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Abstract

Manure treatment technologies have been developed in Europe to better use animal manures and to reduce their environmental impact, but the adoption of these technologies in practice is regionally diverse and still limited. Also, little is known about the opinions of stakeholders towards manure treatment. This study aimed to identify stakeholder perceptions of (1) which factors can facilitate and hinder the implementation in practice, (2) which technologies have the most potential for successful adoption, and (3) how farm characteristics and scale of treatment operations affect priorities for technology adoption. This analysis used data from a survey of various stakeholders engaged in manure treatment in four European countries (Denmark, Italy, the Netherlands and Spain) that have large areas of high animal density, but diverse socio-economic, political and environmental conditions. Pressure from governmental regulations was perceived as a key factor that stimulated manure treatment in all four countries (70% of respondents). Processing manure to produce bioenergy was considered important in Denmark and Italy, but less important in Spain and the Netherlands. The major barriers to technology adoption were related to economic factors -lack of investment capital (60% of respondents), high processing cost (52%) and a long payback period (45%), while there was relatively little concern regarding transport and noise burden and health risks. Slurry separation and anaerobic digestion were perceived to have the greatest potential for a common adoption. Other preferred technologies were more country-specific (e.g. acidification in Denmark, composting in Spain, and drying and reverse osmosis in Netherlands). Manure treatment was considered to be less applicable at small livestock farms. Separation, composting and acidification were perceived to be more applicable at farm scale, while drying, anaerobic digestion, reverse osmosis at large, industrial scales. Our results imply that manure treatment will remain a regional activity. Policy measures and outreach strategies to alleviate the main barriers to the adoption of manure treatment are suggested.

Keywords: Acidification; Anaerobic digestion; Economic barriers; Environmental regulations; Separation; Survey

1. Introduction

Animal manures are valuable sources of plant nutrients, soil organic matter and bioenergy. However, following the introduction of relatively cheap inorganic fertilizers from the 1950s onwards, animal manures were increasingly considered as a waste, especially in affluent countries (e.g., in Europe and North America; Van der Meer, 1987). Recently, inappropriate use and inefficient recycling of animal manures, particularly in regions with high animal density, have exerted a series of negative impacts on the environment, e.g. eutrophication of ecosystems, soil acidification and global warming (Steinfeld et al., 2006). In Europe, the livestock sector is currently responsible for about 80% of total European ammonia (NH_3) emissions, 10-17% of greenhouse gas (GHG) emissions, 40-50% of diffuse nitrogen (N) and 70% of inorganic phosphorus (P) losses to inland and coastal water (Leip et al., 2015). In response, a series of governmental policies have been implemented by the European Union (EU) and some of its Member States to improve the utilization of manure nutrients in agriculture and therefore decrease their environment impact (Oenema et al., 2011). These policies have contributed towards the development of manure treatment technologies, which are important for achieving cleaner production in livestock husbandry.

Historically, manure has always been treated and used for various purposes. Attempts to produce biogas from manure date back to the 10th century B.C. (Bond and Templeton, 2011). Efforts to recover specific nutrients or to increase the agronomic value of manure date from the second half of the 20th century (Van der Meer, 1987). Manure has been dried and used as fuel and building material probably as long as there has been animal agriculture. A wide range of new manure treatment technologies have been developed and are now available in Europe. These technologies are considered to be of great importance for the development of sustainable agricultural systems and societies (Foged et al., 2011a; Sommer et al., 2013). Several technologies (e.g. slurry acidification, anaerobic digestion) are used to decrease ammonia and/or GHG emissions from animal manure, and thereby decrease the risk of climate change and acidification of ecosystems. Technologies have been developed to produce renewable energy from manure, for instance, through anaerobic digestion (i.e. biogas production) and incineration (Billen et al., 2015; Kimming et al., 2015). Manure-based bioenergy production decreases CO_2 emissions by substituting fossil fuel for power and electricity production, and therefore is a crucial contributor to the development of bio-economy. Other technologies (e.g. solid-liquid separation, drying, composting, reverse osmosis) have been developed to improve manure handling and transportation characteristics (Sommer et al., 2013). In addition, various manure-based products resulting from these treatment technologies provide opportunities for better nutrient management in agriculture. These products may reduce unnecessary mineral fertilizer use and so the associated resource use and environmental pollution from fertilizer production (Sommer et al., 2013).

Implementation of manure treatment technologies in practice is however limited and regionally scattered in the EU. Less than 10% of the total animal manure production (excluding excreta of grazing animals) was processed in the EU-27 in 2010, with large variations between countries (Foged et al., 2011a). The extent to which treatment technology advances in a country can be influenced by governmental policies and the perceptions of key stakeholders. Environmental policies and legislations vary between EU countries. Although EU Directives set the framework in which all Member States must create legislations directed at civilians/industries to attain the EU-scale objectives, Member States have some flexibility to implement these Directives (Oenema et al., 2011). For example, there is flexibility in the design of national action programs and the use of mitigation measures and techniques in the Nitrates Directive (1991/676/EC) and National Emission Ceiling Directive (2001/81/EC). In addition, differences in farming systems and environmental conditions in the EU, combined with the complexity of manure management and nutrient recycling, can also affect the adoption of treatment technologies (Sommer et al., 2013). To facilitate the proper development of manure treatment technology, there is a need to improve understanding of the reasons for the limited and scattered implementation of these treatment technologies in practice in the EU, especially in regions with high animal density.

While extensive research has been conducted to evaluate the technical, environmental and economic performance of manure treatment technologies in EU, stakeholder opinions regarding the factors influencing manure treatment in practice have not received significant consideration. The diffusion and exploitation of cleaner technologies relies on a combination of factors including governmental policies, financial incentives, technical and service support, and social acceptance (Montalvo, 2008). A better understanding of needs and perceptions of stakeholders from both the supply and demand side is essential to allow for successful innovations for sustainable production and consumption to be shared, spread and scaled up (Blok et al., 2015). The development of manure treatment involves stakeholders across government, industry, academia, extension services and agricultural production sectors. Integration between policy fields, expert bodies and types of expertise is increasingly required in framing and assessing these EU environmental policies (Kowarsch, 2015). Stakeholders from different sectors may have diverse opinions regarding the objectives of a policy measure as well as on the relevant actions needed to achieve it (Petit and van der Werf, 2003; Van Dam and Junginger, 2011). Policy makers and researchers generally have a broad picture of environmental issues and manure management at regional and national scales. In contrast, the experience of individual farmers are more tied to a particular farm environment, and their decisions are shaped mostly by local socio-economic conditions (Asai et al., 2014; Ingram, 2008). Agricultural advisors have an fair understanding of a group of farmers and their farms through regular contact, enabling them to develop a geographically broad impression of the farming community (Ingram, 2008). Increased understanding among stakeholders involved in the system can help to overcome barriers to the adoption and exploitation of manure treatment technologies.

Few studies have been conducted to investigate stakeholder perceptions of factors influencing the adoption of manure treatment technologies. Examples include studies focusing on composting (Viaene et al., 2016), slurry separation (Gebrezgabher et al., 2015) and anaerobic digestion (Dahlin et al., 2015; Hoppe and Sanders, 2014) in several EU countries. A study in the Netherlands reported that farmer attitudes toward the various properties of manure separation technology were important determinants of adoption. Farmer attitudes were positive towards the agronomic attributes of separation such as the ability to use nutrients (e.g. N and P) in manure optimally, but the economic benefits were generally not appreciated (Gebrezgabher et al., 2015). Barriers to on-farm composting in Belgium were studied based on interviews with stakeholders, which found that strict regulation, considerable financial investment, and lack of experience and knowledge were hindering on-farm composting (Viaene et al., 2016). An analysis of stakeholder perceptions in the biogas production chain in several EU countries indicated that biogas producers and digestate suppliers face many risks and challenges, primarily linked to high financial cost (and sometimes little incentives), legal constraints for operation and market barriers to digestate application (Dahlin et al., 2015; Hoppe and Sanders, 2014). These studies have illustrated that the adoption of manure treatment technology is likely to be affected by a wide range of diverse socio-political, environmental and agronomic factors. There is a need for better understanding of stakeholder perceptions of factors that currently influence manure treatment and also their perspectives regarding successful adoption of these technologies in future.

This study aimed to provide empirical insights into: (1) what stakeholders perceive as important to facilitate or hinder the implementation of manure treatment in practice, (2) stakeholder views of the technologies that have the most potential for successful adoption, and (3) how the preference of technologies with the most potential differs between farm types, farm sizes, and scale of treatment operations. To achieve these objectives, a survey of stakeholders from various groups was conducted in four EU countries: Denmark, Italy, the Netherlands and Spain. All selected countries have large areas of high animal density, but diverse political, farming and environmental contexts.

2. Methods

This section includes a description of the countries surveyed (Section 2.1), stakeholder categories (Section 2.2), the questionnaire structure (Section 2.3) and the methods regarding data collection and analysis (Section 2.4).

2.1 Country selection and context

Denmark (DK), Italy (IT), the Netherlands (NL) and Spain (ES) were selected to represent European countries that have highly-intensive animal production, and as a result, large pressure for manure handling and management (Fig. 1). Average livestock densities are 1.9 and 3.6 livestock units (LU) per ha of utilized agricultural area in DK and NL, respectively (compared to the EU-27 average of 0.8 LU ha^{-1}). In the north of IT (e.g. Lombardy and Veneto regions) and in some regions of ES (e.g. Catalonia and Murcia regions) livestock densities are also higher than 1.5 LU ha^{-1} (Fig. 1).

These four countries were also selected because they vary in governmental policies, manure management systems and environmental conditions (Table 1). All four countries need to comply with the Nitrates Directive, which aims to protect water quality by promoting good farming practices and preventing the pollution of groundwater and surface waters by nitrate from agricultural sources (including animal manure). The implementation of the Nitrates Directive has had a great influence on manure management (Velthof et al., 2014). The whole territories of DK and NL have been designated as the so-called “Nitrate Vulnerable Zones"

(NVZs), while the NVZs cover approximately 21% of total agricultural area in ES and 32% in Italy. Derogations have been granted for specific regions/farms in DK, IT and NL, which allow them to go beyond the limit of 170 kg N ha^{-1} of manure application, while there is no derogation in ES. Renewable energy action plans differ between these countries, e.g. the use of animal manures for renewable energy production (Table 1). Soil organic matter is key to soil quality and productivity, and plays a major role in modifying chemical, microbiological and physical properties in ways that improve soil fertility. Mean organic carbon contents in the top soils are < 15 g C kg^{-1} in most regions of ES, while > 30 g C kg^{-1} on average in NL (de Brogniez et al., 2015; Reijneveld et al., 2009). The organic carbon content of the soil may affect decisions about the most suitable use of manure as a source of organic matter to improve soil quality (Diacono and Montemurro, 2010). In DK and NL, manure management systems of dairy cattle are dominantly slurry-based, in contrast to the large fraction of solid-based systems in ES and IT (Table 1).

2.2 Stakeholder groups

Six stakeholder groups with expertise in the domain of manure treatment were chosen for this study: (i) livestock farmers; (ii) members of the board of farmers' organizations; (iii) agricultural advisors and consultants; (iv) developers and users of treatment technologies from industry (also including contractors with manure treatment facilities); (v) employees of public authorities (working on the development and control of agri-environmental policies); and (vi) researchers from academic institutions (with expertise in animal manure treatment) (Table 2).

2.3 Questionnaire design

The survey consisted of 62 questions divided into five sections. Section 1 dealt with respondents' experience in manure treatment. Section 2 related to opinions on factors that stimulate and hinder the implementation of manure treatment in practice. The selection of these factors (presented in the questionnaire) was based on peer-reviewed studies (e.g., Gebrezgabher et al., 2015; Hoppe and Sanders, 2014; Montalvo, 2008) and views of experts (including the authors) in the research of farm-based studies in the surveyed countries. Section 3 aimed to investigate stakeholder opinions about the technologies that have the most potential for successful adoption. Eight common treatment technologies were listed in the questionnaire: solid-liquid separation, acidification, anaerobic digestion, biological nitrogen removal, composting, drying, combustion/ incineration, and membrane filtration/ reverse osmosis (Foged et al., 2011a). A brief description of each of these technologies is provided in Appendix A. For each technology there were four follow-up questions to investigate why, how and where the selected technologies had the greatest adoption potential (considering farm type, farm size and scale of operation, and the benefits of each technology). Section 4 collected demographic information, including employment categories (to distinguish between stakeholder groups) and farm characteristics (in the case of farmers). The final section allowed respondents to submit any other comments and to give contact information (if they wished to receive the results of the study). Respondents could write additional comments and suggestions for each question (under the response 'other').

2.4 Data collection and analysis

The survey was performed through both face-to-face interviews and online questionnaires, with support from the academic institutions that participated in the joint EU project ReUseWaste [1]. The electronic version of the questionnaire was designed using SurveyMonkey™. The questionnaire used for face-to-face interviews was the same as that used for the online survey. Data were collected between April 2014 and June 2015.

[1] ReUseWaste: http://www.reusewaste.eu/

Survey dissemination strategies differed between countries. In DK, surveys were disseminated by researchers from the University of Copenhagen via an email that described the purpose and background context of the survey, and included a link to the online survey. Agricultural advisors were contacted via a database of advisors obtained from the Danish agricultural extension service (110 advisors were randomly selected; 32 of them completed the survey, Table 2). A list of other stakeholders was prepared via personal contacts. For instance, the questionnaires were emailed to 18 researchers with expertise in manure management and treatment (in Aarhus University, University of South Denmark and the University of Copenhagen), 20 officers in local and national governmental department (e.g. the Danish Environmental Production Agency, the Danish AgriFish Agency), and to the chairmen of 45 farmers' organizations in DK. Similarly to DK, all surveys were disseminated via email and completed online in NL. Requests were sent to target stakeholders (except for researchers) via the secretaries of two large (branch) organizations i.e., CUMELA and Nutrient Platform, and of the main farmers' organization LTO.[2] Furthermore, a selection of 20 researchers from Wageningen UR with expertise in manure management and treatment were asked to complete the questionnaire. In ES, the questionnaire was completed online by stakeholders from the research, industry, extension service and policy communities who were selected and contacted by researchers from the Spanish National Research Council (CSIC). The questionnaire was completed via face-to-face interviews with farmers, instead of by an online survey, as it was considered that farmers would generally have limited access to the internet and were not familiar with online questionnaires. Livestock farmers were visited at their homes (one by one) in regions of high livestock density (Murcia and Catalonia) by researchers from CSIC. These farmers were selected via the contact of local agricultural advisors and also according to their willingness to participate. A hard copy of the

[2] CUMELA: http://www.cumela.nl/, Nutrient Platform: http://www.nutrientplatform.org/, LTO: http://www.lto.nl/.

questionnaire was presented to the respondents. Interviewers were instructed not to present their own opinions, but only to clarify the questions in case farmers did not understand. Results of the face-to-face interviews were uploaded to the SurveyMonkey™ database and analyzed alongside online responses. In IT, stakeholders from the research, industry, extension service, and policy communities were surveyed during two national agricultural meetings held in 2014 (November and December), and further interviews were subsequently conducted via personal contacts of researchers from the University of Turin. Efforts were made to ensure the privacy of the face-to-face interviews, and respondents were interviewed one by one. Respondents representing livestock farmers and members of farmers' organizations came mainly from areas where animal husbandry is highly intensive, i.e. Northern Italy (Piedmont, Lombardy, Emilia Romagna and Veneto). In total across all the countries 291 surveys were completed; each stakeholder group had between 18 and 75 respondents (see details in Table 2 and Section 3).

A draft of the survey was sent to researchers (more than 20 in total) in the four countries to improve clarity and reduce the chance of misinterpretation. Comments and suggestions on the draft questionnaires were used to modify the survey before distribution. The same survey was disseminated to the four target countries, but translated (into Danish, Dutch, Italian and Spanish). The English version of the questionnaire is provided in the supplementary material associated with this article.

Data downloaded from the SurveyMonkey™ were compiled and analyzed using R version 3.0.0 (e.g. Crosstab function) and Microsoft Excel 2010. The number of positive ticks to each option of a question (i.e. the number of respondents) was recorded. Results were analyzed by individual countries and also with the sum of all countries. Since there were multiple-response questions in the questionnaire, the absolute number of respondents referring to each answer of a question was converted to the percentage of the total number of respondents who answered the question. This conversion allowed for the comparison of different variables listed in a question, as well as a comparison between countries.

3. Results

Table 2 provides an overview of the number of respondents per stakeholder group and country. In total, 291 questionnaires were completed: 28% in DK, 22% in ES, 23% in IT, and 27% in NL. A total of 82% of the respondents had experience with manure treatment (Table 2). More than 50% of those had experience with manure separation and anaerobic digestion, except for respondents in ES (Fig. 2). Over 70% of respondents in DK had experience with slurry acidification. In ES, most respondents (40%) had experience with composting. Respondents from NL had more experience with manure drying and membrane filtration (or reverse osmosis) (Fig. 2). Few respondents answered that they had experience with alternative treatment technologies that were not offered as possible responses in the question, e.g. ammonia stripping from liquid manure, phosphorus recovery, or evaporation of liquid manure.

3.1 Factors that stimulate and hinder adoption

Pressure from environmental policies was perceived to be the most important factor affecting the implementation of manure treatment in practice (70% of total respondents), which was the case for respondents from all four countries and all stakeholder groups (Fig. 3; Appendix B.1). The need to facilitate the export of manure from the farm (47%, especially in DK and NL) was also highlighted by many respondents. The need to achieve renewable energy targets by producing bioenergy from manure was ranked relatively highly in DK and IT. Compared to the other factors considered, the need to efficiently use manure nutrients due to increased fertilizer prices was considered relatively important in ES. For all countries, controlling diseases, pathogens and odor was considered the least important among the six factors defined in the survey (Fig. 3).

Economic factors were the main barriers to the implementation of manure treatment in practice, namely the lack of investment capital (60% of total respondents), high processing costs (52%), and a long payback period (45%). These barriers were perceived to be important for all countries (Fig. 4) and by all stakeholder groups (Appendix B.2). Legal constraints (32% of all respondents, highest at 45% in NL) and lack of knowledge (32% of all respondents, especially in ES and IT) were chosen by a moderate number of respondents. Transport, noise burdens and health risks were not seen as important barriers among all stakeholder groups (Fig. 4; Appendix B.2). Interestingly, livestock farmers and agriculture advisors had relatively little concern about the market for manure processing products (Appendix B.2). This suggested that these farmers were possibly interested in using processed organic fertilizers, which is confirmed by the results from a parallel study on farmer perceptions of organic fertilizers in Denmark (Case et al., unpublished results).

3.2 Preferred treatment technologies

Stakeholders indicated that manure separation and anaerobic digestion had the greatest potential for a common adoption in practice (36% and 42% of total respondents, respectively). Other technologies appear to be more country specific. There was a relatively high adoption potential for slurry acidification in DK (47%) and composting in ES (44%), while drying of solid manure fractions and membrane filtration (or reverse osmosis) of liquid fractions were considered positively in NL (Fig. 5).

3.3 Preferred farm structure and scale of operation

Fig. 6 shows that livestock farms with a limited area of land were considered to have a relatively high adoption potential for all of the manure treatment technologies considered with the exception of slurry acidification (Fig. 6a). This exception is possibly due to the fact that farms with sufficient land are more willing, or are required to use techniques that reduce ammonia losses from on-farm storage and application of manures. Overall, manure treatment was considered to be more applicable to pig and cattle farms than to poultry farms (Fig. 6a).

Manure treatment was considered to be less applicable to small livestock farms (i.e. <50 LU). Drying and reverse osmosis technologies were perceived most appropriate for large livestock farms (> 1000 LU) (Fig. 6b).

Stakeholders had different views regarding the optimal scale of the manure treatment plant (Fig. 6c). Separation (67% of respondents), acidification (55%) and composting (52%) were perceived to be most applicable at the farm scale. Anaerobic digestion, drying (pelletizing) and membrane filtration were considered to be most applicable at the industrial scale and for farmer cooperatives (Fig. 6c).

3.4 Benefits of manure treatment

Table 3 shows respondent perceptions of the benefits of manure treatment. A reduction in manure disposal costs and an increase in the fertilizer value of separated liquid and solid fractions were ranked as the main benefits of manure separation. For anaerobic digestion, the main benefits included bioenergy production, the increased fertilizer nitrogen value of digestate, and the reduction of odor and gaseous emissions during further processing and field application. Mitigation of ammonia emissions during slurry storage and application, and the increased fertilizer N value of slurry were ranked as the main benefits of slurry acidification. Increased organic matter quality of manure and improved soil quality after field application were ranked as the main benefits of composting.

4 Discussion

Currently, less than 10% of the animal manure produced in EU is treated and most farmers have little knowledge about manure processing technologies (Foged et al., 2011a). In the present study the survey was disseminated to stakeholders involved in manure treatment, directly or indirectly. This explains why over 80% of the respondents described themselves as having at least some experience with manure treatment. Most of the stakeholders contacted within each group (farmers, farmers' organizations, extension service, industry, policy and research) were considered to be forerunners in the whole domain of the development, implementation and management of manure treatment technologies. By exploring the views of these stakeholders engaged with manure treatment, a better understanding of the future perspectives of manure processing is possibly achieved.

4.1 Key factors that stimulate manure treatment in practice

Pressure from environmental policies and regulations was identified as the most important stimulus for the implementation of manure treatment systems (Fig. 3). This may reflect the fact that current policies and regulations implemented in these four countries have influenced stakeholder decisions on manure handling and management activities. A number of policies have been implemented by the EU and United Nations (UN) bodies to reduce environmental pollution from animal manures (Oenema et al., 2011), which play an important role in stimulating manure treatment activities in Europe. The EU Nitrates Directive sets up the maximum application limit of manure in NVZs, equivalent to 170 kg N ha^{-1} $year^{-1}$ (European Commission, 1991). This limit obliges livestock farms to treat and/or to transport the excess manure to other farms. The EU National Emission Ceiling Directive (European Commission, 2001) aims to reduce emissions of ammonia (NH_3) (including from manures), and thereby stimulate the development of certain manure treatment technologies (Bittman et al., 2014). For example, acidifying slurry was introduced as one of the options for obligatory NH_3 mitigation measures by Danish regulations in response to these EU Directives. On the other hand, the use of manure treatment may remain marginal in regions that have low pressure from these regulations. The authors conducted also a similar survey in Portugal, but the number of responses from targeted stakeholders was small and hence results are not shown. A low response rate from Portuguese stakeholders (in particular farmers) may reflect that the interest for manure treatment is low in regions that have sufficient land for application of the manure produced, as well as low pressure from governmental legislation. These results revealed that variations between countries in manure treatment have a strong relationship with variations in livestock density and national policies.

Producing bioenergy from animal manures was identified as an important reason for the adoption of manure treatment in practice, in particular in DK and IT (Fig. 3). Anaerobic digestion produces biogas that can be used directly for heating, for combined thermal and electricity generation, or to upgrade to bio-methane that has similar characteristics to natural gas (Bernet and Béline, 2009). Using animal manures as feedstock for biogas production has advantages compared to using energy crops, such as less competition with food production and higher mitigation potential of greenhouse gas emissions (De Vries et al., 2012). Further, the digestate can serve as an improved organic N fertilizer (Table 3). The development of biogas production in European countries has been influenced strongly by environmental regulations and the EU Renewable Energy Directive (Edwards et al., 2015). The growth of anaerobic digestion in DK is largely due to policy incentives such as increased investment support for construction of biogas plants, the implementation of fossil energy taxes or renewable energy tariff subsidies and the government support strategies to increase interactions between various social groups (Raven and Gregersen, 2007). Italy has also witnessed an extraordinary growth in biogas generation from animal manures and other agricultural biomass in the last few years, which is largely due to the biogas support programs implemented in Italy (the introduction of Tradable Green Certificate and feed-in-tariff, and increased investment subsides) (Chinese et al., 2014). In comparison, manure-based biogas producers in NL and ES face many financial and socio-political challenges (Fierro et al., 2014;

Hoppe and Sanders, 2014), which may explain why biogas production was perceived as less attractive in these two countries (Fig.3 and Fig. 5).

The pressure from increased fertilizer price was perceived to be important factor for stimulating manure treatment in ES (Fig. 3), which is in line with the conclusion from a study that investigated the existing experience on manure treatment in Catalonia, a region with high animal density in ES (Flotats et al., 2009). The increase in prices of mineral fertilizers could explain the recent growth in composting facilities in Catalonia, in order to recover nutrients in organic forms and produce soil organic amendments that are economically valuable (Flotats et al., 2009). The need to facilitate off-farm manure export was considered to be relatively important in NL and DK, where the average LU is high and a large portion of farms have been involved in manure exchange (Asai et al., 2014); it appears to be less important in ES partly due to the average low animal density (Fig. 1).

4.2 Key barriers to manure treatment in practice

The most important barriers to the implementation of manure treatment in practice were related to economic factors (Fig. 4). This corresponded with findings from several other studies. Results from a survey among 111 Dutch dairy farmers indicated that nearly half of respondents strongly disagreed with the statement that low cost of manure separation is a reason for them to consider the use of manure separation, while only 13% of respondents agreed (Gebrezgabher et al., 2015). Substantial upfront investments, subsidies not being granted, and increased price of co-feedstock were identified as important barriers for biogas producers in NL (Hoppe and Sanders, 2014). In the present study, most respondents (who perceived that anaerobic digestion had the most potential for adoption) stated that subsidies for upfront investment and/or energy production were vital for anaerobic digestion of animal slurries in practice (data not shown). This confirms results from previous studies that subsidies play a large role in the profitability of biogas plants (Chinese et al., 2014; Gebrezgabher et al., 2010; Riva et al., 2014).

A number of respondents brought up legal constraints as an important issue hindering the implementation of manure treatment (Fig. 3). A Dutch respondent indicated that “Licensing can be very restrictive in realizing initiatives, due to lack of objective knowledge (on manure processing) among local residents and licensing authorities”. Likewise, a stakeholder study indicated that legal permits to operate biogas plants were difficult to attain in NL, partly because municipalities did not yet have specific biogas polices in place and therefore there were few staff trained in how to deal with permit requests for co-digestion plants (Hoppe and Sanders, 2014). A Danish respondent also stated that “It is difficult or impossible to get authority approval for treatment operations, because of the resistance of the local community”. Therefore, outreach strategies should be developed to provide more information to local residents, authorities, and extension services regarding the benefits and risks of manure treatment so as to increase social acceptability.

4.3 Differences in priorities of technology adoption and operation structure

The choice of prioritized technologies generally corresponded with the technologies for which respondents had experience (see Fig. 2) and the status of manure processing activities in the countries surveyed (Foged et al., 2011a). An EU inventory study reported that slurry separation was used most in IT and ES; anaerobic digestion was predominantly applied in Germany, followed by IT and DK; and slurry acidification was mainly adopted in DK, while ES had the largest share of composting operations (Foged et al., 2011a). Slurry acidification in DK is typically applied to raw animal slurries either in the animal house (thus reducing emissions from both housing, slurry storage and field application) or immediately prior to land application (in the slurry storage or on the slurry tanker during field application, thus only reducing emissions in the field) (Fangueiro et al., 2015; Kai et al., 2008). In this study, composting was identified to have considerable growth potential in ES (Fig. 5). This is partly because of the low soil organic matter content of arable land in ES (< 15 g C kg^{-1}; de Brogniez et al., 2015) and the ability to improve soil quality following the application of compost (Bernal et al., 2009). Composting was not ranked highly in DK and NL, where soil organic matter contents are relatively high (de Brogniez et al., 2015). Solid-liquid separation, drying of solid fractions and reverse osmosis of liquid fractions (to concentrates) were considered as attractive technologies for livestock farms with a limited area of land in NL (Fig. 5). This may have been chosen due to the need to comply with policy regulations. Obligatory manure treatment was introduced in NL in 2013, which designated that livestock farms with a manure surplus have to treat and/or to export a certain percentage of the surplus. Thus, the need to transport manures can greatly increase the use of treatment technologies that reduce the volume of liquid (separation and reverse osmosis) and solid fractions (drying and pelletizing). Manure-based anaerobic digestion was prioritized in DK (Fig. 5), mainly due to Danish government policy. The Danish government proposed a target of using 50% of the manure produced in DK for renewable energy by 2020, which would need to be met through a strong expansion of biogas plants and capacity (Danish Ministry of Food, Agriculture and Fisheries, 2009).

Farm size and treatment plant operation structure are important for the implementation of manure treatment technologies (Flotats et al., 2009; Gebrezgabher et al., 2015). Clearly, land-limited large farms with >300 LU (representing farms with high animal density) have larger potential (or need) for the adoption of manure treatment than small farms (Fig. 6). Separation and composting were generally considered to be farm-scale treatment technologies, while manure drying and reverse osmosis were considered most applicable at large, industrial scales (Fig. 6). The complexity of the management and the costs of investments and processing varied among treatment technologies (Foged et al., 2011b). This may explain why the potential and suitability of technology adoption is related to the scale of farm and plant operations. Solid-liquid mechanical separation and composting are generally considered to be less complex in operation and of relatively low cost, compared to treatments such as anaerobic digestion and reverse osmosis (Flotats et al., 2009; Foged et al., 2011b). The annual total costs of processing (i.e. the total capacity and operational costs excluding subsidies) can vary from 0.5-3 € t^{-1} of inputs for mechanical separation and slurry acidification to 8-14 € t^{-1} for anaerobic digestion and reverse osmosis; the net costs of processing (i.e. the total costs minus the income from the sale and use of processed products and subsidies) vary form 0.5-8 € t^{-1} of inputs, or on the basis of total N treated, 0.15-3 € kg^{-1} of N (Foged et al., 2011b; Møller et al., 2000). Processing manure in a cooperative form has advantages to reduce financial risks (to individual farmers) and treatment costs, and to make manure treatment viable for small- and mid-sized farms (Flotats et al., 2009; Møller et al., 2000; Swindal et al., 2010).

5 Conclusions and recommendations

Understanding the opinions of stakeholders closely engaged in manure treatment can enhance the effectiveness of programs designed to stimulate diffusion and exploitation of these technologies. Such an understanding is an essential part of attaining EU environmental and renewable energy targets. Based on the main findings from the present study, policy requirements, outreach strategies and future research needs are suggested.

Policy requirements. Pressure from governmental legislation was identified as the key stimulant of technology adoption, while barriers to adoption were mainly related to economic factors. It is recommended that policies for the promotion of manure treatment must be economically appealing to attract new adopters (farmers and industries). Long-term financial support schemes (e.g. subsidies) must be developed to encourage potential adopters to invest, considering the long-term investment requirements of manure treatment. It is also necessary to improve permit request procedures to facilitate their acquisition for operations. Large variations in technology preference between countries, farm types and scale of operation were observed in this study. These variations need to be considered when developing policy support schemes and marketing strategies.

Outreach strategies. More information should be conveyed to livestock farmers (especially those with large, land-limited farms) and other technology users regarding the different aspects of a specific technology, i.e. financial viability, optimal operation conditions (e.g. farm size, operation scale), regulations and incentives, and the agronomic and environmental performance of the technology. Better dissemination of this information to users would alleviate the lack of knowledge and experience and thus to assist with their decisions on technology adoption. Resources should be allocated to enable face-to-face, direct mail contact, as well as internet sources for dissemination of information. Outreach strategies need to be developed to convey these important environmental benefits of manure treatment to local residents so as to increase social acceptability.

Future research needs. This study emphasizes the importance of understanding stakeholder perceptions in countries with large areas of high animal density where manure treatment should be prioritized. However, manure treatment should not be limited to these regions, considering the potential benefits of manure treatment (e.g. not only environmental but also agronomic benefits). Thus, future research addressing the perceptions of stakeholders in regions with contrasting farming systems and socio-political conditions will complement the present findings and provide a more complete picture of the development of manure treatment.

Understanding stakeholder opinions about the development of manure treatment can assist in the design of policies and outreach strategies, leading to a better use of animal manures and a sustainable production and management chain. The results from this study can serve as a basis for such efforts.

Acknowledgments

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Appendix A:..

Appendix B:..

Appendix C. Supplementary data

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Fig. 1. Livestock density in the EU-27, expressed in livestock units (LU) per ha utilized agricultural area (UAA). Data were from Eurostat (2010) for the year 2010.

Fig. 2. Response to the question: “please indicate the treatment technique(s) in which you are involved.” (multiple responses permitted). The number of respondents per country with experience in manure treatment is shown in the legend.

Fig. 3. Responses to the questions (expressed as % of respondents from all survey countries): “please indicate the top three reasons that can stimulate farmers to apply manure treatment techniques.” The number of respondents that answered this question is shown in the legend.

Fig. 4. Responses to the questions (expressed as % of respondents from all survey countries): “please indicate the three most important constraints / barriers to the adoption of manure treatment technologies.” The number of respondents that answered this question in each country is shown in the legend.

Fig. 5 Response to the question: “which techniques have the most potential to be applied in your country during the next 10 years?” The number of respondents (answered this question) for each country is shown in the legend. The number of respondents for each technology/answer is indicated in the Y-axis label.

Fig. 6. Responses to indicate which farm types (a), sizes (b, LU=livestock unit) and operation scales (c) have the most potential for adoption of respective technologies (multiple answers), expressed as % of respondents for all four countries. The number (n) of respondents is shown for each technology. Results referring to biological nitrogen removal and incineration treatment are not shown due to limited number of responses.

688 **Table 1** A comparison of political and agri-environmental characteristics selected for the four European countries.

	DK	NL	ES	IT
Policies				
-Nitrates Directive				
NVZs (% total agricultural area)	100	100	21	32
Derogation granted	Yes	Yes	No	Yes
-Renewable Energy (RE) Directive [a]				
RE from manure in 2006 (ktoe, kilotonne of oil equivalent)	~70	0	~1.6	n.a.
Estimates in 2020 (ktoe)	~145	~98	~143	n.a.
Agri-environmental conditions				
-Average soil organic carbon in top soils (g kg^{-1}) [b]	20-30	30-40	<15	15-20
-Manure management systems (% of manure N from housing) [c]				
Dairy cow	92% as slurry	99% as slurry	70% as solid	60% as solid
Other cattle	60% as solid	83% as slurry	99% as solid	60% as slurry
Pigs	95% as slurry	99% as slurry	90% as slurry	99% as slurry

689 [a] Source from National renewable energy action plans; No information (n.a.) available for Italy

690 [b] Adhikari et al., 2014; de Brogniez et al., 2015; Reijneveld et al., 2009

691 [c] Information from National inventory reports (NIR) to UNFCCC (the United Nations Framework Convention on Climate Change) for the year 2010.

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Table 2 Overview of respondents as number per country

	DK	NL	ES	IT	Total
Do you have experience in manure treatment? [a]					
Yes	73	66	55	45	239
No	9	13	7	23	52
Total	82	79	62	68	**291**
What is your job? [b]					
Farmer	10	18	35	12	75
Representative in a farmer organization	10	3	3	5	21
Agricultural advisor	32	6	1	10	49
Technology developer/ user in company	17	30	4	7	58
Employee in the public authority	8	1	3	6	18
Researcher	7	18	15	23	63
Respondents skipped this question	7	9	3	6	25

[a] single answer

[b] multiple answers

Table 3 Summary of responses to the questions asking about the benefits of each respective technology (for all four countries), measured in % of the total number of respondents for each question.

	% of respondents
What are the top three benefits of separation? (Number of respondents: n =102)	
To reduce cost of manure disposal	47
To increase fertilizer value of liquid fractions	39
To increase fertilizer value of solid fractions	34
To use solid factions for biogas production	27
To use solid fractions for composting	25
To reduce ammonia emissions from liquid fractions after field application	18
To use solid factions as bedding materials	16
What are the top three benefits of anaerobic digestion? (n=120)	
To produce bioenergy	88
To increase fertilizer nitrogen value of digestate	58
To reduce odor and gaseous emissions during processing	43
To reduce odor and gaseous emissions after field application of digestate	42
To increase soil quality after field application of digestate	13
To increase fertilizer phosphorus value of digestate	8
What are the top three benefits of acidification? (n=44)	
To reduce ammonia emissions during field application	82
To reduce ammonia emissions during storage	73
To increase fertilizer nitrogen value of slurry	68
To increase fertilizer sulfur value of slurry	27
To reduce greenhouse gas emissions during storage	25
What are the top three benefits of composting? (n=48)	
To improve the organic matter quality	54
To remove pathogens	46
To reduce the volume and mass of the manure	42
To improve soil quality after field application of compost	42
To increase economic value as compost products	40
To reduce ammonia emissions after field application of compost	19
To homogenize the manure	13
What are the top three benefits of drying/ pelletizing? (n=34)	
To facilitate export	59
To increase the market value of the manure	53
To reduce costs of transporting manure surplus off farm	41
To increase soil quality after field application of dried products	29
To decrease ammonia emissions after field application of dried products	26
What are the top three benefits of membrane filtration/ reverse osmosis? (n=25)	
To increase fertilizer effectiveness of nitrogen as concentrates	64
To make a K fertilizer	48
To reduce cost of transporting phosphorus surplus off farm	44
To remove organic matter from liquid manures	28
To reduce ammonia emissions after field application of concentrates	12

Figure 1

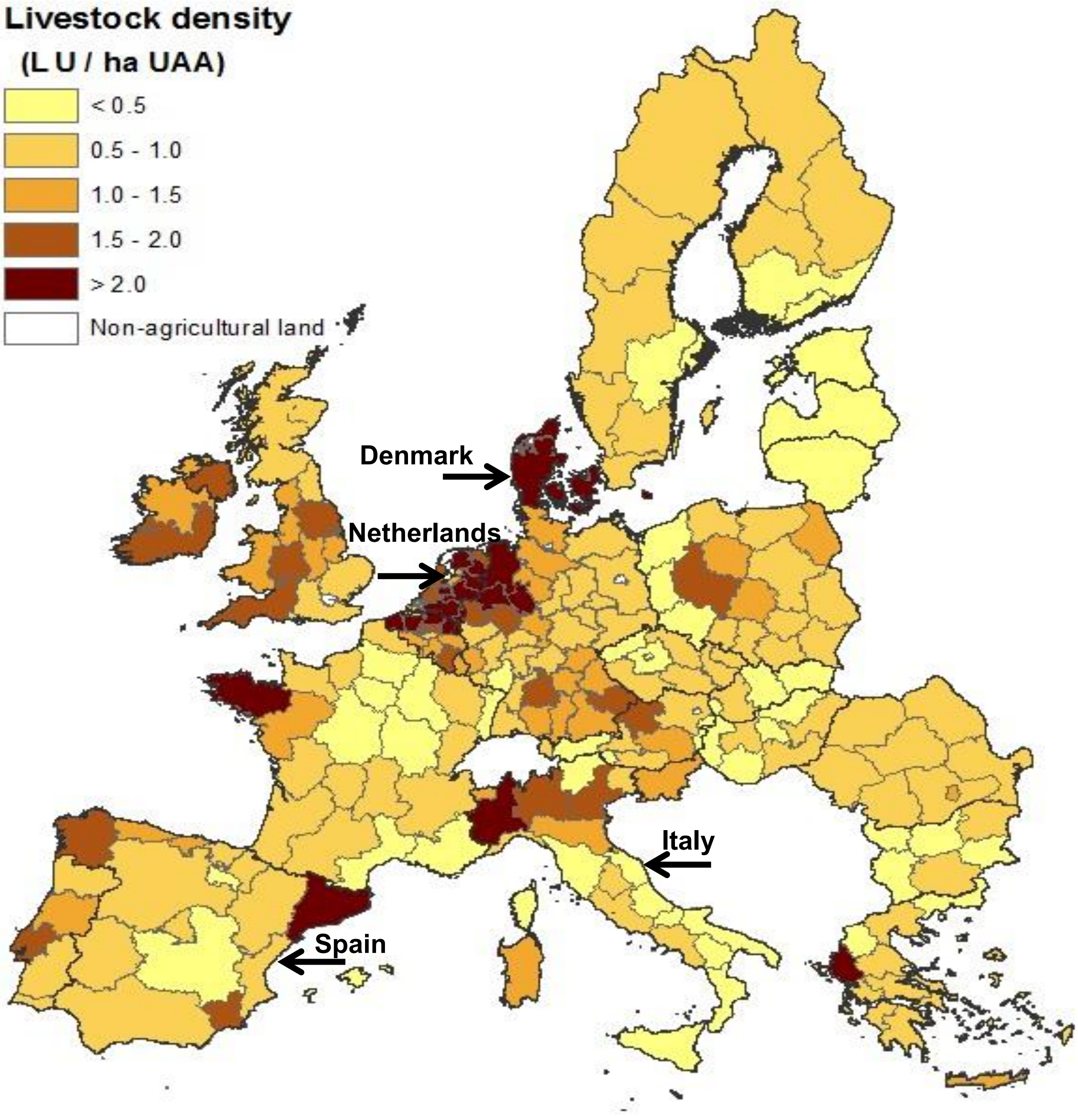

Livestock density
(L U / ha UAA)
< 0.5
0.5 - 1.0
1.0 - 1.5
1.5 - 2.0
> 2.0
Non-agricultural land
Denmark
Netherlands
Italy
Spain

Figure 2

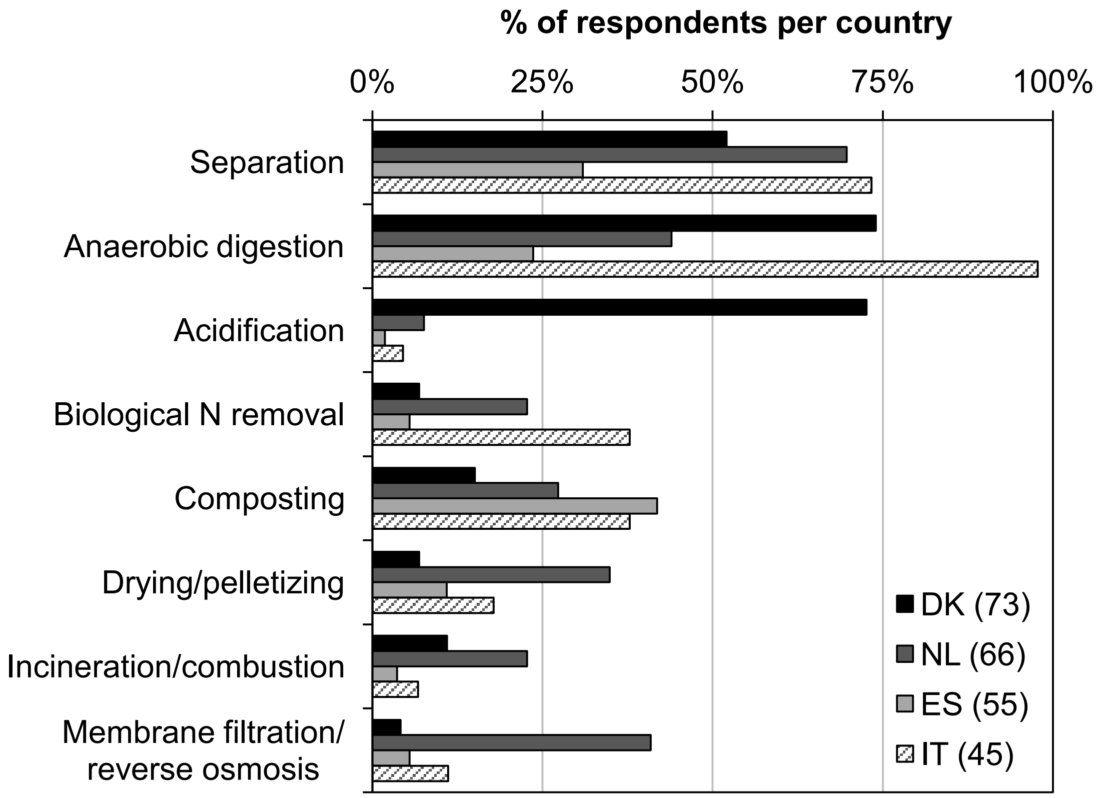

% of respondents per country
0%
25%
50%
75%
100%
Separation
Anaerobic digestion
Acidification
Biological N removal
Composting
Drying/pelletizing
Incineration/combustion
Membrane filtration/ reverse osmosis
DK (73)
NL (66)
ES (55)
IT (45)

Figure 3

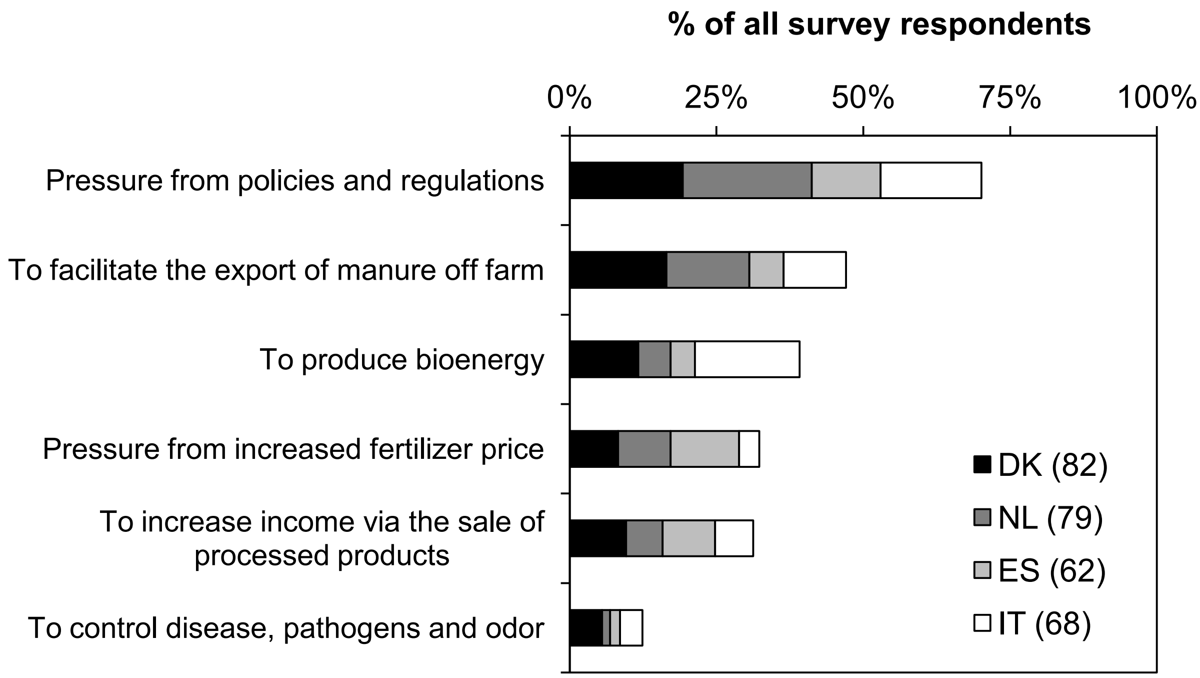

% of all survey respondents
0%
25%
50%
75%
100%
Pressure from policies and regulations
To facilitate the export of manure off farm
To produce bioenergy
Pressure from increased fertilizer price
To increase income via the sale of processed products
To control disease, pathogens and odor
DK (82)
NL (79)
ES (62)
IT (68)

Figure 4

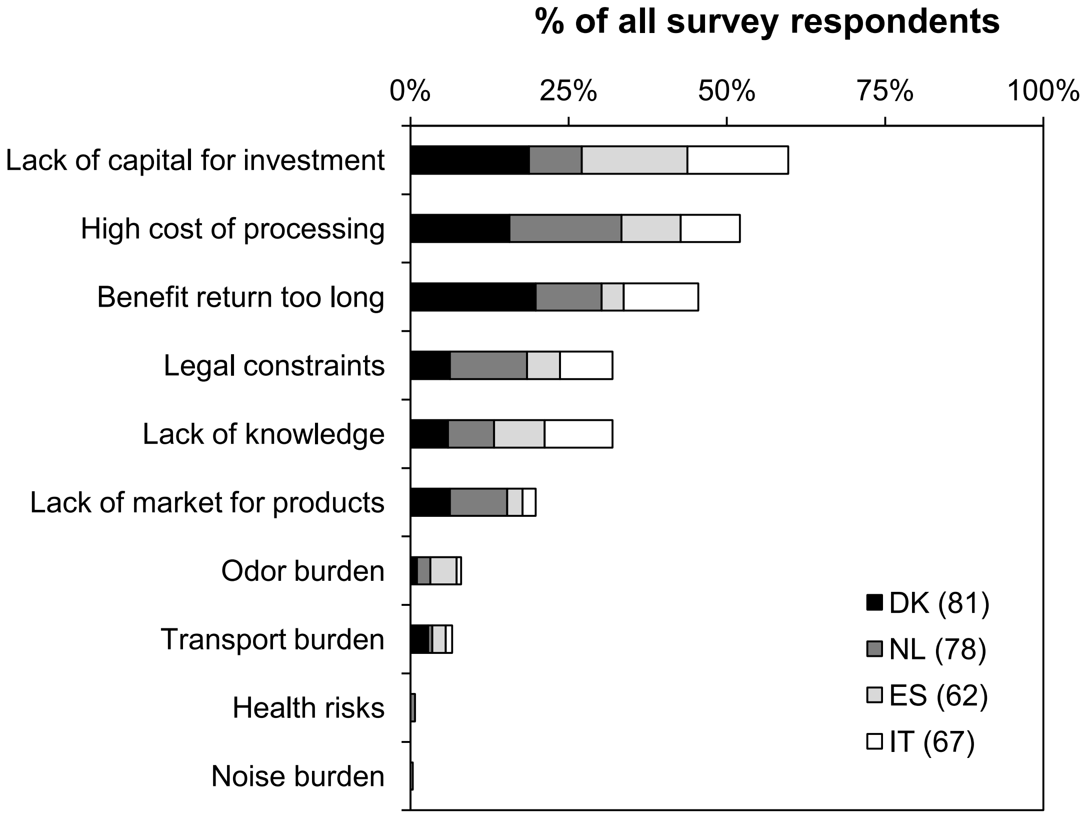
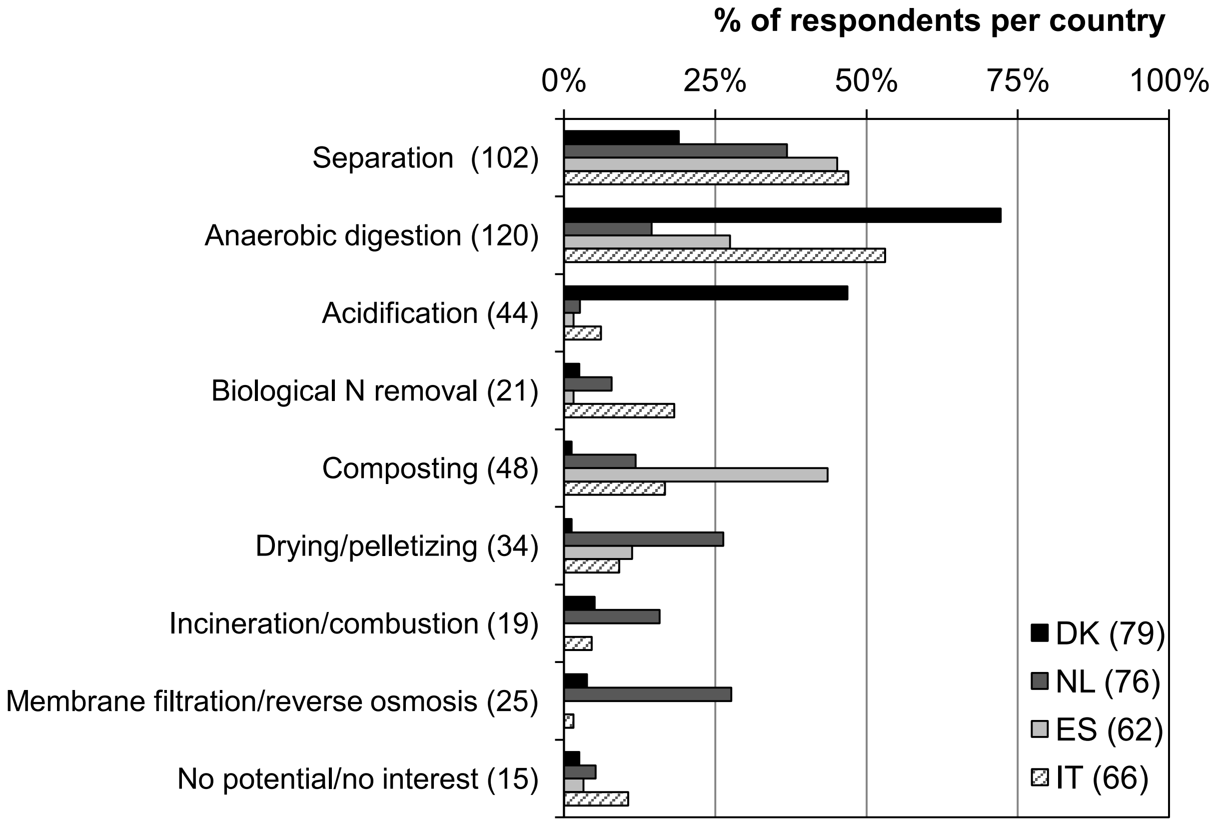
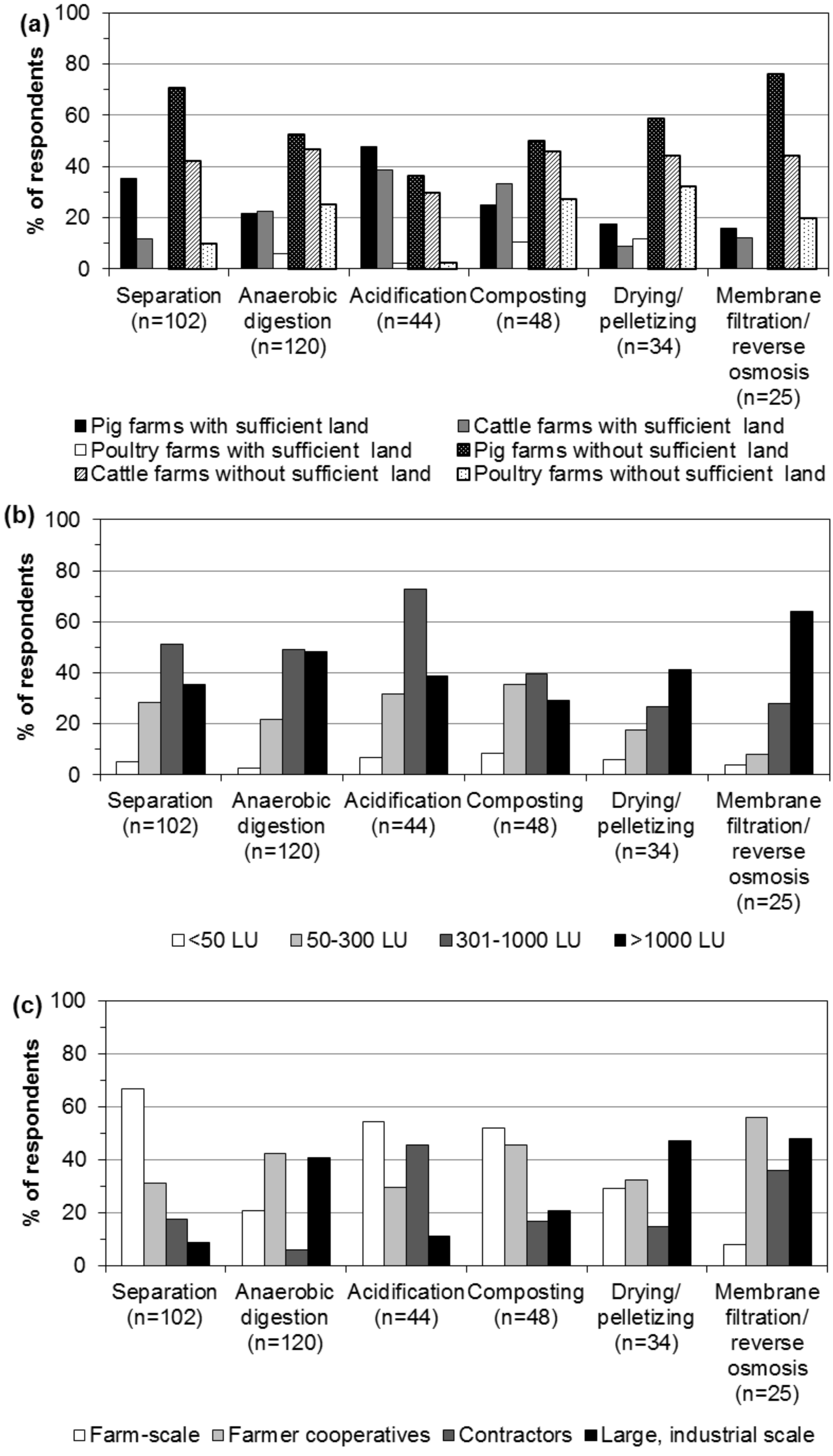

% of all survey respondents
0%
25%
50%
75%
100%
Lack of capital for investment
High cost of processing
Benefit return too long
Legal constraints
Lack of knowledge
Lack of market for products
Odor burden
Transport burden
Health risks
Noise burden
DK (81)
NL (78)
ES (62)
IT (67)

Figure 5



% of respondents per country
0%
25%
50%
75%
100%
Separation (102)
Anaerobic digestion (120)
Acidification (44)
Biological N removal (21)
Composting (48)
Drying/pelletizing (34)
Incineration/combustion (19)
Membrane filtration/reverse osmosis (25)
No potential/no interest (15)
DK (79)
NL (76)
ES (62)
IT (66)

Figure 6



(a)
% of respondents
100
80
60
40
20
0
Separation (n=102)
Anaerobic digestion (n=120)
Acidification (n=44)
Composting (n=48)
Drying/ pelletizing (n=34)
Membrane filtration/ reverse osmosis (n=25)
Pig farms with sufficient land
Cattle farms with sufficient land
Poultry farms with sufficient land
Pig farms without sufficient land
Cattle farms without sufficient land
Poultry farms without sufficient land
(b)
% of respondents
100
80
60
40
20
0
Separation (n=102)
Anaerobic digestion (n=120)
Acidification (n=44)
Composting (n=48)
Drying/ pelletizing (n=34)
Membrane filtration/ reverse osmosis (n=25)
<50 LU
50-300 LU
301-1000 LU
>1000 LU
(c)
% of respondents
100
80
60
40
20
0
Separation (n=102)
Anaerobic digestion (n=120)
Acidification (n=44)
Composting (n=48)
Drying/ pelletizing (n=34)
Membrane filtration/ reverse osmosis (n=25)
Farm-scale
Farmer cooperatives
Contractors
Large, industrial scale

Appendix A
Click here to download e-component: Appendix A.docx

Appendix B

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Supplementary info

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