Livestock Science 196 (2017) 28–35

Contents lists available at ScienceDirect

Livestock Science

journal homepage: www.elsevier.com/locate/livsci

# Mapping sustainability in pig farming research using keyword network analysis

Katharina Schodl[b,c,*,1], Friederike Klein[a,1], Christoph Winckler[b]

[a] Department of Anthropology, University of Vienna, Althanstrasse 14, 1090 Vienna, Austria
[b] Doctoral School of Sustainable Development, University of Natural Resources and Life Sciences, Vienna (BOKU), Peter-Jordan-Strasse 82, 1190 Vienna, Austria
[c] Division of Livestock Sciences, Department of Sustainable Agricultural Systems, University of Natural Resources and Life Sciences, Vienna (BOKU), Gregor Mendel-Strasse 33, 1180 Vienna, Austria

ARTICLE INFO

*Keywords:*
Pig farming
Sustainability
Keyword network analysis
Agriculture
Research

ABSTRACT

Integrating sustainability as normative principle in research has become increasingly important, also in agricultural and livestock sciences. Using a keyword network analysis, the present study aimed at identifying the most important research topics addressing sustainability in pig farming research. For this purpose, publication data was extracted from the Web of Science using 'sustainab* AND pig' and 'sustainab* AND swine' as search terms. The revised matches were converted into a network using the software package 'Pajek'. Both, degree and betweenness analysis suggest that keywords and research topics with an environmental connotation are most important in the network. After crosschecking the respective abstracts, the keywords were assigned to thematic clusters and topics according to their location in the network. In agreement with the concept of *strong sustainability*, a large number of clusters covering environmental issues in the network underlines the importance of environmental research topics in this research area. Furthermore, the network emphasizes animal health and welfare as essential part of sustainable pig farming. However, socio-economic subjects, which also present an important aspect of sustainability in livestock farming, have been less well addressed.

## 1. Introduction

During the last decades the terms 'sustainability' and 'sustainable development' have become a catchphrase among governmental and nongovernmental organisations as well as corporations or research programs (Lélé, 1991; Bettencourt and Kaur, 2011). Although representing a vaguely defined and highly contested concept, these terms already have been integrated as normative paradigm into many areas of scientific research leading to the emergence of a new field of sustainability science (Kates et al., 2001). Core questions evolve around understanding 'the fundamental character of interactions between nature and society' (Kates et al., 2001, p. 641) and are characterized by a high degree of complexity (Jahn, 2013).

Sustainability is a central issue within agriculture and agricultural sciences and vice versa: climate change, finite resources, food security and environmental pollution for example are global issues and agriculture is on the one hand affected and threatened by their effects and on the other hand takes the role of a polluter (Tilman et al., 2002; Vermeulen et al., 2012). Especially the livestock sector is associated with many critical issues regarding sustainability in agriculture. Pig farming as one specific subsection of livestock farming is often viewed in the context of sustainability issues such as animal welfare, environmental impacts or food safety (Stern et al., 2005). Sustainable development and sustainability therefore play – explicitly or implicitly – an important role in this research area.

Research in the context of sustainability is not limited to particular topics nor does it have to follow a certain paradigm. It is, however, important for researchers to define and disclose their understanding of sustainability and the underlying values (Wuelser, 2013). In order to define sustainability or sustainable development (in the present paper these terms will be used synonymously) various approaches and ideas exist (Hopwood et al., 2005). Their common baseline is the aim to diminish the imbalance between what is demanded from the earth and what can be supplied by it (Williams and Millington, 2004) or, as others frame it, the conflicting interests of environmental and socio-economic concerns (Robinson, 2004). Based on the Brundtland report,

* Corresponding author at: Division of Livestock Sciences, Department of Sustainable Agricultural Systems, University of Natural Resources and Life Sciences, Vienna, Gregor Mendel-Strasse 33, 1180 Vienna, Austria.
*E-mail address:* katharina.schodl@gmail.com (K. Schodl).
[1] Katharina Schodl and Friederike Klein, equally contributed to the article.

http://dx.doi.org/10.1016/j.livsci.2016.12.005
Received 2 March 2016; Received in revised form 24 November 2016; Accepted 8 December 2016
1871-1413/ 

which defines sustainability as 'development that meets the needs of the present without compromising the ability of future generations to meet their own needs' (WCED, 1987), sustainability is often described as the intersection of three circles representing the three dimensions environment, society and economy. In line with this, Giddings et al. (2002) advocate for acknowledging the interdependency between these three dimensions, rather than regarding them as separate and independent. They present the three dimensions as concentric circles with economy in the centre being part of society (in the middle) and both of them depending on the environment, reflecting the concept of *strong sustainability* (Williams and Millington, 2004). This concept acknowledges that there are no trade-offs between those dimensions, e.g. meaning that natural resources such as water, biodiversity, fossil fuels, i.e. natural capital, cannot be substituted by any kind of human produced capital such as industrial goods and infrastructure but also knowledge and labour (Costanza and Daly, 1992). Furthermore, natural capital also comprises ecosystem services, which provide essential functions and goods for human and natural systems (Costanza et al., 1997). Hence, an increase of human capital does not compensate a decrease of natural capital.

Following the definition of sustainability given above, sustainable livestock farming systems are 'economically viable, ecologically sound and socially acceptable, both now and in the future' (Dolman et al., 2012, p.144). This similarly applies to sustainable pig farming systems comprising specific issues such as farm income and the livelihood of farmers, ammonia emissions and other detrimental effects on the environment, animal health and welfare, product safety and quality as well as working conditions (ten Napel et al., 2011; Dolman et al., 2012).

To our knowledge, no comprehensive analysis of how sustainability is framed and approached in pig farming research and what topics and questions are addressed, has been carried out. Yet, the increasing popularity of integrating sustainability into research areas such as pig farming calls for a structured overview of issues of interest, disciplines involved and research topics. Keyword network analysis is a suitable method for mapping (knowledge) structures of research areas and has so far mostly been used to visualize structures such as citation networks, author collaborations and importance of institutions in different research areas etc. (e.g. Acedo et al., 2006; Leydesdorff and Wagner, 2008). However, recent studies have performed a keyword network analysis to describe important topics in (new) fields of research (e.g. Baldwin et al., 2003; Su and Lee, 2010; Yaoyang and Boeing, 2013).

The aim of this paper is to apply a network analysis in the context of sustainability in pig farming using publication data extracted from Web of Science in order to disclose important research topics, to analyse how they are interconnected and to assess their relevance for the network as well as concepts of sustainability in livestock farming.

The paper is structured into 3 parts: first, data collection and application of keyword network analysis and the clustering process is explained. This is followed by the presentation of quantitative measures of network analysis (degree and betweenness centrality) and outcomes of the qualitative analysis (Topics and Clusters). Subsequently, the results are discussed with emphasis on a comparison with current concepts of sustainability in livestock farming, including methodological aspects.

## 2. Material and methods

### 2.1. Data

#### 2.1.1. Data collection and selection of publications for further analysis

For this study, Web of Science, an online academic service provided by Thomson Reuters, was used as data source. It provides access to many leading citation databases and the multidisciplinary content covers more than 12,000 of the highest impact journals worldwide, including Open Access journals and more than 150,000 conference proceedings. Publications reach back to 1900 and cover all disciplines - sciences, social sciences, arts and humanities (Reuters, 2015).

**Table 1**
Criteria for choosing or excluding publications for analysis.

| Criteria for choosing publications (min. one has to be met) | Criteria for excluding publications |
|---|---|
| *Formal criteria:* | |
| Research paper, review paper | Books, book chapters |
| Author keywords | No author keywords |
| | Publications without abstracts |
| *Content related criteria:* | |
| Publications about pigs as livestock | Publications about wild or feral pigs or guinea pigs |
| The title contains one of the following words: pig, swine, livestock or farm animals | Publications exclusively considering other livestock species than pigs (e.g. dairy cattle or broilers) |
| Publications about animal husbandry or animal production and organic or sustainable agriculture | Publications about different manure treatments |
| Publications about (swine) manure application | |

Web of Science was searched for the terms 'sustainab* AND pig OR sustainab* AND swine' and included publications from all years (1900 – Jan 2015). The search was carried out in January 2015 and yielded 591 results with the oldest publication from 1992. Subsequently, publications were excluded or included, respectively, based on their relevance for the study using the criteria presented in Table 1. For this purpose, information was taken from the title, keywords and abstracts of the publications.

The application of the content related criteria ensured that all papers covered research topics in the field of sustainable pig farming, and publications from other realms were excluded from analysis. The formal criteria were applied to exclude publications lacking essential information for the following reasons: lack of an abstract was an exclusion criterion because abstracts were used to capture the publication's content for the further keyword interpretation and clustering process (see Section 2.2). For the same reason, all books and book chapters were excluded from analysis. Furthermore, only publications with author keywords were used for this analysis, since they are assumed to best summarise and reflect the key concepts of the research.

Hence, 262 publications were discarded because they did not meet the formal and/or content related criteria. As a result, 329 publications with 2–16 keywords each were considered for further analysis.

#### 2.1.2. Keyword revision & standardisation

The list of keywords of the remaining publications was revised to standardize different keywords with the same meaning (e.g. 'pig' and 'swine'). As shown in Table 2, in the case of synonymous keywords in the database (listed in the left column) one term was chosen as keyword in the network analysis (right column) to represent all the synonyms. Finally, 1004 keywords were included in the analysis.

All abbreviations were eliminated and replaced by the whole terms (e.g. PRRS and PRRSV were changed to porcine reproductive and respiratory syndrome virus). Furthermore, only singular forms of terms were used and keywords occurring in the plural form were replaced accordingly.

### 2.2. Keyword network analysis

Network analysis already has a long tradition and is used in a wide range of disciplines from statistical mechanics to social or environ-

**Table 2**
Keyword revision & standardisation.

| Synonymous keywords from database | Terms used as keywords in the analysis |
|---|---|
| Pig /Swine / hog / Sus scrofa | Pig |
| Sustainability / Sustainable development | Sustainability |
| Animal agriculture / Animal production | Animal agriculture |
| Pig wastewater / Swine wastewater / pig manure wastewater | Pig wastewater |
| Livestock / Farm animals | Livestock |
| Phytase / Microbial phytase | Phytase |
| Cysticercosis / Porcine cysticercosis / neurocysticercosis | Cysticercosis |
| Fatty-acids-profile / Fatty-acid-profile / fatty acids | Fatty-acids-profile |
| Free range / Free ranging | Free range |
| Dehulled / Dehulling | Dehulled |
| Breeding goals / Breeding objectives | Breeding goals |
| Small farms / Small holder farms | Small farms |
| Nutrient balance / Nutrient balancing | Nutrient balance |
| Organic farming / Organic agricultural production / organic farm / organic production | Organic farming |
| Livestock farming system / Livestock system(s) / animal production system(s) | Livestock farming system |
| Deep bedding / Bedded swine housing / deep bedding houses | Deep bedding |
| Sperm / Semen | Sperm |
| Animal waste / Livestock waste(s) | Animal waste |

mental sciences (Wassermann and Faust, 1994; Borgatti et al., 2009; Caschili et al., 2014). Its tools are based on graph theory, which studies and allows to model graphs consisting of vertices (actors) and lines (ties between two vertices). The lines indicate a relationship between vertices, which can be directed or undirected (Nooy et al., 2005). It is often referred to as social network analysis because it is commonly used to analyse social networks in sociology, social psychology and anthropology (Wassermann and Faust, 1994; Borgatti et al., 2009). Furthermore, (social) network analysis has gained increasing importance in the field of bibliometric research to study structures such as citation networks, author collaborations, importance of institutions in various research areas as well as keyword analysis.

Keyword network analysis represents a form of co-word analysis which describes and visualizes a thematic field (Whittaker et al., 1989; Baldwin et al., 2003). The main purpose of a co-word analysis is to elucidate 'structures of ideas, problems and so on, represented in appropriate sets of documents' (Whittaker et al., 1989, p. 473). Hence, these analyses are based on the assumption that keywords occurring in the same paper link related topics or scientific fields (Ding et al., 2001). Moreover, the relationships of keywords, which repeatedly co-occur across different papers in a scientific field, suggest an important and significant relationship between those terms (Whittaker et al., 1989; Baldwin et al., 2003).

The keyword network is therefore set up by relationships between keywords. As already mentioned, keywords are linked if they are mentioned in the same paper. In a keyword network based on several papers, the value of a line between two keywords corresponds to the number of publications mentioning those keywords together.

For this study, the keyword network was analysed with two different quantitative measures and on two different scales to identify the most important keywords. Subsequently, thematic clusters were created by identifying strongly connected groups of keywords. A summary of the data and analysis methods applied in this study is presented in Table 3.

### 2.2.1. Quantitative analysis

As a first step, the results of the Web of Science search were converted into a network using the software package 'Pajek' and the program WoS2Pajek, which allows to convert the Web of Science format into the Pajek format (Batagelj and Mrvar, 1998). The resulting data allows visualising networks between authors, works and keywords – in this case only a keyword network was created.

**Table 3**
Summary of the material used and the research methods applied.

| Whole network | Focal network |
|---|---|
| *Descriptive data* | |
| 329 publications | 196 publications |
| 1004 keywords | 88 keywords |
| *Analysis* | |
| Degree centrality | Degree centrality |
| Betweenness centrality | Betweenness centrality |
| | Clustering process |

The original network, consisting of 1004 individual keywords (in the following it will be referred to as 'whole network'), was analysed by two centrality measures - *degree centrality* analysis and *betweenness centrality* analysis. Analysing both centrality measures is essential for a comprehensive understanding of the importance of keywords in the network because they describe different kinds of centrality (Wassermann and Faust, 1994):

(1) 'The *degree* of a vertex is the number of lines incident with it' (Nooy et al., 2005, p. 63). It reflects the number of ties to other keywords or equivalently is the number of vertices adjacent to it. In other words, it is a measure to describe one form of centrality of a vertex or keyword in a network, the *degree centrality* (Wassermann and Faust, 1994). For example, a keyword with a degree of 5 is directly connected to 5 other keywords in the network. A keyword with a high degree has a high occurrence in publications and therefore takes a prominent role in a research field. In order to compare the degree of the different keywords independent from the size of the network, the calculated degree values were normalized by dividing the numbers of ties of a keyword by the sum of all ties in the network.
(2) 'The *betweenness centrality* of a vertex is the proportion of all geodesics between pairs of other vertices that include that vertex' (Nooy et al., 2005, p. 131) and has a value between 0 and 1. It is another way to measure the centrality of a vertex and it reflects the importance of a vertex as a link between other vertices, in this case keywords. A vertex has a large betweenness centrality (closer to 1) if it is located between many actors on their geodesics (Wassermann and Faust, 1994). For example, a keyword with a high betweenness centrality is a bridge to a high number of other keywords along the shortest pathway. Keywords with a high betweenness centrality link various topics in a research field.

### 2.2.2. Reducing the network

The size of the whole network impeded a useful qualitative interpretation and clustering. In order to facilitate this process and to highlight the relevant connections, a smaller network (in the following it will be referred to as'focal network') was created. This was done by eliminating all single lines - meaning that all connections between keywords originating from one single publication were removed. Hence, only keywords which were connected by a minimum of two publications stayed in the network. As a result, 88 keywords connected by lines with a value higher or equal to 2 remained. In a second step, these remaining 88 keywords were extracted from the whole network, now representing the focal network. Degree centrality and betweenness centrality analysis were also performed for the focal network in order to compare the results with the whole network.

#### 2.2.3. Clustering process

In a next step, strongly connected keywords were subsumed under Clusters (consisting of minimum 3 keywords) or Topics (only 2 connected keywords). The following criteria were applied for identifying Clusters and Topics in the focal network:

- Keywords connected among each other but not connected to the central keyword 'pig' OR keywords connected among each other as well as to the central keyword 'pig'
- Keywords, which connected to another keyword with a high degree ( > 5)
- Large Clusters were further subdivided into smaller Clusters according to the strength of the ties between keywords and by thematic allocation after crosschecking the abstracts.

Clusters were labelled and interpreted qualitatively based on the abstracts of the underlying publications of the keywords. The graphic representation was created using the graphical tools of Pajek and Microsoft Office Power Point.

## 3. Results

### 3.1. Network analysis

#### 3.1.1. Degree centrality analysis

In both networks (Table 4), the following keywords are connected to many different keywords and play a central role regarding their degree: *pig, sustainability, environment, animal welfare, pig production, phosphorus* and *manure*. *Pig* and *sustainability* have the highest degree and therefore the highest occurrence in publications as they have been used as search terms in Web of Science. The degree analysis of the whole network shows high degrees also for *pig manure, pig production, organic farming* and *livestock*, which are not that central in the focal network. On the other hand, in the focal network *phytase, utilization, mineral* and *protein* are ranked higher than in the whole network.

#### 3.1.2. Betweenness centrality analysis

In both of the networks *pig*, *sustainability*, *environment*, *animal welfare, phosphorus, manure* and *livestock* rank among the 10 most central keywords regarding betweenness (Table 5). The keywords *anaerobic digestion, vaccination*, and *porcine reproductive respiratory syndrome virus (PRRS)* have a high betweenness in the focal network whilst they are not part of the 10 highest ranked keywords in the whole network. On the other hand, in the whole network *pig production, pig manure* and *organic farming* play a more important role than in the focal network.

**Table 5**
Results of the betweenness centrality analysis.

| | Whole network | | Focal network | |
|---|---|---|---|---|
| *Rank* | *Keyword* | *Betweenness* | *Keyword* | *Betweenness* |
| 1 | pig | 0.3112 | pig | 0.4315 |
| 2 | sustainability | 0.2315 | manure | 0.1169 |
| 3 | pig production | 0.0695 | sustainability | 0.0957 |
| 4 | phosphorus | 0.0666 | anaerobic digestion | 0.0797 |
| 5 | environment | 0.0625 | environment | 0.0663 |
| 6 | animal welfare | 0.0605 | vaccination | 0.0631 |
| 7 | pig manure | 0.0553 | animal welfare | 0.0489 |
| 8 | organic farming | 0.0479 | PRRS | 0.0481 |
| 9 | manure | 0.0391 | phosphorus | 0.0192 |
| 10 | livestock | 0.0340 | livestock | 0.0180 |

### 3.2. Clusters and Topics

Nine Clusters, 10 Topics and 14 independent (single) keywords, which are all connected with the central keyword *pig*, were identified (Fig. 1). The description and interpretation of the network starts with Clusters and Topics, which are linked to the central keyword pig in the network graph (representing a minimum of two joint appearances in a publication), followed by the unconnected Clusters and Topics. We refrained from a further interpretation of the single keywords because most of them are general terms such as e.g. cattle or genotype and the context they are used in varies between publications. In the following paragraphs, keywords related to topics in the Cluster/Topic description are given in italics.

Research in the **Feed Utilization** Cluster addresses the utilization of nutrients such as P, N or Ca and effects on performance and metabolic parameters of the animals and methods (e.g. *Phytase* as feed additive) to reduce the amount of supplemented minerals (e.g. *Phosphorus*) in pig diets and consequently the environmental impact from excess nutrient excretion. Furthermore, examining the effects of different (alternative) feedstuffs in pig diets on the animals' performance plays an important role. Another important issue is the calculation of nutrient balances (*Nitrogen*) and consequences for fertilization and nutrient management, which relates the Feed Utilization Cluster to the **Manure Cluster** (thematically as well as in the network graph).

Following up on this, the **Manure Cluster** comprises research about different aspects of *pig manure*, e.g. the *treatment* (e.g. *anaerobic* digestion) of *pig waste* and *manure* for *biogas*, biofuel and *energy production*. Besides the above mentioned aspects related to utilization of manure as fertilizer also the mitigation of *greenhouse gas* emissions of pig waste plays an important role. Furthermore, publications taking a more general view on sustainability in pig production were assigned to this Cluster.

The **Manure Cluster** is strongly connected to the **Environment**

**Table 4**
Results of the degree centrality analysis.

| | Whole network | | | Focal network | | |
|---|---|---|---|---|---|---|
| *Rank* | *Keyword* | *Degree* | *Normalized degree* | *Keyword* | *Degree* | *Normalized degree* |
| 1 | pig | 219 | 0.2183 | pig | 36 | 0.4138 |
| 2 | sustainability | 135 | 0.1346 | sustainability | 9 | 0.1034 |
| 3 | animal welfare | 66 | 0.0658 | environment | 8 | 0.0920 |
| 4 | environment | 62 | 0.0618 | manure | 7 | 0.0805 |
| 5 | pig manure | 59 | 0.0588 | phytase | 6 | 0.0690 |
| 6 | pig production | 52 | 0.0518 | animal welfare | 5 | 0.0575 |
| 7 | phosphorus | 50 | 0.0499 | phosphorus | 5 | 0.0575 |
| 8 | manure | 48 | 0.0479 | utilization | 5 | 0.0575 |
| 9 | organic farming | 44 | 0.0439 | mineral | 5 | 0.0575 |
| 10 | livestock | 42 | 0.0419 | protein | 5 | 0.0575 |

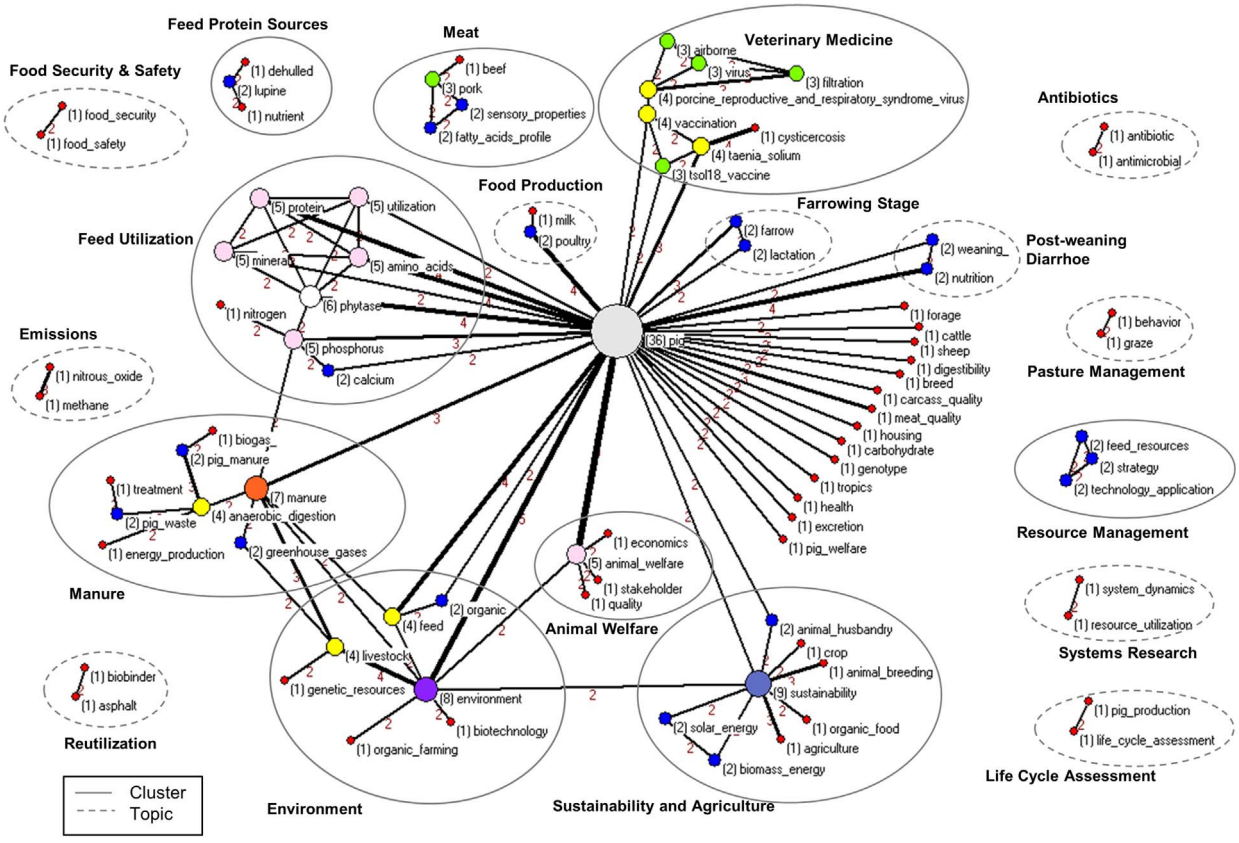


**Fig. 1.** Network graph of the focal network, including the Clusters (connecting > 2 keywords) and Topics (connecting 2 keywords) as well as degree and value of the vertices (in brackets) and lines. Each vertex is given a number and has a certain size, both corresponding to its degree. Each line is given a number and a certain width, both corresponding to its value. The distance between vertices has no relevance as it has been rearranged for better visualisation of the clusters.

**Cluster** through the keywords *feed* and *livestock*. However, both keywords do have a very general connotation and are used in different contexts in the two Clusters. Topics in the **Environment Cluster** comprise conservation of *genetic resources* and *livestock* diversity and genetic improvement of livestock (sustainability) as well as a general perspective on *livestock* production in certain countries or in the 21st century. Additionally, articles also touch on issues similar to those in the **Manure Cluster** such as management of animal wastes, *environmen*tal assessment of nutrient balances or mitigation of negative environmental effects of pig farming in general, using different keywords. A large part of research related to this Cluster focuses on issues around *organic farming* (e.g. comparisons of conventional and *organic farming* practices or special requirements of those practices). The keyword *environment* is used in a different context once, describing the housing conditions of pigs.

The **Environment Cluster** is furthermore connected to the **Animal Welfare Cluster** and the **Sustainability and Agriculture Cluster**. Research in the former relates to husbandry and *animal welfare* issues such as alternatives to tail docking or surgical castration of piglets, (performance of natural) behaviour of pigs in different housing systems or *economic* aspects of animal welfare and/or sustainability improvements. Aspects of feed & food *quality* are further research topics within this Cluster indicating the interdisciplinary approach of animal welfare science, which is also considered in one of the papers. Moreover, societal aspects of *animal welfare* with respect to standards and legislation, interests and (animal welfare) concerns of different *stakeholders* along the supply chain are part of this Cluster.

Research in the **Sustainability and Agriculture Cluster** evolves around global issues such as *animal husbandry* and *animal breeding* for *sustainability* in different parts of the world, (design) principles and assessment of sustainable pig production systems and meat chains as well as technologies in and the role of *organic food* and *agriculture* and integrated *crop*-livestock production systems. Moreover, environmental aspects with respect to the utilization of pig waste and manure or alternative energy sources (e.g. *biomass energy*, *solar energy*) and research using (mathematic) modelling and scenarios for different sustainability questions (e.g. modelling of nutrient budgets) are part of this Cluster.

Finally, the graph shows that the **Veterinary Medicine Cluster** is – in contrast to the other Clusters described above – not connected to any other Cluster. The two key topics in this Cluster deal with *vaccination* programs and health management strategies against parasites (*Taenia solium*) and *viruses* (*porcine reproductive and respiratory syndrome virus – PRRS*).

Finally, three Topics are connected to the central keyword *pig*: **Post-Weaning Diarrhoea** investigating the development of the intestinal immune system in piglets, **Farrowing Sows** dealing with animal welfare in *farrowing* systems as well as nutrition of sows during *lactation* and **Food Production** containing papers on use of slaughterhouse sludge and use of algae as animal feed, both covering also other livestock species.

The subsequent Clusters and Topics are not at all or only connected by one publication with the central keyword *pig*:

The **Meat Cluster** comprises articles on effects of different feedstuff on meat quality as well as factors influencing meat consumption. Though not visually connected to the **Meat Cluster**, similar topics can be found in the **Feed Protein Sources Cluster** with regard to the use of alternative protein feedstuffs and their effects on performance parameters of pigs. The Topic **Food Security and Safety** tackles *food security* issues such as competition between land use for food, feed or fuel production and other purposes such as settlement areas or natural

protection as well as aspects of *food safety* (e.g. contamination of crops fertilized with pig slurry or information services along the food chain). Core questions of the **Emissions** Topic are the construction of greenhouse gas emission inventories and mitigation of relevant greenhouse gases such as *nitrous oxide* and *methane*. Similar to the **Emissions** Topic, **Life Cycle Assessment** deals with environmental assessment of pig farming systems using *life cycle assessment* or carbon footprint approaches. Moreover, this topic investigates multiple aspects of *pig production* systems such as production practices and performance parameters of pig farms in different countries. The Topic **Reutilization** includes research on the suitability of swine manure as sustainable alternative for *asphalt* production and **Systems Research** applies principles of *system dynamics* to understand functions and interdependencies in pig farming agro-ecosystems to develop *resource utilization* strategies. Following this, the **Resource Management Cluster** addresses the availability and efficient use of *feed resources* with respect to social aspects such as poverty and food security or reduction of environmental impact of livestock production. The Topic **Pasture Management** investigates aspects of extensive and outdoor production systems. Finally, the Topic **Antibiotics** investigates strategies for the reduction of *antibiotic* use in pig farming.

## 4. Discussion

### 4.1. Results of the quantitative and qualitative analyses

The two quantitative analyses (degree and betweenness centrality) showed similar results. This means that keywords, which rank high in both analyses, are on the one hand connected to a high number of other keywords (degree centrality) and on the other hand also connect many keywords themselves (betweenness centrality). The keywords *pig, sustainability, environment, animal welfare, phosphorus* and *manure* play a central role in both the degree and the betweenness centrality analysis.

Quantitative and qualitative analyses of the focal network also showed some similarities: in both analyses rather general terms such as *environment*, *manure* or *animal welfare*, which are used in different contexts, play an important role. Their high ranking in the degree analysis shows that they are frequently used in and related to different topics. In the network graph their importance becomes visible through their central position in the respective Clusters. The high ranking of these keywords in the betweenness analysis indicates that they are an important link between different research areas. *Phosphorus* on the other hand is also a prominent keyword in all analyses. However, it is a more specific term describing the environmental issue of efficient use of phosphorus in pig feeding with regard to limited phosphorus resources and excess phosphorus excretion due to the insufficient availability of feed phosphorus in the animals' metabolism (Poulsen et al., 1999; Cordell et al., 2009). Its high degree and betweenness ranking reflects the importance of topics such as environmental degradation or nutrient depletion for sustainability in agriculture and livestock farming (Thompson and Nardone, 1999; Pretty, 2008). Furthermore, *Phosphorus* is part of the Feed Utilization Cluster, which includes also the keywords *utilization*, *mineral* and *protein*. They have a high degree centrality in the analysis of the focal network, which is a result of the high number of connections among the keywords in this Cluster. Hence, this indicates that the Feed Utilization cluster represents a very specific and distinct research area, which was verified by crosschecking the content of the abstracts.

The comparison of results of the betweenness centrality analyses of the two networks may lead to the conclusion that the Veterinary Medicine Cluster forms an important link between clusters in the focal network. However, the high betweenness centrality results from the structure of the Cluster and not from connecting different Clusters in the network: in contrast to Clusters with many interconnections between all keywords, the Veterinary Medicine Cluster consists of two separate subfields basically describing two different diseases (*PRRS* and *Cysticercosis*).

### 4.2. Matching of the network with current concepts of sustainability in livestock farming

In line with the concept of strong sustainability (Williams and Millington, 2004), environmental issues are represented in various Clusters and Topics of the network: the Clusters Feed Utilization, Manure, Environment, Sustainable Agriculture, Resource Management, and Feed Protein Sources, as well as the Topics Emissions, Reutilization, and Life Cycle Assessment. In combination with the results of the degree and betweenness centrality analyses (in particular of the whole network) this underlines the environmental focus of the strong sustainability concept (Williams and Millington, 2004) and the rooting of the sustainability debate in environmental movements (Robinson, 2004).

Referring to the sustainability definition by ten Napel et al. (2011) who advocate that sustainable pig farming comprises environmental issues, animal health and welfare as well as farm income, livelihood of farmers and working conditions, a Cluster representing socio-economic issues is largely missing. *Economics* merely occur as single keyword as a part of the Animal Welfare Cluster. Social aspects can most likely be associated with the Food Security and Safety Cluster, which represents a global social issue. However, social and economic issues play an essential role for sustainability of farming systems on both, a global and local level (Kropff et al., 2001; Darnhofer et al., 2010). Therefore, it is surprising that no separate socio-economic Cluster was identified in the network. At the same time, however, there exist a number of economic studies in the realm of pig farming (e.g. Den Ouden et al., 1997; Huang and Magleby, 2003; Guy et al., 2012), suggesting that the majority of those studies have not been published or keyword indexed in the context of sustainability in pig production systems. For farmers, economic aspects play an essential role in decision making processes and there is often a conflict of goals between economic and e.g. environmental or animal welfare considerations on farm level (Darnhofer, 2010). Moreover, also on a global scale these conflicts between socio-economic and environmental objectives, against the background of scarce resources, are crucial for political decisions and future developments (Tilman et al., 2002) Such global aspects are, to some extent, represented in the Human Nutrition and also in the Resource Management Cluster.

Important (ethical) issues such as animal welfare are addressed in the definition of sustainability in livestock and pig farming and commonly subsumed under the social sustainability dimensions (Thompson et al., 2011). In the present network analysis, a distinct Animal Welfare Cluster and also a Veterinary Cluster were identified. Hence, animal health and welfare are social/societal aspects, which are emphasized more than others because they play an essential role for sustainability in livestock farming (Keeling, 2005; Tucker et al., 2013).

As briefly mentioned before, the clusters depict two aspects of sustainability in agriculture and livestock faming: sustainability on farm level on the one hand and the contribution of agriculture and livestock farming systems to global sustainability on the other (Tilman et al., 2002; Vermeulen et al., 2012). The Human Nutrition Cluster for example comprises the contribution of pig farming to the global issue of food security as well as the importance of the safety of food for human consumption, whereas the topics in the Veterinary Cluster are more related to animal health and treatments of the animals on farm level. However, most of the Clusters contain keywords and topics, which can be related to both of the described approaches. This in turn shows the interconnectedness and interdependency of farm level and global scale.

The Sustainability and Agriculture Cluster probably represents the most diverse and multi-faceted cluster: it involves different topics (e.g. integrated agricultural systems and alternative energy sources), ap-

proaches (assessment of production systems and development of sustainable technologies), and scales (local and global). This underlines once more the broad application of sustainability in livestock sciences and the complexity and multidimensionality of the concept.

### 4.3. Methodological aspects

Regarding the method, the present study shows that keyword network analysis is a suitable tool to map out a research area and identify research topics. Still, there exist some limitations with regard to data collection, keyword revision and interpretation of keywords and network, which have to be taken into account:

- First, choosing only author keywords yielded a comprehensive, yet manageable keyword network for this study. However, some journals require that author keywords must not repeat terms used in the title, which affects the choice of keywords. This issue was not considered in the present analysis because only a small number of articles were affected and it was not clear if journals applied this policy already at the time the papers had been published. Including the title in the keyword analysis may help to avoid this bias, but bears other challenges such as a bigger network size and the inclusion of 'creative' or metaphorical titles.
- Performing a keyword revision to subsume synonymous keywords is helpful to create a consistent network. However, this standardisation appears to be less feasible for very large networks.
- Third, crosschecking the keywords in the context of the abstracts showed that the keywords of different publications were used in the same context and understanding. Only few very general keywords such as *environment* or *livestock* subsumed different issues and were difficult to interpret without scrutinizing the content of the publications. This suggests that also keyword network analyses with larger samples, which limit the feasibility of crosschecking the abstracts, still allow the identification of the main research areas.

Comparing the whole network and the focal network showed that creating a smaller network (by removing the single lines) does not change the results of the quantitative analyses substantially. However, keywords from the Feed Utilization and Veterinary medicine Clusters ranked higher in the quantitative analysis of the focal network than of the whole network. Hence, the structure of the single Clusters and adjacent keywords has to be taken into account when interpreting single keywords' degree and betweenness centrality. Furthermore, removing the single lines may cut new and emergent ideas because they drop out of the focal network. In this study the reduction of the network was performed to verify that keywords were used in the same context in different publications by crosschecking the respective abstracts. In future analyses the identification of clusters or sub-networks may be performed by applying community detection techniques such as suggested by e.g. Fortunato (2010) or Caschili et al. (2014).

Another important aspect is that publications, which would basically fit into the mapped research field, are not considered in the network if the primary search terms (here: pig/swine and sustainab*) do not match with the keywords, title or abstract. In the present network, this might explain the lack of a socio-economic cluster.

If these limitations are taken into account, a quantitative analysis complemented by a clustering of the keyword network presents a helpful method to gain an overview of (emerging) research areas and topics. Furthermore the mapping of a research area facilitates the process of locating research ideas and projects and identifying adjacent topics.

## 5. Conclusions

The results of the network analysis largely correspond to the definitions of sustainability in general and in the context of agriculture, livestock and pig farming, respectively. The environmental background of the sustainability debate is reflected in the variety of topics rooted in an environmental context. However, socio-economic and societal aspects seem to be underrepresented in the analysis. Taking a more interdisciplinary approach and linking research in livestock sciences and agricultural economics could therefore contribute to enhancing and extending research for and knowledge about sustainable pig farming. Furthermore, this study showed that keyword network analysis is a suitable method to map emerging research areas and this way helps scientists to gain an overview on research issues in their realm and locate their own research. Future keyword network analyses may refrain from reducing the network size for keyword interpretation and instead apply community detection techniques for the purpose of cluster identification.

## Conflict of interest

None.

## Acknowledgements

The authors thank all students and supervisors of the Doctoral School of Sustainable Development (dokNE II) and the Animal Husbandry group of the Division of Livestock Sciences at the University for Natural Resources and Life Sciences, Vienna, for valuable input to this work as well as the Human Ecology Research Group at the University of Vienna for fruitful and inspiring discussions.

## References

Acedo, F.J., Barroso, C., Casanueva, C., Galán, J.L., 2006. Co-authorship in management and organizational studies: an empirical and network analysis. J. Manag. Stud. 43, 957–983.
Baldwin, C., Hughes, J., Hope, T., Jacoby, R., Ziebland, S., 2003. Ethics and dementia: mapping the literature by bibliometric analysis. Int. J. Geriatr. Psychiatry 18, 41–54.
Batagelj, V., Mrvar, A., 1998. Pajek - Program for Large Network Analysis. Connections 21, pp. 47–57
Bettencourt, L.M.A., Kaur, J., 2011. Evolution and structure of sustainability science. P Natl. Acad. Sci. USA 108, 19540–19545.
Borgatti, S.P., Mehra, A., Brass, D.J., Labianca, G., 2009. Network analysis in the social sciences. Science 323, 892–895.
Caschili, S., De Montis, A., Ganciu, A., Ledda, A., Barra, M., 2014. The Strategic environment assessment bibliographic network: a quantitative literature review analysis. Environ. Impact Assess. Rev. 47, 14–28.
Cordell, D., Drangert, J.-O., White, S., 2009. The story of phosphorus: Global food security and food for thought. Glob. Environ. Change 19, 292–305.
Costanza, R., d'Arge, R., de Groot, R., Farber, S., Grasso, M., Hannon, B., Limburg, K., Naeem, S., O'Neill, R.V., Paruelo, J., Raskin, R.G., Sutton, P., van den Belt, M., 1997. The value of the world's ecosystem services and natural capital. Nature 387, 253–260.
Costanza, R., Daly, H.E., 1992. Natural Capital and Sustainable Development. Conserv. Biol. 6, 37–46.
Darnhofer, I., 2010. Strategies of family farms to strengthen their resilience. Environ. Policy Gov. 20, 212–222.
Darnhofer, I., Fairweather, J., Moller, H., 2010. Assessing a farm's sustainability: insights from resilience thinking. Int J. Agr. Sustain 8, 186–198.
Den Ouden, M., Nijsing, J.T., Dijkhuizen, A.A., Huirne, R.B.M., 1997. Economic optimization of pork production-marketing chains: i. Model input on animal welfare and costs. Livest. Prod. Sci. 48, 23–37.
Ding, Y., Chowdhury, G.G., Foo, S., 2001. Bibliometric cartography of information retrieval research by using co-word analysis. Inf. Process. Manag. 37, 817–842.
Dolman, M.A., Vrolijk, H.C.J., de Boer, I.J.M., 2012. Exploring variation in economic, environmental and societal performance among Dutch fattening pig farms. Livest. Sci. 149, 143–154.
Fortunato, S., 2010. Community detection in graphs. Phys. Rep. 486, 75–174.
Giddings, B., Hopwood, B., O'Brien, G., 2002. Environment, economy and society: fitting them together into sustainable development. Sustain. Dev. 10, 187–196.
Guy, J.H., Cain, P.J., Seddon, Y.M., Baxter, E.M., Edwards, S.A., 2012. Economic evaluation of high welfare indoor farrowing systems for pigs. Anim. Welf. 21, 19–24.
Hopwood, B., Mellor, M., O'Brien, G., 2005. Sustainable development: mapping different approaches. Sustain. Dev. 13, 38–52.
Huang, W.-Y., Magleby, R., 2003. The economic impacts of Restricting agricultural uses of manure on Hog farms in Southern Seaboard. J. Sustain. Agric. 23, 31–57.
Jahn, T., 2013. Wissenschaft fur eine nachhaltige Entwicklung braucht eine kritische Orientierung [sustainability. Sci. Requires a Crit. Orientat.]. GAIA - Ecol. Perspect. Sci. Soc. 22, 29–33.

Kates, R.W., Clark, W.C., Corell, R., Hall, J.M., Jaeger, C.C., Lowe, I., McCarthy, J.J., Schellnhuber, H.J., Bolin, B., Dickson, N.M., Faucheux, S., Gallopin, G.C., Grübler, A., Huntley, B., Jäger, J., Jodha, N.S., Kasperson, R.E., Mabogunje, A., Matson, P., Mooney, H., Moore, B., O'Riordan, T., Svedin, U., 2001. Sustainability Science. Science 292, 641–642.
Keeling, L.J., 2005. Healthy and Happy: Animal Welfare as an Integral Part of Sustainable Agriculture. AMBIO: A J. Hum. Environ. 34, 316–319.
Kropff, M.J., Bouma, J., Jones, J.W., 2001. Systems approaches for the design of sustainable agro-ecosystems. Agric. Syst. 70, 369–393.
Lélé, S.M., 1991. Sustainable development: a critical review. World Dev. 19, 607–621.
Leydesdorff, L., Wagner, C.S., 2008. International collaboration in science and the formation of a core group. J. Informetr. 2, 317–325.
Nooy, Wd, Mrvar, A., Batagelj, V., 2005. Exploratory social network analysis with Pajek. Cambridge University Press, Cambridge etc.
Poulsen, H.D., Jongbloed, A.W., Latimier, P., Fernández, J.A., 1999. Phosphorus consumption, utilisation and losses in pig production in France, The Netherlands and Denmark. Livest. Prod. Sci. 58, 251–259.
Pretty, J., 2008. Agricultural sustainability: concepts, principles and evidence. Philos T R. Soc. B 363, 447–465.
Robinson, J., 2004. Squaring the circle? Some thoughts on the idea of sustainable development. Ecol. Econ. 48, 369–384.
Reuters, T., 2015. Web of Science. (26.05.2015).
Stern, S., Sonesson, U., Gunnarsson, S., Öborn, I., Kumm, K.I., Nybrant, T., 2005. Sustainable development of food production: a case study on scenarios for pig production. Ambio 34, 402–407.
Su, H.-N., Lee, P.-C., 2010. Mapping knowledge structure by keyword co-occurrence: a first look at journal papers in Technology Foresight. Scientometrics 85, 65–79.
ten Napel, J., van der Veen, A.A., Oosting, S.J., Koerkamp, P.W.G.G., 2011. A conceptual approach to design livestock production systems for robustness to enhance sustainability. Livest. Sci. 139, 150–160.
Thompson, P.B., Appleby, M.C., Busch, L., Kalof, L., Miele, M., Norwood, B.F., Pajor, E., 2011. Values and public acceptability dimensions of sustainable egg production. Poult. Sci. 90, 2097–2109.
Thompson, P.B., Nardone, A., 1999. Sustainable livestock production: methodological and ethical challenges. Livest. Prod. Sci. 61, 111–119.
Tilman, D., Cassman, K.G., Matson, P.A., Naylor, R., Polasky, S., 2002. Agricultural sustainability and intensive production practices. Nature 418, 671–677.
Tucker, T.W., Mench, J.A., von Keyserlingk, M.A.G., 2013. Animal Welfare: an Integral Component of Sustainability. In: Kebreab, E. (Ed.), Sustainable Animal Agriculture.. CAB International, 42–52.
Vermeulen, S.J., Aggarwal, P.K., Ainslie, A., Angelone, C., Campbell, B.M., Challinor, A.J., Hansen, J.W., Ingram, J.S.I., Jarvis, A., Kristjanson, P., Lau, C., Nelson, G.C., Thornton, P.K., Wollenberg, E., 2012. Options for support to agriculture and food security under climate change. Environ. Sci. Policy 15, 136–144.
Wassermann, S., Faust, K., 1994. Social Network Analysis: Methods and Application. Cambridge University Press, New York.
WCED, 1987. Our Common Future. UN Documents.
Whittaker, J., Courtial, J.-P., Law, J., 1989. Creativity and Conformity in Science: Titles, Keywords and Co-Word Analysis. Soc. Stud. Sci. 19, 473–496.
Williams, C.C., Millington, A.C., 2004. The diverse and contested meanings of sustainable development. Geogr. J. 170, 99–104.
Wuelser, G., 2013. Towards adequately framing sustainability goals in research projects: the case of land use studies. Sustain. Sci., 1–14.
Yaoyang, X., Boeing, W.J., 2013. Mapping biofuel field: a bibliometric evaluation of research output. Renew. Sustain. Energy Rev. 28, 82–91.