

Management and Valorisation of Equine Waste: A Review and SWOT Analysis

Sigrid Kusch

Independent Research Scientist

Ulm, Germany

www.sigrid-kusch.de

Abstract—If valorisation strategies are implemented, horse manure is a valuable resource to be used as organic soil amendment and for renewable energy generation. Huge amounts of equine residues are generated in the EU and elsewhere, most of which are currently considered as waste to be disposed of, which places an additional burden on the sector. Under a SWOT analysis perspective it becomes evident that one of the key challenges lies in the fact that horse manure varies widely with view to generated quantities and contents due to utilisation of different bedding materials and different management practices. This study further aims to evaluate the challenges related to valorisation of horse manure and to identify the most promising options. Anaerobic digestion and thermal treatment are currently the two key options that hold potential for more widespread implementation of bioenergy generation in practice.

Keywords- horse manure; horse dung; equine residues; bioenergy

I. INTRODUCTION

A. Introductory Remark: Context and Aim of the Study

This manuscript represents an extended and updated version of a previously published conference contribution [1].

The study provides an overview on challenges related to horse manure handling and in particular highlights the most suitable renewable energy generation technologies. A SWOT analysis frames the main issues related both to opportunities and specific challenges in a comprehensive way, and therefore represents a good basis to further develop and advance strategies for more widespread implementation of energetic horse manure valorisation.

B. The Equine Industry: Overview

Today, in industrialised countries horses are widely domesticated, and are now mainly used in sport and leisure activities. A large number of people are highly engaged in the equine industry around the world, and especially in industrialised countries. For example, in the USA about 4.6 million people are directly involved in the equine industry [2], and the horse industry had a direct impact of 39 thousand million \$ on the economy in the year 2005, based on a horse population of 9.2 million [3]. In Germany, assessments indicate a horse population of around 1.2 million, which means an increase of a factor 4 in the past 40 years, and which provides labour for around 300,000 people generating a turnover of more than 5 thousand million EUR in the year 2012 [4]. In Sweden, the industry provides full-time employment to over 30,000 people, with increasing importance [2, 5].

The worldwide horse population has been estimated with 60 million animals in the year 2012 [4]. When taking the example of Germany as a reference, in which 3 to 4 horses generate one full-time employment [4] it can be estimated, that the global equine sector contributes to 15 to 20 million full-time employments (note: for generation of employment in the

equine industry, data have also been published for UK, US, Sweden, Austria, see e.g. [6], but an assessment at global scale is not yet available).

In Europe (EU27) alone, the horse population amounts to around 5 to 6 million, with the highest total numbers in Germany, UK and France, then followed by Spain, the Netherlands and Poland, while Sweden, Belgium and Denmark have the highest per capita numbers [5, 6]. According to studies from the Netherlands, UK and Sweden, the equestrian sector generates a direct turnover of 1,100 to 2,800 EUR per year per horse [7].

The equine sector has undergone a huge transformation mainly in the second half of the last century. Key tasks of horses in the 1950s have today been taken over by tractors and machinery, but despite this, the total number of horses has increased instead of decreased, while animals have been kept more and more for recreation and sports. Equine activities are among the few growing and most promising industries in rural areas of the EU today. In contrast to main agricultural sectors which are heavily subsidised, the current equine sector is market-driven with very little or no government intervention, and, among others, engages a peculiarly high number of women entrepreneurs and employees [7].

C. Territorial Implications and Basic Managerial Issues

Based on EU data, higher density of horse population occurs in regions with higher consumption level, higher level of education and low unemployment rates [6]. There is often and with an increasing trend a close relationship between horse keeping and proximity to urban population, which reflects that today's equine sector is mainly the result of urban consumer interest [7-10]. At the same time, equine operation can be in conflict with acceptance by the local inhabitants and with environmentally acceptable practices, in which the following reasons are relevant: surface run-off waters from paddocks and manure storage, aesthetic questions, smells and attraction of insects and rodents [9].

Unlike to other animal manures, it is quite common that at the place of generation of horse manure there is not sufficient capacity or a lack of infrastructure for its treatment. Furthermore, unlike to other animal keeping, closing material loops on site has been and is less in focus. This results into a disposal problem and in necessary transports, and can entail considerable costs. In this, management of horse manure resembles to the challenges of other organic residues generated in urban contexts, such as sewage sludge or urban biowaste.

The activities of the modern equine sector have resulted in the fact that the majority of horses are now being housed, and mainly in box stalls. Over 90% of all horses in northern and central Germany are stabled in boxes, with an average surface area of approximately 12 m² per horse [11] (referring to literature and studies). Many horses spend the majority of their time in their stall, which can easily be up to 23 hours per day. Leisure riding horses generally spend more time outside e.g. grazing, while racing horses spend most of their life in the stall [12]. The time in the stall also varies between different regions and can be significantly dependent of the season. In northern European countries such as Sweden, horses spend considerably more time in the stable during autumn and winter [13].

D. Application of Bedding Material

Because the equine respiratory tract is very sensitive, inappropriate housing can cause severe diseases. Keeping the stall dry and clean is a prerequisite for animal health and well-being. Among others, type and application of bedding material is crucial to maintain the necessary air quality and hygiene. Choice of bedding material depends on several factors:

- It should be easily and continuously available.
- It should be low in cost.
- It should be easy to use and allow for rapid and resource efficient cleaning.
- It should ensure a healthy environment, which includes that material is dust free, offers a high water binding capacity, and limits formation of gaseous ammonia.
- Resulting manure should be fit for easy and economically viable management.

Straw (e.g. wheat or rye) is the most frequently used equine bedding material in the world, either in direct use or as pellets. Numerous types of alternative bedding materials are in use, such as wood shavings, sawdust, recycled and chopped paper, peat, flax, hemp and linen shives (residues of lignified plant parts produced during hemp/linen fibre preparation). Conditioned materials such as straw pellets, hemp, linen, wood shavings are in general more expensive than straw, and in addition the disposal of the residue might be more problematic, in particular in urban areas [11]. Dedusted materials are therefore often used for specifically sensitive horses or specific fields of the equine sector. In some regions (e.g. northern Sweden), utilisation of wood shavings is most common due to great accessibility, whereas straw is less easily available [5].

Used bedding material in mixture with horse manure needs to be removed regularly in order to maintain a hygienic environment for people working in the stable and for animals.

Handling of spent horse stall bedding in mixture with solid manure is an issue of increasing concern for equine facilities due to associated costs and environmental attention. At the same time, horse manure has potential to be used for energy generation or for other valuable products. This requires a precise understanding of the characteristics of the material, knowledge about available amounts, and an assessment of suitable treatment technology.

II. AMOUNTS OF HORSE MANURE

Removal of stall waste generates significant amounts of organic material, which depends on stall management and on chosen bedding material. Practicing complete daily mucking-out generates a much higher quantity of spent material compared e.g. to a 14-day deep litter practice, in which new bedding material is added each day without removing the existent one. In practice, the faeces are often removed daily in order to reduce odour nuisances and noxious gasses [14].

It is difficult to obtain detailed data on generation of horse stall waste. One horse itself (à 454 kg) produces on average 17 kg faeces and 9 litres of urine per day (see [15], citing literature). The following figures provide an idea of the horse manure amounts (including bedding material) collected in selected countries:

- USA: 27.6*10⁶ Mg/a [16] (which however is not fully in agreement with below mentioned average figure)
- Germany: 8*10⁶ Mg/a collected from stables (year 2008, see [14], based on data provided by the German Equestrian Association)

On average, one horse produces 8 to 14 Mg of collectable wet manure including bedding material [3, 10]. From previously mentioned data it can therefore be deducted that global annual horse manure production is between 500*10⁶ and 800*10⁶ Mg/a. It can further be deducted that in Europe alone, annual horse stall waste generation can be assumed to amount to a total of 40 to 70 million Mg/a.

Around a quarter to a third of the total wet weight of final manure stems from the bedding material [3, 15]. When looking at the volumes, these relations are different, since the bedding materials typically show low density and therefore have decisive influence on the generated volumes.

On average, manure including bedding from one horse typically accumulates to a volumetric rate of around 0.06 m³ per day [10]. However, horse manure based on straw was noticed to result in up to about twice as much volume as manure with other bedding materials (see Table 1), when stall cleaning was processed in the same way [17] (focus was put on avoiding all removal of clean bedding). Below data provide an indication of minimum amounts to be expected, but it needs to be kept in mind that amounts will be higher if clean bedding material will be removed during the cleaning of box stalls.

TABLE I. AMOUNT OF HORSE MANURE WHEN DIFFERENT BEDDING MATERIALS WERE USED IN BOX STALLS (DAILY REMOVAL OF FAECES AND BEDDING WITH URINE WAS APPLIED, WHILE ALL CLEAN BEDDING WAS LEFT IN PLACE) [17]

Bedding material	Annual amount of manure [m ³ /(horse*a)]	Dry matter [%]	Total content weight [kg/m ³]
Long straw (cut to 10 cm strips)	19.5	36.8	170
Wood chips	12.4	27.0	480
Peat with sawdust (mixture 3:1)	12.4	26.4	440
Shredded newspaper	11.7	32.5	410
Peat with straw (mixture 3:1)	11.7	28.9	410
Peat	9.8	23.7	600
Peat with wood chips (mixture 3:1)	9.1	28.8	440
Hemp	9.1	35.3	340

Storage of removed manure influences the characteristics of the material, and depending on conditions and duration, this can significantly alter dry matter content and weight content, while contents of nutrients such as phosphorus and potassium might undergo fewer changes [17]. Due to associated costs and environmental concerns, storage time should be as short as possible, but many sites practice considerable storage. In Nordic climates (e.g. Sweden), the storage of manure must be done for up to nine months of the year in order to sustain the chain of manure to agricultural field [17].

III. WASTE MANAGEMENT PRACTICES

A. Overview

As highlighted above, huge amounts of horse manure are generated each year. In some regions, generation of horse manure is higher than all other agricultural waste combined (e.g. New Jersey [15, 18]). The following options for handling the manure exist:

- Recycling to agricultural land, either through direct spreading or after composting or anaerobic treatment
- Combustion or other thermal treatment
- Delivery to landfill
- Usages for specific purposes such as delivery to mushroom cultivation sites, soil production for pepper cultivation [19], or soil production for lawns

Treatment on site reduces otherwise necessary transport, which would increase costs and burdens to the environment. However, many horse keepers do neither have the necessary arable land for spreading the manure nor treatment equipment for alternative processing, and many horse owners have significant problems to get rid of the residues to reasonable costs. In Germany for example, most horses are to be found in the regions with the least agricultural land [20].

In many countries, horse manure as organic material has been fully diverted from landfill by legislative restrictions, or high taxes have made this option economically unviable.

B. Spreading Equine Waste to Agricultural Land

In Germany, horse manure is mainly used in agriculture on field [14], as well as in the USA, and this is worldwide the most common option. However, this management also means that environmentally relevant substances such as nitrate, nitrite and ammonia in the leachate can pose risks on the ecosystems related to the soil (acidification of soil, water pollution, eutrophication). Especially in the short term following application, nutrients and organic matter are susceptible to transport by runoff, whereas in the longer term leaching of especially nitrate is a key issue [8]. In particular in the last two decades composting has gained high popularity as effect of growing environmental concerns within the equine sector and legislative restrictions with view to landfill disposal.

In some regions, it is still common that many private horse owners and stable managers place the manure in dumpsters or stockpile it to allow decomposition on its own, while others prefer to spread the manure directly onto their fields without composting [10, 18]. Direct spreading of horse manure without further treatment has a series of advantages such as killing pathogens by exposure to direct sunlight and drying, but it has distinct negative effects such as increasing the loss of nitrogen through volatilisation, leaching and runoff, and limited blending with the soil (see [10]).

Application of horse manure to agricultural land is beneficial for the soil (e.g. for crop production) [21-23]. In addition to supplying nutrients, the organic matter input improves physical soil conditions, replenishes soil organic matter and stops degradation of favourable soil aggregation structures, improves water holding capacity, and stimulates microbial activity. Compared to other animal manures, untreated horse manure (straw-based) has been shown to have a smaller fraction of easily decomposable organic carbon, a smaller amount of nitrogen and a high amount of fibres [21], which limits short-term losses, but does not eliminate possible burdens to the environment.

C. Composting

Composting reduces the negative environmental effects and (if properly done) transforms the material into a very useful, stable, odourless and pathogen-free product, while at the same time achieves mass or bulk reduction [10, 24-26]. Composting has now become a well-known and accepted method to treat horse manure, and is especially viable if arable land is available in the vicinity of the equine facility or if market-demand for compost is high.

Mono-composting, and co-composting with other organic substrates, and in particular with other wastes from urban areas (such as pruning waste from maintaining parks and gardens, biowaste), have been demonstrated to be well feasible and advantageous processes [24, 27-31]. However, in some cases problems can arise depending mainly on the nature of the bedding material contained in the manure, and in particular related to the existent carbon to nitrogen (C:N) ratio [10]. The ideal C:N ratio for composting is around 25:1 to 30:1. Horse manure itself has an excellent carbon to nitrogen ratio exactly at this level [9, 10], but the bedding material is deficient in nitrogen (e.g. C:N ratio paper 772:1, sawdust 442:1, wheat straw 127:1 [10]).

Management practices might therefore have a decisive influence on compostability of the stall waste. Complete daily cleaning results in a high bedding to manure ratio and therefore a high C:N ratio, therefore it is advisable to e.g. selectively collect the manure and soiled bedding and, if available, to also add manure from outdoor areas [10]. Addition of nitrogen-rich substrates such as grass or poultry waste might be beneficial during the composting process as well. With view to necessary structure, addition of pruning/ yard waste has been recommended in order to avoid excessive compaction [10].

Successful composting of horse manure has been demonstrated to result into a product of high quality [32-34]. In cases where compost was amended to suppress plant diseases (this potential effect on soil-borne pathogens is known since several decades), horse manure compost failed to be successful [35, 36], hence it might be more suitable for standard applications. Compost value is also relevant when assessing economic viability of management practices at an equine facility. Although management of residues is in general not the main criteria when deciding in favour of a bedding material, its good compostability is advantageous at this stage, and should be considered. Furthermore, composted material that contains undecomposable bedding material may still absorb soluble nitrogen (which previously had been one of its main functions) from the soil, which could result into very low fertilisation effects [17]. Using bedding material that composts readily also reduces the likelihood of dumping used bedding in urban or other dump sites [17].

IV. BIOENERGY PRODUCTION WITH HORSE MANURE

A. Relevance of Equine Waste for Energy Generation

For many horse stables, the energy content of the annually generated manure would easily be sufficient to cover the energy demand for space heating and hot water of the buildings and facilities on site [5]. This would decrease energy costs and at the same time reduce the ecological footprint.

Although horse manure is a high-energy biomass [5, 37], its utilisation for energy production is limited to few examples. In this, horse manure significantly stands behind other manures and other organic wastes. In addition, only few research studies exist on the topic. According to the further elaboration within this chapter, energy generation with horse manure via either biochemical or thermochemical pathways is a challenging field. However, energetic valorisation of horse manure holds high potential to make a vital contribution towards increasing the share of renewable energy.

Due to the fact that equine waste (1) consists of very different components and (2) undergoes changes/ degradation during storage or transport, it is difficult to assess potential energy recuperation. As a result of missing data, it is not feasible within this study to quantify the overall potential for energy recuperation from horse manure. Nevertheless, a rough preliminary evaluation can provide evidence that the potential for energy production from equine waste is indeed at significant scale. When assuming a heating value of at least 15 MJ per kg dry fuel (which is a value at the very low end of available indications in practice, also see e.g. [38]), and assuming further a dry matter content of 35%, the overall

energy content based on the data derived in Chapter II can be assessed to surpass $2.5 \cdot 10^6$ TJ/a at a global scale, and $0.2 \cdot 10^6$ TJ/a in Europe alone. For comparison, final energy consumption in EU27 amounted to 1,103.3 Mtoe [39] in 2011, which equals around $46 \cdot 10^6$ TJ/a. Although the data would need to be assessed with more precision, this rough assessment indicates that in EU27 the energy content of horse manure is at a level of 0.5% or higher of final energy consumption.

B. Factors Relevant When Looking at the Current Low Level of Bioenergy Production with Horse Manure

One main reason for the current low level of utilisation of solid agricultural substrates such as horse manure e.g. as fuel in power plants is attributed to the lack of sufficient information concerning handling and process characteristics of the material [40]. This would not only be essential for the design and operation of the installations, but also for assessment of economic viability during the planning phase. The large variety of horse manure characteristics is especially challenging.

Aside of generation of energy, biochemical and thermochemical processes generate a residue in general in solid form. While compost from horse manure has been studied in various projects, only little is known about the effects of applying the respective digestate from anaerobic digestion or ash from thermal treatment to agricultural land. Aside of the direct effect on the soil, the residue can be of decisive influence when assessing economic viability and achieving profit. From state-of-knowledge in anaerobic digestion it can be deducted that digested horse manure represents an even more valuable organic fertiliser and soil amendment than compost. Analysis of ash from combustion of horse manure indicated appropriate quality to allow recycling to forests and to agricultural land [5]. Compared to biochemical processes, it needs to be considered that with thermal treatment no nitrogen can be recycled, as all nitrogen leaves in gaseous form during treatment.

Knowledge about technologies and their suitability for the given material, about regional and site-specific factors, as well as economic viability under site-specific circumstances (including necessary investment, running costs, and value of energy and solid residues), and adaptability of the management of the equine unit, are central factors when considering bioenergy production with horse manure.

Management of equine waste and its potential valorisation is not a new problem, but an ongoing subject of discussions since many years [41, 42]. A Chinese adage says 'A good message hardly goes beyond the gate, while bad news spreads far and wide' [43]. Although it is likely that successful results are more often published in scientific literature than results with negative outcomes, any failed bioenergy projects in full scale in practice hold high potential to have significant negative impact on general perception of reliability and economic viability of the technology.

Besides the necessity to generate and make available data by research, it is an objective assessment of both successful and failed full-scale projects which is to be regarded as being essential to advance in the field. The currently poor rate of energetic valorisation of horse manure indicates that without specifically targeted programmes, adoption of best practices

and of promising valorisation strategies is not likely to experience significant increase.

As mentioned previously, the equine sector is not comparable to other agricultural sectors under many perspectives, which means that application of traditional agricultural programmes might not prove sufficiently efficient. In this context, it should in particular be taken into account that the equine sector is highly market-driven, but has often fallen between policy fields in an uneasy way (see e.g. its exclusion from eligibility for the same bonus as agricultural manures in the feed-in tariffs of the German Renewable Energy Law). As pointed out by Häggblom et al. [7], the sector is not sufficiently well organised to efficiently communicate to public authorities or among its own members, is of highly extensive nature, is particularly highly diversified and for many an ambiguous sector, and engages many actors with little knowledge on keeping of other animals as well as of agricultural practices.

C. Thermal Treatment Processes

Comparable to other agricultural solid residues, horse manure is produced locally and has a low density. Due to the resulting high transport costs, it is in general uneconomical to use such agricultural residues as the main fuel in big power stations [40]. Co-firing in coal power plants might be a viable option, if a plant is available in suitable distance. The use of small local power stations reduces transport necessity, but has the disadvantage of higher investment costs, a specific higher need of employees and a lower efficiency degree [40].

The low bulk density complicates processing, transport, storage and firing. Densification by e.g. pelleting increases viability of transport and storage, and combustion properties, but implies additional costs, and therefore needs assessment on individual case basis [40].

Early experiments with combustion of horse manure indicated poor results and process problems [44], but more recent studies using a 250 kW(th) furnace especially designed for wet and inhomogeneous biomass (adapted two-zone furnace) resulted in efficient energy conversion after combustion in good quality [5]. It is now well understood that this type of biomass requires consideration of its specific properties when choosing the basic combustion type system, when designing the firing concept in detail, and when operating the process under giving attention to a range of particularly relevant parameters [40]. A two-stage combustion system with controlled temperature zones and the possibility to easily remove ashes is most suitable for combustion of such agricultural materials with low moisture content due to the following reasons [40]:

- Devolatilisation starts at very low temperatures (due to high content of volatile matter) and releases mainly combustible gases (CO , H_2 , C_xH_y). There is a tendency for instantaneous ignition and rapid completion of the combustion process, which is most relevant for the feeding system and the combustion itself. E.g. in a one-stage fluidised bed system combustion might be completed in the freeboard with very little heat being transferred to the bed. In addition, incomplete combustion (related to temperature and oxygen profile)

may cause smoke formation. A two-stage system allows devolatilisation and gasification in the first stage, and complete combustion in the second zone.

- The low ash melting point (related to contained alkali oxides and salts, and mainly to high K_2O content), can cause severe problems with agglomeration, fouling, slagging and corrosion. Low temperatures in the first stage allow removal of a significant part of the ashes (below grate or from gas flow), before combustibles are completely burnt in an environment low in ash (the second stage). The use of additives might be favourable.

Pyrolysis/ syngas production through gasification has been proposed as possible alternative to combustion, and has been studied at research level [37, 45]. It was pointed out as one advantage of pyrolysis that the liquid product could be potentially fungible with existing diesel-fired boilers, and could therefore be used directly for localised hot water heating (study at an equine centre, based on equine waste containing sawdust and hay) [46].

D. Anaerobic Digestion for Biogas Production

Anaerobic digestibility of horse dung to produce biogas has been studied already by the end of the 19th century, and is documented in various approaches in literature [47-49]. Trials at laboratory scale document good anaerobic digestibility of horse manure, and co-digestion e.g. with fruit and vegetable waste [50] or with sewage sludge [51] has further been found promising. Methane yield of horse manure varies within wide ranges, the bedding material is one key factor [52].

However, application to full scale has revealed that horse dung requires detailed knowledge, adapted technology and appropriate management, and that the risk of failure is not neglected. Horse dung was found unsuitable for co-digestion in higher ratios in conventional slurry-based plants due to its high tendency to float on top of the liquid phase [53]. Stratification and formation of layers of floating material is one typical reason for failure of AD plants run on horse manure. It is further relevant to note that the contained bedding material must be digestible, which is the case for materials such as straw and paper, but not the case for e.g. wood chips and sawdust.

Dry digestion in box type fermenters (with percolation: sprinkling of liquid on top of the stacked solid substrate) has been demonstrated to be a favourable and well suited process for horse manure by Kusch et al. [54], and the process has been further studied by other groups [3, 15]. Trials in full-scale showed that the principle of dry digestion with percolation is applicable for horse manure, though problems can occur (mainly inhomogeneous digestion progress in stacked substrate bodies) [56].

A full-scale plant for mono-digestion of flooded horse dung has been in operation in southern Germany [55], but failed to be successful (it is however worth noticing that the reasons for failure were not related to the material itself, but rather to the general technical equipment and related handling routines).

Dry digestion in a plug-flow digester (co-digestion of horse manure, turkey dung, energy crops) is successfully operated in

Schroberg (Germany). 2-stage digestion and grinding pre-treatment has been implemented at the biogas plant IM Brahm in Essen (Germany) in 2005, digesting cow and horse manure together with kitchen waste. The Bavarian AD plant Kolbermoor digests 80% horse manure in a 2-stage process. Grass silage (+ enzymes) is added to improve hydrolysis, thus improving digestibility and achieving better plant performance [57]. Other easily digestible co-substrates (e.g. glycerol) could have the same positive effect on hydrolysis.

Utilisation of horse dung containing various bedding materials has further been found favourable in an upflow solid-state reactor [58].

Similar to other lignocellulosic biomass, various forms of pre-treatment can increase the biogas yield obtained from horse manure [59, 60], and disintegration might be assessed as necessary in order to achieve a high-performance operation [61]. However, it needs to be kept in mind that all additional treatment steps need to fit into the whole management concept, and must improve economic viability in order to be suitable.

Digestate is a valuable by-product in particular in regions with shortage of organic fertiliser. But it has also been reported that digested and dried horse manure (e.g. by using the waste heat of the AD process) is an excellent solid biofuel. While untreated straw and horse dung require specific technology due to the low melting point, a regular industrial boiler could be used for digestate (increased melting point due to reduced mineral content after hydrolysis) [57]. This indicates that a

combination of different technologies can be particularly well suited in order to improve overall efficiency and economic viability.

Economic viability for biogas projects using horse manure is not necessarily given and needs to be assessed in a detailed study. For German frameworks, dry digestion of horse dung has been assessed to be economically viable, provided that appropriate technology is chosen and that the plant is well operated [62]. Economic viability of biogas production with equine manure was also assessed positive in a Brazilian study [63]. Results of a study applying economic modelling to biogas production in Cornwall indicates that with unsuitable parameters projects can induce severe financial losses, and the results further show that horse manure at small horse keeping sites is among the scenarios in which economic viability of an AD project is particularly difficult to be achieved [64].

V. A SWOT ON HORSE MANURE VALORISATION

Considering the findings of this study, the SWOT analysis in Figure 1 summarises the central issues and can be used to further elaborate strategies for valorisation of equine waste for energy generation. As one result of the SWOT analysis it can be deducted that it seems advisable to use the urban proximity of the sector as a strength, e.g. it should be better analysed to what extent and how the urban lifestyle could be considered as positive factor when advancing the various sustainability dimensions (environmental, economic, social).

<p>Strengths</p> <ul style="list-style-type: none"> - highly diversified sector with huge variety of skills and resources - average level of education and financial resources above average - part of urban lifestyle with various forms of discussions about sustainability and implementation of renewable energy - sector highly market driven - equine waste in sum generally well accepted as potentially valuable resource 	<p>Weaknesses</p> <ul style="list-style-type: none"> - lack of information concerning handling and characteristics of the material, technologies - large variety of material characteristics - currently very low level of adoption, therefore lack of experience at full scale - sector not well organised to efficiently communicate to authorities and decision makers - highly extensive nature of sector - many actors with little knowledge of agricultural practices
<p>Opportunities</p> <ul style="list-style-type: none"> - unlocking of huge renewable energy content - fits well into EU and other energy strategies - establishment of shining examples to serve as models - projects and experiences transferable from one region to other regions - economies of scale - new areas of activities for various industries - new or improved market positions - strengthens equine sector (EU and elsewhere) - potential to serve as model sector (circular economy, sustainable use of resources) 	<p>Threats</p> <ul style="list-style-type: none"> - unfavourable frameworks (legislation, feed-in tariffs for energy, grants) - risk to fall between policy fields - agricultural or other programmes unsuitable for equine sector - general market changes (structures, financial) affect equine sector - economic viability of projects; in particular value of final residues (ash, digestate) unclear - risk of technical failures - risk of general negatively biased perception due to few failed projects

Figure 1. SWOT analysis of equine waste valorisation for energy generation

VI. CONCLUSIONS

The contemporary equine sector is market-driven, highly diverse, and of significant economic importance in the EU and elsewhere. Considerable distance to traditional agriculture is one of its main characteristics, which among others means that agricultural schemes cannot be directly transferred to the equine sector. Equine activities generate huge amounts of organic residues, which under current practices are in most cases treated as wastes to be disposed of, which implies an additional financial burden for the producer. At the same time, horse manure is an organic material that contains significant potential to be valorised to generate energy and/or fertiliser material/ material to be used for soil improvement. Situations and possible management concepts vary in different regions, depending on demands for horse manure as fertiliser or disposal costs, availability and costs for bedding material, stall management, economic viability of energy generation as well as the relevant general frameworks. Bioenergy production is still poorly adopted by the equine sector and should be encouraged by targeted programmes.

REFERENCES

- [1] S. Kusch, "Horse stall waste: amounts, management, bioenergy generation," Proceedings of the online conference EIIC 2013 – The 2nd Electronic International Interdisciplinary Conference, 02-06 Sept 2013, pp. 423-428.
- [2] L. Elfman, R. Wälinder, M. Riihimäki, and J. Pringle, "Air quality in horse stables," in Chemistry, Emission Control, Radioactive Pollution and Indoor Air Quality, N. Mazzeo, Ed., Rijeka: InTech Europe, 2011, pp. 655-680.
- [3] Z. Cui, J. Shi, and Y. Li, "Solid-state anaerobic digestion of spent wheat straw from horse stall," *Bioresource Technology* 102, 2011, pp. 9432-9437.
- [4] Deutsche Reiterliche Vereinigung e.V., Jahresbericht 2012 [Annual report German Equestrian Federation], available at <http://www.pferd-aktuell.de/fn/zahlen--fakten/zahlen--fakten>, accessed 27 July 2013. (in German)
- [5] J. Lundgren, and E. Pettersson, "Combustion of horse manure for heat production," *Bioresource Technology* 100, 2009, pp. 3121-3126.
- [6] C. Liljenstolpe, Horses in Europe, EU Equus 2009 report, Swedish University of Agricultural Sciences, 2009.
- [7] M. Häggblom, L. Rautamäki-Lahtinen, and H. Vihinen, Equine sector comparison between the Netherlands, Sweden and Finland, EquineLife report, MTT Agrifood Research Finland, not dated (probably 2005).
- [8] D. R. Edwards, P. A. Moore, S. R. Workman, and E. L. Busheé, "Runoff of metals from alum-treated horse manure and municipal sludge," *Journal of the American Water Resources Association* 35 (1), 1999, pp. 155-165.
- [9] S. Airaksinen, M.-L. Heiskanen, and H. Heinonen-Tanski, "Contamination of surface run-off water and soil in two horse paddocks," *Bioresource Technology* 98, 2007, pp. 1762-1766.
- [10] A. M. Swinker, M. K. Tanner, D. E. Johnson, and M. S. Benner, "Composting characteristics of three bedding materials," *Journal of Equine Veterinary Science* 18 (7), 1998, pp. 462-466.
- [11] K. Fleming, E. F. Hessel, and H. F. A. Van den Weghe, "Evaluation of factors influencing the generation of ammonia in different bedding materials used for horse keeping," *Journal of Equine Veterinary Science* 28 (4), 2008, pp. 223-231.
- [12] R. A. Casey, "Clinical problems associated with the intensive management of performance horses," in *The Welfare of Horses*, N. Waran, Ed., Dordrecht: Kluwer Academic Publisher, 2002. – here cited from [13]
- [13] J. Lundvall, Comparison of stable environment in prior approved and non-prior approved horse stables, Student report No. 454 of the Swedish University of Agricultural Sciences, Department of Animal Environment and Health, Uppsala, 2013.
- [14] F. Garlipp, E. F. Hessel, and H. F. A. Van den Weghe, "Characteristics of gas generation (NH₃, CH₄, N₂O, CO₂, H₂O) from horse manure added to different bedding materials used in deep litter bedding systems," *Journal of Equine Veterinary Science* 31, 2011, pp. 383-395.
- [15] B. A. Wartell, V. Krumins, J. Alt, K. Kang, B. J. Schwab, D. E. Fennell, "Methane production from horse manure and stall waste with softwood bedding," *Bioresource Technology* 112, 2012, pp. 42-50.
- [16] B. A. Wartell, V. Krumins, R. George, J. Alt, B. Schwab, K. Kang, and D. E. Fennell, "Anaerobic digestion of equine stall waste," Proceedings of the 2008 Annual ASABE meeting, paper no. 084253, 2008. – here cited from [3]
- [17] S. Airaksinen, H. Heinonen-Tanski, and M.-L. Heiskanen, "Quality of different bedding materials and their influence on the compostability of horse manure," *Journal of Equine Veterinary Science* 21 (3), 2001, pp. 125-130.
- [18] M. L. Westendorf, T. Joshua, S. J. Komar, C. Williams, and R. Govindasamy, "Case study: manure management practices on New Jersey equine farms," *The Professional Animal Scientist* 26, 2010, pp. 123-129.
- [19] P. Flores, I. Castellar, and J. Navarro, "Nitrate leaching in pepper cultivation with organic manure and supplementary additions of mineral fertilizer," *Communication in Soil Science and Plant Analysis* 36, 2005, pp. 2889-2899.
- [20] J. Beck, "Pferdemist - Problemlösung durch mechanische Aufbereitung, Kompostierung und thermische Verwertung," *Landtechnik* 60 (1), 2005, pp. 40-41. (in German)
- [21] H. A. Ajwa, and M. A. Tabatabai, "Decomposition of different organic materials in soils," *Biology and Fertility of Soils* 18 (3), 1994, pp. 175-182.
- [22] J. Ofosu-Anim, and M. Leitch, "Relative efficacy of organic manures in spring barley (*Hodeum vulgare* L.) production," *Australian Journal of Crop Science* 3 (1), 2009, pp. 13-19.
- [23] J. Fan, W. Ding, Z. Chen, and N. Ziadi "Thirty-year amendment of horse manure and chemical fertilizer on the availability of micronutrients at the aggregate scale in black soil," *Environmental Science and Pollution Research* 19 (7), 2012, pp. 2745-2754.
- [24] M. Benito, A. Masaguer, A. Moliner, C. Hontoria, and J. Almorox, "Dynamics of pruning waste and spent horse litter co-composting as determined by chemical parameters," *Bioresource Technology* 100, 2009, pp. 497-500.
- [25] S. Komar, R. Miskewitz, M. Westendorf, and C. A. Williams, "Effects of bedding type on compost quality of equine stall waste: implications for small horse farms," *Journal of Animal Science* 90 (3), 2012, pp. 1069-1075.
- [26] S. Komar, R. Miskewitz, C. Obropta, W. Bamka, and R. Mickel, "Evaluation of nutrient runoff from three equine stall waste storage systems," *Applied Engineering in Agriculture* 26 (5), 2010, pp. 827-832.
- [27] M. Das, H. S. Uppal, R. Singh, S. Beri, K. S. Mohan, V. C. Gupta, and A. Adholeya, "Co-composting of physic nut (*Jatropha curcas*) deoiled cake with rice straw and different animal dung," *Bioresource Technology* 102, 2011, pp. 6541-6546.
- [28] G. Desalegn, E. Binner, and P. Lechner, "Humification and degradability evaluation during composting of horse manure and biowaste," *Compost Science & Utilization* 16 (2), 2008, pp. 90-98.
- [29] P. V. Romano, U. Krogmann, M. L. Westendorf, and P. F. Strom, "Small-scale composting of horse manure mixed with wood shavings," *Compost Science & Utilization* 14 (2), 2006, pp. 132-141.
- [30] V. Fontanive, D. Effron, F. Tortarolo, and N. Arrigo, "Evaluation of parameters during composting of two contrasting raw materials," *Compost Science & Utilization* 12 (3), 2004, pp. 268-272.
- [31] P. Sangwan, C. P. Kaushik, and V. K. Garg, "Feasibility of utilization of horse dung spiked filter cake in vermicomposters using exotic earthworm *Eisenia foetida*," *Bioresource Technology* 99, 2008, pp. 2442-2448.
- [32] L. Ferreras, E. Gomez, S. Toresani, I. Firpo, and R. Rotondo, "Effect of organic amendments on some physical, chemical and biological

- properties in a horticultural soil,” *Bioresource Technology* 97, 2006, pp. 635-640.
- [33] A. S. Ball, D. Shah, and C. F. Wheatley, “Assessment of the potential of a novel newspaper/horse manure-based compost,” *Bioresource Technology* 73, 2000, pp. 163-167.
- [34] J. C. Ramirez-Perez, P. F. Strom, and U. Krogmann, “Horse manure and cranberry fruit composting kinetics and measures of stability,” *Compost Science & Utilization* 15 (3), 2007, pp. 200-214.
- [35] R. Noble, “Risks and benefits of soil amendment with composts in relation to plant pathogens,” *Australasian Plant Pathology* 40 (2), 2011, pp. 157-167.
- [36] M. K. Hasna, A. Martensson, P. Persson, and B. Rämert, “Use of composts to manage corky root disease in organic tomato production,” *Annals of Applied Biology* 151, 2007, pp. 381-390.
- [37] E. Balu, and J. N. Chung, “System characteristics and performance evaluation of a trailer-scale downdraft gasifier with different feedstock,” *Bioresource Technology* 108, 2012, pp. 264-273.
- [38] M. Edström, I. Schüßler, and S. Luostarinen, *Combustion of manure: manure as fuel in a heating plant, Presentation (knowledge report) at Baltic Forum for Innovative Technologies for Sustainable Manure Management*, 2011.
- [39] European Commission, *EU energy in figures – statistical pocket book 2013*.
- [40] J. Werther, M. Saenger, E.-U. Hartge, T. Ogada, and Z. Siagi, “Combustion of agricultural residues,” *Progress in Energy and Combustion Science* 26, 2000, pp. 1-27.
- [41] G. Logsdon, “New solutions for an age-old problem,” *Biocycle* 29 (7), 1988, pp. 38-39.
- [42] H. B. Greenber, “Seeking a solution to horse manure problem,” *Journal of the American Medical Association* 228 (12), 1974, pp. 1521-1522.
- [43] L. Jian, “Socioeconomic barriers to biogas development in rural southwest China: an ethnographic case study,” *Human Organization* 68 (4), 2009, pp. 415-430.
- [44] R. Schuster, and B. Strömberg, *Förbränning av gödsel – en orienterande litteraturstudie med kommentarer, Technical report O3-513, Stiftelsen för värmeteknisk forskning, Stockholm, Sweden, 1997. (in Swedish) – here cited from [5]*
- [45] R. Schmalzbauer, *Untersuchungen zur Pyrolyse von Pferdemit, Diploma thesis, University of Hohenheim, 2005. (in German)*
- [46] N. L. Hammer, A. A. Boateng, C. A. Mullen, and M. C. Wheeler, “Aspen Plus® and economic modeling of equine waste utilization for localized hot water heating via fast pyrolysis,” *Journal of Environmental Management* 128, 2013, pp. 594-601.
- [47] T. Mandal, and N. K. Mandal, “Biomethanation of some waste materials with pure metallic magnesium catalyst: improved biogas yields,” *Energy Conversion and Management* 39, 1998, pp. 1177-1179.
- [48] D. Deublein, and A. Steinhauser, *Biogas from waste and renewable resources: an introduction*, Weinheim: Wiley-VHC, Germany, 2008.
- [49] B. A. Wartell, *Anaerobic digestion of equine waste, Master thesis, Graduate School-New Brunswick, Rutgers, The State University of New Jersey, 2009.*
- [50] D. B. Smith, and C. B. Almquist, “The anaerobic co-digestion of fruit and vegetable waste and horse manure mixtures in a bench-scale, two-phase anaerobic digestion system,” *Environmental Technology* 35, 2014, pp. 859-867.
- [51] E. Agayev, and A. Ugurlu, “Biogas production from co-digestion of horse manure and waste sewage sludge,” *Proceedings of the conference Clean Technology*, 2011.
- [52] M. Mönch-Tegeger, A. Lemmer, H. Oechsner, T. Jungbluth, “Investigation of the methane potential of horse manure,” *Agricultural Engineering International: CIGR Journal* 15 (2), 2013, pp. 161-172.
- [53] A. K. Kalia, and S. P. Singh, “Horse dung as a partial substitute for cattle dung for operating family-size biogas plants in a hilly region,” *Bioresource Technology* 64, 1998, pp. 63-66.
- [54] S. Kusch, H. Oechsner, and T. Jungbluth, “Biogas production with horse dung in solid-phase digestion systems,” *Bioresource Technology* 99, 2008, pp. 1280-1292.
- [55] S. Kusch, and H. Oechsner, “Vergärung landwirtschaftlicher Substrate in Feststofffermentern,” in *Trockenfermentation - Evaluierung des Forschungs- und Entwicklungsbedarfs*, FNR, Ed., Gülzower Fachgespräche, vol. 23, 2004, pp. 105-113. (in German)
- [56] S. Kusch, *Methanisierung stapelbarer Biomassen in diskontinuierlich betriebenen Feststofffermentationsanlagen, PhD thesis, University of Hohenheim, Herbert Utz Verlag, Munich, 2007. (in German)*
- [57] W. Danner (operator biogas plant Kolbermoor, Germany), *communication during congress “Progress in Biogas 2”, Stuttgart-Hohenheim, 30 March 2011.*
- [58] J. Böske, B. Wirth, F. Garlipp, J. Mumme, and H. Van den Weghe, “Anaerobic digestion of horse dung mixed with different bedding materials in an upflow solid-state (UASS) reactor at mesophilic conditions,” *Bioresource Technology* 158, pp. 111-118.
- [59] S. Aslanzadeh, M. J. Taherzadeh, and I. S. Horváth, “Pretreatment of straw fraction of manure for improved biogas production,” *BioResources* 6 (4), 2011, pp. 5193-5205.
- [60] S. Kusch, and M. V. Morar, “Integration of lignocellulosic biomass into renewable energy generation concepts,” *ProEnvironment ProMediu* 2, 2009, pp. 32-37.
- [61] M. Mönch-Tegeger, A. Lemmer, and H. Oechsner, “Enhancement of methane production with horse manure supplement and pretreatment in a full-scale biogas process,” *Energy* 73 (C), 2014, pp. 523-530.
- [62] I. Helmer, *Kontinuierliche Trockenfermentation in Biogasanlagen am Beispiel von Reststoffen aus der Pferdehaltung, Master thesis, Fachhochschule Münster, Germany, 2007. (in German)*
- [63] D. C. Catapan, A. Catapan, N. R. Rosset, and J. H. Harzer, “Analysis of the financial viability of biogas production through equine manure,” *Custos e Agronegocio* 8 (4), 2012, pp. 25-51.
- [64] M. Köttner, S. Kusch, A. Kaiser, D. Dörrie, and D. Collins, *Economic modelling of anaerobic digestion/ biogas installations in a range of rural scenarios in Cornwall, Final report of the research project for Cornwall Agri-Food Council, 2008.*