists existing tolerances for manure compounds.

Table 47: Existing tolerances for raw manure compounds

risks	tolerance acceptability	justification
nutrients	no action required	End products being generated during the "ManureEcoMine" project do no exceed existing thresholds due to the high efficiency of various process steps. Groundwater contamination of nitrate is unlikely due to potential values far less than the < 50 mg/l directed by the nitrate directive (91/676/EEC). Also ammonia volatilisation and production of methane and hydrogen sulphide emissions are unlikely due to avoiding these substances emit to the environment by binding nitrogen in granular form in bio fertilisers. Eutrophication caused by high phosphorus concentrations is also unlikely due to the binding of phosphorus as crystalline struvite.
heavy metals	no action required	Even though not even a combination of used state of the art technologies is capable or removing the total amount of heavy metals from the raw livestock manure, the levels are still within the so far only existing guideline for treated digestate, PAS 110. Comparing the threshold levels for digested compost published by the European Compost Network and considering the efficiency of used technologies, the heavy metal concentrations in compost is far lower than the determined thresholds. Also thresholds within the produced bio fertilisers are considered as being low due the potential efficiency of used state of the art technologies.
hormones	no action required	Also potential hormones concentrations in end products can be neglected due to the low concentrations.
antibiotics	action required	Based on the control efficiency of AD and composting, the risk of antibiotics has to be determined as high. Used state of the art technologies cannot guarantee that antibiotics concentrations in raw livestock manure can be removed up to 100%. Due to the fact that thresholds levels in defined end products are not given there do not exist any prove that antibiotics concentrations are within legal thresholds. Based on that assumption no tolerance levels could have been determined and antibiotics are classified as action required substances

6.4.1.2 Tolerances for inhibition processes in anaerobic digestion processes

Most of the manure livestock feedstock compounds play an essential part during the anaerobic digestion process. If certain threshold values are exceeded, the positive effects change into negative effects and potentially lead to a total process failure. Therefore is has to be evaluated if inhibition processes may be tolerated under certain conditions. Table 48 shows existing tolerances for inhibition process during anaerobic digestion processes.

Table 48:Tolerances for inhibition processes in anaerobic digestion

risks	tolerance acceptability	justification
ammonia inhibition	action required	Anaerobic digestion has two major tasks. On the one hand side producing biogas which has an economic benefit the entrepreneur and an environmental effect by treating potential hazardous compounds from livestock manure. Ammonia inhibition has the potential of effecting the biogas production up to 100% at high concentrations. Due to potential financial loss and the loss of effective treatment of hazardous manure compounds, ammonia inhibition cannot be tolerated and has to be treated.
heavy metals inhibition	action required	Based on research by several scientists, heavy metal inhibition is one of the major causes for digester upset or failure. Therefore actions have to be taken.
antibiotics inhibition	potential action	The effect of antibiotics on biogas production is proven but based on the findings of Masse et al. (2000) the loss of biogas yield is usually not higher than max 25-35%. Considering this as the worst case, anaerobic digestion is still functioning, but financial loss may occur. Therefore risks may be tolerated if no proper and financially reasonably measures can be set.
sulphide inhibition	potential action	Sulphide inhibition during anaerobic digestion processes can lead to a decrease in biogas production but the probability of inhibition occurrence is not as a high as comparing it to ammonia or heavy metals. Therefore actions should be set if possible.
volatile fatty acids	potential action	The effect does according to Gourdon ET al. (1987) not affects the overall biogas yield but imposes different types of perturbation imbalances in the anaerobic digestion process. Therefore is it useful of dealing with it in terms of better process stability.

6.4.1.3 Tolerances for by-products originating along the process scheme

In order to protect the environment from hazardous emissions it has to be determined if the generated emissions along the process scheme can be tolerated or need to be treated. As shown in table 49, by-products do originate mainly during nitrification / denitrification processes and partial nitrification / anammox processes and cannot be tolerated due to the fact that N_2O emissions do harm the environment already at low concentrations.

Table 49: Tolerances related to process by-products

risks	tolerance acceptability	justification
N_2O emissions during nitrification / denitrification	action required	Due to the fact that N_2O is a dangerous greenhouse gas which a 300-fold stronger potential than carbon dioxide and is also predicted to be the most dominant ozone – depleting substance in the twenty-first century, no tolerance levels are acceptable.
N_2O emissions during partial nitrification / anammox	action required	Even though, N_2O emissions levels are slightly lower due to the usage of anammox bacteria instead of a dentrification process there does not exist any tolerance levels due to the danger being extinguished by N_2O.

6.4.2 Risk level categorisation

After having identified the tolerances and their acceptance throughout the processes a decision has to be made about whether risks need to be treated and in which order. Therefore risks are categorised into 3 categories:

- Risk level is regarded as intolerable and the risk treatment is essential whatever it costs
- Costs and benefits are taken into account and opportunities balanced against potential consequences
- Level of risk is regarded as negligible, or so small that no risk treatment measures are needed

Based on the information gathered through the risk assessment and risk tolerance determination process, the following risk prioritisation has been determined as shown in table 50.

Table 50: Risk level categorisation

prioritisation of risks	risk	justification
negligible risk treatment priority	nitrogen threats raw manure	Ammonia stripping, struvite precipitation and nitrification / denitrification processes reduce the nitrogen values and transform it into useful forms. Therefore no risks treatment is necessary.
negligible risk treatment priority	phosphorus threats raw manure	Phosphorus concentrations are reduced and transformed during struvite precipitation and during composting processes. In addition levels of potential eutrophication is minimalized and can be neglected.
negligible risk treatment priority	heavy metal threats raw manure	Processes along the process scheme are able to reduce potential hazardous concentrations from manure so that residual concentrations are below the given threshold levels in the relevant environmental ecosystems. Based on the research of Al Seadi et al. (2012), samples of digestate taken in 2009 and 2010 from 3 biogas plants processing livestock manure showed that level of heavy metals were below the level set by PAS 110 standards.
negligible risk treatment priority	pathogenic threats raw manure	Pathogenic compounds are almost completely removed by anaerobic digestion and do no face threats anymore.
negligible risk treatment priority	hormones threats raw manure	Hormones are reduced to an acceptable level along the process scheme and do not have to be considered anymore.
medium risk treatment priority	volatile fatty acids inhibition during anaerobic digestion processes	Volatile fatty acids lead to different types of perturbation imbalances in the anaerobic digestion process. Therefore treatment is advised but not essential for the process function.
medium risk treatment priority	sulphide inhibition during anaerobic digestion processes	Potential of inhibition and consequence is lower related to other risk and therefore not most important risk to be treated.
medium risk treatment priority	antibiotics inhibition during anaerobic digestion processes	Based on research done by Masse et al. (2000) antibiotics do not exceed biogas inhibition percentages beyond 25-35%. Effects of antibiotics inhibition may affect the process but does not lead to complete process failure. Treatment leads to

		higher economic output in terms of more biogas production.
high risk treatment priority	antibiotics threats raw manure	Based on found control effectiveness and due to lack of tolerance levels and antibiotics tolerance levels, antibiotics treatment needs to be categorised as high risk treatment priority.
high risk treatment priority	heavy metals inhibition during anaerobic digestion processes	High risks to process failure which cannot be acceptable due to the importance of the anaerobic digestion for the removal of hazardous manure compounds as well as the economic importance of biogas production.
high risk treatment priority	N_2O emissions during nitrification / denitrification processes	Greenhouse gas emissions should not be tolerated and should be treated if possible
high risk treatment priority	N_2O emission during partial nitrification / anammox processes	Greenhouse gas emissions should not be tolerated and should be treated if possible

6.5 Risk treatment

Risk treatment is based on the risk assessment and the risk evaluation processes and is the decision making process about whether existing controls should be modified or new treatments need to be introduced. In addition it has to be decided how existing risks should be treated. Various generic options have to be considered for treating risks, including: risk avoidance, changing the risk likelihood, changing of risk consequences, sharing the turning over of risks or accepting and tolerating the assessed risks. While assessing existing and appearing risks along the process scheme it has become obvious that risks treatment has to vary drastically throughout the identified risks. While some risks do not need further treatment due to effective existing controls, others cannot be avoided at all and risk treatment needs to minimise the negative impacts resulting from them. Therefore recommended risk treatment measures are getting categorised based on their kind of treatment.

6.5.1 Accepted and tolerated risks

As illustrated in table 51, this category includes risks which do not require further treatment due to the effectiveness of determined control measures or due to the minimal consequences resulting from identified risks.

Table 51: Acceptable and tolerable risks

risk	**justification**
nitrogen threats raw manure	Based on scientific research results, enough evidence has been given in order to ensure that existing controls are capable of dealing with potential risks. In addition, the used technologies transformed nitrogen in a usable form which does not harm the environment anymore.
phosphorus threats raw manure	Similar to nitrogen, existing processes are capable of ensuring that process outcomes do not face any threat anymore.
heavy metal threats raw manure	Even though existing controls are not capable of removing heavy metal concentrations completely, enough evidence was found that remaining heavy metal concentrations are below hazardous levels and therefore do not require further treatment.
pathogenic threats raw manure	Pathogenic compounds are removed completely during the process scheme and therefore a potential risk does not exist anymore.
hormones threats raw manure	Similar to pathogens, used processes are capable of eliminating potential hazardous hormones compounds.

6.5.2 Changing the likelihood and consequences

Risks in this category cannot be avoided due the fact that the compounds itself are necessary for the process. Nevertheless arising concentrations are often the reason for failure or process risks. Table 52 therefore shows risks which need to be treated in order to change the likelihood or the consequences.

Table 52: Risks which require treatment in order to change the likelihood or the consequences of their occurrences

risk	justification
antibiotics threats raw manure	Due to not lack of information regarding tolerance levels and legal threshold levels and based on found control effectiveness it has been concluded that antibiotics in raw livestock manure need to be treated in order to prevent antibiotics from existing in end products or from entering the environment. Changing the likelihood and consequences so far is only possible by changing treatment measure during animal husbandry. Based on scientific data more than 70% worldwide used antibiotic is used for animal treatment. Most of it precautionary. Changing antibiotics concentrations in raw livestock manure therefore relies on changing and more sustainable dosing and medication.
volatile fatty acids inhibition anaerobic digestion processes	Alkaline buffering should be used in order to treat volatile fatty acids inhibitions (Mignone, 2005). This allows anaerobic digestion to keep functioning until the reason for the inhibition process has been determined. Treatment measures are capable or reducing risk consequences but not lower the risk likelihood.
sulphide inhibition anaerobic digestion processes	A proven method of treating sulphide inhibition is by adding iron salts (Mignone, 2005). Due to the fact that treatment is recommended but not vital to process efficiency, the decisions should be made in terms of financial effort. In additions, similar to measures set for volatile fatty inhibition treatment, the adding of iron salts if just capable of reducing the consequences but no the likelihood.
antibiotics inhibition anaerobic digestion processes	Now evidence about concrete antibiotics inhibition treatment measure has been found in literature. Due to the fact, that antibiotics inhibition is based on the concentration of concentrations in the feedstock, risk treatment has to start at the earliest stage of the process. Antibiotics treatment should be reduced to the lowest necessary level instead of overdosing medications prophylactically. Therefore these measures can reduce the likelihood of antibiotics inhibition occurrence.

ammonia inhibition anaerobic digestion processes	As already described in the section of potential control measures, ammonia inhibition can be controlled by changing several process parameters such as pH, the hydraulic retention time or the process temperature (Angelidaki et al., 1992), Callaghan et al., 1999), and Hansen et al.,1998). Due to the fact that low temperatures due not occur at thermophilic anaerobic digestion, pH control is not economical reasonable and does not work at concentrations above 3 g N/l, the exceeding of the hydraulic retention time might be the most viable treatment method.
heavy metals inhibition anaerobic digestion processes	As already described above, heavy metal inhibition can be controlled by sulphide precipitation. Based on the fact that this may lead to sulphide toxicity and therefore increases the chance of sulphide inhibition, it is more suitable to treat heavy metal inhibition already at the livestock feeding stage. Based on studies by Zhang et al. (2010) of more than 120 manure samples and 104 livestock feeds the content of heavy metals in animal feed range from 2,3 –1137,1 mg/kg dry matter (dm) of Cu, As and Cd in pig feeds as well as 2,88 – 98,08 mg Cu/kg (dm), 0,02 – 6,42 mg As/kg dm and non-detectable (nd) – 8,00 mg Cd/kg dm in cattle feeds. Therefore minimising these concentrations can reduce the likelihood of heavy metal inhibitions drastically.
N_2O emissions during nitrification / denitrification processes	Changing the likelihood of N_2O emissions during nitrification/denitrification processes can only be done by on site monitoring by adjusting process parameters up to a point of minimum emission levels.
N_2O emission during partial nitrification / denitrification processes	Similar to nitrification / denitrification, process parameter is so far the only existing controls measure for reducing potential consequences.

6.6 Monitoring and review

Monitoring and review of risk management processes need to ensure that operations are working effectively, that criteria used to evaluate risks are still relevant, and expected results of the risk management have been achieved. Due to the fact that the success depends on the functionality of the used state of the art technologies, sufficient monitoring measures have to be applied throughout the system:

6.6.1 Process quality assurance

In order to produce high quality products, processes need to function properly and influencing factors need to be monitored and kept in a certain range. Therefore all relevant factors are illustrated below.

6.6.1.1 Anaerobic digestion

The effectiveness of anaerobic digestion processes is dependent on various controlling factors according to Dennis et al. (2001):

- **Waste characteristics**: Not all waste constituents are equally degraded or converted to gas through anaerobic digestion.

- **Foreign material**: Addition of foreign material such as animal bedding, sand and silt can have a significant impact on the anaerobic digestion process. Also the quality and quantity of bedding material affect the process. Sand and silt should be removed before the process or must be suspended during the digestion process.

- **Nutrients**: The Carbon to nitrogen ratio should be less than 43. Also the carbon to phosphorus ratio should be less than 187. A carbon to nitrogen ratio of 20 -25 is according to Dennis et al. (2001) the optimum during anaerobic digestion processes.

- **Temperature**: Anaerobic digestion can be maintained at different process temperatures, ranging from 30-38°C (mesophilic) to 49-57°C (thermophilic).

- **pH**: The pH level should be kept in a range of 6,8-8,5. Too low or too high pH levels lead to inhibition processes and process failure.

- **Hydraulic Retention Time (HRT)**: Hydraulic retention time equals the volume of the tank divided by the daily flow and is important because it establishes the quantity of time available for bacterial growth and subsequent conversion of the organic material to gas.

- **Solid Retention Time (SRT):** Most important factor controlling the conversion of solids to gas as well as in maintaining digester stability.

- **Digester loading**: an appropriate measure of the waste on the digester’s size and performance. High loading rates will reduce the digester size but will also reduce the percentage of volatile solids converted to gas.

6.6.1.2 Ammonia stripping

Efficient ammonia stripping operations depend primarily on five factors according to Huang et al. (2006):

- **pH**: Due to the fact that the relative distribution of the dissolved NH_3 gas vs the NH_4^+ ions in true solution depends greatly on the pH. Because only the dissolved gas can be removed from solution, the pH plays an important role in the process and should be risen to 11 or higher in order to achieve optimal efficiency.

- **Temperature:** The liquid temperature can affect the ammonia stripping efficiency in two different ways. First, at a given pH, the percentage of ammonia nitrogen present as dissolved gas increases with the temperature. Second, the solubility of ammonia gas in water increases with decreasing temperature. The greater the solubility, the greater the amount of air required to remove a given amount of ammonia gas.

- **Rate of Gas Transfer:** In order to remove ammonia from water, the dissolved NH_3 molecules must first move from the bulk liquid solution to the air- water interface, and then from the interface to the stripping air flow. Therefore, there exist two factors that affect the rate of ammonia gas transfer from the liquid to the surrounding atmosphere:

    - Transport of the NH_3 molecules from the bulk liquid solution to the air–water interface. This is accomplished by molecular diffusion, but turbulent mixing is much more effective. If the distance of the transport is relatively short, such as that existing within a small water droplet, the rate of gas transport would seldom become a limiting factor governing the overall ammonia release rate.

    - Transfer of the ammonia molecules from the air–water interface to the gaseous phase.

  The maximum rate of the interfacial gas transfer takes place when the surface tension is at a minimum, which normally occurs when the water droplets are being formed. Once the water droplets are formed, the interfacial gas transfer becomes quite difficult. Therefore, by maintaining a condition in which there are repeated formations of water droplets of small size, the gas transfer rates within the droplets as well as on the droplet surfaces can both be maintained at the maximum rate. This is a fundamental necessity for the design of an ammonia stripping tower. Besides the surface tension, the difference in the ammonia partial pressures between the liquid and the gaseous phases is actually the driving force causing the interfacial gas transfer. The maximum transfer rate will occur when there exists a maximum difference in the partial pressures. With a given ammonia concentration, the partial pressure in the liquid phase is constant. The ammonia partial pressure in the gaseous phase can be minimized by supplying an ample amount of air flow to dilute the concentration of the ammonia released into the gaseous phase. Therefore, the amount of air supply also affects the gas transfer rate.

- **Air supply rate:** Because the difference in the ammonia pressures between the liquid and gaseous phases is the force for ammonia to transfer from the liquid to the air flow, an ample supply of air flow through the ammonia tower will dilute the concentration of the ammonia released thereby reducing its partial pressure in the gaseous phase and maximizing the ammonia release rate.

- **Hydraulic loading time:** The hydraulic loading rate on the stripping tower can affect the ammonia removal in two ways. First, for a fixed tower depth, the larger the hydraulic loading rate, the shorter is the air–water contact period. Below a certain critical contact time the ammonia-stripping efficiency will be reduced drastically. Second, for a given internal packing configuration, if the hydraulic loading rate is too high, it may cause sheeting of the water, which reduces the intensity of droplet formation, thus decreasing the ammonia-stripping efficiency.

6.6.1.3 Composting

Composting processes depend on various process factors which are shown in table 53.

Table 53: Relevant composting process parameters (Langenberg, 2010)

factor	acceptable range
temperature	54-60°C
carbon-to-nitrogen ratio (C:N)	25:1-30:1
aeration, percent oxygen	>5%
moisture content	50-60%
porosity	30-36
pH	6,5-7,5

6.6.1.4 Struvite precipitation

Several factors affecting successful struvite process parameters and need to be considered in order keeping the system efficient and functioning. According to Ronteltap (2009) the following factors are viable for struvite precipitation processes:

- **pH:** One of the major influencing factors parameters is pH. Both, NH_4^+ and PO_4^{3-} are strongly pH dependent: with increasing pH values the activities of PO43- increases while NH4+ becomes less prevalent. Therefore, struvite precipitation should be performed at pH between 7 and 11. Based on research by Münch et al. (2001) the minimum solubility is at pH 9.

- **Temperature:** Temperature influences struvite precipitation both over the solubility constant and the reaction rate. Struvite solubility increases with temperature and has its optimum at 50°C. Nevertheless, the precipitation of struvite is more difficult to obtain at high temperatures. Therefore different temperatures lead to different morphologies and need to be monitored continuously.

- **Precipitant addition rate:** According to Adnan et al. (2004), the addition of magnesium can also influence the precipitation process in combination with stirring. If too much precipitant is added at once, the degree of super saturation upon addition is locally very high which further leads to the production of many fines rather than fewer yet larger crystals.

- **Stirring:** Stirring can have negative effects on the process due to the fact that higher mixing speeds lead to a higher percentage of scaling on the reactor wall. In addition, high mixing speeds can accelerate nucleation rate and so limit crystal growth as well as final crystal size may be reduced due to crystal breakage or shearing.

6.6.1.5 Nitrification and denitrification processes

- **Temperature**: For optimal nitrogen removal, temperature should be kept in a certain range. Fontenot et al. (2007) studied different process temperatures and found that temperature should range between 22-45°C for solid process operation and have their optimum between 35-42°C.

- **pH**: According to Metcalf et al. (2003), the pH rate during nitrification should be kept around a pH of 7. He found that the nitrification rates decline up to 20 percent when pH is between 5, 8-6. Based on studies by Wiesmann et al. (2007) the pH should be between 7, 2-8 for optimal growth of nitrifying bacteria. Below 5, 5 and above 9, 0 a significant decrease in nitrification occurs due to protein damage. For denitrification the optimal pH range is assumed between 6, 5-7, 5.

- **Carbon to nitrogen ratio**: Fontenot et al. (2007) studied different carbon to nitrogen ratios and found that the most effective ratios are 5:1 and 10:1. Ratios above that did not show satisfactory results. Also Chiu et al. (2007) observed that a ratio of around 11:1 is the optimum initial carbon to nitrogen ratio, allowing the system to reach equilibrium between nitrification and denitrification reaction and resulting in optimal removal of both nitrogen and organic carbon.

- **Dissolved oxygen**: Ferreira (2000) showed that optimum nitrification rates can be obtained using dissolved oxygen levels higher than 4 mg/L $^{-1}$. Also Seixo et al. (2004) that nitrification should be obtained at levels around 5, 5-6, 4 mg/L $^{-1}$. In relation, denitrification can be obtained a way lower levels, namely in the range of 0, 5-1 mg/L $^{-1}$ (Ferreira, 2000).

6.6.2 Monitoring methods

Control mechanisms need to be monitored continuously and this chapter shows how various process parameters are being monitored throughout the process scheme.

6.6.2.1 Anaerobic digestion

Based on research by Labatut et al. (2009) anaerobic digestion processes should be monitored weekly, at least on a bi-weekly basis by analysing digester operating processes on the one hand side and checking feedstock characteristics when entering and leaving the digester on the other hand side.

- **pH**: pH should be measured in the influent as well as in the effluent of anaerobic digestion systems by using either pH meter or single-junction electrodes in order to guarantee the required range.

- **Temperature**: Temperature has to be monitored constantly with pH meters or thermocouples.
- **Loading frequency**
- **Mixing frequency**
- **Mixing speed**

In addition to process factors the amount of important biological and chemical process compounds has to be monitored as well in order to prevent inhibition effects

- **Total ammonia-nitrogen** (TAN): Ammonia has the potential to cause massive process inhibition and further process failure and therefore need to be measured at both, influent and effluent by using ion meters or ion selective electrodes.
- **Volatile fatty acids** (VFA): Measured at influent and effluent by distilling sample and titrating the distillate with sodium hydroxide 0,1 N to pH 8,3.
- **Total solids** (TS): Drying the sample in gravity convention oven at 105°C for ~8 hours. Samples need to be taking at influent as well as effluent.
- **Total volatile solids** (VS): Measured at influent and effluent by ashing the taking sample in muffle furnace at 550°C for 1h

6.6.2.2 Ammonia stripping

Ammonia air stripping is dependent on various factors which need to get monitored throughout process performance:

- Chemical characteristics of the manure (especially **pH** and **nitrogen**) need to be tested at the beginning and the end of the process.
- **Air temperature** should be measured at various points of the plant: the upper and the button of the reactor, inside the manure, and the hot water circuit of the reactor’s heating system.

6.6.2.3 Struvite precipitation

- **pH**: Due to the fact that pH is an essential process parameter in struvite precipitation it has to be monitored during inflow and while processing by using either pH meter or single-junction electrodes in order to guarantee the required range.
- **Temperature**: Temperature has to be monitored constantly with pH meters or thermocouples.

6.6.2.4 Nitrification / denitrification

- **pH**: pH should be measured in the influent as well as during active processing by using either pH meter or single-junction electrodes in order to guarantee the required range.

- **Temperature**: Temperature has to be monitored constantly with pH meters or thermocouples.

7. Quality management

The “ManureEcoMine” project has two major goals: on the one hand side it aims to reduce and possibly removes hazardous compounds from the raw livestock manure and on other hand side the project has the goal of producing biogas as well as several organic fertilisers for agricultural usage. Only if processes work effectively high quality products as well as environmental protection can be achieved. The production and recycling of digestate as fertiliser requires quality management and quality control throughout the whole closed circle, from production of the AD feedstock until the final utilisation of digestate as fertiliser. Quality assurance is an element of end - of - waste criteria of importance because it is needed to establish confidence in the end-of-waste status. The control of input materials, the required processing and the assessment of compliance with final quality requirements is the common procedure of proper quality management. In this context, quality assurance has to be implemented in order to give producers the possibility to demonstrate that their products fulfil all quality requirements, on the environmental as well as on the product quality side. The process of quality management covers various process steps. First, Input material has to be controlled in order to guarantee that it is suitable and can be treated by the used technologies. If, input material has passed, the production process takes place in accordance with agreed standards and specifications. The produced output has then to be sampled and tested according to the quality requirements and approved standards for designated application. If products meet the international and national requirements they are allowed to enter the market.

7.1 Feedstock quality requirements

A comprehensive list of biowastes, suitable for biological treatment, including AD, is given in the European Waste Catalogue in 2002. Animal livestock manure is more precisely categorised according to the EC - Regulation 1069/2009 commonly known as the animal by-products regulation. Based on this regulation livestock manure is declared as a category 2 product and therefore do not require any pre-treatment for being used an AD feedstock material. An important part of the feedstock quality management process is a detailed description of the used feedstock based on appropriate national regulations in order to allow the plant operator to assess suitability as feedstock, conform to existing protocols and quality standards for digestate destined for agricultural and horticultural use. Basic information which should be provided by feedstock description includes: origin, description in terms of colour, texture, consistency, smell etc., methane potential, and content of chemical pollutants, pathogen contamination, and chemical desription (Al Seadi et al., 2012).

7.2 Sampling and quality assurance

After input material has been analysed and process parameters have been kept in required ranges, end products need to be analysed in order to guarantee that these products fulfil the required international and national requirements. As the risk management already proved, hazardous compounds existing in the raw material can be affectively been eliminated or reduced to levels that aren't harmful for the environment anymore. Nevertheless samples have to been taken after Ammonia stripping and absorber processes in order to control ammonium sulphate quality, after composting of separated solid digestate, and after struvite precipitation. In addition, the produced biogas needs to be monitored as well. Product quality for compost, digestate, and organic fertilisers are generally amongst the following parameters:

- Quantitative minimum limits of elements providing a soil improvement / fertilising function, such as organic matter content, or nutrient (N, P, K, Mg) content.
- Quantitative maximum limits on elements potentially toxic to human health or ecotoxic, such as heavy metals, or persistent organic pollutants.
- Quantitative maximum limits on macroscopic foreign materials (e.g. glass, plastics, metals)
- Limited content of pathogens (if appropriate through quantitative maximum limits).
- Limited presence of viable weeds (if appropriate through quantitative maximum limits).
- Minimum stability (if appropriate through quantitative maximum limits)

Therefore sampling has to be done at several steps along the process scheme. The red circles in figure 5 represent critical points due to the fact that each sampling point represents an end of production line point and therefore is a point where potential hazardous points have the possibility to enter the environment or remain in products.

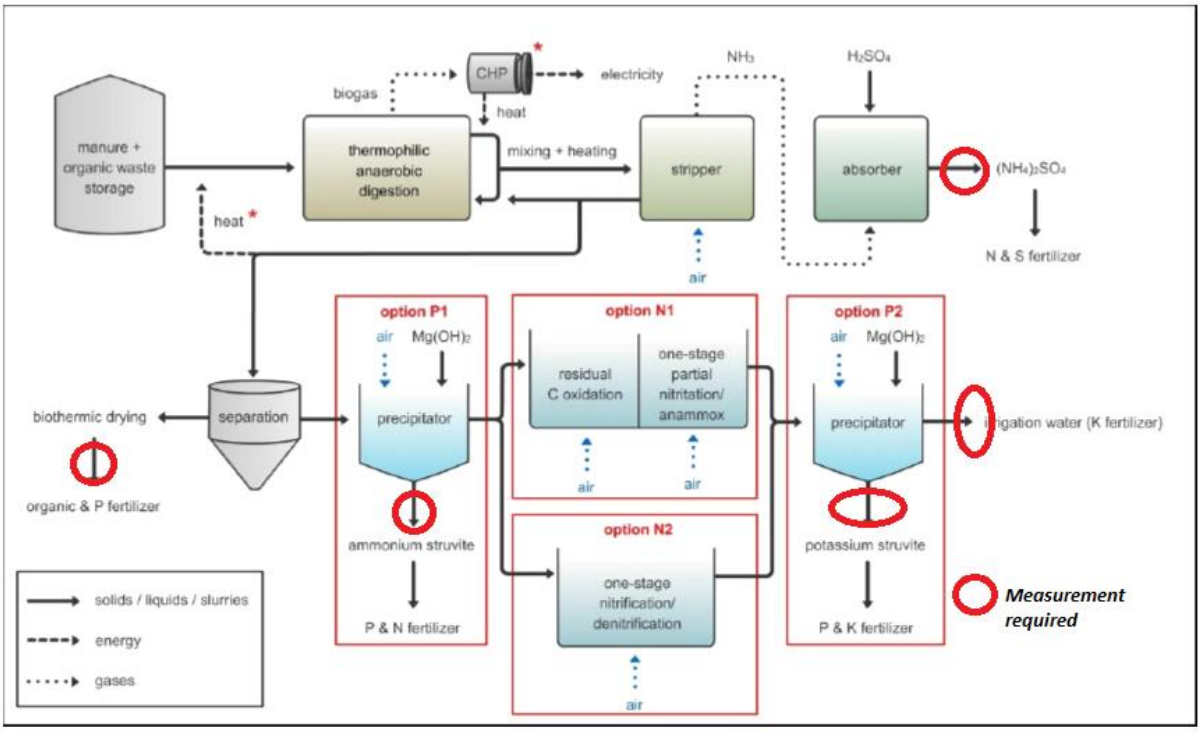

Figure 5: Quality assurance sampling points

- After ammonia stripping and absorber process the ammonia sulphate has to be controlled in order to guarantee its quality and the absence of hazardous compounds.
- After composting of solid digestate to ensure that the product is within the required levels for product usage and that environmental threshold values are kept
- After struvite precipitation to guarantee that struvite fulfils fertiliser requirements and that potential contamination levels are below given threshold values
- At the process effluent outlet where residual process water can be used as irrigation water and it needs to be secured that no harmful compounds remain in the water.

7.2.1 Organic fertilisers

Organic fertilisers produced during the “ManureEcoMine” project have to meet quality requirements according to The European Union Directive 2003/2003 and further the national regulation as well. In addition they have to comply with the European Regulation No. 1774/2002 regarding health rules concerning animal by-products not intended for human consumption. Also REACH threshold values have to be met. Therefore organic fertilisers need to meet at least the requirements of all mentioned regulations before they can be sold on the market.

7.2.2 Compost

Quality end products for compost and are measured in terms of heavy metals and organic pollutants. A specific EU legislation with specific organic pollution values for compost and digestate does not exist currently. Therefore the European Compost network (ECN) developed a quality assurance scheme and published quality criteria for characterising quality compost, which can be seen as guidance levels on the European level.

7.2.3 Process effluent irrigation water

Process effluent used as liquid fertiliser or so called “fertigisers” must comply with the Animal By-Products Regulations (Regulation (EC) 1069/2009 and Commission Regulation (EU) 1042/2011).

8. Economic potential

In order to show that the "ManureEcoMine" project does not solely have a positive environmental impact but also adhere an economic potential, this chapter is going to going to analyse the economic potential of various end products. In addition viable factors of economic feasibility are going to be shown for better understanding of what I required for running such a facility cost-effective.

Economic feasibility is dependent on various key factors which need to be determined:

- Energy, fertiliser, and compost markets
- Regulatory and legislative support
- Biogas energy potential
- Capital costs
- Annual operation and maintenance costs
- Required size of operation for economic feasibility

The key questions relating to this project are if produced biogas / electricity and fertilisers are viable compared to construction and operation costs? Is biogas to electricity conversation cost effective in terms of competing with conventional energy prices? Can digestate fertilisers be competitive on the fertiliser market?

The first step is to determine the biogas energy potential of anaerobic digestion input material and comparing livestock manure to alternative used materials.

Zhang et al. (2013) compared various combinations of animal manure with three crop residues, wheat straw, and corn stalks, and found that depending on mixing ratio and combination of material an increase in biogas yield of 80% can be achieved. Knowing that, co digestion is a viable procedure in the "ManureEcoMine" project for increasing potential biogas production during anaerobic digestion.

The economic potential within the "ManureEcoMine" results in the products produced throughout the process scheme. Anaerobic digestion produces biogas which can be converted to electricity and can be fed to the grid. In addition, anaerobic digestate is further treated and transformed into biofertilisers and compost which can be sold on the particular markets.

Like every other project, the total construction costs are very high and according to feasibility studies in North America, payback periods usually range from 5-20 years depending on operating under optimum or worst conditions. However, most waste processing technologies do not generate revenue like biogas plants.

Table 54: Manure / energy production estimation (Navaratnasamy et al., 2008)

description	manure quantity as excreted (kg/d)	biogas production (m^3/d)	electricity potential (kW)/year	Energy potential (GJ)/year
beef	24	1.1	663	3
dairy	62	2,01	1.227	5.5
piglet	8.8	0,85	516	2,3

For understanding the economic potential of manure table 54 shows potential energy potentials of biogas generated by manure. In addition, table 55 compares different input materials for anaerobic digestion as well as their energy potential.

Table 55: Comparison of various digester input materials and energy potentials (Braun et al., 2013)

feed material	total solids %	volatile solids % of total solids	biogas yield m^3/ tonne	yearly biomass production in tonnes	yearly energy potential in PJ	methane content %
beef cattle manure	8-12	80-85	19-46	51890,736	20-48	53
dairy manure	12	80-85	25-32	3994,195	2-2,6	54
hog manure	9-11	80-85	28-46	2452,800	1.4-2.3	58
municipal wastewater sludge	20-30	90	17-140	539,835	0.2-1.5	65
animal fat	89-90	90-93	801-837	87,000	1.4-1.5	N/A
Rye	25-61	91-95	112-457	4,423	0.00-0.04	N/A
grass silage	20-25	90	75-126	N/A	N/A	N/A
wheat	32-97	N/A	48-146	1390,222	1.33-4.106	N/A

Further, a second study has been undertaken in order to demonstrate the energy potential of various anaerobic digestion input materials.

Table 56: Biogas potential of anaerobic digestion input material (Braun et al., 2013)

input material	**biogas yield (m^3 biogas/t of TS)**
harvest residues	375
animal manures	200-500
yeast and yeast like products	400-800
wastes from plant- and animal fat production	1000
pharmaceutical wastes	1000-1300
sewage sludge	250-350
wastes from pulp- and paper industry	400-800

On behalf of table 56 it can be shown that biogas production from manure is a viable method of waste treatment. Even though the biogas yield is relatively low compared to other input material, high yearly biomass production leads to a relatively high yearly energy potential. In addition biogas / electricity production from manure reduces greenhouse gas emissions and has the potential of replacing fossil fuel-generated electricity which further leads to a reduction in CO_2 emission from not burning fossil materials. Due to the fact that many countries are using different sorts of carbon credits for regulating the overall greenhouse gas emissions, biogas / electricity produced of animal manure can be sold be sold to buyers who are committed to some level of greenhouse gas reduction. Likewise sorts of renewable energy credits (RECs), commonly used in the United States, can be sold to an electricity utility which is under mandate of generating part of their energy from renewable sources. In Minnesota (US), for instance, utilities must obtain at least 25% from renewable source by 2025. These developments towards sustainable energy supply therefore show a massive future potential from which manure treatment can profit.

Besides biogas production through anaerobic digestions, various state of the art technologies are used in order to produce fertilisers out of the anaerobic digestate. These fertilisers can then being sold and thereby generate revenues. For illustrating that, Westerman et al. (2010) studied the economic potential of struvite precipitation. The economic cost effectiveness was based on the total costs considering construction, maintenance, operating costs, as well as process required substances such as magnesium or sodium hydroxide and revenues generated by selling struvite fertilisers. As shown in table 57, Westerman et al. (2010) found that struvite precipitation is economically not cost effective but due to the fact that manure treatment is considered as waste treatment, revenues generated throughout the process minimises the arising expenses.

Table 57: Economic cost-effectiveness of struvite precipitation (Westermann et al. 2010)

item	**unit**	**quantity**	**%/year^{-1}**	**price $/unit**	**annual amount**
capital equipment (6% APR over 7 years)	$	44,000	17.91	-	7,882
construction / installation	$	43,000	17.91	-	7,703
magnesium for adjustments	kg	87,000	17.91	0,55	730
sodium hydroxide for pH adjustments	L	1,327	-	0,337	5,637
electricity	kWh	16,746	-	0,07	4,667
lab	h	66,671	-	12,00	6,480
management	h	540	-	50,00	2,600
maintenance	$	52	5	-	4,350
total costs	$	87,000		-	40,049
revenue from struvite	kg	10,629	0.3	-	3,508
net revenue	$				**-36,541**

Summarising it can be said that anaerobic digestion has the potential to create realistic revenues whereas further treatment of digestate and the transformation to organic fertilisers is still a waste treatment process with little financial benefit but future perspectives.

9. Summary and conclusions

Summary

This thesis was solely based on literature review and tried to develop a risk management concept based on existing scientific research evidence in various fields of study. One of the major aims throughout the thesis was the determination of the project's viability by using mean values of already gathered data, correlated them with proven efficiency of used state of the art technologies and further comparing them to given environmental and market value limit thresholds.

To do so a risk management concept according to the ISO 31000:2009 was used. The first process step included the identification of potential risks.

The risk identification resulted in risks related to the raw livestock manure as well as process related risks. Thereby it further could have been distinguished between process related risks related to the input material and process risks such as emissions occurring during various process steps. Identified manure compounds included chemical, biological, and physical potential hazardous compounds like human pathogens, fed veterinary antibiotics, heavy metals which have to potential to harm the environment as well as life forms if not treated properly. In terms of process risks, process inhibition during thermophilic anaerobic digestion was one of the major identified risks due to the fact that several manure compounds have the potential of reducing the process efficiency of anaerobic digestion and therefore also affect downstream processes. In terms of risks occurring throughout the process scheme, N_2O emissions while nitrification / denitrification and partial nitrification / anammox processes are facing the biggest threat due to their aggressive greenhouse gas potential and their lack of avoidance. In conclusion risk identification showed that raw animal manure contains a variation of potential hazardous compounds which need to be treated properly. In addition, is has been shown that these compounds also face inhibition processes in anaerobic digestion which can affect the whole process chain. Last but not least process related by-products have been identified.

Based on the risk identification, a risk analysis has been done in order to determine risk consequences and probabilities as well as analysing existing control measures. The risks analysis showed that state of the art technologies planned for the "ManureEcoMine" project have the potential of treating identified risks. In addition the potential effectiveness of possible state of the art technologies and measures has been determined. Further risk levels have been determined based on control measures efficiency and risk likelihood and their consequences. Last but not least, the risk analysis determined risk levels in case existing control measures fail and uncertainties arisen throughout the analysis.

Risk evaluation defined tolerance levels and if they are acceptable or not and categorised risk treatment priorities.

Based on that, risk treatment defines measures that need to be taken in order to change the likelihood as well as the consequence level of existing risks.

Besides the risk management concept, a quality management analysis has been done in order to identify quality requirements for raw manure, process quality assurance, sampling requirements as well as quality requirements for end products.

Last but not least an economic analysis has been done to show the economic potential of the “ManureEcoMine” project based on possible biogas and organic fertiliser revenues.

Conclusions

- It can be concluded that according to literature findings the planned process scheme fits to the planned task of treating potentially hazardous animal manure by simultaneously producing tradable biological products.

- Project relevant risks in raw input material and along the process scheme could have been successfully identified, analysed, and prioritised, and potential treatment measures could have been determined. Therefore, vital information for the actual “ManureEcoMine” projects could have been gathered.

- The economic analysis showed that the “ManureEcoMine” project is not profitable and does not generate enough revenues due to not fully developed markets and comparatively high production costs, it still has to be considered that it is a waste treatment procedure and any revenue generated minimises the anyway arising expenses.

- The thesis showed that the expected concentrations in produced end products are within existing legal thresholds. Only exception are antibiotics concentrations which need further investigation throughout the actual project running phase due to lack of data.

According to gathered information throughout the thesis, this project represents a future potential for treating biological waste and generating economic revenue at the same time. Only if both mentioned parameters are achieved, such technologies are going to replace fossil resources based energy as well as chemical fertilisers. Even though, used technologies might not be efficient and effective yet, the planned project still is another step heading for a more sustainable future.

10. List of tables

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12. References

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13. Appendices

13.1 Appendix 1: used antibiotics for therapeutic and sub therapeutic purposes in swine production

Table 58 shows commonly used antibiotics for therapeutic and sub therapeutic purposes in swine production.

Table 58: Appendix 1: used antibiotics in swine production

drug	drug use level (g/ton) / treatment objective
apramycin	150 (disease control)
arsanilic Acid	45-90 (feed effiecincy and growth)
bactiracin methylene disalicyate	10-30 (feed efficiency and growth) 250 (disease control)
bacitracin zinc	10-15 (feed efficiency and growth) 20-40 (feed efficiency)
bambermycins	2 (feed efficiency and growth) 2-4 (growth)
carbadox	10-25 (feed efficiency) 50 (disease control)
chloretracycline	10-50 (feed efficiency and growth)
lincomycin	20 (feed efficiency and growth) 40-200 (disease control)
oxyetracycline	10-50 (feed efficiency and growth) 22 (disease control)
penicillin	10-50 (feed efficiency and growth)
roxarsone	23-34 (feed efficiency and growth) 182 (disease control)
tiamulin hydrogen fumerate	10-11 (feed efficiency and growth) 35-200 (disease control)

tylosin	10-100 (disease control) 10-20 finisher (feed efficiency and growth) 20-40 grower (feed efficiency and growth) 20-110 starter (feed efficiency and growth)

13.2 Appendix 2: Commonly used antibiotics in beef production

Table 59 illustrates commonly used antibiotics for therapeutic and sub therapeutic purposes in beef production.

Table 59: Appendix 2: Antibiotics used for beef production

drug	**drug use level (g/ton) / treatment objective**
bacitracin zinc	35-70 (feed efficiency and growth)
bambermycins	1-5 (feed efficiency and growth) 2-45 (pasture,slaughter,feeder cattle growth)
chlorotetracycline	350 (disease control)
laidlomycin	5-10 (feed efficiency and growth)
laslocid	10-30 (feed efficiency and growth)
monwnsin	5-30 (feed efficiency and growth) 25-400 (intensive feeding and weight gain)
oxytetracycline	75 (feed efficiency and growth) 75 (disease control)
tylosin	8-10 (disease control)
virginiamycin	10-25 (feed efficiency and growth)

13.3 Appendix 3: Hormones used in feedstock farming

Hormones concentrations normalised to dry weight or total nitrogen in two experimental biogas digestates. BG1 shows mesophilic process conditions (37°C), with 95% swine manure and 5% alcohol industry wastes as input source. BG2 is a thermophilic (52°C) plant using 75-80% swine manure, 10-20% slaughterhouse and 5-10% restaurant wastes as input. Findings are compared to findings by Hansen et al. (2011) who analysed swine manure sources using GC-MS.These are illustrated in table 60.

Table 60: Comparison of hormones concentrations in anaerobic digesters to gas chromatography- mass spectometry (GC-MS) (Rodriguez-Navas et al., 2013)

	Digestate byproduct				Other studies			
	BG1		BG2		Digestate		Manure	
	ng g^{-1} dw	mg kg^{-1} N	ng g^{-1} dw	mg kg^{-1} N	ng g^{-1} dw		ng g^{-1} dw	mg kg^{-1} N
Estrogens								
Estrone	593 (69)	5.32 (0.62)	1478 (17)	22.5 (0.25)	–	–	112–1680[c]	0.64–25[d]
17α-estradiol	24 (2.1)	0.22 (0.02)	64 (5.9)	0.98 (0.09)	–	–	116–173[c]	0.93–2.35[d]
17β-estradiol	50 (3.8)	0.44 (0.03)	28 (0.5)	0.43 (0.01)	3–15[a]	6[b]	126–310[c]	1.66–2.56[d]
ΣEstrogens	*667*	*5.99*	*1570*	*23.9*	–	–	*112–2163*	*0.64–30*
Androgens								
Dihydrotestosterone	ND	ND	8.3 (3.5)	0.13 (0.05)	–	–	33[c]	0.19[d]
Androstenedione	72 (65)	0.64 (0.58)	497 (7.6)	7.58 (0.12)	–	–	31–56[c]	0.17–1.14[d]
Testosterone	187 (70)	1.68 (0.63)	33 (30)	0.50 (0.45)	–	–	13–33[c]	0.08–0.68[d]
ΣAndrogens	*258*	*2.32*	*538*	*8.21*	–	–	*31–90*	*0.17–1.82*
Progestagens								
Pregnenolone	ND	ND	3.1 (5.3)	0.05 (0.08)	–	–	27[c]	0.14[d]
Progesterone	321 (380)	2.88 (3.42)	1333 (147)	20.3 (2.24)	–	–	1247[c]	25[d]
ΣProgestagens	*321*	*2.88*	*1336*	*20.4*	–	–	*27–1247*	*0.14–25*
ΣSteroid hormones	**1247**	**11.2**	**3444**	**52.5**			**158–2803**	**0.90–57**

13.4 Appendix 4: HACCP analysis

HACCP analysis

Similar to any other risks assessment tools, hazards need to be identified before analysing them for finding potential solutions. HACCP Hazard identification focuses on biological, chemical, and physical hazards occurring along the flow chart.

Principle I: Hazard analysis

Similar to any other risks assessment tools, hazards need to be identified before analysing them for finding potential solutions. HACCP Hazard identification focuses on biological, chemical, and physical hazards occurring along the flow chart.

Raw input material hazards

Raw input material contains various biological, chemical, and physical hazardous compounds which are illustrated in this chapter.

Biological hazards

Biological hazards are all living organisms that can make the end product unsafe and include bacteria, parasites and viruses. These hazards are either related to the raw input material or to production processes where they might enter the process scheme. In terms of the "ManureEcoMine" project these have been the following biological hazards have been determined based on common livestock manure compositions:

- Pathogens (detailed pathogenic listing is given in annex x)
    - Bacteria: (e.g Salmonella spp., E. coli 0157:H7, Campylobacter jejuni, Yersinia enterocolitica)
    - Protozoa: (e.g. Giardia lamblia, Cryptosporidium spp.)
- Natural hormones (e.g. Estrogens, Androgens, Protestogens)

Chemical hazards

Chemical hazards may be the result of compounds naturally occurring in the product or may occur during diverse processes:

- Heavy Metals (e.g. Zn, Cu, Ni, Pb, Cr, As, Cd)
- Antibiotics (e.g. Penicillins, Tetracyclines, Macroloides, Aminoglycosides, Flourchinolones, Trimethoprim / sulphamethoxazole)
- Synthetic Hormones (e.g Zeranol, Trenbolone acetate, Melengestrol acetate)
- Odorous compounds (e.g Hydrogen sulphide, dimethyl sulphide/ disulphide/ trisulphide, Indole, Phenol, 4- methyl phenol, Acetic acid, Butanoic)
- Volatile organic compounds (can be classified into many different chemical groups including acids, alcohols, aldehydes, amines, hydrocarbons, ketones, indoles, phenols, N- containing compounds, S- containing compounds)
- Gaseous compounds (various forms of nitrogen, CO_2)

Physical hazards

Foreign material such as glass, metal or plastic that enters the manure during livestock husbandry

Analysis of preventive measures used to control hazards

Biological hazards

- Pathogens: Thermophilic anaerobic digestion
- Hormones: Thermophilic anaerobic digestion

Chemical hazards

- Heavy metals: Thermophilic anaerobic digestion, ammonia stripping
- Antibiotics: Thermophilic anaerobic digestion
- Hormones: Thermophilic anaerobic digestion
- Odorous compounds: Thermophilic anaerobic digestion
- Nitrogen: Thermophilic anaerobic digestion, ammonia stripping, nitrification/denitrification and partial nitrification/anammox processes

Principle II: Determination of critical control points

According to the United States Department of Agriculture a critical control point is defined as “A point, step, or procedure at which control must be applied and as a result, a hazard can be prevented, eliminated, or reduced to acceptable levels.

Based on that definition, the following critical control points (CCP) have been identified as shown in table 61.

Table 61: Appendix 4: Critical control points

number	process step	potential hazards and causes	control measures	CCP YES / NO
1	raw material	effects on environment and life forms (see chapter 3)	safe storage	NO
2	thermophilic anaerobic digestion	process inhibition by feedstock compounds, failure of removal hazardous input material compounds	keeping process parameters in certain range, minimisation of hazardous input material compounds	YES
3	combined heat and power unit	process failure, leaching of gaseous compounds	regular monitoring measures to guarantee building safety	NO
4	ammonia stripping and absorber	failure of removing ammonia accurately	keeping process parameters in certain range	YES
5	mechanical liquid / solid separation	process failure	constant servicing	NO
6	composting of separated solid digestate	process failure	constant servicing	NO
7	struvite precipitation	failure of phosphate removal	keeping process parameters in certain range	YES
8	nitrification / denitrification and partial nitrification / anammox	N_2O emissions, failure of nitrogen removal	keeping process parameters in certain range	YES

9	endproducts	environmental harm due to remaining hazardous compounds	measuring the process effluent according to international standards	YES

Principle III: Establishing critical limits for each control point

Thermophilic anaerobic digestion:

Inhibition of process functionality due to input material compounds:

- Ammonia inhibition (4g N/l or 3g N/l at pH > 7.4)
- Heavy metals (80 mg/l Cd, 5 mg/l Cr, 160mg/l Zn, 170mg/l Cu, 0.6 mg/l Ni, 2mg/l Pb)
- Sulphides (800mg/l as dissolved sulphide or 430 mg/l as undissociated H_2S)
- Antibiotics (No critical values were found during research. Nonetheless levels should be kept as low as possible in order to prevent proven inhibition effects)
- Volatile fatty acids (6 g/l if pH is not in a range of 6.6-7.4)

Anaerobic digestion process failure if process factors are not in a certain range:

- Temperature (high temperatures are required remove hazardous compounds from raw material, temperature should be at least mesophilic (> 30°C) in order to guarantee pathogen, hormones, antibiotics, heavy metal, odorous compounds removal)
- pH (should be kept in a range of 6.8-8.5) Too low or too high pH leads to process failure

Ammonia stripping process failure due to lack of keeping process factors in range leads to an inefficient removal of nitrogen:

- pH (if pH is not high enough process fails due inappropriate distribution of dissolved NH_3 gas and NH_4^+ ions)

Struvite precipitation process due to lack of keeping process factors in range leads to an inefficient removal of phosphorus and nitrogen:

- pH (Struvite precipitation has to performed at a pH range of 7-11)

Nitrification / denitrification process failure leads to an insufficient removal of nitrogen

- pH (Nitrification/denitrification should be maintained at a pH range of 7,2-8)

End-products can still contain hazardous compounds

According to PAS 110:2010 anaerobic digestate for further usage need fulfil the following criteria:

- Pathogens (human and animal pathogen indicator species)
    - E.coli (1000 CFU/g fresh matter)
    - Samonella spp. (absence in 25g fresh matter)
- PTE's (Potential Toxic Elements)
    - Cd (1.5 mg/kg dry matter)
    - Cr (100mg/kg dry matter)
    - Cu (200mg/kg dry matter)
    - Pb (200mg/kg dry matter)
    - Hg (1mg/kg dry matter)
    - Ni (50mg/kg dry matter)
    - Zn (400mg/kg dry matter)
- Stability factors
    - Volatile Fatty Acids (0.43 g COD/g VS)
    - Residual Biogas Potential (0.25 l/g VS)
- Physical contaminants
    - Total glass, metal ,plastic, and other non-stone, man-made fragments > 2mm (0.5% m/m dry matter)
    - Stones > 5mm (8% mm dry matter)

Principle IV: Establish monitoring procedures

Monitoring procedures need to include the measurement of performance levels of the system's operation at the CCP, the determination when the performance level of the system result in a loss of control at CCP, and the establishment of records that reflect the performance level of the system's operation at the CCP to comply with the HACCP plan.

Anaerobic digestion

Based on research by Labatut et al. (2009) anaerobic digestion processes should be monitored weekly, at least on a bi-weekly basis by analysing digester operating processes on the one hand side and checking feedstock characteristics when entering and leaving the digester.

- pH: pH should be measured in the influent as well as in the effluent of anaerobic digestion systems by using either pH meter or single-junction electrodes in order to guarantee the required range
- Temperature: Temperature has to be monitored constantly with pH meters or thermocouples
- Loading frequency
- Mixing frequency
- Mixing speed

In addition to process factors the amount of important biological and chemical process compounds has to be monitored as well in order to prevent inhibition effects:

- Total ammonia-nitrogen (TAN): Ammonia has the potential to cause massive process inhibition and further process failure and therefore need to be measured at both, influent and effluent by using ion meters or ion selective electrodes
- Volatile fatty acids (VFA): Measured at influent and effluent by distilling sample and titrating the distillate with sodium hydroxide 0,1 N to pH 8,3
- Total solids (TS): Drying the sample in gravity convention oven at 105°C for ~8 hours. Samples need to be taking at influent as well as effluent
- Total volatile solids (VS): Measured at influent and effluent by ashing the taking sample in muffle furnace at 550°C for 1h

Ammonia stripping

Ammonia sir stripping is dependent on various factors which need to get monitored throughout process performance:

- Chemical characteristics of the manure (especially pH and nitrogen) need to be tested at the beginning and the end of the process

- Air temperature should be measured at various points of the plant: the upper and the button of the reactor, inside the manure, and the hot water circuit of the reactor's heating system

Struvite precipitation

- pH: Due to the fact that pH is an essential process parameter in struvite precipitation it has to be monitored during inflow and while processing by using either pH meter or single-junction electrodes in order to guarantee the required range
- Temperature: Temperature has to be monitored constantly with pH meters or thermocouples

Nitrification / denitrification

- pH: pH should be measured in the influent as well as during active processing by using either pH meter or single-junction electrodes in order to guarantee the required range
- Temperature: Temperature has to be monitored constantly with pH meters or thermocouples

Principle V: Establish corrective actions

Even though defined hazards should be properly treated by using defined control measures it might be necessary to establish corrective actions in order to optimal product quality. In terms of the "EcoManureMine", table 62 illustrates actions determined in order to minimise process risks.

Table 62: Appendix 4: Established corrective measures

risk	justification
antibiotics threats raw manure	Due to not lack of information regarding tolerance levels and legal threshold levels and based on found control effectiveness it has been concluded that antibiotics in raw livestock manure need to be treated in order to prevent antibiotics from existing in end products or from entering the environment. Changing the likelihood and consequences so far is only possible by changing treatment measure during animal husbandry. Based on scientific data more than 70% worldwide used antibiotic is used for animal treatment. Most of it precautionary. Changing antibiotics concentrations in raw livestock manure therefore relies on changing and more sustainable dosing and medication.

volatile fatty acids inhibition anaerobic digestion processes	Alkaline buffering should be used in order to treat volatile fatty acids inhibitions (Mignone, 2005). This allows anaerobic digestion to keep functioning until the reason for the inhibition process has been determined. Treatment measures are capable or reducing risk consequences but not lower the risk likelihood.
sulphide inhibition anaerobic digestion processes	A proven method of treating sulphide inhibition is by adding iron salts (Mignone, 2005). Due to the fact that treatment is recommended but not vital to process efficiency, the decisions should be made in terms of financial effort. In additions, similar to measures set for volatile fatty inhibition treatment, the adding of iron salts if just capable of reducing the consequences but no the likelihood.
antibiotics inhibition anaerobic digestion processes	Now evidence about concrete antibiotics inhibition treatment measure has been found in literature. Due to the fact, that antibiotics inhibition is based on the concentration of concentrations in the feedstock, risk treatment has to start at the earliest stage of the process. Antibiotics treatment should be reduced to the lowest necessary level instead of overdosing medications prophylactically. Therefore these measures can reduce the likelihood of antibiotics inhibition occurrence.
ammonia inhibition anaerobic digestion processes	As already described in the section of potential control measures, ammonia inhibition can be controlled by changing several process parameters such as pH, the hydraulic retention time or the process temperature (Angelidaki et al. (1992), Callaghan et al. (1999), and Hansen et al. (1998)). Due to the fact that low temperatures due not occur at thermophilic anaerobic digestion, pH control is not economical reasonable and does not work at concentrations above 3 g N/l, the exceeding of the hydraulic retention time might be the most viable treatment method.
heavy metals inhibition anaerobic digestion processes	As already described above, heavy metal inhibition can controlled by sulphide precipitation. Based on the fact that this may lead to sulphide toxicity and therefore increases the chance of sulphide inhibition, it is more suitable to treat heavy metal inhibition already at the livestock feeding stage. Based on studies by Zhang et al. (2010) of more than 120 manure samples and 104 livestock feeds the content of heavy metals in animal feed range from 2, 3–1,137.1 mg/kg dm of Cu, As and Cd in pig feeds as well as 2, 88–98, 08 mg Cu/kg dm, 0, 02–6, 42 mg As/kg dm and non-detectable (nd) – 8, 00 mg Cd/kg dm in cattle feeds. Therefore minimising these concentrations can reduce the likelihood of heavy metal inhibitions drastically.
N_2O emissions during nitrification/ dentrification processes	Changing the likelihood of N_2O emissions during nitrification/denitrification processes can only be done by on site monitoring by adjusting process parameters up to a point of minimum emission levels.

N_2O emissions during partial nitrification/ dentrification processes	Similar to nitrification/denitrification, process parameter is so far the only existing controls measure for reducing potential consequences.

Principle VI: Establish verification procedures

Other than monitoring, the verification procedures are responsible for determining the validity of the HACCP plan. Due to the fact that this analysis is solely based on literature review no declaration about verification procedures can be done. These have to be determined throughout the process and need to be specifically adapted along the process scheme.

Principle VII: Establish record-keeping and documentation procedures

Similar to principle VI, record keeping and documentation must be done throughout the real life application of the project. Principle VII therefore has to include a summary of the hazard analysis, a HACCP Plan, as well as support documentation such as validation records.

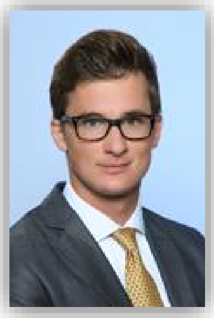
13.5 Appendix 5: Curriculum vitea

Stefan-Alexander Kratzer

MSc. International Management

Born on the 23/06/1986, Vienna

Austrian Citizenship



Education

Oct. 2012 – Oct. 2013

Loughborough University Business School, Loughborough (GB)

Full–time masters study in „*International Management*" with major in:

- International Business Environment
- Strategic Management

Master thesis written on the institute of Business and Economics „*International Business Analysis- Boeing Commercial Airplanes* "Prof. Ursulla Ott

Oct. 2011- Sep. 2014

University of Natural Resources and Life Sciences Vienna

Full-time masters study in „*Water Management and Environmental Engineering* "with major in:

- Sanitary Engineering
- Hydrology and Water Management
- Hydraulic Engineering and River Basin Management

Master thesis written on the institute of Sanitary Engineering and Water Pollution Control (SIG) „*ManureEcoMine- Implementation of a Risk Management Concept for fertilizer upcycling from manure* "Dr. Thomas Ertl

Oct. 2007 – Oct. 2011	**University of Natural Resources and Life Sciences Vienna** Bachelor studies in *„Environmental and Bioressources Management“* with major in: Waste Management, Resource Efficiency: Master thesis written on the institute of Sanitary Engineering and Water Pollution Control (SIG) *„Die Wasserrahmenrichtlinie - institutionelle Umsetzung im Kontext der österreichischen Gewässerpolitik“* DI Florian Kretschmer
Oct. 2006 – Mar. 2007	**Wirtschaftsuniversität Wien** Bachelor studies *„Internationale Betriebswirtschaft“*
Sept. 1996 – Jun. 2004	**Realgymnasium Institut Neulandschule Wien**

Work experience

Jun.2011 – Aug.2012	**Hotel Kunsthof,** Vienna Night Auditor part-time 20 h/week: Front Office, book-keeping
August 2009	**Flughafen Wien AG**, Vienna Internship Aircraft maintenance
Juli 2009	**University of Natural Resources and Life Sciences Vienna** Internship on the Sanitary Engineering and Water Pollution Control (SIG) „ Regenwassernutzung- VVU-Ghana“
Dec.2006 – Jun.2009	**APETA Trading and Business Development**, Vienna Part-time Export Sales Analyser
Oct.2004 – May 2006	**Austrian Military,** Vienna

Languages and IT skills

German	First Language
English	Good knowledge in writing and speaking
	TOEFL - Test of English as a Foreign Language. Score 104 (2012)
Italian	Basic skills
PC	MS Office (Word, Excel, Power Point, Access)
	AutoCAD
	Statistikprogramm – R
	Arc GIS / Arc View
	GaBi Bilanzierungssoftware
	Front Office Software Fidelio 8
	SAP

HOBBIES, INTERESTS

Rowing	2003 – 2009: 7 successful participations at World Championships
	2007 – 2013: 2 times European Student Champion
	2 times 2nd place European Students Championships
	2000 - 2013: 15 times Austrian Champion
	2013: Winner of British University Rowing Championships
	Hiking, travelling, reading

14. Affirmation

I certify, that the master thesis was written by me, not using sources and tools other than quoted and without use of any illegal support.

Furthermore, I confirm that I have not submitted this master thesis either nationally or internationally in any form.

Date: _______________ Signature:_______________