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MASTERS' THESIS

CIRCULAR ECONOMY AND CLOSING NUTRIENT CYCLES: PLANNING SUSTAINABLE BIO-WASTE MANAGEMENT SYSTEM FOR PUOLANKA MUNICIPALITY

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Suomen hallitus on tehnyt viiden vuoden (2018-2023) jätesuunnitelman ”Kierrätyksestä kiertotalouteen”, jonka tavoitteena on kestävä jätehuolto ja jätteiden synnyn ehkäiseminen. Kiertotalouden omaksuminen tuo mukanaan kolme positiivista asiaa: talouskasvun, sosiaalisen kehityksen ja ympäristövaikutusten pienenemisen, edeten samalla kohti kestävää kehitystä.

Teoreettinen osa määrittelee ja täsmentää kiertotalouden termejä ja kuvaa sitä, miten kiertotalous on parempi kuin lineaarinen järjestelmä; kuvaa, mitä ovat teollinen ekologia, vähähiilinen talous, ravinnekierto ja ravinteiden kierron sulkemisen tärkeys, tarkastelee erilaisia lannoitetyyppejä ja syitä miksi valita luonnonlannoitteet keinolannoitteiden sijaan. Myös asiankuuluvat EU:n säännökset ja direktiivit laadun ylläpitämiseksi ja hyvän elinympäristön turvaamiseksi kerrotaan. Lopuksi selvitetään biojätteiden käsittelyyn käytetyt tekniikat ja anaerobisen mädätyksen edut kompostointiin verrattuna kestävyyden kannalta tarkasteltuna.

Kokeellisessa osassa Kainuussa sijaitsevan Puolangan kunnan nykyistä erilliskerätyn biojätteen käsittelyä (kuljetus ja kompostointi Kajaanin Majasaaren jätekeskuksessa) verrattiin muihin mahdollisiin skenaarioihin:
- Skenaario I: Erilliskerätyt biojätteet kuljetetaan Ouluun käsiteltäväksi nykyisessä biokaasulaitoksessa
- Skenaario II: Erilliskerätyt biojätteet käsitellään Puolangassa paikallisesti uudessa biokaasulaitoksessa

Tavoitteena oli suositella parasta ja sopivinta vaihtoehtoa näiden kolmen vaihtoehdon väliltä yleisen kestävyyden kannalta tarkasteltuna sekä ravinnekierron sulkemisen ja kiertotalouden edistämiseksi.

Tiedot kerättiin ja tehtiin asianmukaiset laskelmat biokaasureaktorin mitoittamiseen ja biokaasulaitoksen taloudelliseen kannattavuuteen liittyen. Kestävyysarviointi suoritettiin käyttäen RECENT-projektin kestävyydenarviointitemplaatteja tehtyihin laskelmiin ja kerättyyn tietoon perustuen. Kestävyysarvioinnin tulosten perusteella todettiin, että nykytilanne olisi vähiten suositeltava vaihtoehto, vaikka se olisi ollut skenaarioon I verrattuna taloudellisempaa, koska kompostointiteknologian käyttö aiheutti päästöjä eikä sillä ollut pitkäaikaisia sosioekonomisia hyötyjä. Skenaariossa II oli myös etu skenaarioon I verrattuna, sillä skenaario II vaikutti ympäristöön ja yhteisöön, koska oman biokaasulaitoksen hankkiminen tarjoaa yhteisölle etuoikeuden puhtaaseen uusiutuvaan energiaan (biokaasu) ja sen energiantuotannolla olisi mahdollista vähentää riippuvuutta fossiilisista polttoaineista. Todettiin, että skenaario II on täysin saavutettavissa, ja sen takaisinmaksuaika on vain 3,22 vuotta. Biokaasun laskennallinen energiantuotanto 165,478 tonnille biojätettä vuodessa vuodessa oli 144,8 MWh, joka riittää korvaamaan 10,9 bensiiniauton ja 15,4 dieselauton vuosittaisen polttoaineenkulutuksen. Biokaasuprosessista saatavan mädätteen vuosittainen arvo oli 1 556,3 €; vuosittainen kaukolämmön tuoton arvo 13 694 euroa; ja hiilidioksidipäästöjen väheneminen 40,37 t CO_{2e} vuodessa.

Puolangan saamat taloudelliset edut porttimaksujen ja kuljetuskustannusten alenemisen sekä työpaikkojen tai liiketoimintamahdollisuuksien lisääntymisen myötä lisää selvyyttä siitä, että Skenaario II, Puolangan uusi biokaasulaitos, on paras vaihtoehto jätteenkäsittelylle Puolangan kunnassa ravinnekierron sulkemiseksi ja kiertotalouden aikaansaamiseksi jätteiden kierrätyksen kautta jätteen ollessa syötteenä energiantuotannossa pitkän aikavälin hyötyjen ylläpitämiseksi.

Tämä diplomityö on intensiivinen teorian ja käytännön yhdistely sen ymmärtämiseksi, että resurssien kierrättäminen vahvistaa kiertotaloutta ja ravinnekierron sulkeminen biosfäärissä on tärkeää. Suosituksia jatkotutkimuksille ovat yksityiskohtainen selvitys (investointien osalta) skenaarion II toteutettavuudesta (paikallisten biojalostamojen mahdollisimman suuri käyttö). Myös yhteismädätys (kaksi tai useampi syötettä samalla laitoksella) lisäisi biokaasun tuotantoa, mikä puolestaan lisäisi puhtaan uusiutuvan energian tuotantoa.

Muita tietoja

ABSTRACT University of Oulu, Faculty of Technology

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Abstract

The government of Finland has set five-year National waste plan (2018-2023) with the theme "From recycling to circular economy" and the plan aims to sustainable waste management and waste prevention. Adapting circular economy shall bring three positives: economic growth, social development and lower environmental impact, when progressing towards sustainable development.

The theory part defines and details the terms circular economy and how it is better than linear system; industrial ecology; cradle to cradle; low-carbon economy; nutrient cycle and the significance on closing the cycle; then defining fertiliser and the types of fertilisers and why to choose natural fertilizers over chemical fertilizers? Also, there is a mention of relevant EU regulations and directives for maintaining the quality and providing best living environment for all. Lastly the technologies that are used for managing the municipal bio-waste and the comparative advantages of anaerobic digestion (AD) over composting on the basis of sustainability are defined.

In the experimental part, the current situation of separately collected bio-waste in Puolanka municipality in Kainuu (Status quo: transported to Kajaani for composting in Majasaari waste center) was compared with the other possible scenarios:

- Scenario I: If separately collected bio-waste were transported to Oulu to be treated in existing biogas plant
- Scenario II: If separately collected bio-waste were treated in Puolanka locally in new biogas plant

The aim was to recommend best suitable management-option for long-term sustainability of source separated bio-waste in Puolanka municipality based on closing the nutrient cycle and boosting circular economy.

The data were collected and appropriate calculations for sizing and feasibility studies were made. The Sustainability Assessment tests were performed using RECENT project's sustainability assessment templates based on calculations and collected information. It was observed from sustainability outcomes that Status quo would be the least preferred option even though it was economical than Scenario I because the use of composting technology caused greenhouse gas emissions and didn't have long-term socio-economic benefits. Also, Scenario II had an advantage over Scenario I for an impact on environment and community since creating an own anaerobic digester provides community a privilege of clean renewable energy (biogas) and its energy output was possible to replace our dependency on fossil fuel consumption. It was found that Scenario II is totally attainable, with only 3,22 years of payback period. The calculative biogas energy output for a year with 165,478 t of bio-waste/year was 144,8 MWh that would be enough to replace the annual fuel demand of 10,9 petrol-based cars and 15,4 diesel-based cars. The value of annual digestate (sanitized co-product of biogas process) sales was 1 556,3 €; annual district heating revenue was 13 694 €; and reduction of 40,37 t of CO_{2e} per year.

The economic boost with reduction of gate fee and transportation charges and increase in job or business opportunities at Puolanka itself makes it more evident that Scenario II, the proposed AD plant in Puolanka is the best solution for the source separated bio-waste management for closing nutrient cycle as well as in achieving circular economy through circulation of the waste as an input to convert into energy in maintaining long term benefits.

Thus, this thesis is an intensive consolidation of theory and experiment to understand that circulation of resources boosts circular economy and closing the nutrient cycle in biosphere is important. The future recommendations would be a detailed study on the feasibility (in terms of investments) for Scenario II (maximum use of local bio-refineries). Also, co-digestion (adding two or more substrates) as feed-inputs would boost in the production of biogas contributing to high clean renewable energy output.

Additional Information

FOREWORDS

This thesis tenure has marked an inspirational sensation in me. I started off very casual with an attempt of getting degree but now as I am approaching the finishing line, I have understood the impact this work has made on me on a personal level. In this journey, I had multiple epiphany moments which has led to an immense desire to broaden my knowledge and become a better environmentalist. I would always be grateful for this remarkable change.

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TERMINOLOGIES

Bio-waste: Biodegrading park and garden waste, kitchen and food waste from households, restaurants, caterers and retail premises and comparable waste from food processing plants

Bio-refinery: Use of biomass or biomass derivatives as feed-stocks for integrated production plant to make value-added products and energy

Cascading: Waste from one process becomes an input for another

Carbon-to-nitrogen ratio (C:N ratio): Ratio representing the quantity of carbon (C) in relation of nitrogen (N) in soil or organic material; determines the composting potential of a material and serves to indicate product quality

Compost: The end-product (innocuous humus) remaining after the composting process is completed

Down-cycling process: Recycling the materials into lower value products

Eco-efficiency: Adding maximum value with minimum use and minimum pollution

End-of-waste (EoW): A phase where the waste is no longer a waste and becomes a useful new product, or a secondary raw material

Feedstock: Decomposable organic material usually plants for the compost or biogas plant

Industrial Symbiosis: An exchange of physical and chemical materials, energy and water for competitive advantage in a collective approach than separate entities

Municipal Solid Waste (MSW): Wastes mainly from households and similar from sources such as public institutions, offices and commerce

Sustainable development: Brundtland Commission defines sustainable development as the ability of meeting present needs for development without compromising the needs for generations to come

Throughput flow: Diversion of the flow moving towards waste for recycling and reusing, to put them back in use

Trade-off: Technique of lessening or giving-up one or more desirable outcomes for increasing the effectiveness or return value from other traded desirable outcome within a given circumstance

Up-cycling Process: A process which transforms the fundamental properties of the material like change in chemical composition or physical structure.

LIST OF ABBREBIATIONS

AD	Anaerobic Digestion
CAEC	China-ASEAN Environmental Cooperation Centre
CBG	Compressed Bio-methane Gas
CE	Circular Economy
CNG	Compressed Natural Gas
DBCC	David Border Composting Consultancy
EC	Environmental Commission
EEA	European Environment Agency
EPA	Environment Protection Agency
ERDF	European Regional Development Fund
ESA	Ecological Society of America
EU	European Union
FAO	Food and Agriculture Organisations
GEEREF	Global Energy Efficiency and Renewable Energy Fund
GHG	Greenhouse Gases
HRT	Hydraulic Retention Time
IE	Industrial Ecology
MBT	Mechanical and Biological Treatment
MRF	Materials Recovery Facility
MSW	Municipal Solid Waste
OLR	Organic Loading Rate
RDF	Refuse Derived Fuels
RECENT	Renewable Energy Empowerment in Northern Territories
SRF	Solid Recovered Fuels
UN	United Nations
WEEE	Waste Electricity and Electronic Equipment

1. INTRODUCTION

The management of wastes in the European Union (EU) has been improving over the years but still the loss of potential secondary raw materials like paper, plastics, wood and metals are inevitable. In 2014, EU's waste production went up to 2,5 billion tonnes. According to 2016 statistics, the amount of recycling of the municipal wastes has substantially increased to 47%. However, the recycling rates vary from country to country and it is visible that few EU countries have landfilled quite a large amount of municipal wastes. The landfilling practice remains popular in the southern Europe like Malta, Cyprus (nearly 80%), Croatia, Slovakia (more than 60%) and Spain, Czech Republic, and Hungary (more than 50%). The use of landfill is negligible in countries like Finland, Denmark and Sweden. The use of materials has amplified by 10 times since 1900 and the growth is expected to rise by 75% between 2005 and 2030. (EP, 2017)

The concurrent linear approach of "take, make, waste" may be satisfying only when there is inexpensive supply of abundant resources and environmental impacts are matter of less concern. But the approach is not acceptable because of increasing population, demand and limited resources, deterioration of environment and replenishing non-renewable resources have become serious global threats. Scarcity of natural resources, degrading eco-systems and price inflation are the major threats of the immense global natural resources pressure due to industrial revolution and an intensity of urbanity. Present economic system is inadequate and economically unsustainable. (Lacy and Rutqvist, 2015)

To meet the food requirement of increasing population and sprouting food habits worldwide, the food production needs to double by 2050. (EU, 2018). The demand for fertilizers is forecasted to be increasing annually by 1,5 % N (Nitrogen), 2,2 % P_2O_5 (Phosphorous) and 2,4 % K_2O (Potassium) from the year 2015 to 2020. The supply for these demands is estimated to meet from Ammonia for N, Phosphoric acid for P_2O_5 and Potash for K_2O. However, unanticipated aspects like limitations to raw materials, technical shut downs, natural calamities, logistics, etc can obstruct in the demand-supply balance. (FAO, 2017).

Population and per capita Gross Domestic Product (GDP) growth are the indicators for economic growth in a timeframe. This growth is dependent upon the increase in technological progress and capital stock, also increase in natural resources supply, and energy and waste resistance capability of environment. Since 1960s, the population has doubled, agro-productions have tripled, and GDP and energy use have more than quadrupled. The impacts on the five areas of environment worldwide i.e. air, water, land, biodiversity and waste have had more of threatening challenges like climate change. The unlimited economic growth following the growth models and its relationship between population, resources, industrial output and pollution, states the disintegration of resources, increase in pollution and ultimately failure of ecosystems and economy. (Harris and Roach, 2018)

The ongoing and future food production and consumption trend is unsustainable and needs to be controlled. It is important to restore the nutrients removed with the crops or else the fertility of the soil decreases. (Rakshit, et al., 2015). The linear flow is evidently failure as it is unidirectional and bio-waste management using waste management technologies can help in recycling the nutrients loss in the biosphere. Nutrient flows (either surplus or deficit) can be safely maintained through agricultural operations by internalizing the policies and disregarding the wastes as disposable garbage. (Worldwatch Institute, 1998)

Nonetheless, Circular Economy (CE) offers to limit the wastes and improve the quality of the resources and keep them in circle. The industries are suggested to consider environmental impacts on their product-design with increased focus on extended producer responsibility as well as consumer ownership and responsibilities. (Charter, 2019)

The theoretical part of the thesis defines the terminologies and broadens the knowledge on the “Circular Economy”, “Nutrient Cycle”, “Natural and Chemical Fertilisers” and “Municipal Waste Management Technologies - Composting and Anaerobic Digestion”. Also, the EU directives and regulations are listed to understand the set of treaties with the EU countries forming a legal act that binds the countries together for sustainability and economy, and environment and human development.

The experimental part offers a case study of the municipality of Puolanka. There is a comparison on the current management of separately collected bio-waste in Puolanka with two optional scenarios. The outcomes and results are then analysed on the basis of carbon emissions and sustainability measures (environment, economic and social pros and cons). The sustainability of the options are analysed and summarised.

1.1 Objectives of thesis

The main objective of the research is "bio-waste as an input resource for circular economy and closing nutrient cycle".

The general objectives are as follows:

- To understand the importance of circular economy and closing the nutrient cycle to achieve global sustainability
- To research on the use of bio-waste as a fertilizer in terms of content (nutrient, minerals, waste)
- To assess the technological and economical potential of the biogas plant in Puolanka region with the ongoing status quo using Sustainability Assessment Method

1.2 Research questions

The thesis is based on the following queries:

- Comparative sustainable analysis of separately collected bio-waste in the municipality of Puolanka waste management based on status quo and two optional scenarios
- Closing the nutrient cycle through anaerobic digestion for bio-waste in Puolanka: an attribution to Circular Economy

1.3 Framework of Thesis

The thesis work has been framed as in the figure 1. It consists of two parts: theoretical and experimental. The theory part encloses the definitions and detailing of the important topics to support the experimental part. And in the experimental part, there are case study, data calculations, graphs developed and figurative analysis of the results.

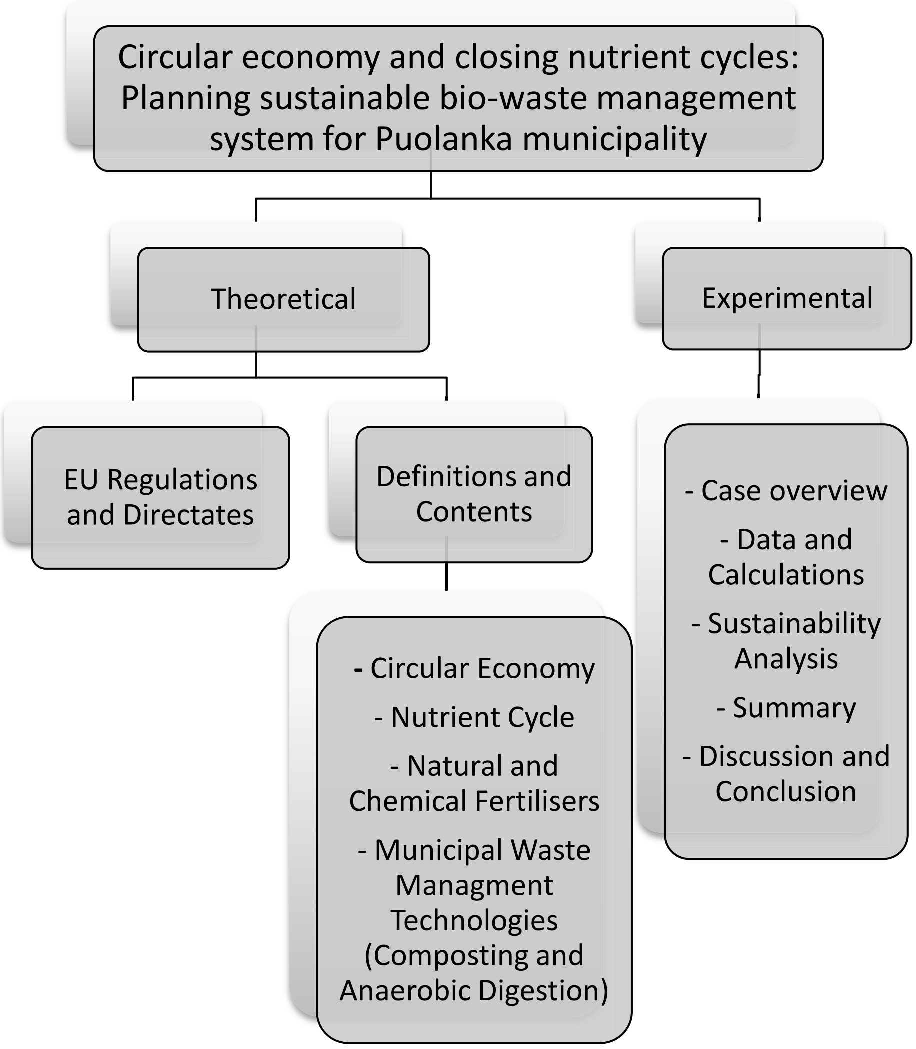

Figure 1: Thesis Framework

THEORETICAL PART

2. CIRCULAR ECONOMY

The European Union (EU) has put an effort to maintain sustainable resource efficient and competitive economy with low carbon emissions. Circular economy makes the extensive use of resources, value the products and reduction in the waste generation. The EU's drive towards the circular economy is taken as an opportunity to all EU countries for renovating the economy and generate new sustainable markets. Circular economy will flourish the business with new and innovative ideas of product production and use (EC, 2018a).

The EU aims to assure right regulatory framework in developing circular economy and provide long term waste targets and concrete, broad and ambitious set of actions before 2020. The legislative proposals on waste together with the circular economy action plan intends on reducing landfilling and increasing recycling and reuse the often-unexploited municipal wastes (EC, 2018a).

In July 2014, the Barroso led European Commission (EC) published its communication Towards a circular economy: a zero-waste program for Europe (EC, 2014); a program outlining its steps to move toward a more circular economic model. In December 2014, this package was withdrawn by the new Juncker Commission with the promise of proposing a 'more ambitious' package in the end of 2015. A public consultation was held between the 28th of May and the 20th of August 2015, accompanied by an EC stakeholder consultation conference on the 25th of June, and the new Closing the loop – An EU action plan for the Circular Economy package was released in December 2015 (EC, 2015).

The people around the world have been continually facing the extreme consequences of changing climate as well as depletion of natural resources. We are using the resources in an unsustainable manner. The supply of virgin materials is limited, and our demands are limitless. Only wise use of resources can minimize this global pressure. A transition towards a circular economy from linear economy can maximize resources usage and minimize production of waste. The Circular economy offers an opportunity to reinvent the economy, making it more sustainable and competitive. (Sitra, 2015)

2.1 Defining Circular Economy

The circular economy (CE) is literally the use of products and materials in a loop even when it reaches its life end to create further added value to economize the cost. This way the sources are invincible, the wastes are minimized contributing to innovative job opportunities (EC, 2018b).

Figure 2 is a simplified picture of circular economy. The inner circle indicating Reuse, Repair, Redistribute, Refurbish and remanufacture means that the input resources are minimised thus retaining the value of products, materials and components to the maximum level possible. The middle circle is the cyclic material flow differentiating the biological and the technical materials. Ideally an increased share of biological materials than the technical would truly make this principle beneficial since the biological materials are renewable. Then, the outer circle is the flow of energy. This way inputs are minimised; less waste is produced and will benefit economically and environmentally. (EEA, 2016)

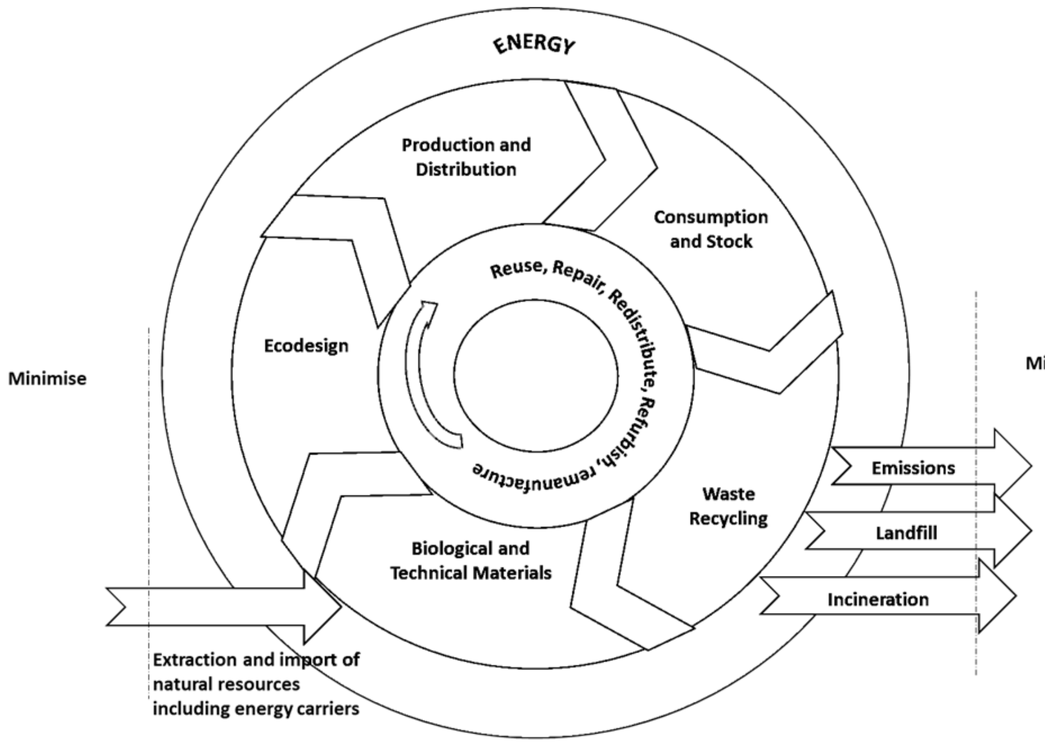

Figure 2 The Circular Economy concept (Based on EEA,2016)

The natural cycles complement one process after the other, the circular economy follows the same cycle to function sustainably. The products are designed in such a way to fit in a cycle, resulting a closed loop that keeps the material value added for longer which results in zero waste. (EEA, 2016). Europe has already adapted this new concept: a resource efficient Europe is one of the Europe 2020 top milestones synchronising through policies to secure sustainable growth and jobs and sensible use of resources. Adapting circular economy shall bring three positive consequences: economic growth, social development and lower environmental impact. (EC, 2018a).

From the very beginning of product's life circular economy embarks. In the product's life cycle, the designing and production phases both have impact on sourcing, resources utilisation and waste generation. The circular economy concept is a response to aspire sustainability in the production and growth of the global resources and environment. Circular economy embraces both technical and biological cycles for any materials to restore and regenerate them aiming in the quality and value in a sustainable way. The circular economy focuses mainly on the maintenance, reuse and remanufacturing of the goods that was once termed 'waste' can be recovered into a resource. (Ellen Macarthur Foundation, 2012)

According to McKinsey (Bismar, 2017) circular economy has five major principles that are:

- **Design for reuse:**

  The products are technologically or biologically recreated or designed for reuse in a new cycle to avoid waste in the life cycle of the product. This ultimately benefits by providing new services, lower environmental impact as well as reducing toxicity.

- **Build resilience through diversity:**

  The unexpected external influences shouldn't hinder or change the business or system or economy that means the business models and networks should have enough diversity with sufficient mutual connections along with alternative suppliers of resources and end-users like the natural ecosystem.

- **Rely on energy from renewables:**

  During the upcycling process, the additional energy should be renewable. CE mainly focuses on the use renewable energy for recycling.

- **Think in system:**

  This principle mainly focuses on the nonlinear system, in which the back-feed loops play a vital role. This requires a long time focus at various levels of the production system. At different scales of industry, the dependencies, system influence, and feedback loops contribute to the resilience of the CE.

- **Bio-based basis:**

The use of “cascading” principle is applied for consumption of goods made from biological materials increasingly: nutrients serve various purposes before they’re restored in the biosphere.

2.2 Circular Economy and 3Rs

David W. Pearce and R. Turner familiarised the term Circular Economy in 1990. Currently, this concept has been widely accepted and used across the globe. The altercations to make, use and dispose linear principle gave an insight to economically and environmentally sustainable system, Circular Economy. (Scott, 2015)

The Circular economy is governed by 3Rs concept Reduce, Reuse and Recycle also it addresses the 4R which includes Recovery. It explains as Reducing the use of resources, Reusing goods and Recycling waste. Both circular economy and 3Rs concept are interchangeable in waste management process. The first stage is altering the unwanted goods for recycling; the second one is transition of downcycling into upcycling for reusing; and third, stage transforms traditional linear “resource-product-waste” material flow pattern to “resource-product-renewed resource” whilst reducing the use of new sources. The products when disposed in the landfill leads to the wastage of residual energy which can thus be recovered while incinerated known as recovery of energy. The circular economy is considered as the legs of sustainability since it influences the entire textile supply chain process. (Manickam & Duraisamy, 2019).

2.3 Comparison of circular and linear economy

Today, natural resources are mined and extracted, turned into products and finally discarded. While the recycling of waste and measures to improve efficiency can both help to reduce the need for extraction of raw materials, this remains a fundamentally open, linear system (fig. 3), and one likely to place unsustainable demands on the environment in the medium term (Bonciu, 2014).

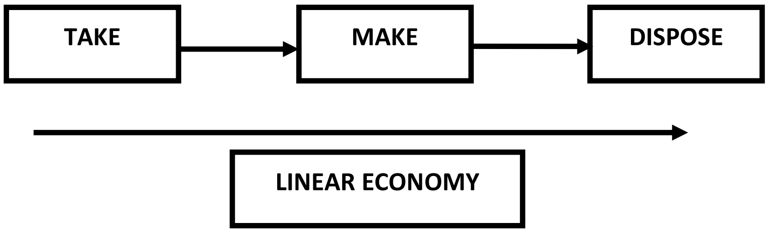

Figure 3: Linear economy modified (Government of Netherlands, 2017)

Linear economy is based on the concept of take, make and dispose. The model relies on the quantitative supply of easily accessible resources (materials and energy) that is operated to form a product and then directed to trash after use. This concept binds every product to reach its 'end of life'. (EC, 2014)

The sustainable approach to linear economy improvises the eco-efficiency; development of healthy and environmentally benign products that ultimately results in the reduction of environmental impact and leads to economic welfare. The adverse effects of linearity are traversed in the sustainable approach of circular economy (fig. 4). The eco-efficiency is improved by concentrating on the system thus, the major focus in circular economy is to cut down the negative impacts prevailing in the traditional system and to concentrate on maximizing the positive impact of the circular system by radical innovations and system change. (Manickam & Duraisamy, 2019)

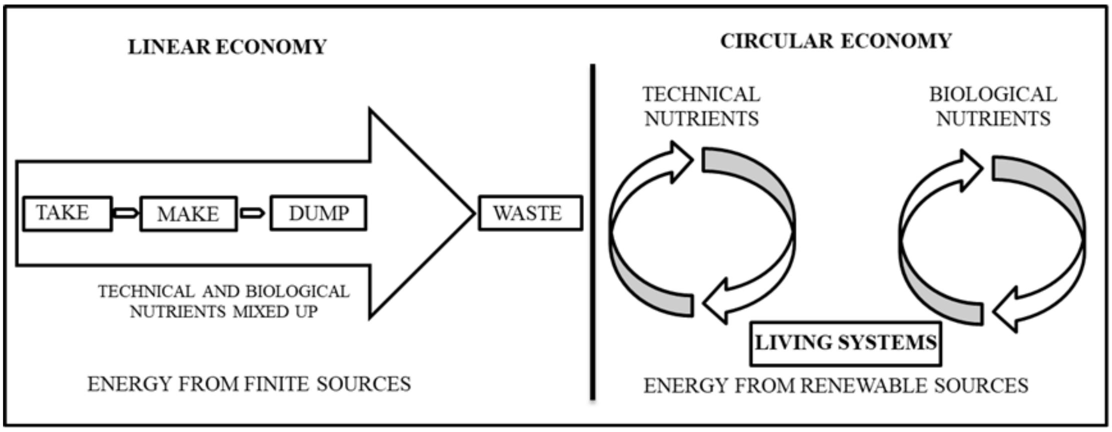

Figure 4 Comparative linear and circular economy modified (PBL, 2016)

The advantages of circular system would also be that less primary production of the same material will be needed as the inputs will be within loops. This way, upstream environmental impacts in the supply chain of that material will decrease. Keeping chemicals in closed technical cycles, helps in reducing the pollution load into nature. If more systems, for example agriculture, were transformed from linearity to circularity, the development towards a sustainable farming is established. (Rupp, 2008)

Circular economy is the economy designed with the analysis of consumption and production rate of society to an appraisal from linear unsustainable design of nature to society and back to nature and throughput energy flow. It can be achieved using renewable energy sources, cyclic flow of raw-materials and cascading type energy flow. The three sustainable development tools, society, ecology and economy, attribute for the successful circular economy. Circular economy utilises economic ecosystem flow and bounds throughput flow level in a limit that nature tolerates with respect to their reproduction rates in biosphere. (Korhonen, et al., 2018)

2.4 Industrial Ecology

Industrial Ecology (IE), the name itself suggests the content it focuses on. Industry as we know is the source of producing the goods and services, the symbiosis with ecology associates industry to not cause harm to the ambient as well as global environment. IE is a concept in which the interactions between human activities and the environment are systematically analysed. (Ayres & Ayres, 2002)

IE has been defined as the "study of all interactions between industrial systems and the environment" (Graedel, 1994) and the "science of sustainability" (Ehrenfeld, 2004). It involves remodelling industrial systems along lines of ecosystems and recognizes the efficiency of resource recycling in the nature (Graedel & Allenby, 1995). IE promotes sustainable development by providing tools, contexts and concepts for decision making of specific designs. IE helps in developing a connection of supplying industrial services to humankind without exploiting limited raw materials in nature with innovative technical solutions in cleaner production. (Lowe & Evans, 1995).

Advantages of IE (El-Hagger, 2007)

- **Benefits to Industry**

  Cost reduction on energy and raw materials, reduction in waste management and treatment costs. Increase in the market value of the industries creating good image worldwide.

- **Benefits to Society**

  New job opportunities are created through use and management of natural resources. Increase in business opportunities as well as participation and cooperation with different industries.

- **Benefits to Environment**

  Less stress on the limited resources by recycling the natural resources. Leads towards sustainable development and limitations in waste and emissions as per the environmental permits and regulations.

Industrial Ecology and Circular Economy

Figure 5 is a summation of circular economy in industries. The resources are extracted from the nature which is used to manufacture products in the industry or company. These outputs are in the market for the consumers to use. The unused or unusable materials are then sorted and recycled to form secondary materials and fed into the system as an input. This cycle reduces the load on the use of natural resources and discharge of large quantities of waste leading to environmental harm. (Rag & Remesh, 2016)

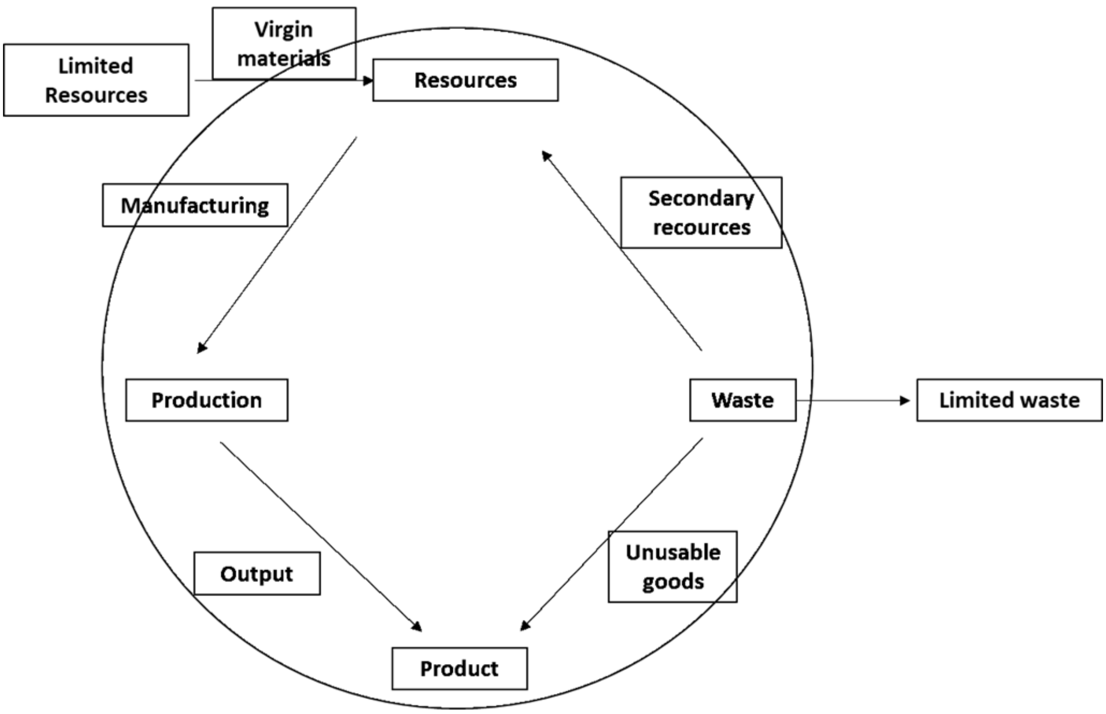

Figure 5 Industrial Ecology (modified from Rag &Remesh, 2016)

IE upholds the capability of human being of creating institutions and complex artifacts that drive in changing flows of energy and materials in both natural and industrial systems. The natural ecosystems serve both as a resource provider as well as sinks for wastes from input and output of industrial activities (Allenby & Richards, 1994). Awareness and regulations about the industrial symbiosis, industrial ecology and circular economy will promote environmental and human health and make sustainable development. (Dupont, et al., 2017)

2.5 Cradle to Cradle

Chemist Micheal Braungart and Architect William McDonough conceived the term "Cradle to cradle". The design is an ecologically intelligent approach to architecture and industry that involves materials, buildings and patterns of settlement which are wholly healthful and restorative. It proposes to create solutions that increase the economic value (eco-effectiveness) with no negative impact on ecology (eco-efficiency) and achieve the "state of zero: zero waste emissions, zero resource use and zero toxicity" (Braungart et al., 2007).

The cradle to cradle design observes human system as a part of nutrient cycle unlike cradle-to-grave systems where life is supported in every material. The biological materials give nourishment after used; and the technical nutrients revolve in closed-loop cycles of remanufacture, recovery and production through industrial systems. The cradle to cradle design is based scientific protocol on maximizing the use of materials with healthful and safe ingredients selected. Responding to physical, cultural and climatic settings, it creates buildings and community plans that generate a diverse range of economic, social and ecological value in industrialized and developing countries (McDonough & Braungart, 2003).

Cradle to cradle concept has been translated into detailed criteria that serve as basis for the certification, and producers can apply for a Cradle to Cradle label according to different levels of compliance with these criteria. The concept and the underlying criteria are based on three fundamental principles (Van Dijk, et al, 2014; Toxopeus, 2015):

- **Waste equals food:**

  The cradle to cradle theory states that waste doesn't exist virtually but becomes a supplement to other metabolisms. The materials or sources should be taken as nutrients or food for other product lifecycles.

- **Use current solar income:**

  Alike, plants and trees make food using solar radiation as energy source, cradle to cradle system takes sun as a huge nuclear power source at a distant from earth. It is assumed that these renewable energies with abundant supply must be used within the design for sustainability.

- **Celebrate diversity:**

Diversity is necessity to improve system's resilience. Biodiversity, cultural and conceptual diversity improves relationships, creativity and innovation rather than having one-direction.

Adopting cradle to cradle principles create a cyclical flow of materials, as opposed to the one-way cradle to grave concept. The materials consumed in industry resemble the nutrients that flow cyclically in natural ecosystems and can circulate in one of two metabolisms biological or technical. (El-Hagger, 2007).

The biological cycle identifies typical consumption products; products that are returned to the environment by diffuse pathways, like water or air emissions, even during the use phase. While, technical cycle have products identified mainly by use the materials in a loop without loss. Non-renewable materials flow into industrial systems acting as nutrients in manufacturing new products. Within the Cradle to Cradle philosophy mere recycling is not enough, in fact the new products should be of equal or preferably of higher quality, for which the term upcycling is introduced (figure 6). (Toxopeus, 2015)

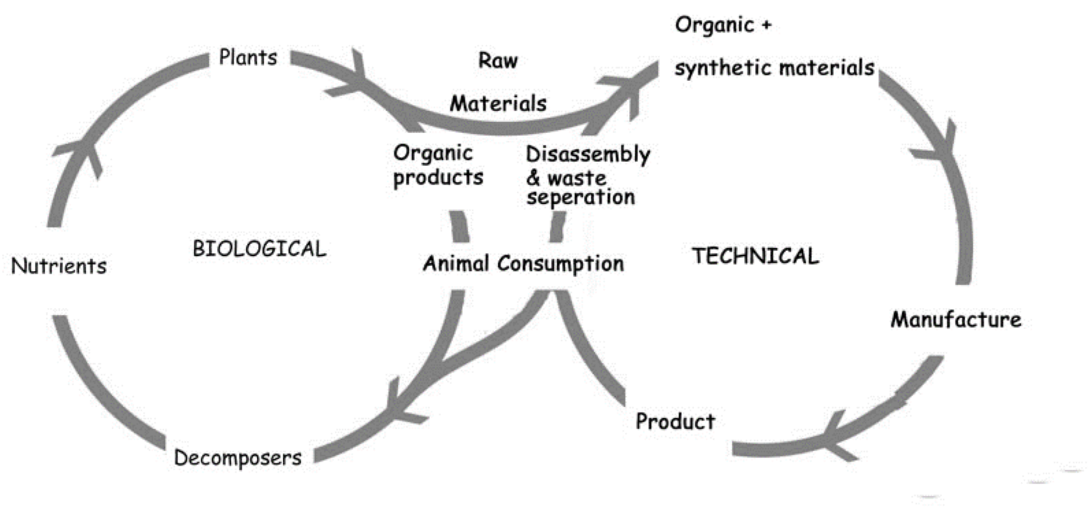

Figure 6: Cradle to cradle: Remaking the way we make things modified from McDonough & Braungart. (2008)

The cradle to cradle concept makes appropriate use of the resources in a closed circle and still maintains high value of products throughout. This way, the waste (if any) can be fed into the system again as a resource for creating a new product ensuring no loss due to waste. It will not only save environment from but the industries get a continuos supply of high grade resources continuously even after reaching the end-life. (El-Hagger, 2007)

2.6 Low–carbon economy

An economy term doing rounds for a while now globally is low-carbon economy, that is based on an economic model of low energy consumption, less pollution, and low emissions. It opens market to sell and buy of greenhouse gas emission allowances and carbon offsets as a commodity. The low carbon emitters will have competitive advantages over heavy carbon emitting countries. Industrial countries which emit carbon dioxide will pay to the developing or carbon restoring countries for offsetting the industrial emissions. (Willey & Chameides, 2007)

The concept of "low-carbon economy" was first formally shaped up in the UK energy White Paper 2003, "Our Energy Future: Creating a Low Carbon Economy" that focuses on the reduction of carbon emissions up to 60% by 2020 and increase in the use of renewable energies including biomass and waste technologies for heat and energy conversion. (Energy White Paper, 2003)

By 2050, EU targets to achieve progressive reduction of greenhouse gases in EU. The major climate strategies and energy targets are mentioned below. EU also tracks the progress on emission controls through regular monitoring and reporting. (EC, 2018c)

- **Climate and energy package (by 2020)**

  The package on climate and energy has three main targets and aims to achieve by 2020. These targets were set in 2007 (by EU leaders) and legislated in 2009.

  - Reduction in greenhouse gas emissions by 20% (from 1990s)
  - 20% energy use in EU should be from renewables
  - Improvement of energy efficiency by 20%

- **Framework on Climate and energy (2030):**

  By 2030, following three major targets are set to be achieved by EU:

  - Greenhouse gas emissions reduction by at least 40% (from 1990s)
  - Renewable energy has a share of at least 27%

- Improvement of energy efficiency by at least 27%

This framework further shapes the climate and energy (2020 package) and is adopted in October 2014 by EU leaders.

- **2050 low carbon economy:**

EU prepares for reductions in its domestic emissions by 80% by 2050 (long-term economy) from 1990s.

Low Carbon economy and Circular economy

Low-carbon economy can speed circular economy and help establish a harmonious society. To alleviate the global warming, it is important to develop green economy, which includes low-carbon productions, low-carbon consumption and new low-carbon technologies. (Wu, 2011). Circular economy includes reduction, reuse, and recycle. Low carbon economy was proposed to address global energy security and climate change. The focus lies in reducing carbon emission intensity and controlling the growth of carbon dioxide (CO_2) emission. (CAEC, 2018)

The concept on 'Sustainable development' and 'Low-carbon economy' seemed broadly accepted globally yet they aren't enough sufficient to address the causes but only the effects. The economists, politicians, environmentalists, sociologists or philosophers are persistently looking for new approach of development and growth feasible within the global boundary. 'Circular economy' is that new wider development approach also supported by European Union that connects and resonates with the realities of today's world. EU is optimistic with the implementation of the concept for benefitting in the opportunities than wasting resources and withstanding the inevitable changes. (Bonciu, 2014).

Progression towards a Low carbon economy

The EU 2050 target of achieving 80-90% reduction on GHGs emissions from 1990s is challenging and requires a decarbonising process. It is imperative to design innovative intensive infrastructures to meet the critical global challenges. These infrastructures and innovations on low-carbon provide new opportunities, growth and jobs as well as proceed towards carbon neutral city on the long-term. (EC, 2018d)

EU also assists technologies, academics as well as finances to other in most need. Global Energy Efficiency and Renewable Energy Fund (GEEREF), an innovative EU initiative global risk capital fund to contribute the developing economies and countries in transition to develop small-scale renewable energy and energy-efficiency projects with limited public financial contribution. This way it aids development as well as contribute in combatting climate change globally. This is enough evidence to understand EU's clear commitment to share and mobilise clean technologies to developing countries. (EC, 2018d)

Low carbon technologies are the core for low-carbon economy. The low-carbon technologies include independent technological innovation, promotion of high-tech industries, as well as the development of clean energy sources, use of renewable energy, control of CO_2 emissions and greenhouse effect. Judged form the current technologies humans have mastered, the most promising emerging low-carbon industries or industry clusters are: 1. bio-industry; 2. the solar energy industry; 3. the nuclear industry; 4. wind, tidal energy industry and 5. water and hydrogen energy industry. A continuous research and development is necessary for productivity innovation of these emerging industries to facilitate the development of low-carbon economy. (Wu, 2011)

3. WASTE LEGISLATION

The revised legislative proposal on waste sets clear targets for reduction of waste and establishes an ambitious and credible long-term path for waste management and recycling. To ensure effective implementation, the waste reduction targets in the new proposal are accompanied by concrete measures to address obstacles on the ground and the different situations across EU Member States (EC, 2016a).

Sludge is an important source of organic matter and essential nutrients (Nitrogen and Phosphorous). Its use is highly recommended as fertiliser on land and soil conditioner but due to presence of potential pathogenic organisms, concentrated heavy metals and trace organic compounds (poorly degraded), it is heavily regulated. The quality of sewage used on land should prevent impacts on environment and human. Untreated sludge is prohibited in use and treated sludge has undergone chemical, heat and biological treatment, stored long-term and other suitable process to minimise after-use health hazards and its fermentability. Also, the nutrients present in the fertiliser fulfil the soil requirement, doesn't impact in the soil quality as well as disrupt the surface and groundwater. (EC, 2016b)

3.1 Waste Hierarchy

Waste Framework Directive 2008/98/EC defines the waste management that is best suited for the environment. It outlines the end-of-waste criteria i.e. when the waste ceases to be waste and become secondary raw resources and helps to distinguish between waste and by-products. The directive states the following principles on managing the wastes: it requires that waste be managed without endangering human health and harming the environment, and without risk to water, soil, air, plants or animals, no noise or odours, and no adverse impact on the special places or countryside. Waste legislation and policy of the EU Member States shall apply as a priority order the following waste management hierarchy (EC, 2008a):

Definition of the stages the waste hierarchy (fig 7) according to (EC, 2010) and Gharfalkar, et al., (2015):

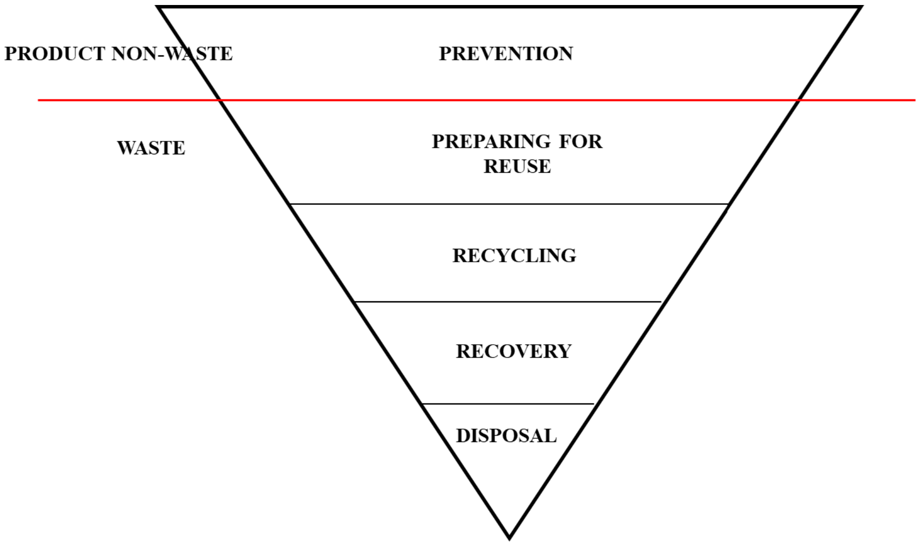

Figure 7: Waste hierarchy (EC, 2008a)

1. Prevention

Measures taken before a substance, material or product has become a waste so as to reduce adverse impacts on the environment and human health, extension of life span of the products and reduce harmful substances in materials and products.

Preparing for reuse

Measures taken to make sure the products and components that were initially thought to be a waste can be re-used without any other pre-processing.

2. Reuse

An operation that allows to use the same product serving the same function all over again and not discarded as waste.

3. Recycling

The recovery operation that reprocesses the waste materials into products or substances serving as same product or other purposes.

4. Recovery

A method serving a useful purpose which would have otherwise ended to be a waste or discarded for wider economy or producing energy.

5. Disposal

The ultimate process where there is no recovery after secondary reclamation of substances or energy.

3.2 EU Directives related to the research

A legislative act that sets an aim for all the EU countries to achieve is a "directive". The countries however, can develop their own laws to attain these goals. Table 1 is a list of the EU directives related on the wastes relevant to the thesis.

Table 1 List of EU Directives on Wastes

European Legislation on Waste	
1975/442/EC	reduction of waste production and restriction of waste landfilling
1991/676/EC	Nitrate Directive
1999/31/EC	limits in biodegradable municipal wastes quantities to be landfilled
2000/60/EC	Water Framework Directive
2003/2003	Fertilisers Legislation
2006/12/EC	recycling of organic substances (biological transformation processes)
2006/208/EC	amending annex VI and VIII of 2002/1774/EC, as regards processing standard for biogas and composting plant and requirements for manure
2006/209/EC	Regulation, partial revision of 2002/1774/EC as regards the extension of the validity of transitional measure for composting and biogas plants
2008/98/EC	Revision of Waste Framework Directive (waste hierarchy, end-of-waste)

These important directives are now detailed in the following chapters.

3.3 Fertilisers Regulation (2003/2003)

The European Union (EU) penned down legislation relating to the fertilisers on 13 October 2003 as Regulation (EC) No 2003/2003 to meet the conditions for EU fertilisers usage and provisions relating to labelling and packaging (EC, 2003).

The Fertilisers regulation was adopted to assign fertilisers use rules into a single legislation and to ensure the uniform packaging under technical supervision. All fertilisers labelled ‘EC fertiliser’ can be freely mobilised and used within the EU nations unless they consider some risk or danger for human kind and environment. The minimum requirements for bearing the word EC Fertilisers are: (EC, 2003)

- ✓ it is effective and has no adverse effects on human, animals, plants or the environment on its use at normal conditions;
- ✓ the relevant sampling and analysis method are specified while labelling

The Fertilisers regulation has forced few technical provisions regarding scope, declaration, identification and packaging of four types of fertilisers:

- ✓ major inorganic nutrient fertilisers: Nitrogen, phosphorus and potassium;
- ✓ secondary inorganic nutrient fertilisers: Calcium, magnesium, sodium and sulphur;
- ✓ inorganic micro-nutrient fertilisers: boron, cobalt, copper, iron, manganese in small quantities;
- ✓ ammonium nitrate fertilisers of high nitrogen content: dangerous type of fertilisers

On 17 March 2016, new regulation on the use of organic and waste-based fertilisers were drafted. The Regulation directs on conversion of bio-waste into raw materials as a fertiliser and defines safety, quality and labelling requirements needed as the standard EU fertiliser to be traded freely across the EU. Producers will have to show that their products meet those requirements, as well as limits for organic contaminants, microbial contaminants and physical impurities (EC, 2016c).

The existing Fertilisers Regulation fails to address environmental concerns arising from contamination by fertilisers of soil, inland waters, sea waters, and ultimately food. The new rules assure to achieve the highest level of soil protection and amends on all fertiliser types. It has introduced strict limits for cadmium in phosphate fertilisers with the purpose of reducing health and environmental risks. The limits shall constrict from 60 mg/kg to 40 mg/kg after three years and to 20 mg/kg after 12 years. At present it is stated that only 5% of bio-waste is recycled. As per the estimation, if recycling bio-waste is encouraged then 30 % of non-organic current fertilisers could be replaced. The EU imports phosphates around 6 million tonnes yearly but bio-waste fertilisers could replace up to 30% of this total by extraction from sewage sludge, biodegradable waste, meat and bone meal or manure. This new draft Regulation is sent to the European

Parliament and Council for adoption. Once formulated, it will be directly applicable within a transitional period (EC, 2016c).

3.1.1 Nitrates Directive (91/676/ECE)

One of the important features of EU environmental policy is ensuring the water protection from nitrates pollution from agricultural activities for human health as well as conserve natural ecosystems. The Nitrates Directive is among the early legislations formulated by EU against pollution (EC, 1991).

On 12 December 1991, Nitrates Directive (91/676/ECE) was established in concern to the protection of water against nitrates pollution from agricultural activities. The directive was applied only on 19 December 1991. The directive intends in reducing the water pollution from nitrates used in agriculture and also preventing further pollution. Few highlights of the directive are: (EC, 1991).

EU nations must:

- ✓ locate the vulnerable water zones which have or are likely to have eutrophication or high levels of nitrate. The situation is reviewed and revised every four years of any possible changes occurred;
- ✓ build compulsory action programmes in reference to ambient environment and available technical and scientific data for these vulnerable areas;
- ✓ monthly or frequent nitrate concentration testing in surface and ground water during flooding;
- ✓ farmers training and information sharing whenever necessary to make a good farming practice with use of fertilisers;
- ✓ The action programmes effectiveness monitored

3.1.2 Water Framework Directive (2000/60/EC)

Providing the best quality and enough outreach of water around EU nations is the prime motive in formulating this directive. Water Framework Directive (2000/60/EC) was adopted on 23 October 2000 (EC, 2000).

The directive made a target to make sure that the water bodies isn't deteriorated, and every EU nation achieves 'good status' for freshwater bodies in Europe by 2015. Precisely, protection of all forms of water sources; ecosystem restoration in and around these water bodies; minimising water pollution and ensure sustainable water usage by people and businesses. (EC, 2000).

Major points are:

- ✓ Identity the river-basing within the defined territories
- ✓ Authorities are designated to manage these water basins with respect to EU rules
- ✓ study the features of the water bodies like flow, temperature, etc to analyse its socio-economic status
- ✓ water bodies status monitoring
- ✓ develop and implement river-basins information/plans to public to avoid deterioration
- ✓ public information/plans sharing on the management of river-basins

3.1.3 Waste Framework Directive (2008/98/EC)

New technologies and creative ways have been invented to break the ancient chain of waste often coined to be mere unfortunate and unavoidable by-product. On 19 November 2008, new and improved Waste Framework Directive (2008/98/EC) was adopted on waste. The directive was brought into action only from 12 December 2008 (EC, 2008b).

The directive provides a legal framework in EU countries on treating the waste. It is developed to implement recycle and recovery techniques to minimize stress on resources, protect human health and conserve nature with proper management of waste. (EC, 2008b).

The main points of the directive are:

- ✓ establish a waste hierarchy: prevention, re-use, recycle, recovery
- ✓ introduces 'polluter pay principle' where the one who pollutes pay the cost to manage that waste
- ✓ announces concept on 'extended producer responsibility' that binds the manufacturer to accept and dispose the product given back by user after use
- ✓ clears a difference between by-products and a waste

- ✓ manage waste without disturbing or further polluting the ambience
- ✓ special handling regulations to hazardous waste, oil spills and bio-waste
- ✓ introduces 50% recycle and recovery targets for household waste and 70% for construction and demolition wastes by 2020

3.1.4 End-of-waste status

When the waste ceases to be unwanted and turns into something useful after undergoing a recovery, recycling, then the end-of-waste criteria is achieved. Following applies for the case for end-of-waste status: (EC, 2008c)

- ✓ those products are used widely for specified purposes;
- ✓ maintains a market or demands for such objects or substances;
- ✓ those products meet the legislation and standards as well as fulfils the technical requirements;
- ✓ no adverse environmental or human health impacts on use

To recycle and reuse quality products, lessen burden on inputs and ensure economic benefits, end of waste criteria was introduced. They further encourage recycling in EU by making legal assurance (EC, 2008c).

3.1.5 Biodegradable waste

Green wastes from gardens and parks, food wastes from households, restaurants and other business firms and those wastes from food processing are all the biodegradable wastes also known as bio-wastes. It excludes sewage sludge and manures, processed wood or paper, agriculture or forest residues, natural textiles, as well as those food-industry by-products that is always reused as a resource. (EC, 2016d)

At present, methane gas from the degrading of waste is a common threat and challenge for sustainable waste management. It mainly arises with the landfill decomposition and that is why landfill is now disregarded as a waste management options in the EU directives. Nevertheless, trapping of methane gas into heat and electric energy is an advantageous approach introduced. Therefore, the bio-waste conversion into compost and digestate to be used as agricultural fertilisers as well as potential use of methane gas in the form of energy is encaptivating. EC hence, carries an assessment on bio-waste management to examine quality criteria for digestate and compost from bio-waste, and to guarantee a high-level protection of human health and the environment. (EC, 2016d)

3.1.6 Landfill directive

Landfill is the least preferred option according to the waste hierarchy. The landfilling must meet directive 1991/31/EC requirements and the waste should be reduced to those with no other alternates than landfill. To reduce or prevent adverse impacts of landfill on environment like water sources, air, soil, and human health in peculiar by engineered landfill technology are the main objectives of the directive. Landfilling isn't allowed for liquid or flammable waste; wastes that are explosive or oxidises; hospital or clinical wastes; used tyres (few exceptions). Landfill directive are classified according to the types of wastes:

- Landfill for non-hazardous waste
- Landfill for hazardous waste
- Landfill for inert waste

To avoid risks, the wastes before landfilling are treated; hazardous waste landfill are assigned for hazardous wastes; other non-hazardous and municipal wastes are directed to non-hazardous waste landfill; and only for inert waste are places in landfill sites for inert wastes. (EC, 2016e)

The directive doesn't apply for covering sludge with soil; restoration or redevelopment work using inert wastes; the deposit of inert non-hazardous waste or unpolluted soil as a result of extraction and prospection in mining activities; and non-hazardous deposits of dredging sludges alongside small waterways. (EC, 2016e)

3.4 Finnish/ National Legislation on Waste

Finnish National Waste Plan is responsive to handling and sorting of municipal waste protect the environment and public health. The waste plan is always based on the intensive background studies, monitoring reports as well as previous waste plan.

National Waste Plan (Ministry of Environment, 2018)

The theme of the national waste plan is recycling to circular economy until 2023. The objectives are set to waste management and waste prevention and actions planned to reach targets in the five years (2018-2023).

The four major areas (construction waste, biodegradable waste, municipal waste and Waste Electrical and Electronic Equipment (WEEE)) have detailed measures and targets for waste plan.

Highlights of waste plan prepared long-term targets by 2030 for waste prevention and management: (Ministry of Environment, 2018)

- Circular economy makes high-quality waste management for sustainability
- The natural resources are conserved with materials-efficient production and climate change mitigated.
- Reuse and recycling has lessened the burden of the amount of waste produced presently.
- Recycling markets have flourished. New jobs and opportunities in re-use and recycle area.
- Recycled materials are beneficial as they help in extracting valuable raw materials even in low levels.
- Material cycling can be less harmful and fewer hazardous substances are used in production.
- High-quality research and experimental activities have been carried out in the waste sector has under high-level waste expertise.

4. NUTRIENT CYCLE

Living organisms exchange ions and molecules as food / inputs also known as nutrients with each other in the ecosystems from one biosphere to another forming a cycle called nutrient cycle. Nutrient cycle is also known as bio-geochemical cycle which basically includes two phases: the organismic and the environmental as given in the figure 8. In the organismic part, the nutrients move from producers to consumers to microbes while in the environmental part, the nutrient are available in soil, air and water and sometimes in two or more physical environments all at once. (Chiras, 2016)

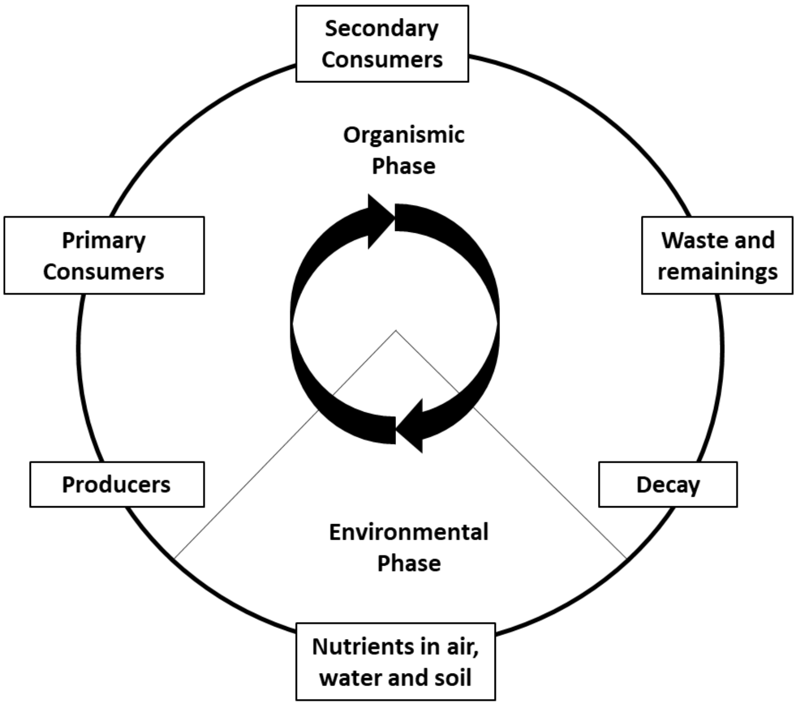

Figure 8: Nutrient cycle (Modified from Chiras, 2016)

4.1 Nitrogen cycle

One of the most important nutrient cycles is nitrogen cycle. There is abundant amount of nitrogen (N) in the atmosphere in the form of gas (N_2). This form is usable for only few organisms hence, it needs to be converted into either nitrate or ammonia for being usable for remaining organisms. (Chiras, 2016)

Nitrogen fixation that is the conversion of nitrogen to ammonia occurs in the aquatic and terrestrial environments. As in figure 9, nitrogen gas in the atmosphere undergoes fixation with the help of cyanobacteria (in soil) and converts into ammonia. Ammonia with other soil bacteria converts into nitrites and then to nitrates. This process is the

nitrification. Plants take up nitrates from the soil and convert into nucleic and amino acids. The dead plants and animals are also the source of nitrate in soil. The bacteria and fungi decay the remnants and dead cells and give ammonium in the soil and the process is called **ammonification**. Not all nitrates are taken up by plants, some are converted into nitrous oxide formed on the topsoil and eventually escape to environment again as nitrogen gas. This process is called **denitrification**. (Chiras, 2016)

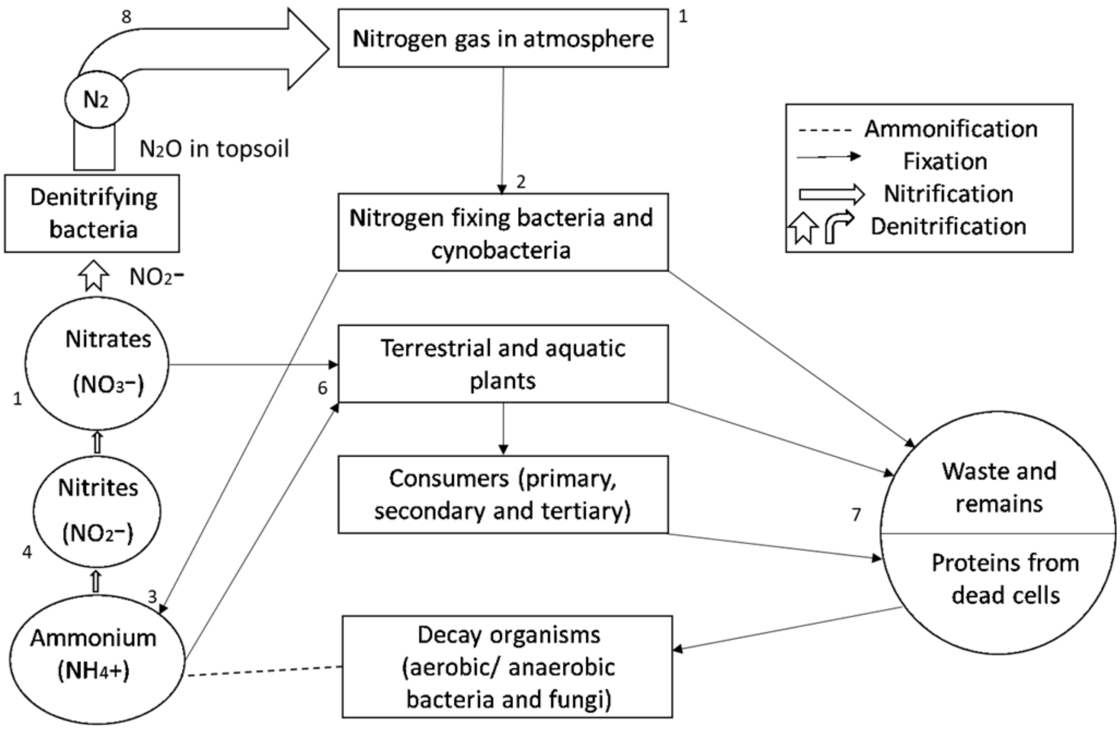

Figure 9: Simplified figure of nitrogen cycle (Based on Chiras, 2016)

4.2 Anthropogenic activities in nitrogen cycle

Nitrogen is a good source to help plants and crops foster. But the higher concentrations are deteriorating to human health and nature. High levels of nitrogen are one of the major sources of water pollution. Agriculture activities has substantially increased the total nitrogen effluents into water sources since 1950s. (Freedman, 2007).

Anthropogenic activities change the nitrogen cycle in four common ways:

- production of nitrogen oxides while burning fossil fuels in the atmosphere which converts into nitric acids and shower in the atmosphere as acid rain. Thus, changing the pH of the soil and concentration of nitrogen in water sources;
- disposal of nitrogen containing municipal sewages into the waterways;

- excess use of nitrogen rich fertilizers in the soil which ends up on the waterways; and
- cattle feeding on pastures near to nitrogen run-off or waterways

The last three activities increase the concentration of nitrogen in soils or water sources eventually unbalancing the ecosystem. Excess nitrogen also produces pollutants such as ammonia and ozone which leads to breathing inability for animals and limit to visibility in the environment. If the excess nitrogen returns on the atmosphere, it has impacts on forests, soils and waterways and alters plant growth. (Chiras, 2016)

4.3 Phosphorous cycle

Phosphorus (P) is endogenic since it doesn't have stable gaseous states; P compounds are restricted to land and water. It also is crucial because it is limiting nutrient in the ecosystems. The major environmental P reservoir is deposited in the form of phosphate as poorly soluble minerals like hydroxyapatite (a calcium salt). Plants take up soluble forms of P from fertilizers and phosphate minerals and incorporate them into nucleic acids (forming organismic genetic materials). P returns to a soluble salt solution through decomposition process and later as mineral matter through precipitation (fig 10). (Corbridge, 2013)

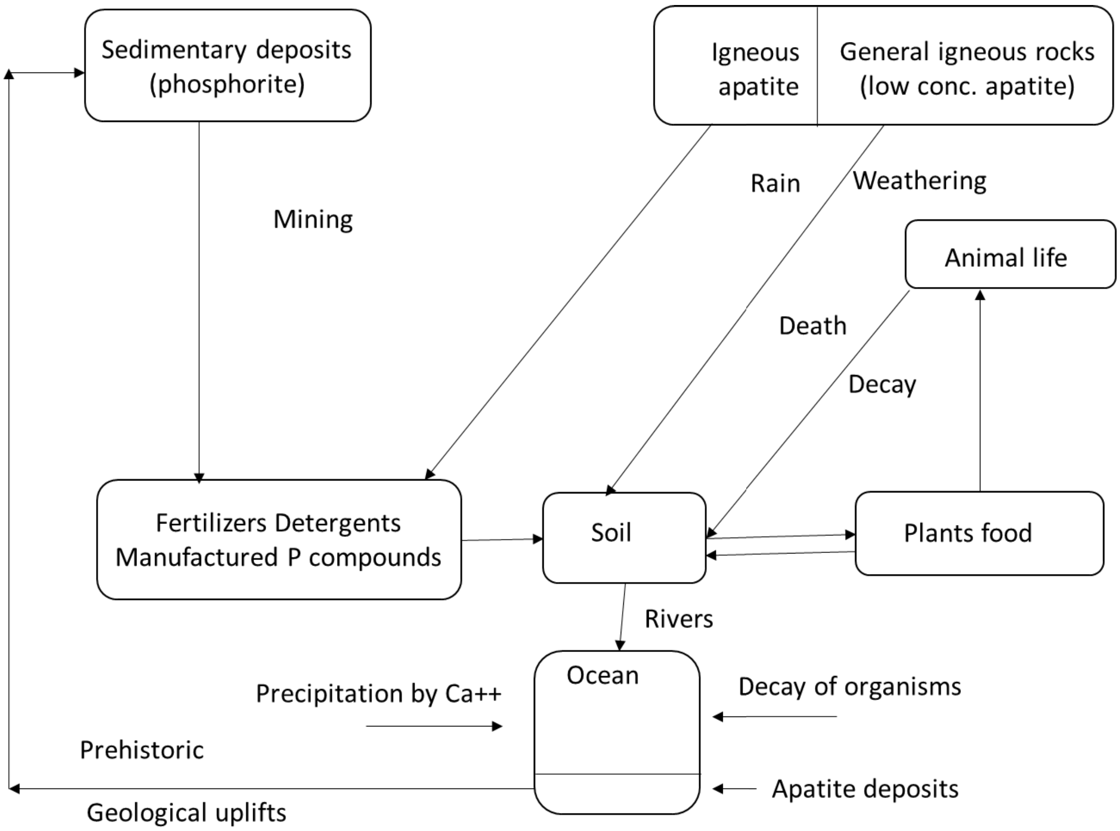

Figure 10: Simplified natural and artificial phosphorous cycle (Corbridge, 2013)

Since the phosphorus has a long-life cycle it is not replaceable in plant cultivation. Thus, for sustainable food production there is a need of sustainable P nutrient. Phosphorus cannot be considered as a renewable resource on short time frame. Organic waste and use of P -chemical fertilisers is the only way of adding P into the biosphere. The modern terrestrial phosphorus cycle is dominated by agriculture and human activity. Due to increased use of fertilizers, deforestation and soil loss, and sewage sources load of P has doubled in the water sources. This has led to eutrophication of lakes and coastal areas and will continue to have an impact for several thousand years based on forward modelling of human activities. (Valsami-Jones, 2004)

It has been globally recognised that the P rocks are finite, surface run off is the primary reason for the loss of P from soils to water causing imbalance in the aquatic life. Also, P holds a critical level in the plant which means above the level no further P can be added in soils and below this level there is a huge drop in the yield of plants (impacts due to scarcity of P). Therefore, an optimum level needs to be maintained and checked periodically. When the P level is more than less than critical level from the soil, it needs to be restored in the soil again for productivity. It is suggested to minimise the use of phosphate rock for municipal and agriculture uses. (Valsami-Jones, 2004)

4.4 Phosphorus as a critical mineral

Phosphorus is also an essential and un-interchangeable nutrient for plants and animals, but while the global reserves of atmospheric nitrogen are effectively unlimited, the reserves of phosphate rock are finite. Recent estimates of the reserve suggest that at the current rate of use this resource will become exhausted within some hundreds of years. The annual increment of phosphorus contained in the human population is estimated to be in the order of 1 Mt/year, which is a small proportion of the quantity mined. There is a clear requirement to ensure that phosphorus is recycled to a large extent, so that the rate of exhaustion of the reserves of phosphate rock is significantly reduced. Legislation relating to the management of phosphorus appears entirely associated with its potential to upset natural ecosystems, with apparently no regulations yet requiring the efficient use and reuse of a scarce resource. (Dawson & Hilton, 2011)

4.5 Nutrient pollution

Nitrogen and phosphorus are naturally occurring nutrients in the aquatic ecosystems. Nitrogen and phosphorus support growth of the all living organisms (animals and plants). But excess of nitrogen and phosphorus in the atmosphere i.e. water and air usually from the wide anthropogenic activities can result in nutrient pollution. Nutrient pollution is one of the most widespread and challenging environmental problems. (EPA, 2015)

Nutrient loading is a global threat and leads to substantial changes in the aquatic ecosystems and biogeochemical processes. Anthropogenic activities can be credited for the oxygen depletion and nutrient over-enrichment in the coastal areas. From 1860-2005, the nitrogen production has increased by 20 times i.e. 187 tonnes annually by 2005. That means its increasing at the rate of 1,5-2 times. It has been estimated that about 90 tonnes of them end up in the marine ecosystem due to human activities. Approximately 20Mtonnes of phosphorous is mined yearly, and it is estimated that half of the quantity is estimated to reach the world's oceans. (Joint Technical Report, 2014)

Nutrient pollution in many coastal ecosystems is a serious problem. Sewage, fertilizers and use of detergents are the potential sources of nutrients. And the consequences are hypoxia (loss of oxygen in the water bodies), eutrophication resulting in solar radiation block-up in the water as well as loss of aquatic life leading in the change adverse effects on environment and human health. (ESA, 2000)

4.6 Surface water pollution

Baltic Sea is considered to be in a critical condition. For the coastal countries to the Baltic Sea, including Finland, Baltic Sea has been a matter of concern for years now. The nutrient enrichment mostly in the densely populated cities like Helsinki, Stockholm, etc has led it to be the most polluted seas in the world. In Europe, the most heavily loaded coastal areas exhibit signs of severe eutrophication such as through algal boom during warm summer and filamentous algae over the bottom of sea in coastal areas (Ærteberg, et al., 2001). Many environmental assessments identify agriculture as the major cause of surface water quality problems in the developed countries (Shortle & Abler, 1999). In the Nordic countries, the intense farming technologies have increased agriculture sector as the significant source of eutrophying nutrients while municipal and industrial nutrient loads have been reduced. (Turner, et al., 1999)

4.7 Ground water contamination

Groundwater is the water that permeates through the different membranes of the soil collects below the water table. Nutrients overused also enter the soil and contaminates the groundwater. These eventually end-up either getting extracted for anthropogenic activities or travel towards river or marine life disturbing yet again the aquatic biosphere. These nutrient contaminated groundwater treatment processes are usually economically challenging. EPA, 2010 (report on United Nations streams and groundwater) found that it is a growing problem of drinking nitrate contaminated groundwater near agricultural areas from specifically shallow domestic wells. (EPA, 2015)

4.8 Closing the nutrient cycle

The global threat due to agroeconomic output is increasing every year. The linear approach of make, use and dispose along with the increasing global population is going to be disturbingly chaotic to manage in the future. The over-use of chemical fertilizers, groundwater contamination, etc as discussed earlier are unstoppable unless we try to overcome it by closing the nutrient cycle. (Vellinga, et al., 1998)

Several technologies and approaches have been introduced to maximise recycling and reusing those valuable nutrients that ends up being a waste. EU's circular economy package encourages and boosts the emerging markets for natural fertilizers redesigned for improved ecological function. The new ideas for recovering key nutrients from biomass through bioconversion processes will allow restoring nutrients to soil, thereby closing nutrient loop and decline in use of chemical fertilizers. Such advanced bioconversion matched with complementary biomass production may contribute in achieving circular bio-economy and sustainability. (EC, 2018e)

5. NATURAL AND CHEMICAL FERTILIZERS

The substances whose main purpose is to give nutrients to plants are the fertilizers. In other words, the supplement of nutrients fed in the crops or plants either as compost (organics decomposed and recovered) or chemicals (manufactured in the industries) are known to be fertilizers. Sustainable production of crops isn't possible without fertile soils and very few soils are sufficiently arable. Thus, the fertilizers provide the basic macronutrients such as potassium (K), nitrogen (N) and phosphorous (P) that support the plants in their productivity. (Dawson & Hilton, 2011)

Fertilizers have some adverse environmental impacts along with the benefits. Few are listed as: (Vaneeckhaute, et al, 2013)

- accumulation in the plants and soil of heavy metals
- add acid and increase pH of the soil
- nutrients contaminate the waterways through soil-erosion, surface-run-offs, leaching, etc

These positives and negatives are both discussed further in natural and chemical fertilizers sections below.

5.1 Natural fertilizers

The natural fertilizers (also called as organic fertilizers) can be green manure or waste from non-synthetic sources (poultry farm and human sewages, that replace organic matter) and increase macronutrients (N and K) to the soil and labelled nutrient value specified. Natural fertilizers are one of the important sources to maintain soil fertility through organic matter replenishment. Natural fertilizers are vital for sustainable agricultural system. They enrich soil with advantageous microbes, improve the soil structure and tilt. They also improve the water holding capacity of the soil because organic matter acts like sponge in the soil. The fertilisers also reduce the erosion and soil crusting caused by wind and rain. The nutrients in the fertilizers are slowly released onto the field which reduces the danger of being over-fertilized. Natural fertilizers provide an optimal environment for the growth of nitrogen fixing bacteria. They help to prevent important minerals from leaching and tend to prevent soil acidity shifting. Therefore, they lead to longevity of nutrients in the soil and less application in the future. (Chiras, 2016)

Though the natural fertilizers have many benefits, there are still few limitations which cannot be overlooked. The fertilizers from bio-waste have been successfully implemented in many countries but still the transportation of manures from pipelines or carriages/trucks have been difficult. The presence of pathogenic organisms like parasites, bacteria and viruses in the organic wastes needs proper biological and chemical processing to ensure the pathogens are not transferred into the organic matter and then to soil. These pathogens end up in the food-chain and impact human health. Another is the presence of toxic heavy metals like mercury and lead in sewage sludge from the industries. Optimum control measures need to be followed to alleviate these metals from the source. (Chiras, 2016)

Natural fertilizer contents vary from phosphates solubilizing or nitrogen fixing microbes to VAM (vesicular-arbuscular mycorrhizal) fungi spores and can be applied either over the field through spreading or by seed treatment. Few natural fertilizers include *Rhizobium, Azotobacter azotococcus, Bacillis megatheriu*, etc. (Panda, 2011)

Use of fertilizers enhances the soil fertility and boost productivity. The wastes (food or human) to composts and sewage-sludge treated fertilizers are recognised worldwide as efficient fertilizers since these return the valuable nutrients to the soil again. Thus, they are helping to avoid water sources pollution as well as close nutrient cycles. (Chiras, 2016)

5.2 Chemical fertilizers

A fertilizer based on inorganic or synthetic materials obtained from extraction or chemical or physical industrial processes added for improving soil productivity are called chemical fertilizers. They are also added when the nutrients are removed for increasing crop production. Commonly used chemical fertilizers are urea, ammonium phosphate, N, P, K-containing single or compound / mixed fertilizers. (Morris, et al., 2007)

The chemical fertilizers contain mainly these three nutrients: potassium, nitrogen and phosphorous (macronutrients). Because of this, they only contribute little in restoring soil fertility and have no contribution on supporting organic matter as well as micronutrients. Micronutrients provide nutrients to plant for overall growth and add up value in human nutrition but chemical fertilizers lack micronutrients leading to limited growth and productivity of plants. (Vaneeckhaute, et al., 2013)

Chemical fertilizers don't undergo decomposition, so they are easy to use, and the cultivation time of plants is predictable. But they are relatively expensive, their demand increases in every use but the yield rate decreases. Thus, increasing demand of costly fertilizer and reduction of productivity is a threat on the sustainability of the agriculture in agriculture dependent countries and other developing countries. (Morris, et al., 2007)

5.3 Natural vs chemical fertilizers

Table 2 illustrates the differences of organic fertilizers to industry made chemical fertilizers based certain uses, productivity, longevity and others.

Table 2: Comparison of natural and chemical fertilizers (Vaneeckhaute, et al., 2013; Morris, et al., 2007; Chiras, 2016)

No.	Topic	Natural	Chemical
1	**Land application**	Gradual release of nutrients in the soil which raise the organic matter content	They release quick on to the soil and the crops get the nutrients soon. It's a good choice if there is a need of emergency fertilization of plants
2	**Economic and ecological evaluation**	Application of bio-based provide significant profit as well as ecological benefits through reduced GHGs-emissions and energy use	Application of chemical fertilizers results in almost doubling the profit while 2,5 times reduction in GHGs-emissions and energy use
3	**Mineral loss**	Use of green manure and human wastes on farmlands returns the vital minerals back to the soil	Excessive use of chemicals increased NPK ratio that plants require to about 20 to 60%
4	**Pollution**	Organic matter decomposition is temperature and moisture dependent and is uncontrollable. Nutrients get washed and leached onto water sources if not used according to the crops planted	They get washed away from surface to the waterways causing threat to the aquatic ecology and ultimately human health
5	**Sustainability**	Increase in use to restore sustainable agriculture	Reduction in production and use. Don't support in building the soil. In the long term it only depletes the soil structure making it infertile
6	**Environmental threats**	Health risk due to presence of heavy metals and pathogens	The mineral fertilizers can also leach when irrigation or rain water reaches below the plant root level. Thus, nitrogen leaching in the

			water table can worsen the situation
7	**Production**	the inputs can be composted or digested at household levels or industrially	Only industries, fully or partially comprised of man-made materials. manufactured in big industries and are highly commercialised
8	**Demand and impact on land**	The use improves the organic content of the soil	More and more use in land since the fertility rate decreases with time

With the comparative analysis, it is evident that natural fertilizers are advantageous than the chemical fertilizers in terms of sustainability, environmental point of view as well as economically on a long term. Therefore, natural fertilizers comply with the circular economy and are better solutions to closing the nutrient cycling.

6. MUNICIPAL WASTE TREATMENT TECHNOLOGIES

Waste is inevitable, everyone produces waste. The waste production is growing every year and it is mainly because of the changed and improved lifestyle of the people in the EU. The consumption rate has dramatically increased but the life-span of the products is designed to be short leading to more consumption and more waste. However, the municipal waste generation in EU countries has been declining at the rate of 3% from 2004 to 2014 with per capita generation decrease by 7%. But the waste generation rate varies from country to country with EU (increase in per capita waste generation in 16 countries and decrease in 19 countries). Nonetheless, EU is continuously approaching new technologies for making quality products and amending regulations and directives for waste management with the intention of improving environment and health and creating energy and resource-efficient economy. (EEA, 2019)

Municipal solid waste management (MSWM) includes multidisciplinary activities from waste collection, transfer and transport, storage, processing, energy recovery and disposal. MSW is usually treated in two ways namely mechanical and biological treatment and thermal treatment (Chang & Pires, 2015). Each system is classified in fig 11. MSW technologies involve Mechanical and Biological Treatment (MBT) and Thermal Treatment. Under MBT, mechanical process includes refuse derived fuels (RDF) and solid recovered fuels (SRF) and biological treatment involves composting and anaerobic digestion which will be discussed further in the following sections.

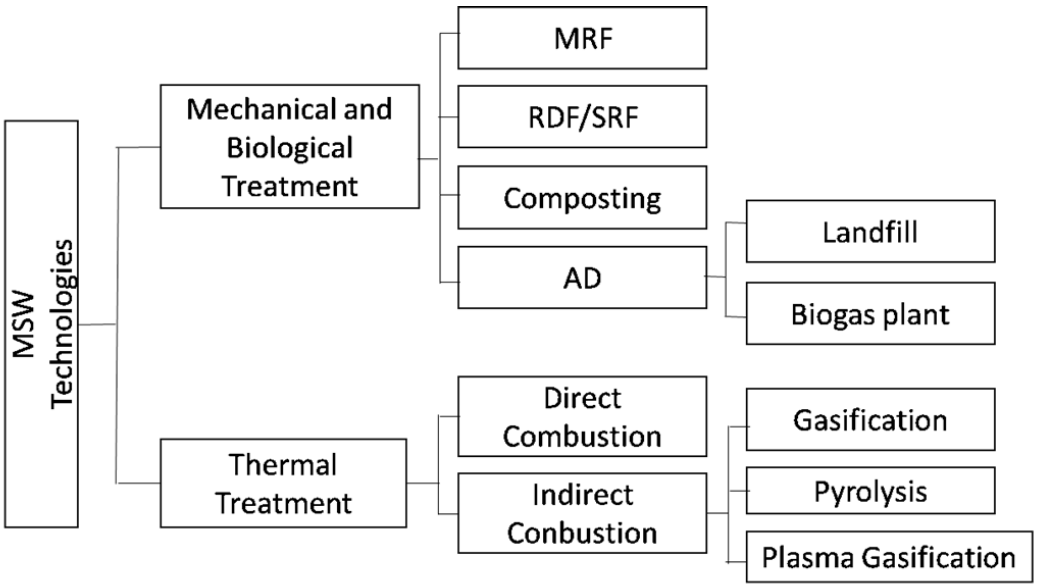

Figure 11 MSW treatment technologies (Modified from Chang & Pires, 2015)

6.1 Composting

Composting process include the conversion of organic solid waste with chemicals (bulking agents and amendments) in the presence of various bacteria, fungi and actinomycetes, surplus supply of air to produce numerous chemical changes and water which further breaks down into resistant substances called compost and water with the release of energy. (DBCC, 2002)

6.1.1 Types of Composting

Three widely used methods for composting are (RTI, 2010):

- **Windrow composting**

The raw materials for composting are aerated time to time by turning the pile placed in rows also known as "windrow" mechanically or manually.

- **Aerated static pile composting**

A single pile of bio-wastes is placed in with loose piled layers of bulking agents such as newspapers, wooden chips to allow air passage throughout the pile (bottom to the top). Also, aerated pipes can be used for regular air circulation in the compost.

- **In-vessel composting**

The waste materials are kept in the closed vessel like silo, drum, or such under controlled environmental conditions (aeration, moisture, temperature). The vessel usually has a mechanism to maintain for proper air flow.

6.1.2 Compost

The humus end-product generated after the composting process as shown in figure 12 is the compost. The quality of the compost is likely to depend upon feed substrates, pre- and post-processing time and operating conditions and high-rate and curing design parameters maintained in the system. The pre- and post-processing mechanisms of the delivered compost depend upon the quality of the feed. For example: garden or yard wastes in a plastic cover compost is likely to be shredded in the pre-process and will get plastic residues in the end-product too. 100% separation of unwanted materials cannot be guaranteed if the feed substrates are mixed waste. They need yet another refining. (Haug, 1993)

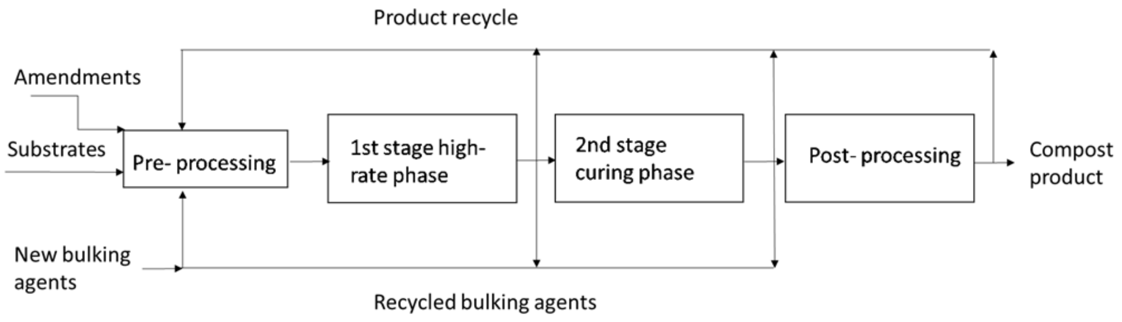

Figure 12: Composting process showing feed substrates, amendments and bulking agents (Based on Haug, 1993)

25% of the carbon if retained in the compost from the substrate (Chen & Inbar, 1993). High quality compost is possible with high quality of feedstocks. However, marketable compost can also be made from heterogeneous substrates like municipal solid wastes, but it will be time-taking for refining and also less quality than from homogenous substrates. (Haug, 1993)

6.2 Anaerobic Digestion

Anaerobic digestion (AD) (fig 13) is the process where microbial decomposition of the organic materials occurs in the absence of oxygen (in airtight containers) and biogas (a mixture of carbon dioxide and methane) is produced along with a residual solid or liquid called digestate or bio-fertiliser. Biogas has been widely tapped in to generate electricity, gas, heat or as a biofuel. (Lukehurst, et al., 2010)

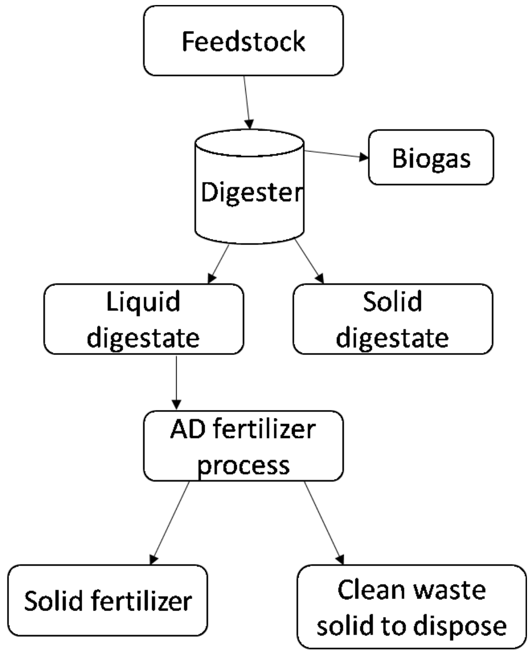

Figure 13 Basic anaerobic digestion process (Modified from Nkoa, 2014)

Anaerobic treatment itself is efficient in converting the organic substrates into important minerals like phosphates (PO_4^{3-}), ammonium (NH_4^+) and sulphides (S^{2-}), minimal the excess sludge is produced that means the output loss is minimum and the biogas released is considered extremely valuable renewable energy. (Lier, et al., 2008)

6.2.1 Feedstock

AD ferments about any organic matter such as crops, food-processing residues from industries, kitchen wastes, green manures, industrial by-products, sewage sludge, etc. These feedstocks also referred as substrates can either be fed in single or two or more feedstock types. Two or more feeds in the digestion are called co-digestion. Multiple substrates are used in a biogas plant usually. (Lukehurst, et al., 2010)

6.2.2 Microbiology of anaerobic conversions

Anaerobic digestion process involves four stages: hydrolysis, acidogenesis, acetogenesis and methanogenesis. Different microbial species perform at each stage. Thus, it is crucial to maintain a well-balanced microbial ecosystem for the process and approaches like codigestion. The products output in one stage acts as a substrate for another stage. (Tchobanoglous, et al., 1993)

- **Hydrolysis:** The step at which biopolymers such as lipids, proteins and carbohydrates are degraded into higher fatty acids, glycerol, monomeric carbohydrates, amino acids and alcohols. Hydrolytic bacteria like *Clostridium* sp., *Proteus vulgaris,* and *Bacillus* sp., are involved (Stronach et al., 1986)

- **Acidogenesis:** It is the formation of fatty acids from monomers after hydrolytic cleavage and is also known as fermentation. Products formed during hydrolysis are converted into primary fatty acids, including propionic acid. Acidogenic bacteria like *Lactobacillus* sp., *Staphylococcus* sp., and *Streptococcus* sp. are involved in this digestion process (Tchobanoglous et al., 1993).

- **Acetogenesis:** In this process acetic acid is formed from the previously obtained volatile fatty acids and homoacetogenic bacteria which use hydrogen and carbon dioxide. *Clostridiu* sp., *Syntrophomonas wolfei* and *Syntrophobacter wolinii* are the acetogens involved in the process (Stronach et al., 1986).

- **Methanogenesis:** It is the last stage where microorganisms from the Archea domain convert either acetic acid to methane or carbon dioxide and hydrogen.

Methane is also produced by anaerobic digestion of methanol, formate or methylamines (Boone et al., 1993)

6.3 Digestate

Digestate is a fully fermented nutrient-rich material and can be used as such, or it can further be processed and upgraded into liquid and solid fractions. Digestate is rich in macronutrients and organic materials as the nitrogen, phosphorous and potassium present in the feedstock will remain in the digestate as none is present in the biogas. (Monson, et al., 2007)

Digestate (fig. 14) can be used as produced (whole digestate) or can be refined using several technologies and treatments further. The most renowned is screw-press separators and decanter centrifuges, a cost-efficient and simple method for separating digestate into solid and liquid fractions. When the whole digestate or fractions aren't suitable for agricultural purposes, then it is either used as landfill cover for municipal solid waste digestate, when dewatered for energy or as feed input in industrial processes. (Wellinger, et al., 2013)

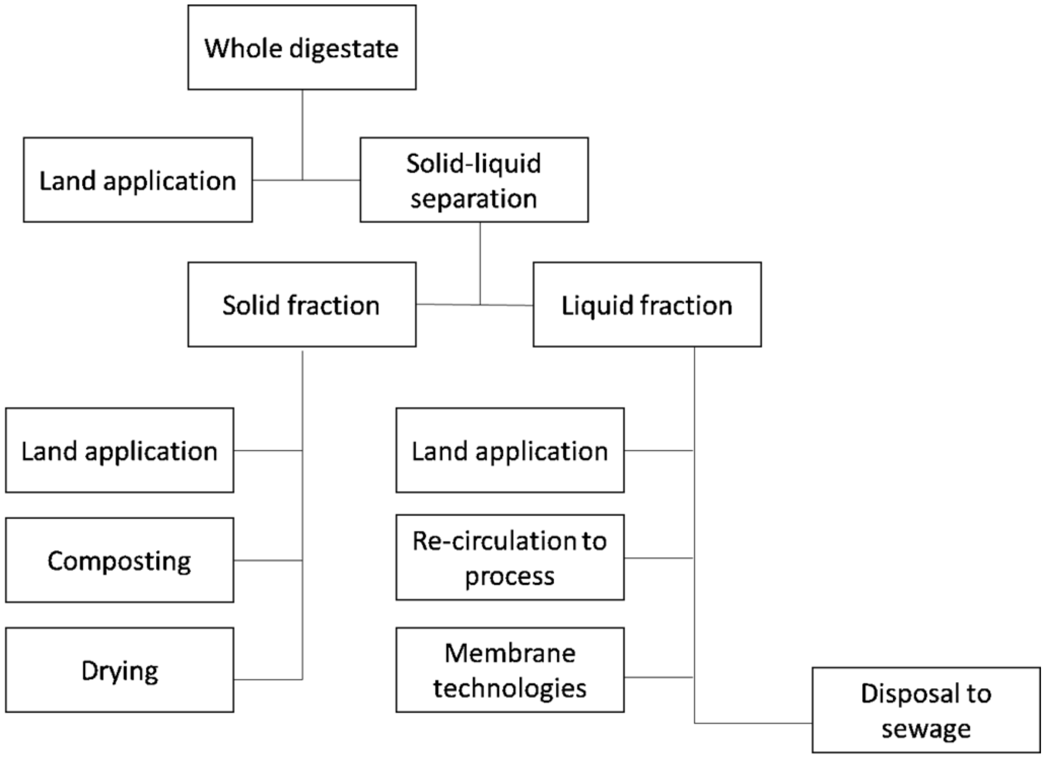

Figure 14 Simplified view of digestate process (Modified from Wellinger, et al., 2013)

6.3.1 Types of Digestion

Depending upon the feedstock, AD plants either use wet, dry, or liquid technology for digestion. (Monson, et al., 2007)

1. **Mesophilic or thermophilic**

Mesophilic: Optimum temperature (35-37°C). Bacteria are active and adapt the changing environments.

Thermophilic: Optimum temperature 35°C. Highly reactive.

2. **Wet or dry**

Wet digestion: operates at 2-12% dry matter. Sewage sludge, food wastes and agro manures are used for wet digestion.

Dry digestion: occurs at <25% dry matter. It is used for municipal waste and green waste.

3. **Single or Multi-step**

Single step: All One vessel is used for all the digestion process

Multi-step: Consists of many vessels usually separating hydrolysis step is separating from methanogenesis for increasing the efficiency of two bacterial groups with different optimal conditions

4. **Batch or continuous feeding**

Batch: One batch of raw materials is added along with the inoculators and removed completely after being degraded. Then second batch is processed.

Continuous: The raw materials and inoculators are continuously added with the removal of fully degraded digestates continuously.

6.3.2 Process Conditions

The factors affecting the anaerobic digester are: (Cossu & Stegmann, 2018; Nayono, 2009; Monson, et al., 2007)

1. **Temperature:**

The digestion rate and metabolic activities are temperature dependent. It is the most influencing parameter which is usually divided into two groups i.e. mesophilic and thermophilic as stated above in types of digester.

2. **Pressure:**

Pressure is crucial parameter in the production of methane. The pressure fluctuations complicate the operational conditions as well as microbic activities. Therefore, to minimize complications and smooth function of microorganisms the pressure is always maintained slightly above atmospheric pressure i.e. 0.02 bar.

3. **pH:**

pH value is an important indicant for performance and stability. The optimum pH value for the process is 6.8-7.6. Methanogenesis and acidogenesis usually drop the pH value making the mixture acidic. Usually, alkaline substances like lime are mixed in the mixture to retain the pH to the optimum level.

4. **Hydraulic Retention Time (HRT) and Organic Loading Rate (OLR):**

HRT is the average number of days the feed remains in the digester before it matures into digestate. HRT time is about 14 days comparatively fast in a single-stage thermophilic digester and varies from 15-40 days in a two-stage mesophilic digestion.

OLR is the rate in which the organic load is treated at the given period of time. OLR is dependent upon the type and quantity of feedstocks added and also changes the HRT.

5. **Moisture Content:**

Raw MSW may contain 30-60% of water, with moisture content in some areas reaching field capacity (50-60% of total solids). Minimum moisture content of less than 20-30% is optimum for microbiological processing. Also, homogenization of the mixture is important, so the feed is also mixed in a regular time interval.

6. **C/N Ratio (Carbon to Nitrogen Ratio):**

The C/N should be suitable for the microorganisms and typically between 20-40 for AD. Nitrogen release rate impacts the ratio. High C/N ratio leads to growth limitation in lack of nitrogen and low C/N ratio increases ammonification leading to nitrogen toxicity. C/N ratio is dependent on the feedstocks and can be controlled with the use of different other substrates to obtain optimum input. C/N ratio decreases in the process as carbon is converted to carbon dioxide (CO_2) and methane (CH_4). (Poltronieri & Fernando D'Usro, 2016)

6.3.3 Process hygienization

To maintain the quality of digestate, AD process ensures that most of the pathogens and contaminants from the original feeds are eradicated. The resulting digestate has been sanitised with minimum transfer of probable pathogens. The pasteurization process kills weed seeds mostly except clover seeds. Hygiene measures and intelligent handling are done to minimise the risk of re-contamination of digestate. These include storage of feedstocks, storage of digestate as well as disinfectant transportation and loading/ unloading of digestate and firstly avoidance of feedstocks from infected-sources. (Pullen, 2015)

6.3.4 Post-treatment

Depending upon the characteristics of substrates and fertilisers regulations, the digestate (end-product of AD process) can directly be applied over land. However, digestate is improvised into separate solid and liquid phase using centrifuge or press prior field application. The centrifuge or press could be further pelletized, dried or composted depending upon the use. Post-treatment is standard practice for municipal waste digestion. Different steps are used depending upon the use and characteristics of the digestate: (Poltronieri & Fernando D'Usro, 2016)

- Dewatering: Press or a centrifuge is used in many installations to dewater the digestate. The subsequent (processed water) is then again recirculated in the digester to maintain good moisture.

- Composting: Aerobic post-composting is used to transform the centrifuge or press cake to mature compost. The primary separators separate the contaminants like plastics usually in municipal wastes. This process can also be done without dewatering in case of dry AD, where it is mixed with fresh feed usually with high dry content to attain best moisture content. These composts are further refined and packed.

6.4 Biogas

Biogenic matter forms biogas naturally under anaerobic conditions. These biogas with methane as main component is a significant contributor of global warming. Methane, however is rapidly gaining attention because it can be used as a fuel for heating, power generation as well as transportation purposes. Thus, commercial harnessing of the methane gas from degraded biomass under controlled and optimised environment to produce sustainable biofuel can be beneficial economically and environmentally. (Wellinger, et al., 2013)

Biogas is the most valuable product of AD process. It consists of methane and Carbon dioxide (major components) along with water, hydrogen sulphide and ammonia (minor components). An activated charcoal is used for attaining high quality of methane and removing the impurities and minor components. Biogas is further used as a renewable energy as it is a source for production of heat and energy. It has been upgraded and widely used as a bio-fuel (an alternate to non-renewable natural gas) in many countries like Italy, Sweden and Germany as CBG (compressed biomethane gas) and CNG (compressed natural gas). (Poltronieri & Fernando D'Usro, 2016)

6.5 Comparing compost and digestate

Based on the definitions as well as physical, chemical, biological and thermodynamic parameters, compost and digestate are compared and listed in table 3:

Table 3: Comparisons between compost and digestate (Edelmann, et al., 1999; Pullen, 2015; Chang & Pires, 2015; Wellinger, et al, 2013)

No.	Topic	Digestate (Anaerobic digestion)	Compost (Aerobic composting)
1.	Definition	Nutrient rich substance formed from decaying organic matter along with methane gas and carbon dioxide in the absence of air	Humus substance formed from organic matter composted in the presence of air along with carbon dioxide gas
2.	Feed inputs	Agricultural wastes, green wastes from garden area, kitchen wastes, sewages, animal slurry	Kitchen wastes, green wastes and agriculture wastes
3.	Moisture	Moisture is retained	Moisture gets lost through evaporation
4.	Turning/	Mixing should be done	Feedstocks should be

	Mixing substrates	regularly to maintain pH, temperature of the feedstock	regularly turned even in the high efficient windrow system because the microbes consume a lot of oxygen quickly and create anaerobic condition.
5.	Physical parameters	It is better to shred the mixture before feeding in as it increases the rate of digestion	Particle size affects the porosity, moisture retention and air availability of the compost mixture
6.	Odour	Chances of unpleasant odour	Soil-like odour
7.	Toxic elements	Depends on feedstock	Depends on feedstock
8.	Storage Emissions	Emissions of CH_4 and NH_3 if remained uncovered	Possibly little CO_2
9.	Emissions	Methane and carbon-dioxide. Methane is captured and used as a bio-fuel, an alternative renewable resource	Aerobic treatment produces large and uncontrolled emissions of volatile compounds, such as ketones, aldehydes, ammonia and methane.
10.	Heat	Small release of heat	Large release of heat
11.	Ammonium content	Retained from feedstock but can be lost during storage and application	Lost by leaching or volatilisation
12.	Nitrogen	High levels of readily available nitrogen	Low levels of readily available nitrogen
13.	Land-use	Anaerobic digestion effluents are not suitable for direct use onto the land since they are too wet, contain a prominent quantity of volatile fatty acids which are slightly phytotoxic and are not even considered sterilised if digestion has not occurred within the thermophilic range of temperatures. Thus, post-treatment after anaerobic digestion is needed to obtain a high-quality, finished product	Reduction in production and use. Don't support in building the soil. In the long term it only depletes the soil structure making it infertile
14.	Air supply	No need of air supply, the process is non-aerobic under closed area.	Needs continuous supply of air and weekly or monthly turning so that the waste is continuously aerated
15.	Cost	Anaerobic technology is complex and costly	Cost effective, also can be prepared at household levels
16.	Space	The space is built in a closed dome-shape and can be made under ground	Uses a lot of open space and make site look unattractive
17.	Bio aerosols	Uncertain	Storage and use might agitate potential hazards

18.	Stability	Often microbially unstable	Usually, mature composts are microbially stable

Digestate and compost are nutrient rich and serve the same purpose of increasing the quality of soil. However, the future of anaerobic digestion should be sought in the context of an overall sustainable waste-management perspective. AD is a very flexible technology, accepts wide range of inputs, produces energy and other valuable end-products. The biogas can be used in the form of electricity, vehicle fuel, power, combined heat and electricity replacing use of fossil fuels (limited non-renewable resources); anaerobic digestion allows closing nutrient and energy cycles and is considered more beneficial to composting, thereby in sync with the circular economy. (Chang & Pires, 2015; Wellinger, et al., 2013)

6.6 Sustainability Assessment Method

The sustainability is assessed with the help of sustainability templates (appendix II) developed for Renewable Energy Empowerment in Northern territories (RECENT) project by Niemelä, (2016) in his Diploma Thesis work on "Sustainability of Small-scale Renewable Energy Solutions in Northern Rural communities - Case of Eco-district in Päivänpaisteenmaa". There are a set of assessment templates developed to assess the sustainability of renewable energy projects. The radar diagrams on sustainability issues are created with the help of sustainability templates in reference to the nine sustainability indicators. The method aims to offer local level and authorities to understand the sustainability of the project. Even though it doesn't give straight solutions but it helps in decision making and realising the issues that might probably be hidden somehow or remain unnoticed. It is most suitable for small communities creating own local energy like small-scale hydropower plants or biogas plant and promote the use of renewable energy technologies. The sustainability templates are used to evaluate given scenarios and discussed further in the experimental part.

EXPERIMENTAL PART

7. OVERVIEW OF THE CASE: PUOLANKA

The experimental part of the thesis is conducted to suggest a sustainable bio-waste management strategy for the selected municipality. Selected case is the municipality of Puolanka in the province of Kainuu within 200 kilometers to Oulu region and with about 2 700 inhabitants. The amount of bio-waste generated in the municipality is estimated to be the same average bio-waste generated per year in the area of Ekokymppi (2018). The present municipal waste management were compared with the other possible alternatives using Sustainability Assessment Method, for which, the RECENT project's sustainability assessment templates were used (explained in chapter 6.6 (Sustainability Assessment Method)). In addition to the presenting the Status quo of the waste management in Puolanka, the other two scenarios for the new bio-waste treatment are:

1. Scenario I: Separately collected bio-waste is transported to Oulu to be treated in existing biogas plant and mixed waste transported to Leppävirta for incineration
2. Scenario II: Separately collected bio-waste will be treated in Puolanka locally (the municipality will build their own digester and utilize the bio-wastes) and mixed waste is transported to be incinerated in Leppävirta

The expectation is to recommend best suitable option in consideration with the overall sustainability based on the sustainability assessment method.

7.1 Background information on Puolanka municipality

Puolanka is the municipality selected for the research and it lies in the north-west of the Kainuu province (figure 15). The total area of the municipality is about 2 599 square kilometers. The population as of 31 December 2017 is 2 669. The municipality of Puolanka was founded in 1867. In the same year, Puolanka church became independent from the Hyrynsalmi church, to which it belonged administratively. The City Council has been in Puolanka since 1916. The waterways in the municipality account for approximately 138 square kilometers. The municipality is about 159 km far from Oulu and 67 km from Kajaani. The main occupations of the people in Puolanka are mostly own business (entrepreneurs), tourism, farming and other services. Tourism is important since the area is blessed with

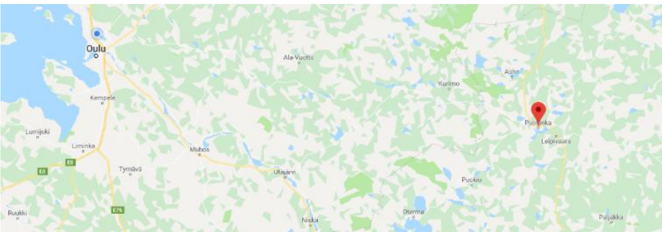

Figure 15: Maps featuring Puolanka and Oulu in Finnish map retrieved from Google maps.

colorful backdrops, landscape views, sloppy hills and unique natural attractions like Hepoköngäs waterfall (also Finland's highest water natural falls). (Puolangan kunta, 2018)

7.1.1Waste management regulations

Under the Waste Act (646/2011), the local regulations on municipal waste management regulations are issued. The waste disposal regulations serve in promotion of effectiveness of Waste Act in the local level. Its objective is to promote healthy atmosphere for living and alleviate dangers of waste or waste management on environment and human health. Local municipal waste management organization in Kainuu, later known as "Ekokymppi", handles in collection, recycling, treatment and final disposal of waste in the Kainuu region as well as provides consultation/ information centre regarding the waste matters (Ekokymppi, 2018a)

The waste management regulations are regional but vary from region to region. Whether the waste is handled by the waste holder or an authorized company, the waste management must be separately collected or sorted then transported and treated in a safe and controlled manner. Also, the wastes are managed in compliance with the EU waste hierarchy as stated in the legislations section 3. (Ekokymppi, 2018a)

7.1.2 Waste collection, sorting and emptying

SORTING

As per Ekokymppi (2018a), these wastes are sorted as bio-waste, mixed waste for energy generation and recyclable waste and collected separately in a labelled container.

Bio-waste: Leftover foods, vegetable and fruit residues, tea bags and coffee grounds, plants and soil, kitchen paper, drain liquids. These wastes need to be packed in biodegradable bags or paper or newspaper before throwing into the waste collection container, plastics aren't used for packing.

Mixed waste for energy generation (later referred as Mixed waste): Products related to hygiene, unfit or old clothes, shoes, rugs and carpets, cleaning wastes and dust-bags, cigarette butts and ash, halogen light and incandescent bulbs, pet litter, chewing gum, plastics and polystyrenes, plastic and paper packages, dirty cardboards, wrapper and gift-wraps and wood-based small-sized waste.

Recyclable wastes: In addition, there is separate collection allotted for other recyclables such as metal, glass and ceramics, plastic, paper and cardboard, textile, etc. These wastes are the recoverable wastes and used for making new products. For instance, paper is recovered again as newspaper and other paper products, cardboard or cartons can be turned into carton packaging and corrugated cardboards, similarly plastics recycled to plastics and plastic products and so on. This way, these wastes are used as raw materials to recover and serve similar purpose.

COLLECTION AND EMPTYING

The municipal wastes are collected by the owners or contracted companies depending upon the number of apartments on a certain area. Wastes are labelled (table 4) and collected accordingly. "X" mark means that these wastes are compulsory to be collected separately on that criteria.

Table 4: Collection of wastes and sorting with labels (Ekokymppi, 2018a)

No.	Number of apartments	Bio-waste	Plastic packing	Metal	Glass & Ceramics	Carton	Mixed Waste
1	1-3 apartments	X					X
2	4 or more apartments	X	X	X	X	X	X
3	Other owned by municipality	X	X	X	X	X	X

The waste types are only limited to bio-waste for this thesis. The treatment of mixed waste and recyclables has been maintained in the best way till now. The municipal waste collection containers must be regularly emptied (table 5) so that the waste collected doesn't create odor and other harm effects on the ambience. There are certain emptying time and regulations to be followed and maintained by the transport operator depending upon the weather and type of waste. (Ekokymppi, 2018a)

Table 5: Waste containers emptying (Ekokymppi, 2018a)

No.	Waste types	Summer (1.5 - 30.9)	Winter (1.10 - 30.4)
1	Bio-waste, 1-3 apartments	2 weeks	4 weeks
	Bio-waste, 4 or more apartments	1 week	4 weeks
2	Mixed waste	8 weeks	8 weeks

7.1.3 Riikinvoima Ekovoimalaitos

Ekokymppi is one of the waste management companies sending the mixed wastes to Riikinvoima. Ekovoimalaitos (Eco Power Plant) replaces the use of limited resources (fossil fuels) in generating energy from wastes. Also, it reduces the burden of landfilled waste (landfills are anyway planned to be closed by the EU) and reduces carbon emissions from non-renewable energy (coal and fuel) and methane production from landfill. It is located at Leppävirta (fig. 16) about 342 km from Puolanka. (Riikinvoima, 2018)

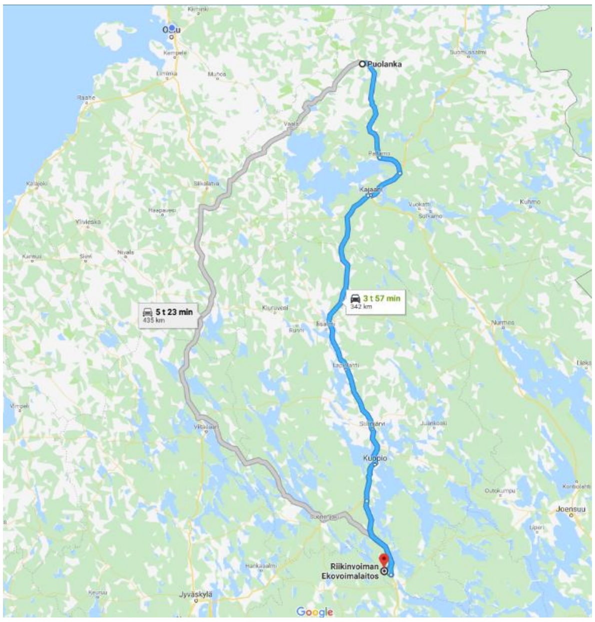

Figure 16: Car distance from Puolanka City to Leppävirta (source: Google Maps)

Riikinvoima Ekovoimalaitos (Eco Power plant) is responsible in producing clean energy from non-recyclable combustible mixed municipal waste for electricity and district heat. This technology contributes significantly in turning waste to energy. Wastes are burnt in a circular high-tech burning technology. The flue-gas emitted is purified and is below the emission limits of the waste incineration regulations. The ash is utilized for example in road construction or wherever possible and final cleaning of remnants are handled and disposed safely. (Riikinvoima, 2018)

7.2 Solid waste management in Puolanka (Status quo)

The municipal waste authority of Kainuu (Ekokymppi) established in 2001 is responsible for managing the wastes within the 8 municipalities of Kainuu region; Hyrynsalmi, Kajaani, Kuhmo, Paltamo, Puolanka, Ristijärvi, Sotkamo and Suomussalmi. The population of Kainuu municipalities (fig. 17) is approximately 74 790. (Kainuun liitto, 2018)

Figure 17: Kainuu region (From Kainuun liitto, 2018)

7.2.1 Waste collection points in Puolanka

The waste transport companies in contract are responsible for collecting the municipal solid waste. In addition to the collection bins in the properties (e.g. housing companies, detached houses, administrative and service buildings), about 130 local waste collection points are placed at the scattered settlements for summer cottages and other homes which do not have contract with the waste transport companies. Nine municipalities have their own waste station for hazardous waste. Wastes are then handled at the Majasaari Waste Centre in Kajaani. Around 30 Ecopoints are in Kainuu province for other sorted recyclable materials such as glasses, papers, cardboards, etc. RINKI Oy is taking care of these recyclable packaging wastes. (Ekokymppi, 2018a)

7.2.2 Majasaari waste centre

The Majasaari waste center is in Kajaani (fig. 18) about 111 km by car from Puolanka city centre. The waste center serves in sorting all the different wastes from bio-waste to paper, plastics and sends them to the concerned waste management companies for further treatment. Other municipal wastes (recyclables) and construction wastes are received, sorted and pre-treated. Also, the special wastes and hazardous wastes are received by the center. (Ekokymppi, 2018b)

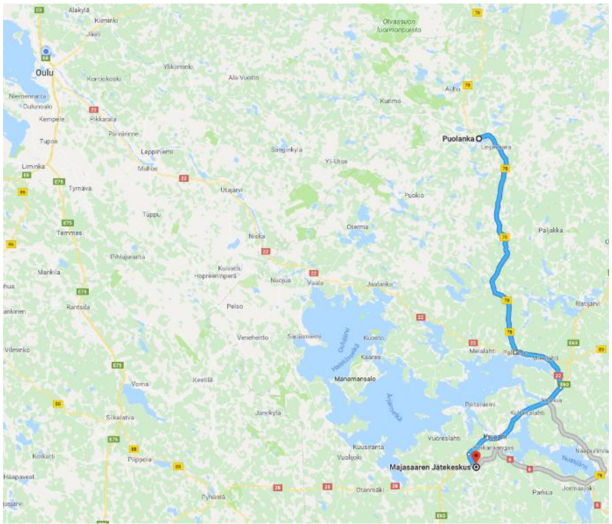

Figure 18: Majasaari Waste center from Puolanka City (Source: Google Maps)

Bio-waste is handled and treated there through windrow composting. The wastes are crushed by a wheel loader and covered with the wooden chips. The compost is about two meters high and 50 meters long. The temperature is monitored, and the compost rows are turned regularly for maintaining the efficiency of the process. The mature end-product is used in covering the soils nearby the waste center. (Ekokymppi, 2018b)

7.3 Scenario I

Mixed waste is transported to be incinerated in Riikinvoima Eco Power Plant, Leppävirta and separately collected bio-waste is transported to the biogas facility of Gasum Oy in Oulu (Kiertokaari Oy).

7.3.1. Waste Management in Oulu

Kiertokaari Oy is responsible for handling and managing all types of wastes in the Oulu region. The municipal company serves approximately 300 000 population in 13 municipalities including domain shareholders (Hailuoto, Ii, Kempele, Oulu, Pudasjärvi, Siikajoki and Raahe) and remaining other (Liminka, Simo, Utajärvi, Muhos and Tyrnävä). (Kiertokaari, 2019a)

7.3.2. Oulu biogas plant (Gasum Oy)

Gasum Oy, located at Rusko waste centre is responsible to handle the separately collected bio-waste from these 13 municipalities and from wide areas in the Northern part of Finland. The bio-wastes are then forwarded to the digester which produce biogas (renewable clean energy) which serves as biofuel and also is used for generating heat and electricity supplied to communities and industries and digestate as a by-product, also used as natural fertilizers replacing chemical fertilizers available in the market along with. (Kiertokaari, 2019b). Kiertokaari Oy is 125 km (fig 19) on car from Puolanka city centre.

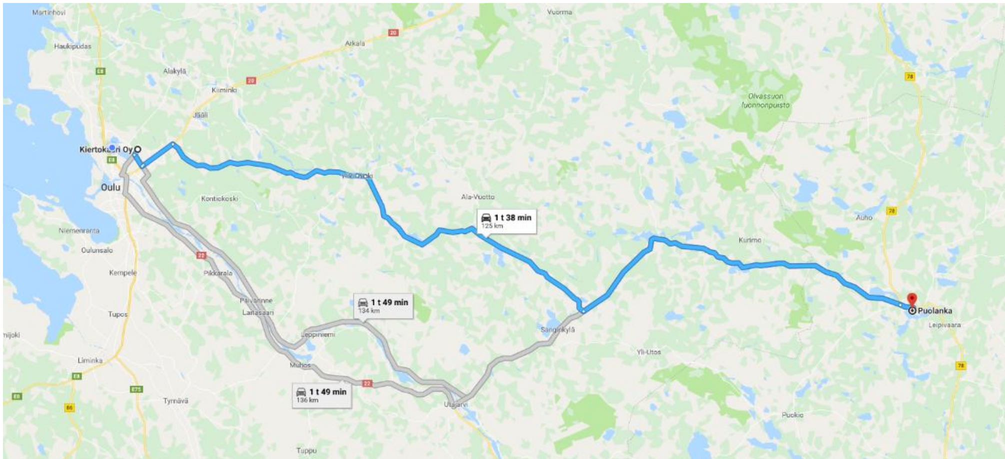

Figure 19: Kiertokaari Oy from Puolanka City (source: Google maps)

There is 100% renewable and environmentally friendly biogas plant (Gasum Oy) in the Rusko waste center. It has been in operation since 2015 with waste processing capacity of 19 000 tonnes per year. This biogas plant uses mesophilic process type and has about 15 GWh capacity of gas production in a year. From 2017, the plant is expanded and now has a waste processing capacity of 60 000 tonnes per year. Biogas is commercially available at the local gas network and managed under Kiertokaari Oy. There is also an additional pumping station and gas upgrading system in the area since 2017. It has been serving Oulu residents as well as passer-bys with bio-fuel for cars. Annual production of biogas in Oulu is more than six million cubic meters which is equal to 30 000 MWh of energy and is being used as vehicular fuels and district heating as well as commercial plants. The feedstock for the digester is mostly separately collected bio-waste and sewage sludge. The digestate is further sanitized and used as natural fertilizer in agriculture. (Gasum, 2019; Kiertokaari, 2019b)

7.4 Scenario II

Mixed waste is transported to be incinerated in Riikinvoima Eco Power Plant, Leppävirta and separately collected bio-waste will be treated in Puolanka, as the municipality will build their own digester and treat bio-waste locally at Puolangan Biokeskus.

7.4.1. Puolangan Biokeskus study

Biocentre of Puolanka (Puolangan Biokeskus) study was from 01.03.2016-30.11.2018. The project aimed in investing in bioproduct operations within the Puolanka municipality to strengthen the region's economy and create jobs and employment locally. The project was funded mainly (70%) by Regional Council of Kainuu (ERDF), 10% municipality funding, 17,2% private funding and 2,8% Kainuun Etu Limited's funding. The project has progressed and here are few updates: (Kainuun etu, 2018)

- Renovation of municipality's heat plant and biogas plant implementation study
- Targets for various use of biogas: electricity production also to be investigated
- Energy investments to further strengthen the overall economy in the municipality as well as fulfil the entrepreneurs, cooperative partners and stakeholders

This scenario II is based on assumption that the biogas plant will be built in Puolanka.

7.4.2. Feedstocks

The input materials for the AD plant in Puolanka is mainly bio-waste and also other degradable wastes from food industries, by-products from farms, sludge, etc. For the case, only separately collected bio-waste is considered.

Separately collected bio-waste

Bio-waste is collected separately in the Puolanka municipality. The biodegradable waste from home, hotels, restaurants or any other recreational or public areas can be collected separately.

8. DATA AND CALCULATIONS

The following are the data and calculations for Puolanka municipality commonly used in all the three options.

8.1 Bio-waste in Puolanka

The amount of separately collected bio-waste is calculated for Puolanka municipality based on the population of Puolanka on 31 December 2017 and average per capita per annum bio-waste generated in Puolanka Municipality is from Ekokymppi (2018a). From the table 6, we find that the total amount of bio-waste generated in Puolanka yearly is 165 478 kg. These data are used in the following sections for further calculations.

Table 6: Amount of separately collected bio-waste in Puolanka municipality

No.	Parameters	Quantity
1	Population	2 669
2	Amount of bio-waste generated per person yearly (kg/a/p)	62
3	Puolanka area total bio-waste in a year (kg/a)	165 478
4	Puolanka area total bio-waste per week (kg/wk)	3 182,27
5	Puolanka area total bio-waste in a year (t/a)	165,478
6	Puolanka total bio-waste in a week (t/wk)	3,18

8.2 Gate Fees and Transportation

The gate fees for bio-waste at Majasaari waste center, Kajaani and Kiertokaari Oy, Oulu are 52,084 and 57,2 €/t respectively (table 7) (Ekokymppi, 2018b; Kiertokaari, 2019c) and the gate fee for bio-waste for scenario II (Puolangan biokeskus) is assumed to be 50 €/t (Alaraudanjoki, 2016).

Table 7: Gate fees and transportation distances from Puolanka Municipality

Scenarios	Bio-waste		Mixed waste	Distance (km)		Gate fees with taxes (€/t)
	From	To	To	Bio-waste	Mixed waste	
Status quo	Puolanka	Majasaari Waste Center, Kajaani	Leppävirta	111	342	52,084
Scenario I	Puolanka	Kiertokaari Oy, Oulu (Gasum Ltd.)	Leppävirta	125	342	57,2
Scenario II	Puolanka	Puolangan Biokeskus	Leppävirta	10	342	50

The distances from Puolanka to the waste centers in Oulu and Kajaani are based on the google maps by car and Puolangan biokeskus is 10 kms (an assumption).

The gate fees for mixed waste is (184,80 €/t) is usually more expensive than the bio-waste to enhance the sorting practices. The mixed wastes are transported to the same place (Riikinvoima in Leppävirta) for all three options.

8.3 Waste containers sizing and emptying frequencies

The bio-waste collection container sizing and emptying frequencies (table 5) and the amount of waste produced in Puolanka municipality (section 8,2) are taken from the Ekokymppi (2018) in table 8.

Table 8: Sizing waste containers and emptying frequencies

No.	Parameters	Amount
1	Bio-waste in Puolanka (kg/d)	453,36
2	Volume weight (kg/m^3)	180
3	Containers (l)	240
4	Emptying frequency	Every week (more than 4 apartments)

Volume weight of bio-waste is 100-180 kg/m^3 and we assume it to be 180 kg/m^3. (JLY, 2016). From, 140 l and 240 l of containers for municipal bio-wastes collection, 240 l containers are chosen. Larger containers ensure that the volume is enough in case of over-production of waste especially during holidays or feasts. The sizing is also based on the average waste amounts produced in the area (Puolanka). The 240l brown color containers can carry 96kg maximum of load (Meltex, 2018).

8.4 Transportation costs and CO_2 emissions

The costs and CO_2 emissions for local collection of bio-waste from the center and from Puolanka to Majasaari waste center in Kajaani (Status Quo), Puolanka - Kiertokaari Oy in Oulu (Status I) and Puolanka –Puolangan biokeskus (Status II) are calculated (table 9):

Table 9: Transportation costs and CO_2 emissions (Lipasto, 2017)

Options	Distance (km)	Distance (km/a)	Avg. Fuel price (€/l)	Avg. Fuel consumption (l/100km)	Round trip cost (€)	Yearly Round-trip cost (€/a)	CO_{2e} (g/km)	CO_{2e} (t)
Local collection	10 * 2	3 120	1,5	21,9	6,57	1 024,92	521	1,63
Status Quo	111 * 2	4 674		33,7	112,2	1 810,32	796	2,87
Scenario I	125 * 2	4 870			126,4	1 909,72		3,02
Scenario II	Calculations for the local collection for the bio-waste cover the transportation and emissions for Scenario II							

For local collection of bio-waste in the center of the municipality of Puolanka, delivery type heavy weight lorry with maximum cargo volume of 8m^3 was chosen. The fuel consumption for the lorry is 21,9 l/100km (an average of 18,3 l/100km empty lorry and 25,5 l/100km fully loaded). 17,7 m^3/wk of bio-waste is generated in Puolanka. It is collected three times and the yearly cost would be (3 times a week times one round trip cost) i.e. (3*52*6,57). The average diesel price 1,5 €/l is taken to calculate the round trips for all three scenarios.

For status quo and scenario I, load is transported using semi-trailer truck for highway driving and the heavy weight lorry isn't suitable due to the distance and volume of the waste. The fuel consumption is as an average value of 26,6 l/100km for empty truck and fully loaded is 40,7 l/100km, 33,7 l/100km is used for calculation (Lipasto, 2017). Since, the semi-trailer truck has a maximum capacity of 25 tons, the truck would carry bio-waste to the destinations only once in 8 weeks so, the yearly cost would be 6-7 times the round-trip cost (table 10).

But, in practice to avoid odor and other harmful impacts around the surrounding, the frequency of transporting the waste would be at least once a week. The truck collecting bio-waste from neighboring municipalities could also collect the bio-waste from Puolanka waste collection center in Puolanka. Since the wastes are collected from the Puolanka city first, we need to add local collection and transportation costs as in scenario II too in the yearly cost of status quo and scenario I. Thus, the annual round-trip cost for status quo is calculated as (7*112,2+1 024,92) and scenario I is as (7*126,4 + 1 024,92). Thus, the annual collection costs for status quo, scenario I and scenario II are 1 810,32 €/a and 1 909,72 €/a respectively and scenario II is similar to local collection i.e. 1 024,92 €/a.

CO_2 emissions from waste transportation

For local collection, since the heavy lorry is used for transportation, an average of CO_2 emissions (empty 436 g/km and full load 606 g/km) i.e. 521 g/km is used (Lipasto, 2017). And the annual CO_2 emissions is calculated to be (20*3*52*521) equals 1 625,52 kg of CO_2 i.e. 1,63 t of CO_2 emissions.

For status quo and scenario I case semi-trailer truck is used for transporting the waste through the highways, an average of CO_2 emissions for empty 630 g/km and full load 962 g/km i.e. 796 g/km is used (Lipasto, 2017). Also, the emissions while collecting and transporting the wastes locally within the city is also added. The annual CO_2 emissions for status quo is calculated to be (222*7*796 +1 625,520) kg and for scenario I is calculated to be (250*7 *796 + 1 625,520) kg. Thus, the total annual emissions for status quo and scenario I are 2,87 t of CO_2 and 3,02 t of CO_2. The CO_2 emissions for local collection for bio-waste is same for scenario II as well so, the emission is 1,63 t of CO_2.

8.5 Calculations for Status quo and both Scenarios

In this chapter are the calculations for the organizing the local waste management for status quo and scenarios I and II.

8.5.1. Waste management prices

Since the wastes in Puolanka are being handled and transported from Puolanka municipality to different waste centers, waste handling scenarios are similar and are calculated together. The cost of managing the wastes i.e. handling waste, container and transportation to Majasaari composting center (Status quo), Kiertokaari Oy (scenario I) and Puolanka (scenario II) is listed below (table 10).

Table 10: Waste management prices for Status quo and Scenario I (JLY, 2019; Puirava, 2018)

No.	Parameters	Unit price (€)	Amount	Total Status Quo & Scenario I (€)
1	Containers (240 l)	-	92 (Based on table 11)	-
2	Emptying	10,09	Once a week = 52*10,09 €	524,68
3	Washing	18/container	2 times/a	36

			= 18*2 €	
4	Collection point maintenance	50/a	1 time	50
5	Investment	31,4 €/p		1350
6	Management	79,5 €/p		3418
7	**Total cost per annum**			**5378,68 €**

The unit prices for maintenance, investment and management of the waste management are based on the calculations of Puirava, (2018). The total waste handling cost (table 10) for bio-waste in Puolanka is 5378,68 € /a. The price for one waste container is 49,9 € (Jätekuljetus, 2019) but we are using the same old bins and might not need to buy the new one, so the prices are not calculated in the work.

8.5.2. CO_2 emissions for composting in Status Quo

The CO_2 emissions for a year by composting can be calculated with the equation (1) (RTI, 2010)

$$E_{CO_2} = EF_{compost} * \sum_{n=1}^{N} \left(M_{compost,n} * TS_n\right) \quad (1)$$

where:

E_{CO_2} is Annual emissions for CO_2 in composting process (Mg CO_2/a)

$EF_{compost}$ is emission factors for composting (kg CO_2/kg dry solids)

= 0,44 kg CO_2/kg dry solids

n is bulking agent or waste index;

N is number of waste materials added in the compost process;

$M_{compost,n}$ is Annual waste input in the compost (Mg/a, wet basis) = 165,478 Mg/a

TS_n is total solids of waste input in the compost (kg dry solids/kg wet solids)

= 41,37 Mg/a

Upon calculation, we found that the CO_2 emissions from Status Quo is 3 012,16 Mg CO_2/a also expressed as 3 012,16 t CO_2/a.

8.5.3. CO_2 emissions for anaerobic digestion in Scenario I and II

Through the online calculator (Appendix I), it is calculated that the AD plant with an input of 165,478 t of separately collected bio-waste in a year, reduces the CO_2

emissions by around 36 t of CO_2/a from diversion in landfill and 8 t of CO_2/a for producing renewable energy. In total it is 42 t of CO_2/a.

8.6 Sizing and feasibility calculations for the Scenario II

Building a biogas plant (Puolangan biokeskus), using separately collected bio-waste from the Puolanka municipality.

8.6.1. Feed composition

Availability and pre-treatment:

Separately collected bio-waste (feed) is available every day in a year. It is collected once a week for both summer and winter (Table 8). During winter in Finland, bio-waste is frozen and needs to be warmed enough for pre-treatment. Pretreatment of feeds are necessary. Bio-wastes are usually crushed, sieved and sanitized at 70 °C an hour before feeding into the reactor (Kiertokaari, 2019b). Sanitization is important to avoid the pathogens as explained in section 6.3.3.

Temperature:

In Finland, mesophilic process (35 °C) is popularly used as the process is resistant to temperature fluctuations and the heating need is low which eases the operation also in Finnish winter. (Latvala, 2009)

pH and OLR:

Usually, the OLR is between 3-9 kg VS (l)m^3/d which is calculated with the VS content in the feed input divided by volume of the reactor. (Latvala, 2009)

HRT:

The HRT of the bio-gas plant is between 12-30 days for Finland (Latvala, 2009) and we assume it to be three weeks i.e. 21 days. The reactor's performance determines the HRT of the plant. So, it can be adjusted accordingly. (ENKAT, 2013)

Total Solids (TS) % and Volatile Solids (VS) %

Total Solids (TS) % and Volatile Solids (VS) % are calculated as in Table 11.

Table 11 TS% and VS % of the bio-waste

Feed input	Amount	TS %	TS (t/a)	VS %	VS (kg/d)
Bio-waste (t/a)	165,478	25%	41,37		
Bio-waste (kg/d)	453,364			17,5	79,34

The VS percentage in bio-waste is 17,5% (Vögeli, et al., 2014) and the number of volatile solids in bio-waste is calculated as 79,34 kg/d. The TS % is 25% (Rahikainen, 2009) and thus calculated as 41,37 t/a.

8.6.2. Planning Biogas digester

Reactor design

The volume of the reactor is calculated using the equation (2) (Biosantech, et al., 2008)

$$V_R = \frac{AF_v}{\left(\frac{365}{RT}\right)} * f \tag{2}$$

where,

V_R is volume of the reactor (m^3),

AF_v is the volume of the bio-waste fed into the reactor in a year (m^3),

RT is the retention time (days, d), = 21 d; and

f is the reactor's oversize coefficient factor.

Since the reactor is designed 20-30 % larger than the amount of feedstock fed in the reactor. Oversize coefficient factor (f) is taken 1,2 for probable foaming and biogas produced.

From equation (2), the volume for the reactor is calculated to be 63,47 m^3 (table 12).

Table 12: Parameters for reactor design

No.	Parameters	Quantity	Remarks
1	Puolanka total bio-waste (kg/wk)	3 182,26	
2	Volume weight (kg/m^3)	180	Assumptions (JLY, 2016)
3	Puolanka bio-waste volume (m^3/wk)	17,67927	
4	Puolanka bio-waste volume (l/wk)	17 679,27	
5	Size of containers (l)	240	Based on volume of waste and emptying frequency

6	Degree of filling	0,8	(20-30) % less than the volume of container (Latvala, 2009)
7	Amount of bio-waste in one container (l)	192	If 80% is assumed to fill
8	Number of containers needed	92,08	Bio-waste in whole Puolanka area. Old bins are used.
9	Emptying (times/week)	1	Summer or winter timing are considered same for calculation purposes
10	Total volume of bio-waste in a year (m^3/a)	919,32	Using volumetric weight
11	Total volume of reactor (V_R) (m^3)	63,47	Using equation 2

The reactor is designed based on these data.

8.6.3. Output Assessment

Methane potential and methane yield

Methane potential for bio-waste is 100 $m^3_{CH_4}$/t (Kiviluoma-Leskelä, 2010). The total methane yield for bio-waste is calculated using the equation (3).

$$MP = AF_t * MP_t \quad (3)$$

where,

MP is amount of methane produced in a year ($m^3_{CH_4}$/a),

AF_t is amount of feed input in a year (t/a), and

MP_t is the methane produced from a ton of fresh feed input ($m^3_{CH_4}$/t).

Thus, the amount of methane produced in a year is calculated with the simple equation (3) as 16 547,8 $m^3_{CH_4}$/a

Biogas upgrading

Methane gas is upgraded to be used as a bio-fuel and serves the same purpose as petrol and diesel. The techniques used for petrol-based vehicles are too similar for gas-based motors but there is a difference in system for fuel-injection and storage of fuel. And, so it is also possible to store both diesel and methane and petrol and methane on the same vehicle. (Motiva, 2015)

The percentage of methane in the biogas varies from 50 to 75% (EC, 2006) and remaining are CO_2 and small traces of H_2S and water. The methane must be upgraded to about 95% to be suitable to be used as a fuel for transporting. In Finland, water scrubbing process is used for refining the methane from the digester process. The scrubber is placed beside the bio-gas plant and the bio-gas supply station is placed within 1-2 km from the refinery to reduce extra costs in constructing pipelines. (Alaraudanjoki, 2016)

The methane content in the biogas is considered to be 65% of total biogas production in a year. So, the annual volume of biogas is calculated to be 25 458,15 m^3/a.

Energy output from biogas

We calculate annual energy output from the total biogas produced. A cubic meter of methane is equivalent to 9,97 kWh/m^3 or 36 MJ energy (Rutz et al., 2015). We get,

Total energy from biomethane = 65% of total volume of biogas produced m^3/yr * 9,97 kWh/m^3 = 144,8 MWh/yr

In Finland, annual average driving by a car is about 18 800 km which is equivalent to 13,5 MWh/yr of energy consumption by petrol-based cars and 9,4 MWh/yr of energy consumption by diesel-based cars (Tulli, 2016). Thus, from this data, it is calculated that with an annual 144,8 MWh of biofuel energy, it is able to replace 15,4 diesel-driven cars and 10,7 petrol-driven cars annually.

Heat energy production

Assuming 10% losses in energy, about 90% can be trapped and converted into heat energy (assumption for the case as the total energy is utilized for district heating within the Puolanka city). The biogas energy output is expressed in kWh/yr and is based on bio-gas operating hours in a year, usually it is assumed to be about 8 000 hrs/yr. (Rutz et al, 2015)

From the total energy produced from the biogas plant, approximately 90% of the energy is converted to be usable (10% is assumed as loss) in the form of Combined Heat and Power (CHP) with 90% heat energy.

The thermal output is calculated as:

$$\begin{aligned} Thermal\ output\ (kW) \\ &= methane\ production\ per\ hour\ \left(\frac{m^3}{h}\right) \\ &* calorific\ value\ of\ methane\ \left(\frac{kWh}{m^3}\right) \\ &* \ thermal\ efficiency\ of\ CHP \end{aligned}$$

Where,

Methane production per hour is $\frac{16547,8}{8000}$ m^3/hr = 2,07 m^3/hr;

Calorific value of methane is 11,06 kWh/m^3; and

CHP thermal efficiency is 90%

Therefore, the thermal output is calculated to be 20,6 kW.

Now, the annual thermal energy produced from the biogas plant is calculated as:

Annual thermal energy production (GJ/a) = biogas plant operational hours * thermal output (kW) (4)

Thus, the total thermal energy produced from the biogas plant is calculated to be 164 800 kWh equal to 164 MWh.

1 kWh is 3,6MJ so, it would be 593 280 MJ which is 593 GJ/yr.

Using the online biogas calculator (Appendix I) the following results are found (table 13). Clearly, there is a big difference in the results calculated manually from online calculator. These may be few reasons for this alteration, i) use of different methodologies and assumptions for calculating same parameter; or ii) different climatic conditions since the online calculation was designed by a US company may differ situationally with the Finnish conditions. The results from manual calculations are used in this thesis as the assumptions and methodologies are better known.

Table 13: Energy outputs from biogas plant

Parameters	**Results**	
Mode of calculation	Online bio-gas calculator (appendix I)	Manual calculation using equations
Biogas (m^3/a)	19 515	25 458,15
Heat produced (GJ/a)	356	593

The heat energy from the biogas is distributed within the residents of Puolanka connected through district heating supply. The energy is 100% clean and renewable. Thus, biogas plant evidently converts waste to energy and aids in circular economy.

Revenue from thermal energy production

Unit price for heat is 83,5 €/MWh (Pohjoista voimaa, 2018). Therefore, the annual revenue from heat energy sale could be 13 694 €.

Biomethane Cost

Biomethane is expressed in kilos and according to (Gasum, 2014), a kilo of biomethane has an energy equivalent to diesel (1,39 l) and petrol (1,56 l). On average price of petrol is 1,5 €/l with VAT and 1,21 €/l without VAT.

Total revenue from biomethane (€/a) = 16 547,8 $m^3_{CH_4}$/a (volume of biomethane) * 1.21€/l (market price of petrol without VAT) (FAO, 2014) is 20 022,84 €/a.

Total weight (kg) of biomethane from the bio-waste per year is calculated as:

16 547,8 $m^3_{CH_4}$/a (volume of bio-methane) * 0,72 kg/m^3 (methane density) is 11914,42 kg/a.

Amount of digestate

After the digestion completes in the reactor, the remaining mixture of material (digestate) is further separated into solid and liquid. In Finland, the both are termed natural fertilizers and used in arable lands. These waste-recycled fertilizers are tested to ensure to be economically sound and environmentally friendly. (Biosandtech, et al, 2008)

Digestate is the leftover percentage of the anaerobic digestion process and usually it is the amount is estimated to be 10% reduced from the total substrate and expressed in t/yr (Akoore, 2018). So, it is calculated to be 148,9 t/yr.

Digestate value

It is not easy to label a price for digestate because usually it is not common for a farmer to buy 'digestate' but the price can be estimated with the percentage of nutritional contents like amount of Nitrogen or Phosphorous or other minor elements require to nourish the soil. Based on calculative value it is assumed that the solid and liquid portions would be 90 cents/m^3 and 8 €/m^3 respectively. With additional nutrients the amount can be even 12 €/m^3. (Kari & Häkkinen, 2016)

So, for the calculation purposes, we assume an average of these amounts i.e. 10,45 €/m^3. [{90% of 165,478 (equivalent to amount of bio-waste in a year)} m^3/a * 10,45€/m^3]

And, we calculate the digestate value to be 1 556,3 €/a.

8.6.4. Economic assessment

Investment cost of Reactor

The size of the reactor determines its cost. Other factors are the technologies and refineries used, location and also the quality of feedstock used. The investment cost is about 210-310 €/m^3 (Latvala, 2005) and also about 1000 €/m^3 (Latvala, 2007). Since, the feedstock for the reactor is only limited to bio-waste for Puolanka now, we suppose the investment cost to be an average of these two sources 600 €/m^3. The bio-gas upgrading cost is between 0,34-0,45 €/m^3 for a small biogas plant. (Latvala, 2005)

Assessing Profitability

Following three methods are used for assessing profitability of the bio-gas plant in Puolanka.

1. Net present Value (NPV)

NPP checks whether the investment is profitable or not. If the value is positive than there is profit or else loss. The calculation of NPV is based on Vedenjuoksu (2009)

$$NPV = C_t * \frac{(1+r)^t - 1}{r(1+r)^t} - C_o * \frac{(1+r)^t - 1}{r(1+r)^t} - C_i \quad (3)$$

Where,

C_t is net cash inflow per year;

C_i is total bio-gas plant investment cost;

C_o is net cash outflow per year;

r is discount rate; and

t is the lifetime of the bio-gas plant

2. Payback Period (PP)

Based on (Vierros, 2009), PP is calculated as:

$$PP = \frac{C_i}{(C_t - C_o)} \quad (4)$$

PP doesn't take account of discount rate and therefore gives an approximate result. It is suggested to use one other methods for calculating the profit.

The following assumptions are made for assessing the profitability:

- Lifetime of the bio-gas plant: 25 years;
- Discount rate (r) is 5%;
- Plant's residual value is zero

Investments:

- Investment cost of reactor: 600 €/m^3 = 38 082 € (600 * V_R) (table 11);
- Investment cost of bio-gas refineries: 33% of reactor's cost (Luostarinen, 2011) = 12 756,06 €;

(Investment cost of bio-waste containers are not considered because the old bins are used)

Total investment cost (C_i): 50 649,06 €

Cash outflow:

- Gate fee: 50€/t = (50*165,478) €/a = 8 273,9 €/a
- Bio-gas upgrading costs: 0,45 €/m^3 = 7 446,51 €/a (equation 3);
- Transportation cost: 1 024,92 €/a (Table 9);
- Operation and maintenance cost: 25 000 €/a (Luostarinen, 2011)

Total cash outflow (C_o): 41 745,33 €/a

Cash inflow:

It is assumed that there is no loss of methane and digestion process is complete;

- Digestate sell = 1 556,3 €/a;
- Heat energy revenue = 13 694 €/a

Total cash inflow (C_t): 15 250,3 €/a

Therefore, NPV is -55 948,1 € and PP is -1,91 years. It is calculated that the payback period of Scenario II is low near to 2 years which is really good, but it is mainly so because the investments for the project were low and limited to the costs of 63,47 m^3 reactor (small volume in this case) and refineries as calculated based on Alaraudanjoki (2016).

Therefore, it was assumed again that the investments be calculated based on Akoore (2018) who had an extensive all-round estimation for the investments in his work where it was calculated that the price for a reactor of 288,8 m^3 size to be 387 713€. That would make the price for unit m^3 of reactor 1 342,49€. Therefore, for 63,47 m^3 reactor the total costs would be 85 208 € (**new C_i**) and upon calculations, **new NPV** is -90 508 € and **new PP** is about -3,22 years (still very low PP value but more realistic because of exclusive investment cost assumptions).

8.7 Results and discussion

The key results from the data and calculation are listed in table 14 and summarized.

Table 14: Main output of the calculations

Physical parameters	
Temperature (^oC)	35
Total Solids (%)	25
Hydraulic retention time (HRT) (d)	21
Technical results	
Amount of bio-waste in Puolanka (t/a)	165,478
Volume of the reactor (m^3)	63,47
Biomethane production (m^3/a)	16547,8
Biogas production (m^3/a)	25 458,15
Biogas production (m^3/a) using online calculator	19515
Energy output from biogas (MWh/a)	144,8
Economic Assessment	
Digestate sale (€)	1556,3
Heat production revenue (€)	13694
NPV (€)	-90 508
PP (years)	-3,22
CO_2 emissions	**(t CO_{2e} /year)**
Status Quo (composting and transportation emissions)	+3 017,03

Scenario I (AD plant and transportation emissions)	-39,98
Scenario II (AD plant and transportation emissions)	-40,37

Puolanka, the municipality in the Kainuu region of Finland have 2 669 people with 165,478 t of bio-waste per year. Currently, bio-wastes have been separated and treated in the Majasaari waste center in Kajaani where the bio-waste are treated through composting mechanism. It was studied that if given two alternative choices, to transfer the bio-wastes to other locations with different waste management mechanisms than status quo, how the results varied.

Scenario I was transportation of bio-waste to Oulu and treated by Gasum Oy. It has AD plant for degrading the source separated bio-waste anaerobically under favourable conditions to produce biogas (as energy) and other by-products (digestate and liquid slurry). Except transportation distances costs and gate fees, there were no differences to the data and figures for the Puolanka municipality. This scenario looks costlier than status quo but definitely environmentally sustainable because of reduction of carbon emissions with the use of AD plants. This scenario is mostly favourable for people in Oulu because the feed-input in AD plant of Gasum Oy has increased, increasing the energy output of the biogas and therefore, benefitting from the energy transformation to heat and electricity for the welfare of the community in Oulu and adjoining cities as well as bio-fuel replacement reducing the use of non-renewable resources for vehicle transportation.

Scenario II was to build a new AD plant about 10 km distance from the center of Puolanka municipality and to use separately collected bio-waste as a feed-input. The physical parameters, technical data and economy were assessed and listed in the table 14. It is found that project is totally attainable, with only 3,22 years of payback period which means high turnover for the investors. The biogas energy output for a year is 1 44.8 MWh which is enough to replace 10,9 petrol-based cars and 15,4 diesel-based cars. The annual digestate sales is 1 556,3 € and per year district heating revenue at the unit price of 83,5 €/MWh is 13 694€. The project is beneficial also because it creates the job and business opportunities in Puolanka itself as well as likely to attract more tourists every year for its environmentally sound technologies.

The carbon footprint for all three scenarios were calculated and it was found that AD plants both in Oulu and Puolanka reduce the carbon emissions while ongoing composting phenomenon in Majasaari emits a lot of greenhouse gases per year.

The three options are then analysed based on sustainability in the following chapter with the main data and calculations from table (14).

8.8 Sustainability outcomes

Analysis are made with the 9 assessments indicators on Environment, Economic and Social Sustainabilities. The nine sustainability assessments indicators are listed below. The solutions are then marked positives and negatives from 2 to -2 (2,1,0,-1,-2) depending upon the responses the solution has on that criteria (appendix II).

Environmental Sustainability assessments

Indicator 1 – CO_2 reduction

Indicator 2 – Synergy Advantages

Indicator 3 – Land Use Implication

Indicator 4 – Impact on Environment

Economic Sustainability Assessment

Indicator 5 – Payback time

Social Sustainability Assessments

Indicator 6 – Impact on Citizen Health

Indicator 7 – Sustainable value teaching

Indicator 8 – Community Impact

Indicator 9 – Energy Security

Based on these indicators and their values for the three options, the data and radars are developed in the following chapter.

8.8.1. Status Quo

Upon using the templates for assessment analysis, the following data and graphs (fig. 20) were observed:

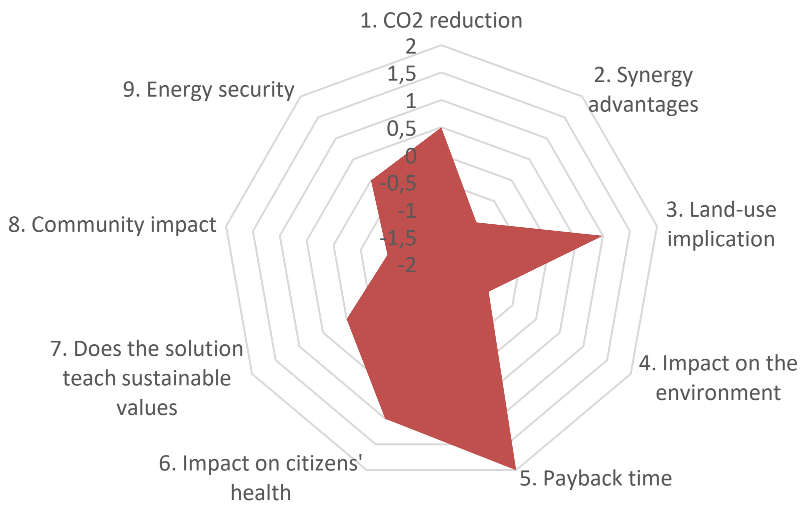

Figure 20: Sustainability assessment outcome in status quo

Table 15 in brief states that current practice is not the best solution for managing the bio-waste for Puolanka municipality. Impacts on the community and environment are visible though it doesn't pose risk on the health of the citizens.

Table 15: Status quo table for sustainability indicators

Dimensions	Advantages	Disadvantages
Environmental	Bio-waste are composted to produce composts (natural fertilisers)	
	Wastes are handled safely in a destined area, i.e. no impact due to land-use	
	Better solution to landfilling or incineration	
Economic		Wastes are transported and treated in another city, no local job opportunities
Social	Separate collection of bio-waste raising consciousness among the society	Less local participation of stakeholders since the waste is treated in another city
	No aesthetic harm to society and risks to human health	

Carbon footprint		Still notable high CO_2 emissions from composting and transportation of wastes No contribution in producing clean renewable energy

It isn't considered sustainable for long-term because the solution neither overcome CO_2 emissions issues nor provides clean renewable energy. Also, the wastes are transported to another city so no opportunities for flourishing local businesses are available.

8.8.2. Scenario I

The following data and graphs (fig. 21) were observed using the templates from the RECENT project for assessment analysis of Scenario I (appendix II):

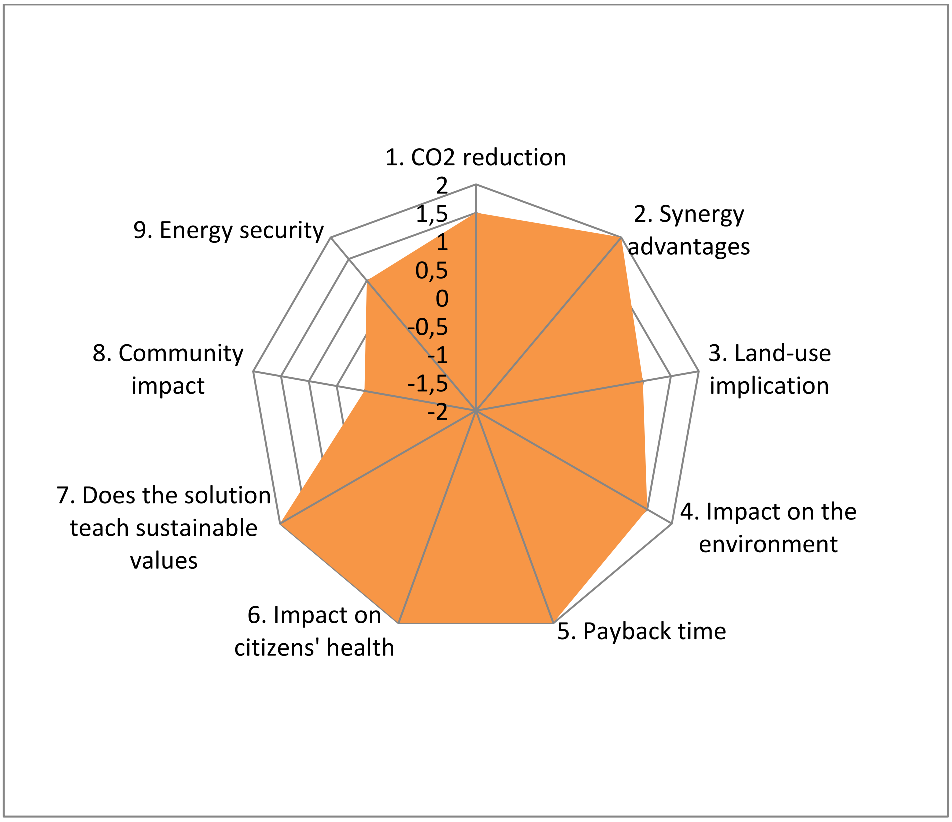

Figure 21: Sustainability assessment outcome in scenario I

Scenario I (Table 16) is one of the best solutions for the management of separately collected bio-waste in the municipality of Puolanka. Though the wastes need to be transported far-off, the wastes aids in production of clean renewable energy in the form of biogas. The biogas is further processed in the production of electricity and heat to the communities (in Oulu) and it replaces the use of petrol and diesels in the cars with the biofuels.

Table 16: Scenario I table for sustainability indicators

Dimension	Advantages	Disadvantages
Environmental	Replaces use of non-renewable sources such as wood, coal, fossil fuels for heat, electricity and vehicle fuels	
	No harm to biodiversity and land-use	
	Closing the nutrient cycle through use of AD by-product onto land	
Economic	Benefits from energy utilization and digestate revenue	Increase in gate fees for waste handling as well as transportation charges
Social	Community mobilization and knowledge sharing of separate collection of bio-wastes	
Carbon footprint	Reduction of CO_2 emissions due to AD conversion of wastes to clean renewable energy	Still additional carbon footprint because of transportation of wastes to a distant location

It is a sustainable solution, but it is comparatively costlier (higher gate fees and transportation costs) and neither provides job or business opportunities for the local people of Puolanka nor they're privileged with the clean energy produced.

8.8.3. Scenario II

The following data and graphs (fig. 22) were observed using the templates from the RECENT project for assessment analysis of Scenario II (appendix II):

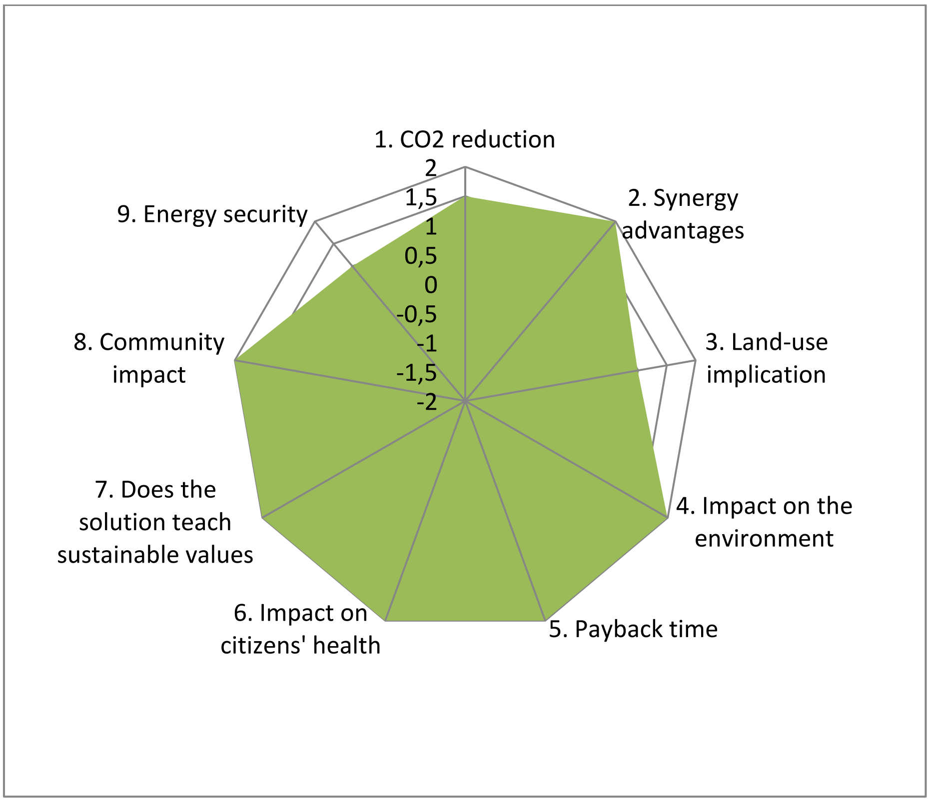

Figure 22: Sustainability assessment outcome in scenario II

Scenario II (Table 17) is the best solution for the separately collected bio-wastes in the Puolanka municipality in terms of sustainability because of various reasons:

- the solution offers job opportunities within the municipality
- the solution doesn't pose any harm or threat on society, environment and human health
- The payback time is within 3,22 years means the project's turnover will be high
- the solution is sustainable for long-term because it provides clean renewable energy in the form of biogas
- it replaces our dependence on fossil fuels for electricity, heating and car-fuels on a day-to-day basis

Table 17: Scenario II table for sustainability indicators

Dimension	Advantages	Disadvantages

Environmental	A waste to energy solution for the treatment of bio-waste through AD plant	
	Biogas is a clean renewable energy and further upgraded to produce heat, electricity and fuels to car	
	Closing the nutrient cycle by the use of AD by-products for the loss of nutrients in the soil	
Economic	Waste management within the municipality- no extra transportation costs	
	Enhances circular economy	
	Local opportunities for job and businesses	
Social	Waste sorting knowledge sharing within the community as well as communication and visits to the waste center	
	Use of locally available clean renewable energy	Limited feed input produces limited energy
Carbon footprint	Notable reduction in carbon emissions	

It is recommended to add other feed-inputs such as sewage sludge, agriculture by-products, bio-wastes from food industries, etc for increasing biogas energy output.

8.8.4. Comparative analysis of the sustainability outcomes

The sustainability of the three scenarios can be compared in radar (fig. 23).

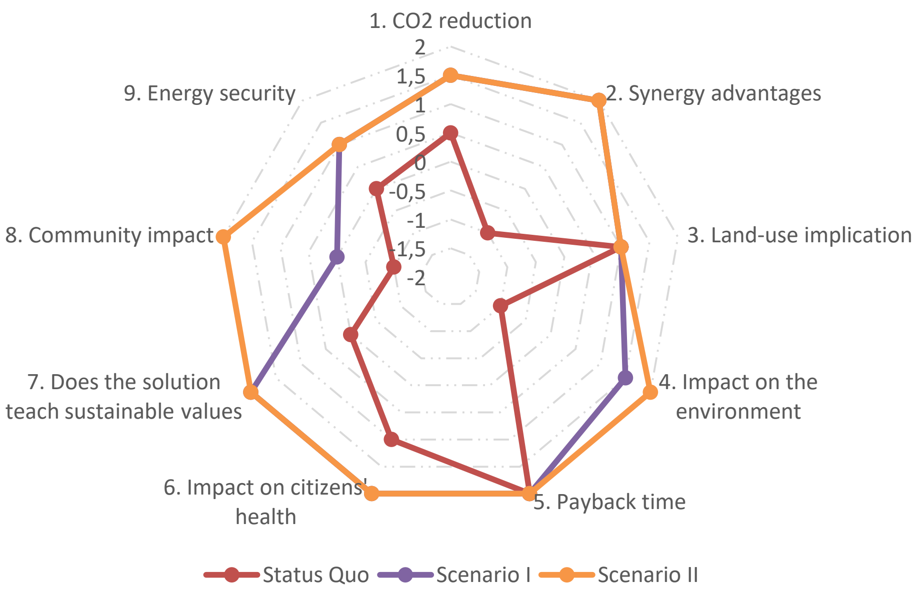

Figure 23: Sustainability assessment outcome in all three scenarios

It is now understood that the current practice of transportation of source separated bio-wastes from Puolanka to Majasaari composting centre, Kajaani is the least favourable scenario in terms of sustainability assessments based on nine sustainability measures: CO_2 reduction, synergy advantages, land-use application, impact on community, environment and human health, teaching sustainable values and energy security.

The heavy carbon emissions and no socio-economic returns in status quo made it worse in comparison to scenario I despite being economical option. The pay-back time for status quo and scenario I (Puolanka to Kiertokaari Oy, Oulu) is categorised as high (2 point) because the respective waste centres in Majasaari and Kiertokaari Oy are already existing and have been in operation from a long time and its investment returns cannot be considered for the case.

Scenario II (bio-waste treatment by AD plant built within the municipality) has an advantage over scenario I for an impact on environment and community since creating an own anaerobic digester provides community a privilege of 100% clean renewable energy (biogas) and its energy output to replace dependency on fossil fuel consumption, and district heating for the city area. Also have advantages of reduction in gate fee and transportation charges due to the distant waste centres and increase in job or business opportunities at local level.

It is more evident and clear that scenario II, the proposed anaerobic digester plant in the Puolanka is the best solution for the source separated bio-waste management in Puolanka municipality which helps in closing nutrient cycle (nutrient restoring with digestate and liquid by-product as fertiliser) on the soils as well as boosts in achieving circular economy for the people in Puolanka through circulation of the wastes as an input to deliver energy and products as long term economic benefits.

9. SUMMARY AND CONCLUSION

The theme of this thesis is to recognize wastes as a resource and recycle them into the system so as to get surplus energy and financial benefits leading to long-term sustainability. Also, it is based on the theory that states that bio-refinery process (conversion of organic compounds into bio-fuels) with bio-wastes is beneficial to environment and reduces greenhouse emissions (CH_4, CO_2). The thesis work is divided into two parts: theoretical and experimental part. The theory part has an in-depth study on extensive subjects and experimental part has a case study on Puolanka municipality in Kainuu region, the comparative sustainability analysis of present bio-waste management (Status quo) with two other optional scenarios.

Circular economy is the important chapter in the theory part with major highlights on Industrial ecology, Cradle to cradle economy and Low-carbon economy. Next, definitions for nutrient cycling and the importance of closing the nutrient cycle in the biosphere are presented. The major nutrients such as Nitrogen and Potassium and their cycles were closely studied along with the impacts due to natural and anthropogenic activities. In the following chapter, fertilisers were defined along compositions and examples. Also, the types of fertilisers: natural and chemical were defined and compared in terms of use and sustainability. It was summarised that natural fertilisers had a comparative advantage over chemical fertilisers.

A chapter on EU regulations and directives on wastes was also mentioned to understand the rules, guidelines and regulations EU countries are bound to follow in order to maintain quality of life. At last, theory part concluded with a detailed chapter on municipal waste management technologies. Composting and anaerobic digestion processes were thoroughly defined as well as compared. It was studied that even though both process turn bio-waste into a stable humus compound that can be used as fertiliser, anaerobic digestion technology had an upper hand over composting technology on the basis of its attribution towards reduction in greenhouse emissions (environmental benefits), production of biogas which is further upgraded to clean renewable energy (economic benefits and carbon sequestration) as well as digestate (by-product of biogas process) which closes the nutrient cycle by restoring the once used nutrients back to the soil.

For the experimental part started the Puolanka municipality (selected for the experimental study) was firstly introduced with a background information. The annual amount of source separated bio-waste was then calculated to be 165 478 kg with the total population (2 669) and annual average per-capita bio-waste production in that region (62). At present, the municipal waste is handled by Ekokymppi, the bio-waste is treated in Majasaari waste center in Kajaani (111 km from Puolanka) using composting technology (Status quo). Two other scenarios are given to understand better waste management option for future sustainability using the sustainability templates.

ii) Scenario I – bio-waste treatment in Gasum Oy in Oulu (125 km from Puolanka) for anaerobic digestion

iii) Scenario II – bio-waste treatment in the newly constructed AD plant within the municipality (10 km from the Puolanka center)

Using the data from sources, calculations using equations (both manual and online) and sustainability templates it was found that status quo is the worst option for managing bio-wastes. The composting mechanism in Majasaari waste management centre scored low in terms of long-term sustainability as it doesn't produce any non-renewable clean energy but in turn releases 3017,03 t of CO_2 every year, therefore making it the least preferred option among the three options. It was also observed that scenario I had an advantage over status quo despite expensive travelling cost because of the use of better technology (degradation of bio-waste using AD technologies), the bio-wastes were used as a resource that recovered into energy and fertiliser benefitting the community in Oulu region.

Scenario II was found out to be the best option for the management of bio-waste in the municipality, although scenario I had the same technology as Scenario II, it was more expensive in terms of transportation cost and served no socio-economic benefits to the community people in Puolanka. The annual methane produced was 16 547,8 m^3 with an energy output of 144,8 MWh per year that were considered to be used for district heating in the city centre area, also, it was assumed that the output energy is enough for replacing the annual fuel use of 15,4 diesel-driven cars and 10,9 petrol-driven cars.

Moreover, the digestate (by-product from AD plant) can be sold to the local farmers and can replace the use of chemical fertilisers sold in the market as it is already discussed that the natural fertilisers such as digestate has an advantage to chemical fertiliser for a long-term sustainability of the soil and the growth of plants. The per kg value of digestate was estimated to be 10,45 €/kg and annual income from digestate was calculated to be 1 556,3 €. This digestate is enriched with major and minor nutrients like

Nitrogen and Phosphorous, therefore its use on the soil ensures replenishment of the nutrients back to the soil for the nutrient loss during the growth of plants. Hence, it is understood that the nutrient cycle is closed, and the soil is no more nutrient deficit.

EU no longer accepts landfilling for organic waste and it is recognized to be the worst bio-waste treatment option. Landfilling of bio-wastes produces methane gas which is 3 000 times harmful greenhouse emissions than CO_2 gases. It also increases nutrient loading into soil and water sources through surface water run-off as well as leaching impacts on ground-water quality and damages aesthetic environment of the land-fill area. According to waste hierarchy, as the prevention comes first, the aim if that the product is firstly prevented from becoming a waste but some of bio-wastes are inevitable also it cannot be reused either but can definitely be recovered in the form of useful product or energy (waste to energy) through composting and anaerobic digestion technologies. It is however, experimentally proved that AD mechanism is the best option for recovering bio-waste to both stable product and clean renewable energy. Meanwhile, the mixed waste (combustible wastes) too can be recovered to energy through incineration process.

The experimental part of the study was discussed and under writing process from early June 2018 and now on the verge of completion of this thesis, there has been recent development on the bio-waste management of Puolanka Municipality. Starting 1st of January 2019 (01.01.2019), the bio-wastes are transported to AD plant of Gasum Oy in Oulu. The governing bodies justified the changes stating that the Majasaari waste centre in Kajaani was no longer viable and it is closed because of its legally unsustainable issues as environmental permits were not continued (Appendix III). It can be taken as a mere coincidence that the Scenario I (bio-waste transport to Oulu) discussed in this study occurred already in reality. It can be taken as a strength of the study that the scenarios were coincided with the realism. The governing bodies and authorities have well-realised that Majasaari composting center wasn't the good option for treating bio-wastes.

It is now evident that the research is heading towards the right direction in achieving sustainability in terms of managing the bio-waste. But it is also studied that transportation of bio-wastes to Oulu though better with the use of technology (AD plant) isn't still good in-terms attaining the long-term sustainability because the people of Puolanka have no socio-economic benefits. Also, the gate fees to Kiertokaari Oy, Oulu have now more than doubled from 52,080 €/t to 140,12 €/t for the Ekokymppi customers (Ekokymppi, 2019a; Appendix III) as they cover the new, higher transportations costs from Puolanka to Oulu and customers in Puolanka are obliged to pay. The transportation route was anyway longer and this gate fee changes have mounted the price and have made the situation even more expensive.

At this moment, the governing bodies should also realise that the ongoing transportation of bio-waste for treatment in Oulu doesn't contribute for the economic and local development in the municipality of Puolanka. Therefore, it is recommended to have a detailed feasibility study of Puolangan Biokeskus in Puolanka for building its own biogas plant for bio-waste management at local level to assure sustainable future of the inhabitants.

To expand economic and energy output of the future AD plant in Puolanka, it is also recommended to have co-digester process i.e. add more substrates as feed-inputs such as agricultural by-products, bio-wastes from the food industries as well as business centers and sewage sludges. This would help in maximising bio-refineries and productivities from the AD plant for use within the municipality.

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11. APPENDICES

Appendix I Online biogas calculator (Biogas World, 2019)

Biogas Plant Specifications

- **Feedstocks**: 166 tons/year of Residential source sorted organic (SSO) - DRY (25%TS)
- **Digester Type**: Wet
- **Contaminants Level**: 5%
- **Biogas Usage**: CHP (combined heat and power)
- **Digestate Usage**: Compost
- **Total solids (TS)**: 25% TS (adjusted as per the digester type)

Results

- Biogas Production: **19 515 m³/yr or 2 m³/hour**
- Thermal energy production via the boiler: **356 GJ per year**
- Total Digestate: **134 tons/year**
- Contaminants to Landfill: **8 tons/year**
- Greenhouse Gas **(GHG) reduction will be around 36 tons CO_2 eq./yr for landfill diversion and 18 tons CO_2 eq./yr for renewable energy production**

Potential revenue per year

3 560$ from heat sales. (1USD$ = 0,872 €)

Plant cost estimation

The first estimation of the cost, +/- 30%, is 249 000$ for your Municipal Type System.

Appendix II Sustainability Assessment

Status Quo: Separately collected bio-waste from Puolanka municipality is transported to Kajaani to be treated in the Majasaari composting centre.

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Environmental Sustainability Assessment

The template below should be completed when a RECENT partner performs Environmental Assessment.

Background information of the pilot community	
Name of the community/settlement	Municipality of Puolanka
Country	Finland
Region	Puolanka
Population of the community	2669

Indicator 1 – CO2 Reduction				Total points:	-0,5
1.1 How does the pilot contribute to CO_2 reduction?	Increases CO_2 emissions		Neutral Effect	Decreases CO_2 emissions	
	Notably (-1p)	Little (-0,5p)	0p	Little (0,5p)	Notably (1p)
	Bio-waste is transported to Majasaari waste management centre and composted, both contributes in increasing the CO_2 emissions.				
1.2. Does the chosen energy technology(ies) replace fossil fuel- based energy production?	No (0p)			Yes (0,5p)	
	No, it doesn't.				
1.3 Does the solution(s) utilize unused biomass, such as forest or agriculture biomass?	No (0p)			Yes (0,5p)	
	Separately collected bio-waste is utilized				

Indicator 2 – Synergy Advantages	Total points:	-1

2.1 Synergy advantages – How many of the following challenges does the pilot contributes to?	None (-2p)	One (-1p)	Two (0p)	Three (1p)	Four or more (2p)
	The solution considers only waste management.				

Indicator 3 – Land Use Implication					Total points:	1
Indicator 3 – Land use implication collects information on how much the pilot solution occupies land area and on how does it affect its surroundings. How valuable is the occupied land area and is there multiple possibilities to use the area of land?						
3.1 Does the land area occupied by the pilot solution have significance, cultural value or other importance?	No (1p)		Yes (-1p)			
	It has been in use for waste management.					
3.2 Estimate the impact of the pilot solution on the land area occupied	High Negative -1	Negative -0,5	Neutral 0p	Positive 0,5p	High Positive 1p	
	No changes because the land is already separated for waste management.					

Indicator 4 – Impact on Environment					Total points:	-1
4.1 Pilot's effect on air quality?	High Negative Effect -1p	Negative effect -0,5p	Neutral Effect 0p	Positive effect 0,5p	High Positive effect 1p	
	Composting impacts on the quality of ambient air. **High Positive effect** = Produces high amount of energy without harming air quality **Positive effect** = Produces notable amount of energy without harming air quality **Neutral effect** = Produces energy and does not cause significant harm to air quality **Negative effect** = Decreases air quality **High Negative effect** = Decreases air quality significantly					
4.2 Does the solution decrease the quality of water and soil or does it have negative impact on biodiversity?	High Negative Effect -1p	Negative effect -0,5p	Neutral Effect 0p	Positive effect 0,5p	High Positive effect 1p	
	Yes, composting can create leaching and impart toxic metals in the land and water sources but still better option than landfilling.					

Economic Sustainability Assessment

The template below should be completed when a RECENT partner performs economic Assessment.

Indicator 5 – Payback time					Total points: 2
Size of the investment and payback time are central factors to be considered in making an investment. Relatively small or easily affordable investments with positive environmental impact can considered positive even due to long payback. Therefore, answer this indicator as follows: If the investment is relatively large with long payback time answer 5.1 If the investment is relatively small with long payback time answer 5.2					
5.1 How long is the Payback time of the pilot investment?	+25 years -2p	25-17 years -1p	17-12 years 0p	12-5 years 1	<5 Years 2p
	N/A				
5.2 How long is the Payback time of the pilot investment?	+25 years 0p	25-17 years 0p	17-12 years 0p	12-5 years 1	<5 Years 2p
	The project is already in operation so, there is no investments made and payback time cannot be calculated.				

Social Sustainability Assessment

The template below should be completed when a RECENT partner performs social Assessment.

Indicator 6 – Impact on Citizen Health	Total points: 1
6.1 Positive impacts on Citizen Health	Yes = 0,5p, No = 0p 6.1.1 Solution is safe (does not pose danger or risks) to inhabitants nearby? Yes 6.1.2 Solution ensures clean and healthy habitat for living? Yes 6.1.3 Solution offers sustainable water treatment or waste management possibilities? Yes 6.1.4 Does the solution enable citizen with safe, clean, renewable and reliable energy? No

6.2 Negative Impacts on Citizen Health	Yes = -0,5p, No = 0p 6.2.1 Does the solution emit noxious gasses in harmful quantities? Yes 6.2.2 Does the solution release toxic compounds in harmful quantities? No 6.2.3 Does the solution cause a significant risk of injury? No 6.2.4 Does the solution cause significant noise or aesthetic harm? No

Indicator 7 – Does the solution support teaching sustainable values?		Total points:	0
7.1 Does pilot include implementation of clean or renewable energy technologies?	No -0,5p	Yes 0,5p	
	No		
7.2 Does the pilot promote the energy efficiency?	No -0,5p	Yes 0,5p	
	No		
7.3 Does the pilot promote participation of stakeholders?	No -0,5p	Yes 0,5p	
	Pilot activates the residents of Puolanka to sort bio-waste.		
7.4 Is the solution visible? (Can the implementation of the solution be noticed, such as solar panels on rooftop etc.)	No -0,5p	Yes 0,5p	
	The bio-waste bins are visible and well distributed along the Municipality of Puolanka.		

Indicator 8 – Community Impact		Total points:	-1
	No = -0,5p	Yes = 0,5p	

8.1 Does the solution support social cohesion and interaction?	Source Sorting and Collection of bio-wastes are good for the community.	
8.2 Does the solution(s) improve the community's adaptation to climate change?	No= -0,5p	Yes = 0,5p
	No, the solution doesn't contribute in producing renewable energy.	
8.3 Does the Pilot improve local job creation and local business?	No = -1p	Yes = 1p
	No	

Indicator 9 – Energy Security	Total points:	0
9.1 To what degree does the solution contribute to energy needs of the community?	0-50% -0,5p	51-100% 0,5p
	Not at all.	
9.2 How many months per year the solution functions due to seasonal variance?	Less than 6 months / year = -0,5p	More than 6 month / year = 0,5p
	Solution function throughout the year	
9.3 Is the solution prone to intermittency issues?	No 0,5p	Yes -0,5p
	The feed of bio waste is expected to be constant	
9.4 Does the pilot offer energy storing capacity?	No -0,5p	Yes 0,5p
	No	

Sustainability Assessment

The template below should be completed when a RECENT partner performs Social, Economic and Environmental Sustainability Assessments.

Sustainability Assessment template includes the instructions on how to perform the final stage of Sustainability Assessment. Please read through the instructions provided below and fill the Radar Diagram as instructed and answer the questions on the final page.

Instructions for filling the Sustainability Radar

1. Rate the performance of each of the nine indicators by comparing the total number of points to the impact / performance scale provided below.
2. Fill the Sustainability Radar Diagram on the 2nd page with the performance color of each indicator
3. On third page, fill the Sustainability diagram in the provided excel file and copy it here
4. Answer the questions to reflect on the current state and sustainability of the pilot

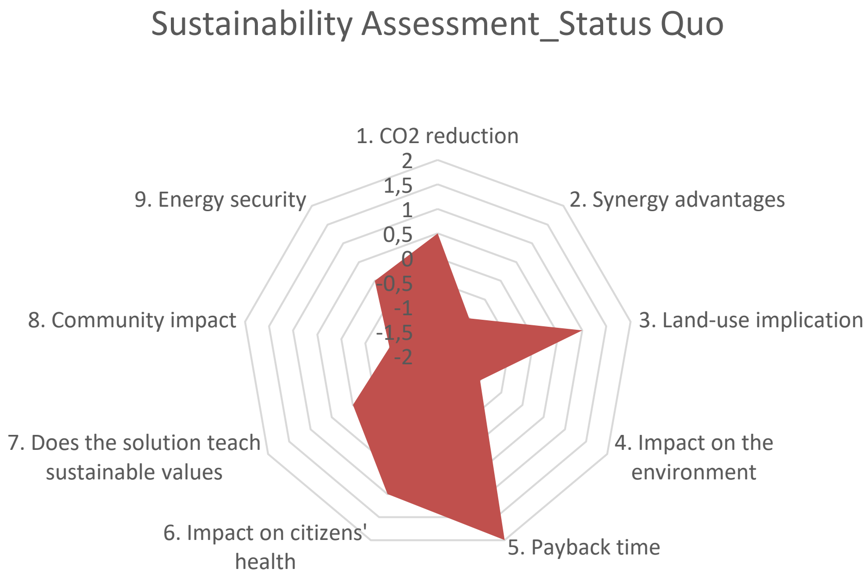
Impact / Performance	Points
High Positive	2
Positive	1
Neutral	0
Negative	-1
High Negative	-2

After filling in social, economic and environmental templates, transfer the values to the Sustainability Assessment Excel:

Dimension	**Indicator**	Points
Environmental	1. CO_2 reduction	-0,5
	2. Synergy advantages	-1
	3. Land-use implication	1
	4. Impact on environment	-1
Economic	5. Payback time	2
Social	6. Impact on citizen's health	1
	7. Does the solution teach sustainable values	0

	8. Community impact	-1
	9. Energy security	0

The values will be illustarted in the radar diagram seen below.



Finally, fill in the following summary on the pilot's the long-term sustainability assessment below:

2. Long-term sustainability assessment
2.1 Please describe the outcome of the sustainability assessment and consider sustainability long-term
Not the best solution for managing the bio-wastes for Puolanka Municipality. Impacts on the community and environment are visible though it doesn't pose risk on the health of the citizens'. It isn't considered sustainable for long-term because the solution neither overcome CO_2 emissions issues nor provides clean renewable energy. Also, the wastes are transported to another city so, no opportunities for flourishing local business are available.
2.2 Please specify points of success and strengths of the pilot

- bio-waste is separately collected and composted to produce composts (natural fertilizers)
- the composting mechanism is processed in an area designed for waste management which means no impact to its surroundings in terms of land use
- The impacts on citizen's health is quite positive
- Better solution to landfilling or incineration
- Knowledge sharing within the community for separate collection of bio-waste

2.3 Please specify weaknesses and points of improvement

- Notable CO_2 emissions with composting and transportation of wastes to the composting area
- Only solves in waste management issues and no contribution for clean renewable energy production, greenhouse gas emissions reduction and lessening the burden of fossil fuels use in transportation
- No opportunities for local employment

Scenario I: Separately collected bio-waste is transported to Oulu from Puolanka municipality to be treated in existing biogas plant (Gasum Oy).

Environmental Sustainability Assessment

Indicator 1 – CO2 Reduction					Total points:	1,5
1.1 How does the pilot contribute to CO_2 reduction?	Increases CO_2 emissions		Neutral Effect	Decreases CO_2 emissions		
	Notably (-1p)	Little (-0,5p)	0p	Little (0,5p)	Notably (1p)	
	Yes, AD plant reduces CO_2 emissions.					
1.2. Does the chosen energy technology(ies) replace fossil fuel-based energy production?	No (0p)			Yes (0,5p)		
	Yes, the bio-fuels are used for vehicles. Also, generation of electricity and production of heat for district heating.					
1.3 Does the solution(s) utilize unused biomass, such as forest or agriculture biomass?	No (0p)			Yes (0,5p)		
	Separately collected bio-waste is utilized to produce biogas					

Indicator 2 – Synergy Advantages					Total points: 2
2.1 Synergy advantages – How many of the following challenges does the pilot contributes to?	None (-2p)	One (-1p)	Two (0p)	Three (1p)	Four or more (2p)
	The solution considers all of the following: Waste, Energy, Climate Change and Transportation				

Indicator 3 – Land Use Implication					Total points: 1
Indicator 3 – Land use implication collects information on how much the pilot solution occupies land area and on how does it affect its surroundings. How valuable is the occupied land area and is there multiple possibilities to use the area of land?					
3.1 Does the land area occupied by the pilot solution have significance, cultural value or other importance?	No (1p)			Yes (-1p)	
	No, the pilot is already designed for waste management.				
3.2 Estimate the impact of the pilot solution on the land area occupied	High Negative -1	Negative -0,5	Neutral 0p	Positive 0,5p	High Positive 1p
	No impacts since the anaerobic digestion plant is already built in that area.				

Indicator 4 – Impact on Environment				Total points:	1,5
4.1 Pilot's effect on air quality?	High Negative Effect -1p	Negative effect -0,5p	Neutral Effect 0p	Positive effect 0,5p	High Positive effect 1p
	Solution aids in producing energy through bio-fuels, electricity generation and district heating and has negative greenhouse gas emissions release. **High Positive effect** = Produces high amount of energy without harming air quality **Positive effect** = Produces notable amount of energy without harming air quality **Neutral effect** = Produces energy and does not cause significant harm to air quality **Negative effect** = Decreases air quality **High Negative effect** = Decreases air quality significantly				
4.2 Does the solution decrease the quality of water and soil or does it have negative impact on biodiversity?	High Negative Effect -1p	Negative effect -0,5p	Neutral Effect 0p	Positive effect 0,5p	High Positive effect 1p
	AD aids use of digestate in closing the nutrient cycle and reduces leaching and eutrophication. The solution does not cause harm to biodiversity except transportation emissions.				

Economic Sustainability Assessment

Indicator 5 – Payback time				Total points:	2
Size of the investment and payback time are central factors to be considered in making an investment. Relatively small or easily affordable investments with positive environmental impact can considered positive even due to long payback. Therefore, answer this indicator as follows: If the investment is relatively large with long payback time answer 5.1 If the investment is relatively small with long payback time answer 5.2					
5.1 How long is the Payback time of the pilot investment?	+25 years -2p	25-17 years -1p	17-12 years 0p	12-5 years 1	<5 Years 2p
5.2 How long is the Payback time of the pilot investment?	+25 years 0p	25-17 years 0p	17-12 years 0p	12-5 years 1	<5 Years 2p

	The project is already in operation so, there is no investments made and payback time cannot be calculated.

Social Sustainability Assessment

Indicator 6 – Impact on Citizen Health	Total points: 2
6.1 Positive impacts on Citizen Health	Yes = 0,5p, No = 0p 6.1.1 Solution is safe (does not pose danger or risks) to inhabitants nearby? Yes 6.1.2 Solution ensures clean and healthy habitat for living? Yes 6.1.3 Solution offers sustainable water treatment or waste management possibilities? Yes 6.1.4 Does the solution enable citizen with safe, clean, renewable and reliable energy? Yes
6.2 Negative Impacts on Citizen Health	Yes = -0,5p, No = 0p 6.2.1 Does the solution emit noxious gasses in harmful quantities? No 6.2.2 Does the solution release toxic compounds in harmful quantities? No 6.2.3 Does the solution cause a significant risk of injury? No 6.2.4 Does the solution cause significant noise or aesthetic harm? No

Indicator 7 – Does the solution support teaching sustainable values?		Total points: 2
7.1 Does pilot include implementation of clean or renewable energy technologies?	No -0,5p	Yes 0,5p
	Yes, anaerobic digester uses bio waste which can be considered as renewable sources of energy.	
7.2 Does the pilot promote the energy efficiency?	No -0,5p	Yes 0,5p
	The solution aims for energy efficiency both in production of biogas for biofuel, electricity generation and in the heat production.	
7.3 Does the pilot promote participation of	No	Yes

stakeholders?	-0,5p	0,5p
	Pilot activates the inhabitants of Puolanka to sort bio-waste.	
7.4 Is the solution visible? (Can the implementation of the solution be noticed, such as solar panels on rooftop etc.)	No -0,5p	Yes 0,5p
	The bio-waste bins are visible and well distributed along the Municipality of Puolanka. Also, the AD plant along with pumping station is visible at Kirtokaari Oy in Oulu.	

Indicator 8 – Community Impact		Total points: 0
8.1 Does the solution support social cohesion and interaction?	No = -0,5p	Yes = 0,5p
	Yes, source sorting and collection knowledge of bio-wastes and waste management are good for the community.	
8.2 Does the solution(s) improve the community's adaptation to climate change?	No= -0,5p	Yes = 0,5p
	Yes, AD aids in reducing the CO_2 emissions.	
8.3 Does the Pilot improve local job creation and local business?	No = -1p	Yes = 1p
	No.	

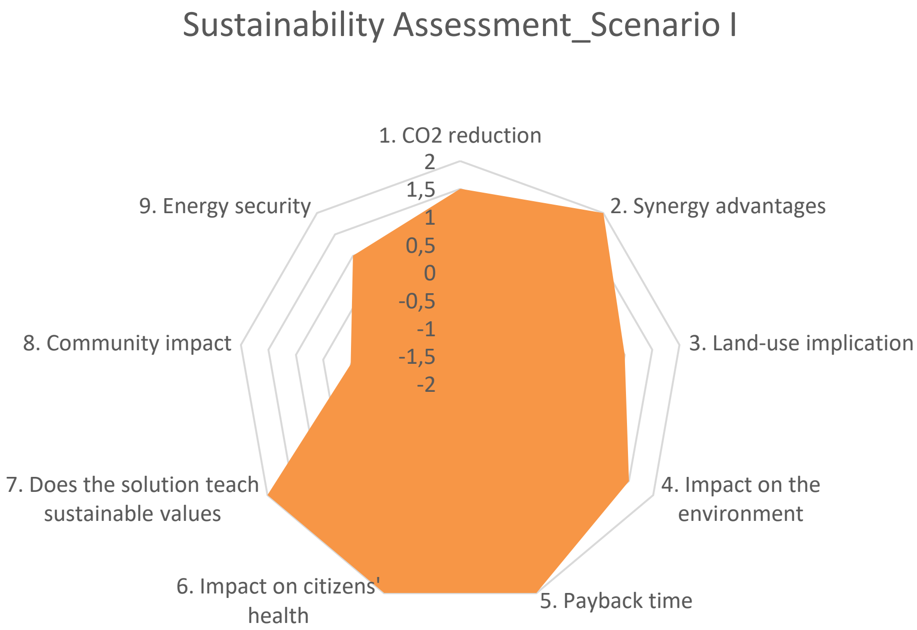
Indicator 9 – Energy Security		Total points: 1
9.1 To what degree does the solution contribute to energy needs of the community?	0-50% -0,5p	51-100% 0,5p
	Since the volume of bio-wastes from Puolanka is low, the contribution to energy needs is most probably less than 50% in Oulu. Also, it doesn't fulfil the energy need in Puolanka city.	
9.2 How many months per	Less than 6 months / year = -0,5p	More than 6 month / year = 0,5p

year the solution functions due to seasonal variance?	Solution function throughout the year	
9.3 Is the solution prone to intermittency issues?	No 0,5p	Yes -0,5p
	The feed of bio waste is expected to be constant	
9.4 Does the pilot offer energy storing capacity?	No -0,5p	Yes 0,5p
	Energy can be stored in the form of Biogas	

Sustainability Assessment Excel

Dimension	Indicator	Points
Environmental	1. CO_2 reduction	1,5
	2. Synergy advantages	2
	3. Land-use implication	1
	4. Impact on environment	1,5
Economic	5. Payback time	2
Social	6. Impact on citizen's health	2
	7. Does the solution teach sustainable values	2
	8. Community impact	0
	9. Energy security	1

The values will be illustarted in the radar diagram seen below.



Summary on the pilot's the long-term sustainability assessment:

2. Long-term sustainability assessment
2.1 Please describe the outcome of the sustainability assessment and consider sustainability long-term
This is one of the best solutions for the management of separately collected bio-waste in the Municipality of Puolanka. Though, the wastes need to be transported far-off, the wastes aids in production of clean renewable energy in the form of biogas. The biogas is further processed in the production of electricity and heat to the communities (in Oulu) and replace the use of petrol and diesels in the cars with the biofuels. It is definitely sustainable solution but it neither provides job or business opportunities for the local people of Puolanka nor they're privileged with the clean energy produced.
2.2 Please specify points of success and strengths of the pilot

• Community mobilization and knowledge sharing for collection of bio-wastes separately • Anaerobic digestion of separately collected wastes ensures waste to energy transformation, renewable energy production in the form of biogas which can further be used as biofuels as well as for heat and energy generation • Replacement of fossil fuel use for cars • Aids sustainability with reduction in the greenhouse gas emissions and development of clean renewable energy • No aesthetic harm to the society, biodiversity and no risks to human health • Closing the nutrient cycle through use of digestate and liquid fertilizer to the soil
2.3 Please specify weaknesses and points of improvement
• transportation of separately collected bio-wastes to a distant destination • no local job opportunities

Scenario II: Separately collected bio-waste from Puolanka municipality to be treated locally at Puolanka's bio-centre.

Environmental Sustainability Assessment

Indicator 1 – CO2 Reduction					Total points:	1,5
1.1 How does the pilot contribute to CO_2 reduction?	Increases CO_2 emissions		Neutral Effect	Decreases CO_2 emissions		
	Notably (-1p)	Little (-0,5p)	0p	Little (0,5p)	Notably (1p)	
	The AD plant aids in reducing the CO_2 emissions.					
1.2. Does the chosen energy technology(ies) replace fossil fuel-based energy production?	No (0p)			Yes (0,5p)		
	The pilot's calculated bio-methane energy potential is 144,8 MWh a year and accordingly could replace the gasoline need of 15,4 diesel-cars and 10,7 petrol-driven cars. Also, production of heat and electricity generation for the residents of Puolanka city.					
1.3 Does the solution(s) utilize unused biomass, such as forest or agriculture biomass?	No (0p)			Yes (0,5p)		
	Separately collected bio-waste is utilized to produce biogas					

Indicator 2 – Synergy Advantages					Total points:	2
2.1 Synergy advantages – How many of the following challenges does the pilot contributes to?	None (-2p)	One (-1p)	Two (0p)	Three (1p)	Four or more (2p)	
	The solution considers all of the following: Waste, Energy, Climate Change and Transportation					

Indicator 3 – Land Use Implication					Total points:	1
Indicator 3 – Land use implication collects information on how much the pilot solution occupies land area and on how does it affect its surroundings. How valuable is the occupied land area and is there multiple possibilities to use the area of land?						
3.1 Does the land area occupied by the pilot solution have significance, cultural value or other importance?	No (1p)		Yes (-1p)			
	The AD plant is planned to be built about 10 km away from the city of Puolanka, separated for industrial use (not near residential or holding significant or cultural importance).					
3.2 Estimate the impact of the pilot solution on the land area occupied	High Negative -1	Negative -0,5	Neutral 0p	Positive 0,5p	High Positive 1p	
	Though the AD plant is new, there won't be significant impact because the area will be separated for industrial use.					

Indicator 4 – Impact on Environment					Total points: 2
4.1 Pilot's effect on air quality?	High Negative Effect -1p	Negative effect -0,5p	Neutral Effect 0p	Positive effect 0,5p	High Positive effect 1p
	Solution replaces fossil fuels use in vehicles as well as aids in district heating and has negative greenhouse gas emissions release. **High Positive effect** = Produces high amount of energy without harming air quality **Positive effect** = Produces notable amount of energy without harming air quality **Neutral effect** = Produces energy and does not cause significant harm to air quality **Negative effect** = Decreases air quality **High Negative effect** = Decreases air quality significantly				
4.2 Does the solution decrease the quality of water and soil or does it have negative impact on biodiversity?	High Negative Effect -1p	Negative effect -0,5p	Neutral Effect 0p	Positive effect 0,5p	High Positive effect 1p
	AD aids use of digestate in closing the nutrient cycle and reduces leaching and eutrophication. The solution does not cause harm to biodiversity.				

Economic Sustainability Assessment

Indicator 5 – Payback time					Total points: 2
Size of the investment and payback time are central factors to be considered in making an investment. Relatively small or easily affordable investments with positive environmental impact can considered positive even due to long payback. Therefore, answer this indicator as follows: If the investment is relatively large with long payback time answer 5.1 If the investment is relatively small with long payback time answer 5.2					
5.1 How long is the Payback time of the pilot investment?	+25 years -2p	25-17 years -1p	17-12 years 0p	12-5 years 1	<5 Years 2p

5.2 How long is the Payback time of the pilot investment?	+25 years 0p	25-17 years 0p	17-12 years 0p	12-5 years 1	<5 Years 2p
	$PP = \frac{\text{Cost investment}}{(\text{Cost inflow/yr} - \text{Cost outflow/yr})}$ = 3,22 yrs Return of investment is dependent on the price of biogas and it is estimated to be 3,22 years.				

Social Sustainability Assessment

Indicator 6 – Impact on Citizen Health	Total points:	2
6.1 Positive impacts on Citizen Health	Yes = 0,5p, No = 0p 6.1.1 Solution is safe (does not pose danger or risks) to inhabitants nearby? Yes 6.1.2 Solution ensures clean and healthy habitat for living? Yes 6.1.3 Solution offers sustainable water treatment or waste management possibilities? Yes 6.1.4 Does the solution enable citizen with safe, clean, renewable and reliable energy? Yes	
6.2 Negative Impacts on Citizen Health	Yes = -0,5p, No = 0p 6.2.1 Does the solution emit noxious gasses in harmful quantities? No 6.2.2 Does the solution release toxic compounds in harmful quantities? No 6.2.3 Does the solution cause a significant risk of injury? No 6.2.4 Does the solution cause significant noise or aesthetic harm? No	

Indicator 7 – Does the solution support teaching sustainable values?		Total points:	2
7.1 Does pilot include implementation of clean or renewable energy technologies?	No -0,5p	Yes 0,5p	
	Anaerobic Digester uses bio waste which can be considered as renewable sources of energy.		
7.2 Does the pilot promote the energy efficiency?	No -0,5p	Yes 0,5p	

	The solution aims for energy efficiency both in production of biogas and in the use of heat production.	
7.3 Does the pilot promote participation of stakeholders?	No -0,5p	Yes 0,5p
	Pilot activates the inhabitants of Puolanka to sort bio-waste. Participation of decision makers and stakeholders take place too.	
7.4 Is the solution visible? (Can the implementation of the solution be noticed, such as solar panels on rooftop etc.)	No -0,5p	Yes 0,5p
	AD plant is visible and possible to make visits to, also the bio-waste bins are visible and well distributed along the Municipality of Puolanka. The connection of heat generated to district heating system is also easily visible.	

Indicator 8 – Community Impact		Total points: 2
8.1 Does the solution support social cohesion and interaction?	No = -0,5p	Yes = 0,5p
	If solution is implemented it requires active participation of stakeholders and therefore importance of actively communicating of the bio-waste related issues to stakeholders would enhance and support interaction.	
8.2 Does the solution(s) improve the community's adaptation to climate change?	No= -0,5p	Yes = 0,5p
	It offers solution to use the waste as a resource and reduce emissions caused by transportation of wastes and composting mechanism too.	
8.3 Does the Pilot improve local job creation and local business?	No = -1p	Yes = 1p
	More local job opportunities with the establishment of AD and production of digestate for agro-economy.	

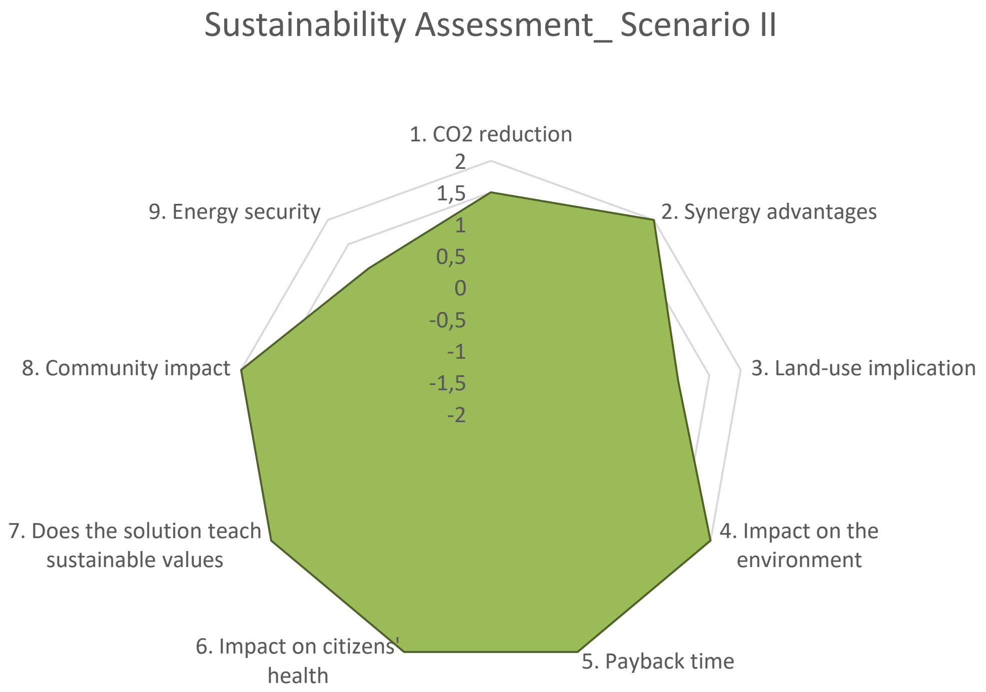
Indicator 9 – Energy Security		Total points: 1
9.1 To what degree does	0-50% -0,5p	51-100% 0,5p

the solution contribute to energy needs of the community?	Biogas is sufficient approximately for the need of 10-15 cars annually and the annual heat energy generated is 144,8 MWh, which is not too much on community scale.	
9.2 How many months per year the solution functions due to seasonal variance?	Less than 6 months / year = -0,5p	More than 6 month / year = 0,5p
	Solution function throughout the year	
9.3 Is the solution prone to intermittency issues?	No 0,5p	Yes -0,5p
	The feed of bio waste is expected to be constant	
9.4 Does the pilot offer energy storing capacity?	No -0,5p	Yes 0,5p
	Energy can be stored in the form of Biogas	

After filling in Environmental, Economic and Social templates, transfer the values to the Sustainability Assessment Excel:

Dimension	Indicator	Points
Environmental	1. CO_2 reduction	1,5
	2. Synergy advantages	2
	3. Land-use implication	1
	4. Impact on environment	2
Economic	5. Payback time	2
Social	6. Impact on citizen's health	2
	7. Does the solution teach sustainable values	2
	8. Community impact	2
	9. Energy security	1

The values will be illustarted in the radar diagram seen below.



Finally, summary on the pilot's the long-term sustainability assessment below:

2. Long-term sustainability assessment
2.1 Please describe the outcome of the sustainability assessment and consider sustainability long-term
This is the best solution for the separately collected bio-wastes in the Puolanka Municipality in terms of sustainability because of various reasons: • the solution offers job opportunities within the Municipality • the solution doesn't pose any harm or threat on society, environment and human health • The payback time is within 3,22 years means the project's turnover will be high • the solution is sustainable for long-term because it provides clean renewable energy in the form of biogas • it replaces our dependence on fossil fuels for electricity, heating and car-fuels on a day-to-day basis.
2.2 Please specify points of success and strengths of the pilot

- Clean technology is developed within the Municipality, no need of waste transport to distant waste management centers
- Community mobilization through waste management knowledge sharing and probably visits to the waste management center
- Anaerobic digestion in the waste management center ensures waste to energy transformation, renewable energy production in the form of biogas which can further be used as biofuels as well as for heat and energy generation
- Replacement of petrol and diesel use for cars
- Aids sustainability with notable reduction in the greenhouse gas emissions and development of clean renewable energy
- Closing the nutrient cycle through use of digestate and liquid fertilizer to the soil
- Local employment and business opportunities
- Boosts circular economy

2.3 Please specify weaknesses and points of improvement

- The energy potential is low as the feed input is limited to source-separated bio-wastes, more inputs such as sewage sludges, industrial food wastes and agriculture wastes are suggested to be use for increasing the energy output further

Appendix III: News and Change in gate fees

Biowaste from the Ekokymppi region to the biogas plant in Oulu (translated to English) (Ekokymppi, 2019b)

01/25/2019

The biowaste collected from the municipalities in the Ekokymppi area has been transported to the biogas plant in Oulu since the beginning of the year. The plant deals with sewage sludge, food industry by-products and source-separated and packaged municipal bio-wastes for which the plant has its own treatment plant (Gasum Oy). The biogas from the plant is sold to the local gas network of the waste management company in the area and the hygienic residue is used in agriculture as a fertilizer. The Oulu biogas plant will also open its own pumping station this year.

Change in Gate fees

Municipal bio-waste (code 90302) price per ton 140,12 € published on 30.11.2018 (fig 24).

Yhtymähallitus 9.11.2018 § 21 Yhtymäkokous 30.11.2018 § 5

Jätteenkäsittelyhinnasto 2019
Kainuun jätehuollon kuntayhtymä
Koodit viitteellisiä

Tuotenumero	Tuotenimi	yks	Hinta alv 0%	Hinta alv 24 %
90102	Sekajäte energiaksi	tn	149,03 €	184,80 €
90103	Sekajäte energiaksi, säkkimaksu 200L	kpl	6,39 €	7,92 €
90302	Biojäte	tn	113,00 €	140,12 €
90303	Biojäte, kaupan erillispakattu	tn	113,00 €	140,12 €
90304	Biojäte, lietemäinen	tn	120,00 €	148,80 €
90305	Biojäte, EU-alueen ulkopuolelta	tn	120,00 €	148,80 €
90401	Asbesti	tn	158,87 €	197,00 €
90404	Öljynerotuskaivon liete (altaaseen)	tn	135,85 €	168,45 €
90405	Öljyiset sakat, säiliön puhdistusjäte	kg	0,14 €	0,17 €
90406	Öljy- / liuotinerotinjäte, säiliöön	kg	0,24 €	0,30 €
90407	Öljyjäte, emulsiot alle 100L	kpl	17,66 €	21,90 €
90408	Öljyjäte, emulsiot yli 100L	kg	0,23 €	0,29 €
90409	Öljypitoinen vesi, lievästi öljyä	tn	6,00 €	7,44 €
90410	Painekyllästetty puu	tn	150,00 €	186,00 €
90412	Liete, maalia sisältävät vesipitoiset	tn	158,87 €	197,00 €
90413	Öljyjäte, kiinteä, pastat, vaseliinit	kg	0,57 €	0,71 €
90414	Elohopea	kg	28,50 €	35,34 €
90415	Emäkset	kg	1,50 €	1,86 €
90416	Filmijäte	kg	1,50 €	1,86 €
90417	Freonit	kg	6,00 €	7,44 €
90418	Halonit	kg	6,00 €	7,44 €

Figure 24: Gate fee prices for Kainuu region (Ekokymppi, 2019a)