Master's Thesis

Use and perception of biosolids through a literature review and a case study in Ndola, Zambia

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Even though sewage is seen as the most unpleasant of wastes and stigmatized in many cultures, finding ways to utilise this waste can create incentives to improve sanitation systems and therefore provide positive impacts not only to the environment but also human health and wellbeing. The amount of sewage sludge produced is increasing with population growth, urbanisation in the developing world and increasingly stringent wastewater treatment standards, therefore increasing the pressure to find sustainable solutions to its end use. Agricultural use of sewage sludge, i.e. biosolids, is a common practise but is not free from risks as sewage sludge can contain a variety of pollutants and face public opposition. The attitudes towards biosolids were studied through a literature review and a case study among farmers in Ndola, Zambia through structured interviews. The reasons for stakeholders to accept the use of biosolids were related to their benefits: it is an affordable local fertilizer containing organic matter that provides an option for the end use of sludge and promotes nutrient recycling. Reasons for unacceptance of biosolids are more diverse and vary between the developed and developing countries. In the case study, the interviewees were receptive of biosolids use and identified benefits of using an organic fertilizer but referred to practical problems related to its application. Risk related to biosolids use were largely not identified suggesting that in addition to addressing practical issues, there is a need for education, clear regulations, and certifications if biosolids use is to be implemented safely and sustainably in the area.

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Jätevesilietteen hyödyntäminen voi vaikuttaa positiivisesti ympäristön lisäksi ihmisten terveyteen ja hyvinvointiin kannustamalla kestävän sanitaation kehittämiseen. Tämä on yhä tärkeämpää, sillä lietteen määrä on kasvamassa väestönkasvun, etenkin kehitysmaissa tapahtuvan kaupungistumisen ja tiukentuvien jäteveden puhdistustavoitteiden myötä. Lietteen käyttö lannoitevalmisteena on yleistä, mutta käytännössä on riskinsä eikä se ole aina yleisesti hyväksyttyä. Tässä tutkimuksessa asenteita lietteen lannoitekäyttöä kohtaan tutkittiin kirjallisuuskatsauksen ja tapaustutkimuksen avulla. Tapaustutkimuksessa haastateltiin maanviljelijöitä Ndolassa, Sambiassa. Kirjallisuuskatsauksesta ilmeneviä syitä lietteen lannoitekäyttöön olivat lannoitteen edullisuus, sen sisältämä eloperäinen aines, ravinteiden kierrätys ja lietteen hyötykäyttö. Negatiiviset asenteet lietteen lannoitekäyttöä kohtaan vaihtelivat eri sidosryhmien sekä kehittyvien ja kehittyneiden maiden välillä. Tapaustutkimuksessa haastatellut maanviljelijät suhtautuivat positiivisesti lietteen lannoitekäyttöön. Haastatellut pitivät eloperäisiä lannoitteita hyödyllisinä maaperälle ja kasveille, mutta pitivät kemiallisia lannoitteita käytännöllisempinä. Lietteen lannoitekäytön riskit eivät tulleet usein esille haastatteluissa. Jotta lietteen lannoitekäyttö voitaisiin toteuttaa kestävästi, alueella tarvitaan vankkaa lainsäädäntöä, koulutusta riskeistä ja lannoitekäyttöön päätyvän lietteen sertifiointia.

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1 INTRODUCTION

1.1 Overview to the sanitation issue

According to a report by Boarini et al. (2014), the ultimate goals of development are to improve current and future wellbeing, that is the satisfaction of objective needs and the quality of life people experience – not solely the increase of gross domestic product (GDP). Wellbeing within countries in different stages of development can be measured with similar dimensions such as income or consumption possibilities, jobs and work, education and skills, health, social connections, housing, and environment (Boarini et al. 2014). However, the issues within these dimensions differ greatly between developed and developing countries. An example of this is the housing and infrastructure dimension. In wealthier countries the basic features of adequate shelter and working infrastructure can be taken for granted and the issues of housing are more related to its location and connectedness to work place and services. This is not the case in developing countries where the existence of adequate housing and its related infrastructure are a particularly critical consideration in people's assessment of their wellbeing (Boarini et al. 2014). One of the important parts of infrastructure is supply of clean water and sanitation.

Whilst sanitation concerns every human being it can often be ignored, or even stigmatised, being a matter one doesn't necessarily want to think about or discuss. That said, people everywhere, regardless of their background or country of origin, need to have systems in place to mitigate the risks associated with sanitation waste on human health and the environment. The importance of adequate sanitation systems has been recognised more and more over recent decades bringing it from a neglected issue to the forefront. The United Nations (UN) declared 2008 as the international year of sanitation, in 2010 water and sanitation were declared a human right by the UN and in 2015 sanitation was declared a human right as a standalone issue (UN 2015). Safe sanitation is the foundation for a successful nation, providing health that can create wellbeing and prosperity. As estimated by an OECD report (2011), tackling supply of clean water and sanitation can generate significant advancements in further dimensions of wellbeing such as health, the environment, and even work by improvements in certain economic sectors including fisheries, tourism, and property markets. Benefit-to-cost ratios for basic water and sanitation services in developing countries have been reported to be as high as seven to one (OECD 2011). Additionally, improving access to supply of clean water and sanitation can bring benefits that are difficult to quantify, such as dignity, social status, and cleanliness (OECD 2011).

Sanitation has been taken into consideration in various international agreements, including the Sustainable Development Goals (SDGs) formed by the UN (UN 2019). Successor to the Millennium Development Goals, these SDGs, which target up to the year 2030, define water and sanitation as one of the 17 main goals. Within the water and sanitation goal there are targets of gaining adequate and equitable sanitation for all, to end open defecation, halving the amount of untreated wastewater, and expanding support to developing countries in, among other things, wastewater treatment technologies. Due to its significance to human life, sanitation is also closely linked to other SDGs, such as health and wellbeing and ending poverty. According to the UN's report on progression towards the SDGs (2019), the proportion of the global population who have access to improved sanitation solutions has increased from 28% in 2000 to 47% in 2017. Even though 73% of the global population have access to at least basic sanitation systems, as of 2017, 701 million people still resort to open defecation (UN 2019). This highlights that although improvements have been made since the launch of SDGs in 2016, meeting the sanitation targets set for 2030 is, unfortunately, looking unlikely for most countries (UN 2019).

Achieving the targets is vital, as deficient sanitation solutions lead to serious problems. Children who do not have access to sanitation facilities are more likely to have problems with their development resulting in stunting (Cumming and

Cairncross 2016). Sanitation is a major factor in both mental and social wellbeing, causing anxiety and distress to those who do not have access to it (Hirve et al. 2015). A lack of adequate sanitation facilities is a factor in gender inequality, as without them girls struggle with accessing education during menstruation. This is not a minor matter, since, as of 2016, one third of the world's primary schools still lacked basic drinking water, sanitation, and hygiene services (UN 2019). Unhygienic sanitation practices can spread pathogenic bacteria, viruses or protozoa and parasitic worms. Sanitation related health problems often result in diarrhoea, which is a common cause of disease and death for children under five years old in low- and middle-income countries (LMICs) (Prüss-Üstün et al. 2016). Over half of diarrhoeal diseases (57 %) in the world are attributable to environmental causes, and could be prevented by improving water quality, sanitation, hygiene, and agricultural practices (Prüss-Üstün et al. 2014). In LMICs 19 % of all cases of diarrhoea are estimated to be attributable to inadequate sanitation, compared to 34 % for water quality and 20 % to hygiene (Prüss-Üstün et al. 2014). In 2012 alone, 280 000 deaths were caused by diarrhoea associated with inadequate sanitation in LMICs (Prüss-Üstün et al. 2014).

Different areas have their distinctive challenges in the path to adequate sanitation. Rural locations can lack the infrastructure needed for improved sanitation systems, while in urban areas, where sewage systems exist, there may be a lack of adequate wastewater treatment processes or a shortage of space for treating and disposing of by-products of the existing treatment processes. The problems are unique for each setting and therefore sanitation solutions need to be tailored to the local conditions. According to World Health Organisation (WHO) Guidelines for Sanitation and Health (2018) the first step in addressing the sanitation issue is to have systems that safely contain excreta to prevent the spread of vector-borne diseases i.e. diseases transmitted by animals. The second step is to create context specific systems where the whole sanitation chain is safe. Containment, emptying, conveyance, treatment, and end use/disposal all need to respond to the local physical, social, and institutional conditions.

Once the first steps are taken, it is important to find out how to use the unavoidable waste material. While the scarcity and degradation of fresh water resources and the increased need for irrigation due to climate change bring pressures to water supply (WHO 2006), the amount of wastewater is projected to increase, especially in developing countries (UN-HABITAT 2008). Wastewater is an unavoidable part of human settlements and the prevalence of it may lead to an increased use of wastewater for irrigation, particularly given the scarcity of fresh water supplies. For many farmers, wastewater is a reliable, and sometimes the only, source of irrigation the whole year round which makes it a common practice in some areas (WHO 2006). According to Qadir et al. (2020), current wastewater production could irrigate 31 million hectares (ha) without further dilution if none of the generated wastewater is lost. Irrigating even with untreated wastewater can decrease the pollution downstream compared to discharging directly into waterways, but there are hygienic and environmental risks involved (WHO 2006).

Aside from irrigation, wastewater is considered to have other potential benefits and as its quantity increases, so does the importance of harnessing this potential. Qadir et al. (2020) assessed in their study that 380 billion m^3 of sewage is produced annually and projected this figure to increase to 470 billion m^3 and 574 billion m^3 by 2030 and 2050 respectively. The study estimates that wastewater not only contains the energy needed for its treatment process, but in addition has the potential to produce heat and power to those cities that generated it. Energy embedded in 380 billion m^3 of wastewater could provide electricity to 158 million households, based on maximum theoretical levels of energy recovery (Qadir et al. 2020).

Even though sewage is seen as the most unpleasant of wastes and stigmatized in many cultures, finding ways to utilise this waste can create incentives to improve sanitation systems and therefore provide positive impacts not only to the environment but also human health and wellbeing (UN-HABITAT 2008). Incentives can help to meet the SDG targets. The safety risks of wastewater use can be managed by treating the wastewater with processes that yield sewage sludge as a by-product. While its disposal can be difficult, the sludge has potential to become an agricultural fertilizer that is recovered from sewage; a biosolid (UN-HABITAT 2008).

Using human waste in agriculture needs to be done intentionally and safely. There are multiple steps that can be taken, starting with treating the wastewater and sludge but also including crop restriction, waste application techniques, withholding periods to allow pathogen die-off and restricting public access (UN-HABITAT 2008). For vector-borne diseases reduced vector contact; disease, vector and intermediate host control; and personal protective equipment are important risk minimising factors (UN-HABITAT 2008).

1.2 Overview to sewage sludge

The production of sewage sludge is an unavoidable part of the wastewater treatment process. The processes generate sewage sludge as a by-product at the primary, secondary (biological), or tertiary treatment phases (Collivignarelli et al. 2019a), where the wastewater is skimmed from the top and the sludge forming heavier matter settles to the bottom. Dealing with the sludge is one of the main challenges in wastewater management along with the projected increase in wastewater volume, especially in developing countries (UN-HABITAT, 2008). As excreta and wastewater collection and treatment systems develop, there will be more and more waste water treated, resulting in more sludge to manage.

The management of sludge is particularly difficult, as the handling accounts for up to 50% of operating costs of waste water treatment, while the volume of the sludge amounts to only few percent of the processed wastewater (Spinosa et al. 2011). Traditionally the sludge may have been used directly as a fertilizer or a soil amendment, but this has been increasingly restricted (through stricter standards) or banned through legislation (Spinosa et al. 2011). Additional challenges in the management of sludge include the opposition to agricultural use by local stakeholders, reduction of available landfill area, and increasing disposal costs for off-site solutions according to Mininni et al. (2015). Other studies emphasize the same aspects; the large quantities of sludge produced prevent natural assimilation into the environment (Jimenez et al. 2010) and the decreased amount of available land for stockpiling (Jimenez et al. 2010, Tyagi and Lo 2011) have caused sludge management to become an issue only relatively recently. Landfilling may have been a good choice in the past to prevent health risks, but the challenges mentioned above mean that landfill costs are increasing (Tyagi and Lo 2011). The management of excess sludge is the most challenging task for the wastewater treatment sector (Tyagi and Lo 2011). Despite the challenges, sludge can be beneficial depending on the way its treated and then used. UN-HABITAT Global Atlas of Excreta, Wastewater Sludge and Biosolids Management (2008) defines sludge management systems into three main categories: landfilling, incineration, and land application.

According to the UN-HABITAT Atlas (2008), in many settings, landfilling has been the most affordable way of dealing with sewage sludge, and one that is favoured by the public because the waste is managed out of sight. Should the sewage disposal be unregulated, the dumping sites can have a negative impact to the environment and public health. This kind of disposal method might still be the cheapest in some developing countries, but modern landfills are neither cost effective nor convenient sites for disposal. In most countries, wastewater sludge needs to be dewatered before disposal to landfill and some regulations only allow landfilling sewage sludge when its properties are not valuable for energy or soil amendment use. In several European Union countries wastewater sludge disposal in landfills is legally banned, and in some developed countries its disposal is charged by weight. Decomposing sludge produces methane, which could theoretically be harvested as a fuel from landfills, however as the release of methane is a relatively quick process, it can be challenging to ensure that all of it is captured (UN-HABITAT 2008).

Incineration recovers the energy embedded in sewage sludge while significantly reducing the volume. The volume of the sludge is reduced by 90 % compared to dewatered sludge (Spinosa et al. 2011). The resulting ash is inert, free of pesticides, viruses, and pathogens, contains metals in less soluble oxide form, and has potential for phosphate recovery (Spinosa et al. 2011). The ash is usually landfilled but could be used as fill material in construction projects or as an ingredient in cement (UN-HABITAT 2008). Due to increasingly strict air pollution control standards, the infrastructure needed for incineration can be complex and costly. Incineration also requires fuel, for which usually fossil fuels are used (UN-HABITAT 2008). This method of sludge management can be very beneficial, especially in densely populated areas which are lacking sufficient farmland for land application. Incineration may become increasingly popular as the technology advances, and population density is increasing.

Unlike the relatively modern method of the incineration of sludge, land application has been used in parts of the world for centuries (Jimenez et al. 2010). Depending on the definition, land application can include agricultural use, compost production, silviculture, forestry, land reclamation and green areas (Collivignarelli et al. 2019b). Using sludge or biosolids on soils does not always seem favourable to the public due to the intrinsic human reaction of seeing excreta as something unhealthy, and therefore to be avoided. However, biosolids, the organic matter recovered from the waste water treatment process through processing the sludge, can significantly boost the soil's properties and provide nutrients. Markets reflect these properties. Around the globe biosolids are sold to farmers, horticulturists and landscapers, the revenues of which can partially offset the costs of wastewater treatment (UN-HABITAT 2008). Beyond the use as a fertilizer, biosolids can be used in land reclamation of contaminated sites or landfill closures, forestry, horticulture, and landscaping (UN-HABITAT 2008).

1.3 Aims of the study

Despite having its challenges, using sludge or biosolids as a fertilizer is still a relatively common practice both in developing and developed countries. It is considered as a cost-effective waste disposal method which recycles organic matter and nutrients while improving the soil quality (Lu et al. 2012) and could assist in meeting of SDG targets. Agricultural use can, however, face a major constraint in public perception. This study investigates biosolid use in agriculture and its acceptance among different stakeholders.

The study consists of two parts: a literature review and a small case study consisting of structural interviews. The purpose of the study was to find out

- what are the (real or perceived) pros and cons of biosolids use
- which factors affect their perception among stakeholders
- are there differences in the factors of acceptance between developed and developing countries
- what are local farmers' perceptions towards biosolids use in Ndola, Zambia

The two parts of this study; the literature review and the case study, are presented separately before drawing together the findings for discussion and conclusions.

2 LITERATURE REVIEW

2.1 Material and methods

The literature review was conducted using Scopus, Web of Science and Google scholar databases. Relevant publications were searched in the above databases by using the keyword search feature using the terms "*biosolid* AND public accept*", "*Sludge AND Agriculture AND Attitude**", and "*Sludge AND Agriculture AND risk*". Articles were selected for inclusion within this literature review if the abstract of a paper included reference to perception of agricultural use of biosolids, wastewater sludge or human derived fertilisers by any stakeholder or reference to the current or previous use of biosolids.

The search and selection criteria yielded 50 publications which were used as the base for the literature review. Of the publications, 21 were directly studying the perception of biosolids by a stakeholder group, while 29 were studying biosolids land application with a broader perspective than specifically the perception towards their use. The data used consisted of peer-reviewed international research articles, books, and UN publications. The selected article publication dates range from 1995 to 2021 and only publications in English were considered.

In the next sections the pros and cons of biosolids use will be reviewed as presented by the chosen literature base. The publications were also studied to examine biosolids use in developed and developing countries separately to highlight possible differences.

2.2 Advantages of biosolids use as fertilizer or soil amendment

Biosolids are produced from sewage sludge through one or more treatments. The treatments of sludge include anaerobic or aerobic digestion, composting, alkaline stabilisation, and thermal drying (Ozores-Hampton and Peach 2002, Lu et al. 2012) to yield biosolids in which the number of pathogens is greatly reduced or eliminated (Goodman and Goodman 2006). In addition to killing pathogens one objective of the treatment is to reduce odours (Ozores-Hampton and Peach 2002) and vector attraction to avoid the spread of any pathogens left in the biosolids (Lu et al. 2012). Compared to chemical fertilizers, the main advantages to using biosolids are the nutrient-content, their organic matter and associated impact on soil quality, the locality, availability, and affordability of the product. Biosolids can improve the soil's properties through better water holding capacity and by increasing microbial content.

An adult human being does not have a net intake of nutrients, and as such the nutrients ingested are largely excreted and present in the wastewater (Bracken et al. 2009). Sewage sludge therefore contains the common nutrients of nitrogen (N), phosphorus (P) and potassium (K) as well as several micro nutrients (such as copper, nickel, and zinc) that are important for plant growth (UN-HABITAT 2008). These nutrients can both be a valuable resource in agriculture as well as a threat to ecosystems – all depending on the management of the sludge (UN-HABITAT 2008). While nutrients are critical for plants and animals, excess nitrogen in drinking water can be a human health risk and stimulate undesirable growth in marine ecosystems and excess phosphorus can cause eutrophication in fresh waters (UN-HABITAT 2008).

Currently, nutrients can accumulate in cities where more wastewater is generated, while the countryside that provides the cities with their produce becomes nutrient poor (Bracken et al. 2009). This kind of linear and one-way flow of nutrients presents a clear threat to cities and societies; if the nutrients are not replaced in agriculture, the soils inevitably lose their productivity. The linear flow presents a problem for utilizing these nutrients, which is exacerbated by the distance between nutrient accumulation sites and agricultural sites, leading to significant transportation costs (Bracken et al. 2009, Chen et al. 2012, Peccia and Westerhoff 2015). According to Bracken et al. (2009) nutrients in human excreta are the biggest single wasted nutrient flow out of agriculture.

Turning this flow of nutrients from linear to circular would have great potential benefit to agriculture, at least in theory. Qadir et al. (2020) estimated in their study that the nutrients embedded in wastewater across the world annually could offset 13.4% of global demand for nitrogen, phosphorus, and potassium in agriculture. This could result in annual revenue generation of $13.5 billion globally and could help to reduce our dependency on chemical fertilizers, which are increasingly expensive. Chemical fertilizers increase food prices, which disproportionately affects the urban poor (Bracken et al. 2009). They also use fossil fuels in both their production and transportation (UN-HABITAT 2008) and are not free of contaminants (Moya et al. 2019b).

The production of chemical fertilizers is problematic. Nitrogen production uses abundant amounts of natural gas (UN-HABITAT 2008) and as fossil fuel prices rise along with the demand for fertilizers, so does the price of the fertilizer (Bracken et al. 2009). Phosphorus on the other hand cannot be produced chemically and is obtained through the mining phosphate rock, which is both environmentally challenging and short-sighted (Cordell et al. 2009). As a finite resource phosphate rock is not only bound to run out but mining also has adverse effects such as radioactive by-products, heavy metal pollutants and carbon emissions (Cordell et al. 2009). As the prices increase, low-income farmers may be priced out of chemical fertilizers thus causing nutrient depletion on arable land.

Unlike commercial fertilizers, biosolids contain organic matter combined with a larger diversity of nutrients (Jimenez et al. 2010). The amount of naturally present organic matter in human excreta and hence wastewater is further increased by the biological treatment of sewage. Organic matter is important to the health of soils. It improves soil's physical properties by increasing bulk density, porosity, stability of aggregates and water holding capacity (Saha et al. 2017). Biological processes are enhanced by increasing microbial biomass carbon and soil enzyme activities, which promote the recycling of nutrients for crops (Saha et al. 2017). Organic matter in biosolids also impacts soil's chemical properties by helping in the production of humic substances and several other organic acids and by increasing cation exchange capacity (Saha et al. 2017). The organic matter in biosolids makes the fertilizer theoretically superior to chemical fertilizers not only in terms of soil quality and plant growth but also environmental pollution; the nutrients in biosolids only become available for plants and susceptible to runoff or leaching once microbes break down the complex molecules in which the nutrients are held (UN-HABITAT 2008). Compared to chemical fertilizers, biosolids therefore present a lesser risk of environmental pollution from nutrients or nitrate leaching into groundwater and creating a human health risk (UN-HABITAT 2008).

According to UN-HABITAT Global Atlas of excreta, wastewater sludge and biosolids management (2008) various research projects have demonstrated the value of biosolids to soils. Two examples in this literature review were a study conducted by Moya et al. (2019a) and Cocârță et al. (2019). Moya et al. (2019a) compared three human derived fertilisers, digestate, compost and vermicompost, to chemical fertilisers in maize fields in Antananarivo, Madagascar. Human derived fertilisers gave comparable yields, demonstrating the potential for them as a substitute for inorganic fertilisers. The results may be impacted by manure application on soil in previous years, reducing the need of nutrient additions as well as heavy rainfall during the study that may have resulted in nutrient run off, and as such neutralising the results. However, the results show not only comparable yields, but that human excreta derived fertilizers did not have detrimental effect on maize. Cocârță et al. (2019) observed in their experimental study in Romania over a three-year period that wheat productivity was greater when using sewage sludge compared to inorganic fertilizers. However, they also measured increased cadmium and lead concentrations in the soil following sewage sludge application. Application of relatively high level of sewage sludge can also result in significant accumulation of nutrients and organic matter in the topsoil (Breda et al. 2020). Thus, although the nutrients and organic matter in biosolids bring many benefits, their application and doses must be carefully weighed against the risks.

2.3 Disadvantages of biosolids use as fertilizer or soil amendment

2.3.1 Practical complexity compared to inorganic fertilisers

Compared to chemical fertilizers, biosolids are a source of fertilizer that is locally available, affordable and would present a solution to increasing amounts of sewage sludge (UN-HABITAT 2008). However, as an end use option for sewage sludge, recycling to biosolids involves more stakeholders than other options, which provides challenges to their adoption. As described by UN-HABITAT Atlas (2008), there are several different steps in generating sludge from wastewater, as well as processing, transporting and then applying to land. For each of these steps to be done safely and avoid pathogen transfer, there is a requirement for education for all the people involved in each of the processes, as well as robust legislation and monitoring of compliance (UN-HABITAT 2008).

The chemical composition of sewage sludge and biosolids can vary greatly depending on the sources of wastewater and treatment processes (e.g. Cocârță et al. 2019, Gianico et al. 2021). As Ozores-Hampton and Peach (2002) mention in their study about biosolids in vegetable production systems, making recommendations on biosolids use can be difficult and complicated due to this variability. There are more factors to be taken into consideration compared to chemical fertilizers, such as the properties of the biosolid (success of pathogen removal, pollutants, nutrient content), properties of the soil it is used in, local regulations and management practices. Doses and rates need to be carefully considered to manage risk of pollutants (Chen et al. 2012). In terms of pathogens, the quality of the biosolid and the crop produced need to be considered (Ozores-Hampton and Peach 2002). For example, vegetable crops with short production cycles where the harvestable part would come in contact with the biosolid/soil mixture cannot feasibly utilize biosolids, not even the higher-grade products (Ozores-Hampton and Peach 2002). This is due to the long withholding period required before harvest is allowed to manage pathogen risk. Lesser grade of biosolids in turn can only be used if the harvestable part does not come into contact with the biosolid/soil mixture. With the lesser grade biosolids, plastic sheets can be used for vector attraction reduction (Ozores-Hampton and Peach 2002). Biosolids texture also affects the success of their application (Moya et al. 2019a). Liquid or sludge-like texture can be difficult to apply for small-scale farmers, but achieving a dry grainy texture takes significant further energy (Moya et al. 2019a). As such there are multiple factors to take into consideration with the use of biosolids in agriculture, with no one size fits all solution. This makes the application of biosolids more challenging from both a practical and regulatory perspective.

2.3.2 Pathogens

The transmission of pathogens is the biggest short-term danger to humans related to the agricultural use of sewage sludge according to UN-HABITAT Atlas (2008). The risk of transmission of pathogens through the use of wastewater and sludge is generally greater in developing countries compared to developed countries. Developed countries usually have adequate water and wastewater treatment and hygienic food handling systems in place, and as many waterborne diseases are less prevalent in developed nations the presence of pathogens in wastewater is less common (UN-HABITAT 2008).

The risks are not limited to farmers, agricultural workers, and their families; crop handlers, consumers and those living near the areas where sludge is used can also be affected (Jimenez, 2010). Additionally, animals and plants can be impacted by pathogens (UN-HABITAT 2008). It is therefore important that pathogens are reduced to acceptable levels of risk before using biosolids. However, as stated by Clarke et al. (2017) although substantial reduction of pathogens is possible, complete sterilisation of sewage sludge is difficult to attain and particularly enteric viruses may persist. In addition, there is the risk of emerging viruses such as Norovirus (Peccia and Westerhoff 2015). Mininni et al. (2015) state that only additional pasteurisation or multistage treatments would achieve enhanced treated sludge for microbial quality. The level of risk acceptable, although hard to quantify, and the extent of treatment needed depends heavily on the crop chosen. Acceptable level of pathogens for energy crop which is not meant for human consumption and those of fruits and vegetables that may have direct contact with the biosolid/soil mixture are very different.

Whilst achieving pathogen free biosolids is challenging, monitoring the levels of pathogens in biosolids is also difficult. It would be easy to suggest that the best way of assessing the performance of sludge treatment process would be to monitor the amount of pathogen reduction in the biosolid. As Mininni et al. (2015) explain this is difficult due to the large variety of pathogens, for some of which the detection process can be very complex. Often the number of pathogens in sludge is estimated by determining the amount of some known bacteria (such as clostridia or salmonella) as determining the amount of all different types of bacteria would be very time consuming and costly. These bacterial indicators have limitations when it comes to indicating the number or parasites or pathogenic viruses, which is why research is looking into somatic coliphages, the viruses that infect coliform bacteria, as a viral indicator (Mininni et al., 2015).

Another constraint related to the number of bacteria is their potential regrowth after treatment. Clarke et al. (2017) and Fane et al. (2020) stated that the regrowth phenomenon, where pathogen numbers increase after treatment, is a common issue. However, according to a review study conducted by Collivignarelli et al. (2019a) only a few other studies had reported this phenomenon. The reasons for regrowth of pathogens may be incomplete destruction during treatment, contamination from external sources and a large drop in temperature of biosolids to reallow pathogen growth (Clarke et al. 2017). Additionally, Dane et al. (2020) stated in their review study that the dewatering processes, nutrient environment and physical environmental conditions are all key factors to consider in biosolids storage. Dewatering processes may release growth inducers and transform the environmental conditions of the sludge (Fane et al. 2020). The storage of sludge is much less controlled and understood compared to its treatment and has frequently resulted in increased levels of pathogenic indicator bacteria being observed in stored biosolids (Fane et al. 2020).

In addition to sludge treatment and storage, the risk of disease transmission can be decreased by limiting crop harvesting, animal grazing, and public access for certain periods and by reducing the attractiveness of biosolids to vectors, i.e. animals that may harbour and transfer diseases (Lu et al. 2012) and by choosing the crop produced accordingly (Ozores-Hampton and Peach 2002). As described by Lu et al. (2012), the soil environment is relatively hostile for pathogens since desiccation and ultraviolet light will destroy pathogens on the soil surface. There are many factors affecting the pathogen's survival when biosolids are incorporated into the soil, such as pH, organic matter, soil colloidal matter, temperature, and competitive organisms (Lu et al. 2012). As stated by Lu et al. (2012) the risks from pathogens in biosolids should be minimal with proper processes and precaution.

2.3.3 Heavy metals

Heavy metals are regulated in the modern use of biosolids and as such the risk of them is considered small compared to the risk of unmanaged excreta and wastewater sludge (UN-HABITAT 2008). That said, some of the same micronutrients that are vital for plant growth are in larger quantities considered as toxic heavy metals that can affect humans, animals, and plants. Unlike with pathogens, the concern with heavy metals is not usually the short-term impact but that they accumulate through time and are likely to stay in the soil or else may migrate to the surface or subsurface waters (Lu et al. 2012). This persistence in soil is particularly notable in the context of their interactions with biological processes and transferability to the food chain (Collivignarelli et al. 2019a). Whilst some plants can excessively uptake heavy metals others can immobilise them, thus protecting the food chain and human health (Collivignarelli et al. 2019a).

Lu et al. (2012) describe three hypotheses on the behaviour and fate of biosolids in the ground: plateau, time bomb and soil-plant barrier hypotheses. The plateau hypothesis considers that heavy metals are retained in the upper layer of the soil because they are tightly held by the organic matter of biosolids, hydrous oxides of Fe and Mn and clays in the soil, thus decreasing their bioavailability and toxicity. There are studies both supporting and challenging the plateau theory. The time bomb theory suggests that when biosolids application is terminated and the organic matter degrades the heavy metals could become available and toxic to plants. The soil-barrier theory suggests that plants provide an effective barrier against the uptake of most metals (Lu et al. 2012).

Most countries have limits on the total concentrations of each heavy metal allowed in soil varying across countries and regions (UN-HABITAT 2008). The limits give a site life for biosolids application to a specific site. The site life is the number of years a biosolid with certain concentration of heavy metals can be applied before the maximum allowable soil concentration of heavy metals is reached (UN-HABITAT 2008). Therefore, the heavy metal content in biosolids is a key factor in determining its end use and its sustainability as a fertiliser (UN-HABITAT 2008). As described by Collivignarelli et al. (2019b) the European legislation uses both limit values on soils as well as in biosolids. The effect of biosolids application to soil's heavy metal content have been studied with conflicting results: some have presented no issues while others reported significantly increased levels of heavy metals (Collivignarelli et al. 2019b).

2.3.4 Organic contaminants

The migration of organic contaminants to the environment from biosolids is concerning as they are persistent, difficult to degrade and they bioaccumulate (Lu et al. 2012, Collivignarelli et al. 2019a). Over critical concentrations and certain periods or exposure time they can be toxic or carcinogenic to organisms (Lu et al. 2012). Chemical contaminants present in wastewater may interact with endocrine systems in humans or animals, but initial studies suggest minimal effects to environment and human health through biosolid application (UN-HABITAT 2008). Jiménez et al. (2010) state in their study that the risk from wastewater bound organic components is generally lower than via direct pesticide application. Lamastra et al. (2018) research results also echo this: according to them suggested regulatory limits in Europe for substances on biosolids are sufficiently conservative to avoid negative effects on soil fauna. However, these regulations are currently only in draft, while the sewage sludge directive is being updated, and only Germany, Denmark, Sweden, France and Austria have set national limits for the organic contaminants in sewage sludge (Lamastra et al. 2018). Collivignarelli et al. (2019a) also found no evidence of harm in their review study on biosolids application: although theoretically possible, presence of organic contaminants, pathogens and heavy metals have not been demonstrated to cause problems to human health or environment on the studies they reviewed. On the other hand, they found in their review study that some authors considered the use of biosolids imprudent for the consequences on human health as several emerging organic contaminants have been identified in biosolids, such as perfluorinated chemicals (PFOS, PFOA), polychlorinated alkanes (PCAs), antibiotics and pharmaceuticals. It is theoretically possible that these compounds enter human and ecological food-chains and therefore organic contaminants are considered a matter particularly needing more investigation (Collivignarelli et al. 2019a). According to Öberg and Manson-Renton (2018) chemicals present in biosolids are not thoroughly tested and very little is known about potential synergistic effects. Pharmaceuticals in sludge is also a matter that concerns consumers (Lassen 2015).

Both research into decreasing pollutants in wastewater and continuous sludge analysis is needed (Lamastra et al. 2018).

2.3.5 Odours and nuisance concerns

Odours and other nuisance concerns, such as increased truck traffic, can be the biggest problem in getting support from the local public for biosolids application. According to UN-HABITAT (2008) unlike pathogens, chemical contaminants and heavy metals, malodours present little or no risk to public health or environment. Lu et al. (2012) take a more precautionary approach and state that research still needs to identify potential health effects of malodours. Whether or not odours affect human health, they can have detrimental effects on property values and the quality of life in communities subjected to them (Lu et al. 2012). In the USA the regulations do not cover odours, although odour complaints have led to bans of biosolid application (Lu et al. 2012). Eliminating odours is therefore among the great challenges in gaining public acceptance of biosolids (Lu et al. 2012) and needs to be addressed to ensure the future of biosolids application (UN-HABITAT 2008). It has become a significant part of the necessary infrastructure of wastewater sludge management. Other issues include dust and noise from the operation of sites, compaction of farm soils and increased truck traffic on roads (UN-HABITAT 2008). It is important to consider these nuisance factors as many studies raise public acceptance as one of (Collivignarelli et al. 2019a, Mininni et al. 2015) or the most (Ozores-Hampton and Peach 2002) important obstacle regarding biosolids use.

2.4 Developed countries

2.4.1 The use of sewage sludge in developed countries

Developed countries have adequate wastewater treatment processes which produce sludge as a by-product of the process (UN-HABITAT 2008). This makes sludge management a bigger issue in developed rather than developing countries; when more people are connected to the sewage system, more wastewater is treated, and more sludge produced (UN-HABITAT 2008). Additionally, higher degrees of wastewater treatment yield more sludge. The overall amount of sludge per capita is therefore larger in developed countries. Wastewater treatment has evolved greatly through implemented legislation over the last 50 years; from discharging wastewater to the sea, rivers, lakes, and bays to increasingly stringent legislation for not only the water effluent but also for the sludge produced (Lu et al. 2012). Discharging to waterways is no longer considered sustainable and dumping sludge to seas has been prohibited since 1991 in the USA and 1997 in the EU (Spinosa and Vesilind 2007).

Sludge applied to agricultural land must meet regulations for its pollutant content and its application must follow the guidelines. Much comprehensive research on wastewater sludge disposal options has been conducted in the EU and in the USA (UN-HABITAT 2008), forming the basis upon which many countries have built policies, laws, and regulations by integrating their local needs and conditions (Jiménez et al. 2010). Both USA and the EU have created similar regulations in addressing pathogen reduction, potential for accumulation of persistent pollutants in soils and appropriate amount of nutrients but their approach has differed; the EU regulations have been formed with a precautionary, no-net-degradation approach while USA has used risk assessment approach (UN-HABITAT 2008). The risk assessment approach has been used to form Canadian legislation as well (Öberg and Manson-Renton 2018). In the American and Canadian legislation, the absence of evidence of harm has been taken as proof that a practice is safe while in the European context that absence alone is not considered enough and a more cautious approach has been applied (Öberg and Manson-Renton 2018) which has resulted in European legislation being generally stricter (UN-HABITAT 2008).

The prevalence and limits of using WTTP originated sludge as an agricultural fertilizer differs greatly between countries, even within the same governmental area. The European union is an example of this. All countries in the union are required to follow the minimum standards set in directive 86/278/EEC, but still the legislation between countries is very heterogenic (Collivignarelli et al. 2019b, Hudcová et al. 2019). Some countries' national requirements for biosolids follow roughly the limits on the directive (Bulgaria, Cyprus, Estonia, Latvia, Greece, Italy, Portugal, Slovakia, Spain and the United Kingdom) while others have established more stringent limits (Czech Republic, Denmark, Finland, Luxembourg, the Netherlands, Sweden, Austria, Belgium, Malta, Croatia, France, Germany, Hungary, Lithuania, Poland, Slovenia, and Romania) (Collivignarelli et al. 2019b). Some national regulations have included pathogen and a variety of organic contaminant limits which are absent from the directive. Italy is the only EU member state to set minimum values for organic matter for sludge used as agricultural fertilizer. The level of requirements affects the prevalence of land application of sludge (Hudcová et al. 2019). In EU countries it ranges between zero (Malta, Slovenia, Slovakia, The Netherlands) to 80% (Ireland) (Hudcová et al. 2019). To many land application is still the main sewage sludge recovery route and half of the sludge produced in the EU-28 is spread on agriculture soils, while 28% is incinerated and 18% is disposed in landfills (Rashid et al. 2017, Collivignarelli et al. 2019b). Land application is also prevalent in the USA where around 55% of the biosolids are applied to soils (Peccia and Westerhoff 2015). Differences between countries are in particular due (among aspects like economic impact and public perception) to the extent of agricultural land and stakeholders' positions that influence the policy decisions (Collivignarelli et al. 2019b).

While land application of biosolids is considered a cost-effective, sensible waste disposal method by many sources (e.g. UN-HABITAT 2008, Lu et al. 2012), increased opposition to agricultural use and stringent standards of treatment are some of its challenges (Mininni et al. 2015). Despite the challenges, land application is an attractive option for sludge disposal because of costs of incineration and landfilling (Lu et al. 2012). It can also present a sustainable local source of nutrients, as in the case of Europe where most of the phosphorus is imported (Gianico et al. 2021).

2.4.2 Public acceptance

Whilst a number of articles stated that the land application of sludge has faced significantly increased public opposition in the US (Goven and Langer 2009, Peccia and Westerhoff 2015) and in the EU (Mininni et al. 2015), this study did not find many publications which focused on the public perception on the use of biosolids, or data which tracked changing public perception over time. However, the importance of public perception is often cited with biosolids, even if is not directly studied. Public perception is identified as the main pressure mentioned by stakeholders, one of the reasons to move away from land application of sludge (Peccia and Westerhoff 2015) or the driver for more scientific research to disseminate ambiguity and provide assurance to agriculturalists, retailers and public (Fane et al. 2020). Public perception is also stated as one of the incentives to find ways of minimising biosolids production and maximising alternative reuse options (Joo et al. 2015) and as a major reason why farmers would not want to use biosolids (Krogmann et al. 2001). Compliance with regulations is therefore not enough (Evans et al. 2004).

Public perception and lobbying of policy makers can stop land application of sludge altogether. At the turn of the millennium in Flanders (Belgium), stakeholders' influence in policy decisions developed regulations for biosolids to be so onerous they were virtually impossible to meet (EC 2001). According to European Commission report (EC 2001), many stakeholders saw the low levels of biosolids application to be due to lobbying for use of surplus animal manure. Farming associations however did not see biosolids land application as a "real" recycling policy but rather a cheap and easy solution for federal authorities and wastewater treatment companies (EC 2001). This resulted in bad publicity in the farmers' specialised press which in turn helped to develop a negative perception among the public and national authorities.

According to Öberg and Manson-Renton (2018), biosolids land application has winners and losers, which highlights how the extent to which different stakeholders can affect policymaking makes a big difference. The study defines the collective urban population, polluters, sewage treatment plants and farmers as the winners and the collective rural population as losers. The benefiters get rid of their waste or gain affordable fertilizer while the rural population is faced with fears of odours, reduced property value, perceived risks related to negative health and environmental impacts and increased truck traffic. On the other hand, the rural population also includes winners through increased job opportunities. The stakeholder categories are not simple, making determining the acceptable level of risk difficult.

Due to lack of public acceptance and the high cost, a move away from land application of biosolids and further research into biosolid use is being called for by some studies. Peccia and Westerhoff (2015) argue that valuable heavy metals could be extracted from the sludge, nitrogen and phosphorus should be extracted better during the wastewater phase and lipids could be recovered to produce biodiesel. They call this an economic and environmental win-win situation. Like Bracken et al. (2009), Peccia and Westerhoff (2015) highlight the problem of nutrient accumulation in the cities, but from a different perspective. While Bracken et al. (2009) promote land application, seeing nutrient accumulation in cities as a wasted resource and a threat to cities and societies, Peccia and Westerhoff see it as a logistical and economic problem and a reason to move away from land application. They state that due to the long distances, the transport of sludge from cities to agricultural sites is a waste of resources: it results in an energy intensive dewatering processes and high transport costs. However, on occasion, land application has been the preferred method of disposing of sludge according to the public, even if other methods are deemed more efficient in that specific situation. UN-HABITAT Global Atlas of Excreta, Wastewater Sludge and Biosolids management (2008) highlighted cases where public preference of biosolids over incineration had resulted in sludge being transported significant distances for land application. In these cases, incineration was opposed by the public, even though it was estimated to be the most sustainable sludge management option in the specific context discussed. Public perception does indeed have a strong influence when choosing any sludge management type.

2.4.3 Response to public opposition

In earlier articles, especially written by those who advocate biosolid use, public opposition to the land application of biosolids is explained as a result of not providing the public enough information (Draman 1995, Logan 1995, Beecher and Goldstein 2005). While accepting that there are risks and unknowns, studies call for providing more information to the farmers (Krogman et al. 2001) and better communication by the scientific community to the public and stakeholders (Lindsay 2000, EC 2001, Evans et al. 2004). They believe this would increase acceptance and biosolids use and discount misinformation or emotional judgements. Opposition is seen as a result of intuition: we perceive risks mainly intuitively and sewage and wastes are inherently considered “bad” (Krogman et al. 2001). Some articles see this as a perception that needs to be corrected by providing scientific evidence. The importance of public and stakeholder attitudes is acknowledged as a requirement in addition to compliance with regulations (Evans et al. 2004).

It is believed that the opposition to biosolids has increased due to the approach of disseminating information with lack of public engagement from the other stakeholders. While it is noted that there has been a great amount of research into biosolids use and that the risks can be managed to acceptable levels (e.g. Evans et al. 2004), there have been complaints about lack of community control (Robinson et al. 2012). Harrison and Oakes (2002) found in their study that most of the alleged illnesses reported by people living near sludge land application sites in the US were not tracked or investigated, suggesting that the number of illness cases is not actually know nor the symptoms tracked and studied. Educating the public with facts can increase acceptance, but not when little attention is given to the values and beliefs that drive public perception of the risks related to biosolids (Robinson et al. 2012). Growing frustration due to the lack of public engagement and attention given to the issues raised by the public has not been adequately addressed according to Robinson et al. (2012). Community-specific outreach programmes have been suggested as a solution (Lu et al. 2012) but as emphasized by Goven and Langer (2009) the purpose of public engagement cannot be to impose an already decided strategy.

In later studies, biosolids programmes and advocates have been criticised over considering public opposition lacking real argument and being a result of a knowledge deficit (Goven and Langer 2009, Robinson et al. 2012, Öberg and Manson-Renton 2018). Opposition has been assumed as a mistaken view that can be changed by better communication strategies, when public engagement would be valuable both from public-participation and social-learning perspectives (Goven et al. 2012). Goven and Langer (2009) argue that instead of taking the opposition as a “wrong opinion”, there should be better public engagement in decision making to create sustainable practices. Another way of framing this is saying that the land application of biosolids has been considered by the scientific community to be a technical problem. According to Öberg and Manson-Renton (2018) the importance of public acceptance regarding biosolids application and the varying stakeholders make it also a social problem. They argue that considering biosolids land application as only a technical problem ignores the various conflicts of interests and values related to it and is therefore a reason for many failed projects.

The underlying reason for public opposition to biosolids land application according to the data studied is a lack of trust. This is a lack of trust that biosolids would be treated properly and safe practices followed (Beecher and Goldstein 2005, Hébert 2007), that enough is known about the technological treatments and risks involved (Krogmann et al. 2001), or that the community’s view is listened to (Goven and Langer 2009, Goven et al. 2012). Depending on the way public opposition is addressed, this can be seen either to be because of lack of communication from scientists, engineers and technologists (Evans et al. 2014, Hébert 2007), lack of public engagement (Goven and Langer 2009) or that the limits of science-based knowledge and the large uncertainties surrounding the risks haven’t been publicly addressed (Öberg and Manson-Renton 2018). As previously mentioned, there are differences between the USA, Canada, and

Europe on how biosolids legislation has formed; the European legislation is more cautious whereas American legislation is based on known risks, not on the unknowns. The more cautious approach has been better in gaining public acceptance, according to Öberg and Manson-Renton (2018) in their study comparing Sweden and Canada. They argue that the persuasive tone and lack of transparency within the Canadian legislation appears to negatively impact residents' trust in regulatory agencies. On the other hand, European Commission report from 2001 suggests that tight stringent legal limits do not necessarily imply greater acceptance. The report also uses Sweden as an example, showing that attitudes towards sludge use vary over time.

To address the issue of mistrust and improve public perception of biosolids, many countries, including Sweden, Australia, the USA, and the UK, have created specific certification assurance schemes (Moya et al. 2019b). In the UK, through initiatives from the water companies, the Biosolids Assurance Scheme (BAS) was launched in 2013 to deal with the challenges related to perception and risks (whether real or perceived) (ABL 2018). It is there to ensure that the recycling of biosolids into the land is transparent and subject to external controls and provides evidence and assurance of the quality of biosolids (Moya et al. 2019b). Although there are still major barriers for widespread use of biosolids in agriculture (such as limitations on crops grown), the creation of the assurance scheme seems to have had a positive effect on the acceptance of biosolids for agriculture in the UK (Moya et al. 2019b).

Certification could be the necessary solution to mistrust; the independent auditing of wastewater treatment facilities producing biosolids can gain public trust and the acceptance of biosolids, as long as the certification is well known (Hébert, 2007). Hébert presents two examples of certifications: a private National Biosolids Partnership (NBP) certification in the USA and certification by SYPREA, an association of private professionals in France. According to Hébert, the SYPREA certification has been more successful; it has been developed in collaboration with and by endorsement of the government and a farmers' union and is therefore well known by the public unlike the NBP certification. SYPREA certification meets or exceeds the national regulations, whereas even though the NBP certification meets local federal standards, those standards are not endorsed by all stakeholders. These examples again highlight the importance in the engagement of different stakeholders in the biosolids management planning.

2.4.4 Media's role

The media plays an influential role in biosolids acceptance. Goodman and Goodman (2006) analysed news articles about biosolids between 1994 and 2004 in Florida, Virginia, and California, USA. They found that biosolids were more often described in negative tone rather than positive and that the term biosolids was either not defined or defined inaccurately. There were no significant changes to this during the decade of the study. Hébert (2007) describes a case in Canada, where the release of a movie affected public perception; the movie presented biosolids land application as dangerous to human health and soils, with biosolids containing chemicals and hence not being natural and that the process cannot be trustworthy as land application is done by private companies. After the movie was published, two cases where people had died due to untreated cow manure polluting their drinking water were wrongly presented in major newspapers as being biosolids related deaths resulting in more negative perceptions around biosolids (Hébert 2007). Beecher and Goldstein (2005) also refer to legal cases over illnesses and deaths due to biosolids where no evidence to base the allegations on were found, but the allegations negatively affected biosolids acceptance. A survey conducted by Lindsay et al. (2000) in the USA suggests that the lower the volume of information presented by the media the more supportive residents are of land application. While biosolid advocates cannot directly affect how the media talks about biosolids, they can affect the information they provide to ensure the risks are understood, to discount emotional judgements and misinformation (Lindsay et al. 2000). It is important that biosolids management addresses the perceptions people have towards biosolids to ensure sustainable use of them. Open communication between the science community and public is important to avoid the obstacle of mistrust: not believing that safe practices would be followed or endorsed (Hébert 2007).

2.4.5 Perception of stakeholders

The reasons for stakeholders to accept the use of biosolids are related to their benefits: it is an affordable local fertilizer containing organic matter that also solves the problem of end use of sludge and promotes nutrient recycling. The reasons for unacceptance of biosolids are more diverse and depend a lot on the individual stakeholder (EC, 2001). Odours, health implications, fear of legal liability in case of pollution, heavy metals, organic contaminants, Not In My Back Yard (NIMBY) effect, mistrust towards producers and regulators and fear of loss of livelihood are among the reasons reported. New Jersey farmers considered that the economic incentives and soil improvement benefits of biosolids are outweighed by the risks: negative public perception, odour complaints, and increase of contaminants like heavy metals (Krogmann et al. 2001). In Europe farmers mainly mentioned customer quality requirements (EC 2001) and odour nuisance for neighbours (Case et al. 2017) as reasons not to use biosolids. Negative public perception and potential threat to brand is seen as the main reason not to use biosolids by the agri-food industry and food retailers (EC 2001). Much of the industry opposition to its use is therefore rooted in lack of public acceptance and the fear that the public will not buy the product. The risk of liability for damages to land or potential health effects is also among the reasons mentioned by landowners (EC 2001) and farmers (Krogmann et al. 2001). Other reason for farmers to not use biosolids is its complexity of use: there is increased difficulty in planning compared to mineral fertilizers (Case et al. 2017).

Farmers are also worried about the public's reaction to malodours (Krogmann et al. 2001, Case et al. 2017). Malodours are indeed the most frequent cause of complaints regarding biosolids land application (Harrison and Oakes, 2002) and can cause enough opposition to shut down programs (UN-HABITAT 2008). Odour reduction is one of the aims of treatment process (Peccia and Westerhoff 2015), but they are not included in standards or regulations (Spinosa and Vesilind

2007, Lu et al. 2012). Other main reasons for opposition along with malodours is health implications and discomfort at the idea of mixing human lavatory waste with food (Lassen 2015). Trace pharmaceuticals and other organic pollutants cause worry among consumers (Lassen 2015) and the scientific community (Collivignarelli et al. 2019a).

2.5 Developing countries

2.5.1 Use of biosolids in developing countries

While in developed countries the main issue related to wastewater treatment is the growing amount of sludge and how to deal with it, the issues in developing countries (especially the poorest) are very different. UN-HABITAT (2008) highlights the staggering divide: most developed countries focus money and resources on now-marginal improvements in water quality and environmental integrity, while in the poorest countries millions of people die because of a lack of basic sanitation. The focus in the poorest countries is on preventing disease transmittance and reducing pollution in natural waters through basic sanitation, not in finding solutions to increasing amounts of sludge (UN-HABITAT 2008).

That said, in a similar way to developed countries, sludge disposal issues grow in line with the volume of wastewater treated as the technologies develop (Jiménez et al. 2010). The more comprehensive the collection of wastewaters and their treatment, the more sludge is produced (UN-HABITAT 2008). Along with the better collection and treatment, the amount of sludge is increasing due to population growth. Additionally, the urban, and peri-urban population is expanding in developing countries (UN-HABITAT 2008). Sludge disposal is more challenging in urban settings due to the shortage of available land for disposal or reuse.

Sludge management is becoming increasingly important as wastewater treatment advances and more complex regulations are being developed (as is the case in South America and other areas), but examples of sludge management policies in developing countries are rare, while the existence of properly functioning wastewater treatment plants is still evolving (Jiménez et al. 2010). Risks need to be managed, but stringent regulations can be impossible to achieve and a balance is needed between strong regulations and enforcement with what is practical and achievable (UN-HABITAT 2008, Jiménez et al. 2010). Regulations are an important base when deciding sludge end use strategies, but the social, environmental, economic, and technical sustainability need to be considered as well (Chen et al. 2012, Ferrans et al. 2020). While in developed countries, improved integrated sludge management with multiple stages can be preferred (Spinosa et al. 2011) in developing countries highly technical options are not necessarily feasible (Ferrans et al. 2020). Agricultural use of sludge has low investment costs, high potential monetary profits and low energy requirements making it a sustainable option in developing areas (Ferrans et al. 2020). Additionally, the use of organic fertilizer can help to combat nutrient depletion of soils (Moya et al. 2019a). Wastewater and sludge use in agriculture is therefore happening and as Jiménez et al. (2010) put it, water and nutrients are recovered extensively already but the practice is not free from risks.

Still, the use of sludge in agriculture is not as widely accepted as the use of wastewater and the main motivation for using sludge is linked to disposal issues rather than to its benefits (Jiménez et al. 2010). In LMICs, faecal sludge, excreta and biosolids are increasingly being applied on land instead of landfilling due to the high management costs and difficulty of finding suitable sites for landfills (Jiménez et al. 2010). While the reduced availability of land and pollutant risks related to biosolid use also limit sludge land applications, there are political and economic incentives to increase its use because of the organic matter and nutrients, especially phosphorus, that it contains (Chen et al. 2012). Many farmers consider sludge as being a valuable resource in terms of nutrients, similar to animal manure (Jiménez et al. 2010, Moya et al. 2019a, Moya et al. 2019b).

Estimating the amount of sewage sludge used for agriculture in developing countries is challenging according to Jiménez et al. (2010). Large numbers of on-site sanitation systems (latrines, unsewered public toilets or septic tanks) are difficult to monitor compared to the amount of sewage sludge or biosolid produced at a waste water treatment plant. Some of the faecal sludge produced in unsewered sanitation systems is transported to treatment ponds but more often it is dumped in depressions, streams, lakes, or the ocean, or reused untreated on farmland. Farmers are known to bribe septic truck drivers to dump the sludge on their fields in Ghana, Mali, and Benin (Jiménez et al. 2010).

2.5.2 Acceptance of biosolids

Public acceptance of biosolids varies between cultures in developing countries. As explained by Jewitt (2011), some cultures are used to handling of excreta while in others it is a taboo. For example, in China and Vietnam using human waste as fertilizer has long tradition, while in India and in areas of Ghana the whole topic is found abhorrent and dealing with human waste is acceptable to only lower castes (Jewitt 2011, Chen et al. 2012, Appiah-Effah et al. 2015). Interestingly, the avoidance of excreta has not necessarily resulted in functioning systems: the management of human waste is not thought of and as long as it can be disposed of out of the house, the issue is preferred to be out of sight and out of mind, however unsustainable this situation may be (Jewitt 2011). In China by contrast, the use of excreta in agriculture has continued to be a common practice, creating a strong economic linkage between urban dwellers and urban farmers (Jewitt 2011). However, perceptions towards human waste use in agriculture can change substantially between communities and over time as the cultural attitudes shift (Jewitt 2011).

Among stakeholders, the perception of biosolid use is mainly studied among farmers. For farmers, the opposition to biosolids use does not appear to stem from environmental or health risks, but rather from cultural beliefs that faecal sludge is total waste and therefore not to be used (Appiah-Effah et al. 2015), from perceived customer attitudes (Nassar et al. 2009, Rashid et al. 2017, Moya et al. 2019a) or concerns it will limit their ability to export the products (Moya et al. 2019b). Some studies suggest that farmers, while happy to use fertilizers derived from human excreta, would not want to disclose this to the customers of their products, showing a fear of stigma (Nassar et al. 2009, Jiménez et al. 2010, Moya et al. 2019a). In a study conducted by Nassar et al. (2009) in Palestine only 23% of the farmers interviewed about potential use of sewage sludge as fertiliser considered the safety aspect of sludge use; with the biggest concern being that customers would not buy products fertilised with sludge (54%) while the rest were concerned about practicality of its application. As such, in developed countries environmental and human health risks caused by pollutants are often cited when opposing biosolid use, whilst in developing countries the reasons given are very different. In addition to the cultural reasons and concerns over stakeholder reactions are the practical difficulties of application, low purchasing power or willingness to pay for such product, and lack of knowledge of the effectiveness of the fertilizer (Nassar et al. 2009, Moya et al. 2019a).

3 CASE STUDY – PERCEPTION TO BIOSOLIDS AS A FERTILIZER AMONG FARMERS IN NDOLA, ZAMBIA

3.1 Material and methods

The objective of this case study was to evaluate farmers' perceptions of using organic fertilizer originating from a wastewater treatment plant (WWTP) in a developing country. The study location was Ndola area in the Copperbelt province of Zambia (Figure 1). In Ndola there is a wastewater treatment plant, where the anaerobic digestation of sewage sludge presents a possibly viable option. The interviews were thus conducted with the hypothesis that in the future there may be an anaerobic digester introduced to the WWTP which would yield digestate and reject water to be used as biosolids in the area.

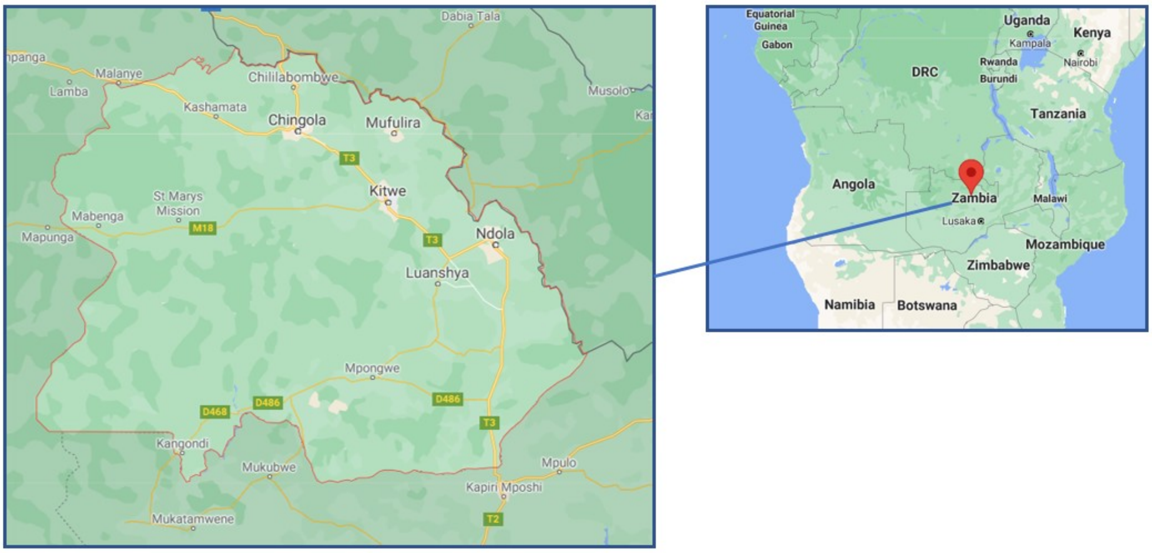

Figure 1. Location of the case study was Ndola area in the Copperbelt province in Zambia (map by Google maps).

Local farmers were interviewed on the crops grown, fertilizer use, their perception of organic fertilizers and their willingness to both use and pay for fertilizers derived from a wastewater treatment plant. The structural interviews were carried out in November and December 2013 and aimed to determine the acceptability and feasibility of digestate use in the area. Despite the aim to have as many interviews as possible conducted, due to constraints in the data collection, only 10 interviews were completed.

In order to conduct interviews, some farms were visited in the region around Ndola, Mufulira and Mpongwe while rest of the interviews were conducted in the Ndola office of the Zambia National Farmers' Union (ZNFU) where farmers would visit (mainly to collect fertilizers). The interviews were conducted in a structured form, using the same questionnaire for each interviewee (Appendix 1). The interviews were conducted in person, which allowed adaptation of the terms used as needed to make the questionnaire more understandable. In addition to the interviews, ZNFU representatives, the Ministry of Agriculture and Livestock, and a local provider of farming goods and seeds were visited and interviewed to gain understanding of the farming practices of the area.

The study focused only on the farmers’ perception towards fertilizers originating from a wastewater treatment plant. Although it is important that the wider community also sees the value and benefits of biosolid application, the neighbours and communities around the farmers were not included in the scope of this study. This is due to large number of small-scale farmers in the area and the subsistence nature of many of the smallholdings, leading to difficulty in determining the supply chains in the area, and differentiating between producer and consumer.

There were few challenges in the data collection. The main challenge faced was finding participants to complete the interviews. The main method of finding the interviewees was to wait at the ZNFU’s office in Ndola, and if and when farmers visited, to request an interview. However, there was no certainty farmers would visit on a certain day. Yet it was positive that all the farmers who were invited to take part in an interview were happy to participate, which helped to reduce bias in the study. In addition, a couple of interviews were sourced through visiting specific villages to find participants. The opportunity to visit further locations was limited by the rural location and lack of public transport. As such, the number of interviews conducted was limited to 10 farmers.

3.2 Farming practices around Ndola

The Ministry of Agriculture and Livestock (https://www.cbt.gov.zm) was visited to gain understanding of the farming practices in the Copperbelt province and in particular in Ndola. Farming is one of the most important sources of livelihood in the Copperbelt province as well as in Zambia as a whole. According to the Ministry there are 13 994 farmers in the Ndola area. The number of farms is more difficult to estimate, since in an individual farm there might be between one to five people listed as farmers. Farms in the Ndola area are divided into three blocks, which are called Misundu, Kafubu and Munkulungwe. Each of them is then divided into camps and zones. For example, in Misundu block there are 2940 ha of maize production, 440 ha of sweet potatoes and 12 600 ha of bananas.

As detailed in the information given by the Ministry representative, most of the farms are non-commercial small-scale farms ranging from quarter of a hectare (1 lima) up to 10 ha in size, with approximately 10 larger, commercial farms in Ndola. In the whole Copperbelt the number of commercial farms is around 40 to 50 farms. The size of the commercial farms ranges from 50 to over 1000 hectares. The crops grown are mainly maize, which is the dominant crop, sweet potatoes, and groundnuts together with beans, cassava, soya beans, sorghum, barley, millet, wheat, and some small amounts of cotton, tobacco, and sugar. Commercial farms mainly produce maize, wheat, and soya beans. Vegetables, such as cabbage, tomatoes and okra, and fruits, especially bananas and mangoes, are also produced in the area. Livestock includes dairy, cattle, piggeries, sheep, goats, and poultry such as village chickens and guinea fowls. Some fish farming is also done in the area.

According to the ZNFU (https://m.facebook.com/Zambia-National-Farmers-Union-526925740720577/), the agriculture in Ndola area is largely dependent on rainfall and only some of the farms have irrigation systems. The irrigated crops are mostly wheat, barley, and soya beans. Few farmers have irrigation systems which enable them to grow maize throughout the year. The majority of the crops are cultivated during the rainy season (from mid-November to March), but with irrigation the growing season can be extended to the dry season (May to October), especially in the case of vegetables. During the rainy season the risk of disease is high, and it is usually too wet for vegetable growth, excluding some types of vegetables like okra, rape, herbs, or hybrids developed specifically for the season. Commercial farmers grow wheat and barley during the dry season with the help of irrigation.

Most of the soil in the area is classified as alluvium soil. Soil consists of mostly sand and clay and tends to be acidic, which is why the farmers are encouraged to use lime. The fertilizers used are mostly inorganic, of which compound D (NPK-value: 7-14-7) is used as a base fertilizer applied while planting. Urea is added as a top dressing, for example for maize when the crop is knee-high. Some farms use organic fertilizers such as chicken manure and cow dung and it is usually used together with inorganic fertilizers. Many small-scale farmers acquire their fertilizers with loans through the ZNFU, for which 50% of the fertilizer's price is paid for by the farmer when received with the rest funded by a bank. The loan is then paid back following the harvest. With subsidized fertilizers there are frequently delays with the supply due to logistical issues. Demand for fertilizers is high and there is a call for a cheaper and locally produced source of fertilizer.

According to ZNFU, organic farming is relatively uncommon in Ndola area. There is an association for organic farmers in Mpongwe, a town 100 km from Ndola, where several farms do organic farming certified on German standards.

3.3 Results of the interviews

The interviewees of this study were farmers from Ndola (5) and near-by cities of Mufulira (2), Mpongwe (2) and Kitwe (1). Farming practices of the interviewees echoed the information received from the Ministry of Agriculture and Livestock and the ZNFU. The sizes and types of the farms ranged from four-hectare tenancy on government land to 233 ha of privately owned land. All the farms had maize as their main crop, used urea and Compound D as fertilizer, had similar inorganic fertilizer application rates, and reported similar prices paid for the fertilizers. Many of the respondents considered the inorganic fertilizers expensive. Three of the respondents received subsidies from the government during the year and one had had a loan from the ZNFU. In addition to maize, the farmers cultivated soya beans, sweet potatoes, groundnuts, bananas, and a variety of vegetables.

Half of the interviewees were using organic fertilizers, which were mainly used in addition to inorganic fertilizers and did not decrease the amount of inorganic fertilizers used. The source of organic fertilizer was mainly animal manure from the interviewees' own farms and the application rates were not closely monitored. Only one respondent reported of buying chicken manure outside of their farm. The benefits of organic fertilizers were mainly recognised by the respondents (Table 1). One benefit mentioned was customer feedback of better taste of vegetables fertilised with organic compared to inorganic fertilizers. The use of organic fertilizer had therefore resulted in higher customer demand of the products grown. Those that did not identify any benefits cited that they had never used organic fertilizers and as such were not aware of the benefits. Drawbacks of organic fertilizers identified were related to costs of transportation and labour-intensive application. The small-scale farmers did not have any machinery to spread manure or liquid fertilizer, and the work would have been done manually. Many of the small-scale farmers also reported lack of vehicles and relying on public transportation. There was therefore a market for organic fertilizers, however, particularly for the small-scale farmers, only local or dried and bagged fertilizer would present a viable option.

Table 1. Benefits on application of organic fertilizers according to the respondents.

Benefits	Number of farmers	Example quotations
Not aware	3	*"I haven't seen them because I have never used it. There might be some benefits for the soil, scientifically."*
Affordability	5	*"First thing it is cheap. Value of it is higher than the cost since it's natural and holds water longer. Can hold 2 weeks of moisture."*
Better quality and quantity of crop	5	*"Maize will stay greener lot longer with chicken manure than without it."* *"It's easier to get higher yields when you combine the two [inorganic and organic fertilizers]."*
Improved soil quality	4	*"They decompose and improve soil fertility."*
Longevity of benefits	2	*"They stay longer in the soil"* *"Rain won't wash it away"*
Availability	2	*"You can have it any time you want unlike subsidized fertilizers."* *"Why use oil in Saudi-Arabia to produce fertilizers when we have organic fertilizers just here?"*
Public perception	1	*"Sometimes people complain the taste [of vegetables] is not very good when using chemical fertilizer. So, we use chicken manure. People enjoy eating the harvest and we get good market."*

When it came to knowledge of biogas plants the farmers were divided by their level of education. Those with higher education (6 participants) were aware the of the biogas processes whilst those with a lower level of education (4 participants) were not aware of them. None of the participants had experience in using digestate as a fertilizer, but one of the larger scale farmers with higher education had an interest in having a biogas plant on their own farm. The participants would be happy buying vegetables and fruits grown with digestate. The farmers were willing to use the digestate originating from a WWTP for their own crops, with some of the farmers having reservations (Table 2). Six of the respondents would have been happy to use the digestate for all crops (Fruits, Vegetables, Trees, Cereals, Pulses and Grasses), while one respondent would not use digestate for fruits, one for vegetables and one for cereals. One of the respondents said they are only familiar with growing maize and hence felt unable to answer the question. None of the respondents had objections to their neighbour using WWTP originated digestate as a fertilizer.

Table 2. Farmers' willingness to use WWTP originated digestate or liquid fraction for their own crops.

Level of willingness	Digestate		Liquid fraction	
	No of farmers	Example quotations	No of farmers	Example quotations
Not happy	0		1	*"No, because of pathogens"*
With reservations	5	*"If it's available and fully digested"* *"For crops intended for human consumption I would use it ploughed. If it's just from toilets I would not mind if I knew there is no other garbage, such as batteries."* *"Yes, if it has no side effects."*	2	*"If tested and no pathogens present."* *"Yes, when you see other people using it. Especially if it would be cheaper. It's difficult to use something you don't understand but after you understand it you can use it."*
Happy to use	5	*"No there is no problem with that. It's manure, it's fertilizer."*	7	*"That's the normal way because it is treated. Surely will use then."*

The farmers were not willing to pay the same amount for WWTP originating digestate that they are currently paying for fertilizers (Table 3). That was a common opinion about all organic fertilizers despite identifying their benefits; as they are locally available and more laboursome to apply, they should be cheaper. While not directly asked, it also came apparent during the interviews that the farmers found the current fertilizers very expensive and the amount of subsidies insufficient. Therefore, an alternative option for fertilizers was welcomed. As stated by one respondent:

"I think it is good for you to have that [a biogas plant yielding biosolids] *that will help us. That can reduce the price of fertilizers. When there is more than one source the prices can decrease. When there is only one source it's not good."*

The need for education was also stressed. As described by two of the respondents:

"The technology should be first explained fully to the people. You need to educate people. Somebody will say no [to using human waste]. The reason is they don't have the knowledge about the process. That's why people need to be educated first."

"Sometimes we get worried if we don't understand the process. Especially if you don't know if it is treated or not."

Table 3. Farmer's willingness to pay the same amount for digestate originating from a WWTP as for their current fertilizer.

Willingness to pay	Number of farmers	Example quotations
Happy to spend the same amount	2	*"Definitely because chemical fertilizer is not good."*
No, because of labour intensive application	3	*"It won't be the same since organic fertilizers need a lot of work. It's dirty, it's a lot of work. I can use inorganic fertilizer myself in one or two days but for organic fertilizer I need some help."* *"If I have to change technology it must be more profitable than previous fertilizer."*
No, because raw materials are local and easily available	5	*"There will be a difference. I suggest that maybe organic is cheaper as it can be processed very near the place it is produced."* *"It [land application of digestate] is the cheapest way to get rid of it."*

4 DISCUSSION

4.1 Literature review

Extent of agricultural land and different stakeholders' impact into policy making have resulted in variable levels of biosolids land application in developed countries (Collivignarelli et al. 2019b). While there are differences between nations, the land application of biosolids plays a significant role in the quantities of biosolids used in developed countries. In developing countries quantifying the use is very difficult due to lack of reliable data. Some of the needs and main benefits of biosolids land application differ between the developing and developed world. While in developing countries the agricultural use of biosolids could alleviate food security challenges and land degradation issues through a local, available, and affordable fertilizer (Moya et al. 2019a), in developed countries it most importantly presents an option to the reuse of increasing amounts of sewage sludge (UN-HABITAT 2008). Globally, the use of biosolids could reduce the one-way flow of nutrients from agricultural lands to cities and provide an alternative to the unsustainable use of inorganic fertilizers (Bracken et al. 2009).

Number of factors make biosolids land application challenging in terms of its perception. Firstly, there is an increasing pressure for finding ways to dispose of or utilize sewage sludge. Seemingly low technology requirements of land application compared to other management types, such as incineration, can give the perception that land application is preferred as a cheap and easy solution for disposal. This can degrade the level of trust towards the product. Secondly, even if the benefits of biosolids are understood, there are still many unknowns related to the risks, especially in terms of emerging pollutants such as organic contaminants (Öberg and Manson-Renton 2018, Collivignarelli et al. 2019b). Chemicals present in biosolids are not thoroughly tested and very little is known about potential synergistic effects (Öberg and Manson-Renton 2018). Even the relatively well-known risks, such as the accumulation of heavy metals, will need to be carefully managed. Thirdly, biosolid application has many stakeholders, but only a few actors (wastewater treatment plants, contractors, and farmers) (Öberg and Manson-Renton 2018), each with differing priorities and incentives. The risks are not distributed evenly between the actors and stakeholders or between rural and urban community which makes determining the acceptable level of risk or uncertainty challenging.

Balancing between the benefits and drawbacks of biosolids land application can result in very different levels of accepted risk depending on the stakeholder. Table 4 presents the factors affecting stakeholders' unacceptance of biosolids drawn from the literature review and categorised between developing and developed countries. The factors mentioned in developing countries were mainly related to short-term issues such as pathogens and practicalities. By contrast, in developed countries the factors included long term risks and factors affecting quality of life in the biosolids application area.

Research of biosolids is ongoing (e.g. Brisolara et al. 2020), but it may never be possible to achieve completely risk-free biosolid; there is always the possibility that it may contain some unknown harmful substance or that the synergistic effects of pollutants are not known. While alternative solutions for sewage sludge reuse are being studied (e.g. Joo et al. 2013), more research into the risks of emerging organic contaminants is needed. Determining the level of risk that is acceptable by the stakeholders is important in order to achieve biosolids land application practices that are not only economically and environmentally but also socially sustainable.

Table 4. Factors affecting stakeholders' unacceptance of biosolids use in developing and developed countries according to the literature review – with most commonly mentioned factors bolded.

Developed countries	Mutual issues in both	Developing countries
Odours **Heavy metals** **NIMBY** **Lack of trust** Organic contaminants such as pharmaceuticals Permanent contamination of land due to pollutants Potential liability of customer health issues or soil contamination Complexity of use: more planning involved than when using inorganic fertilizers Local management problems; increased truck traffic, vectors, stockpiling Decrease of property values Method seen as a simple way to dispose of sludge rather than beneficial reuse option Surplus of animal manure	**Farmers worried of customer acceptance and losing sales** **Pathogens** (issue mainly mentioned in studies of developing countries)	**Impracticality of use** – lack of transport, equipment for applying, and storage space needed Impact on export opportunities Cultural unacceptance

4.2. Case study

Despite the low level of respondents, this case study found similar results in perception towards biosolids use to the literature review in developed countries among small-scale farmers. Whilst farmer perception was generally open to biosolid use, there were reservations. Practicality was a far greater issue than the perception, due to the lack of machinery and transportation. However, biosolids were perceived as a waste substance needing to be disposed of. This and the locality and availability of the product were suggested as reasons why the farmers would not be willing to pay as much for biosolids as for their current type of inorganic fertilizer. This could be a barrier to adoption due to the significant investment needed to make biosolids use a viable option. Principally the only risk mentioned was pathogens, and this was not highlighted by all the respondents. The fact that the risks weren't fully understood and that the small-scale farmers would be applying the product by hand suggest that the pathogen content in biosolids needs to be reduced significantly before application. Because of the significant infrastructure investments needed source separated and composted human waste could potentially provide a better solution to nutrient recycling in the area.

5 CONCLUSIONS

Biosolids land application is a common, but variable practice around the world. In developed countries, whilst infrastructure for biosolids treatment and practicalities needed for land application exist, the varying conflicts of different stakeholders and extent of agricultural land have resulted in very different levels of use of biosolids across regions, proving that the public perception of biosolids is a key factor in its widespread adoption. Biosolids use is further complicated by the level of unknowns regarding the risks of pollutants and due to the disproportionate distribution of the risks and perceived risks between stakeholders. As such, determining the acceptable level of risk is an ongoing challenge. In developing countries perception is not the most significant barrier in biosolids use but rather the lack and quality of infrastructure. The reasons for opposing biosolids land application are more based on practicality rather than risks as in developed countries. The case study results highlighted that in order to ensure safe and sustainable use of biosolids in the study area, although perception of biosolids was mainly positive, education of the risks, strong regulatory support and certification would be needed.

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APPENDIX 1. INTERVIEW STRUCTURE

Questionnaire on the use of by-products of a biogas plant

Thank you for taking the time to fill in this questionnaire and providing me with valuable information for my master's thesis. All the information used is confidential and from the final work it is not possible to trace the answers to the private person giving them. The information will also be used to contribute to a feasibility study on a biogas plant conducted by Doranova oy and Elextract Energy Ltd. If the respondent is willing to give his/hers contacts they can be used in further collaboration in the development of this project.

Personal data

Age: ____ Sex: ☐ Male ☐ Female

Education:

Hometown:

Land ownership

How many acres of 1. own land : _________ 2. tenant farming :_____________

Soil type: ☐ Red soil ☐ Black soil ☐ Other

Water source: ☐ Rainfed ☐ Irrigated

Current agricultural practices

Crops grown:

Area under each crop:

Area	Crop	Area	Crop

Agricultural inputs:

Fertilizer use: ☐ Organic ☐ Inorganic

Inorganic fertilizer application rates:

Crop	N (kg/ha)	P (kg/ha)	K (kg/ha)

Inorganic fertilizer requirement per year: (N = Urea; P = DAP; K = ?)

N (kg)	P (kg)	K (kg)

Cost of the inorganic fertilizer

N (€/kg)	P (€/kg)	K ((€/kg)

If *organic* fertilizer are used,

What kind of organic fertilizers are in use?

Source of organic fertilizer:

How did you come to know about this organic fertilizer?

To what crops do you use organic fertilizer?

Organic fertilizer application rates:

Crop	(kg/ha)	(kg/ha)	(kg/ha)

How much of an organic fertilizer do you need per year?

Crop	(kg)	(kg)	(kg)

Are there any pre-treatments for the organic fertilizer at issue?

Have you received any kind of subsidies for fertilizers in the recent years?

Are you expecting to receive subsidies in following years?

Cost of the organic fertilizer

(€/kg)	(€/kg)	(€/kg)

How do you store it?

How do you apply it?

Are there any benefits on application of organic fertilizer?

If so, what kind of benefits

☐ Good yield ☐ Improve quality ☐ Improve appearance

☐ No benefits ☐ Can't say

Use of digestate as fertilizer

Have you heard of biogas plants: ☐ Yes☐ No

Have you heard of benefits of biogas process and its by-products?

☐ Biogas ☐ Digestate ☐ Haven't heard

Are you aware that digestate contains all the nutrients required for crop growth?

☐ Yes ☐ No

Are you familiar with using digestate as a fertilizer? ☐ Yes☐ No

Would you purchase vegetables or fruits grown with digestate fertilizer?

☐ Yes ☐ No

If not, why?

☐ Pathogen ☐ Dirty material ☐ Not hygienic ☐ Safety

☐ Something else ____

Would you approve if your neighbor were using digestate as a fertilizer?

☐ Yes ☐ No

If not, why?

Would you be willing to use digestate originating from a wastewater treatment plant as a fertilizer for your crops? The digestate is one of the end products of the biogas process.

☐ Yes ☐ No

Would you be willing to use the liquid fraction (reject water) of the digestate as fertilizer?

☐ Yes ☐ No

If not, why?

☐ Pathogen ☐ Smell/odours

☐ Not hygienic ☐ Safety ☐ Dirty material

If yes

Which is the furthest distance you would be willing to acquire organic fertilizer from?

For digestate: For liquid fraction of the digestate:

Do you have the technology needed to spread liquid fertilizers in your fields?

For which crops (if not all) would you like use the digestate?

	Fruits		Cereals		
	Vegetables		Pulses		
	Trees		Grasses		All crops

Would you be willing to handle the digestate yourself?

☐ Yes ☐ No

Are there other members of your family than you that would be handling the digestate? Who?

How do you plan to handle/apply the digestate?

Would you like to get training or education on how to use and handle digestate from sewage sludge?

☐ Yes ☐ No

Would you be able store the digestate yourself or would you rather be willing to use it right after purchase?

☐ Store it ☐ Use it right away ☐ I don't have the possibility to store the digestate

Where would you store the digestate?

Would you be willing to pay for digestate as a fertilizer?

Would you consider using the same amount of money that you currently use for inorganic/organic fertilizers for digestate originating fertilizer?

☐ Yes ☐ No

If not, why so?

☐ I would not use digestate as fertilizer ☐ I'm happy with the current fertilizer

☐ I think organic fertilizers ought to be cheaper ☐ I prefer inorganic fertilizers

☐ Something else: ____

Do you have any agricultural waste that you would be willing to give to the biogas process if you could in turn receive digestate?

Do you have the possibility to store the organic waste at your farm?

What do you like to know about the digestate and its use in agriculture?

Thank you for your answers!