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Review article

Sustainable livestock production: Low emission farm – The innovative combination of nutrient, emission and waste management with special emphasis on Chinese pig production

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ABSTRACT

Global livestock production is going to be more and more sophisticated in order to improve efficiency needed to supply the rising demand for animal protein of a growing, more urban and affluent population. To cope with the rising public importance of sustainability is a big challenge for all animal farmers and more industrialized operations especially. Confined animal farming operations (CAFO) are seen very critical by many consumers with regard to their sustainability performance, however, the need to improve the sustainability performance especially in the ecological and social dimension exists at both ends of the intensity, i.e., also for the small holder and family owned animal farming models. As in livestock operations, feed and manure contribute the majority to the three most critical environmental impact categories global warming potential (GWP), acidification (AP) and eutrophication potential (EP) any effort for improvement should start there. Intelligent combination of nutrient-, emission- and waste management in an integrated low emission farm (LEF) concept not only significantly reduces the environmental footprint in the ecological dimension of sustainability, but by producing renewable energy (heat, electricity, biomethane) with animal manure as major feedstock in an anaerobic digester also the economic dimension can be improved. Model calculations using new software show the ecological improvement potential of low protein diets using more supplemented amino acids for the Chinese pig production. The ecological impact of producing biogas or upgraded biomethane, of further treatment of the digestate and producing defined fertilizers is discussed. Finally, the LEF concept allows the integration of an insect protein plant module which offers additional ecological and economical sustainability improvement potential in the future. Active stakeholder communication about implementation steps of LEF examples improves also the social aspect of sustainability.

1. Introduction

Over the last few years, sustainability has become a new megatrend and even a business imperative (Lubin and Esty, 2010). It has also become the key driver for innovation (Nidumolu et al., 2009) and Cargill President and Chief Executive Officer Dave MacLennan declared that sustainability is even the "new normal" (Cargill, 2015). Sustainability related risks and opportunities become standard elements in the non-financial reporting of stock-listed US meat companies (SASB, 2015). In the broad sense "sustainability" means the ability to maintain a process. The term is frequently used in connection with biological systems and can be defined as the ability of an ecosystem to maintain ecological processes, biodiversity and productivity into the future. Livestock is a major contributor to global environmental issues (Steinfeld et al., 2006; FAO, 2009). The huge and fast growing demand for feed crop production shapes entire landscapes and can reduce natural habitats, causing degradation in some areas. In terms of environmental degradation, agriculture in general – and livestock farming in particular – are very important sources of pollution globally and especially in livestock production areas with a high animal density. In China for example, livestock farms produce

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more than 4 billion tons of manure annually, much of which contributes to nutrient overload in waterways and subsequent eutrophication and dead zones. Globally, as more and more land is converted to intensive monocrop production of soybeans and corn (and others in a narrow range of industrial feed crops), pesticide and fertilizers pollute waterways, biodiversity declines, natural carbon sinks are destroyed mainly due to direct and indirect land use change (dLUC, iLUC), and greenhouse gases (GHG) are emitted in all stages of intensive feed production and transport. Technological improvement is a key driver of global livestock production. Growing productivity has been achieved through advanced breeding and feeding technology, and through irrigation and fertilizer technology in crop production, leading to higher yields per hectare. Intensification, the vertical integration and up-scaling of production also lead to larger units and larger and more intensive livestock operations. There are also geographic shifts, with production moving away from local natural resources. Animal production is very often separated from crop production and is seen responsible of more than 14.5% of human induced GHG emissions in terms of CO_2-equivalents (CO_2e) (Gerber et al., 2013). According to the same authors (2013) it is important to set up advanced technologies such like modern feed strategies using beneficial feed additives like enzymes, amino acids and gut modulation products, manure management practices and energy use efficiency to further reduce livestock production related emissions. Modern livestock production is characterized by efficient nutrient management to reduce feed consumption and reduced use of feed ingredients with critical environmental load, i.e., soybean meal (SBM) originating from areas having undergone LUC, waste management to reduce waste volumes and finally emission management to reduce environmental impacts. All three are followed by efficient energy use and recycling trying to achieve closed loops as much as possible. This is what is generally understood as ''sustainable intensification'' and is seen by many as the key element how to satisfy the rising demand for animal protein without depleting natural resources. As production intensity enhances biological efficiency and as production intensity and emission intensity are inversely related, more intensive animal production systems generally show lower values for important global environmental impact categories like global warming potential, eutrophication potential, acidification potential, energy use and land use (de Vries and de Boer, 2010; MacLeod et al., 2013, Dourmad et al., 2014) when the functional unit selected is kg of product (i.e., life weight, milk, egg, meat) in life cycle assessment (LCA) studies.

2. Sustainability – definition and challenge for livestock

The United Nations Brundtland commission in 1989 defined sustainability as ''meeting the needs of the present without compromising the ability of future generations to meet their own needs''. Fig. 1 Shows a typical sustainability model, the so called triple P model. There are three overlapping ellipses which reflect the social (people), the economic (profit) and the ecological (planet) dimensions. Overlapping of only two dimensions might be viable, bearable or equitable, but only the intersection of all three can be regarded as sustainable.

At a fundamental level, impacts of human activities are now seen in harmful changes to the global geochemical cycles that are critical for life on earth and thus the elementary pillars of the ecological dimension of sustainability. They are the nitrogen cycle, the water cycle, the carbon cycle and the oxygen cycle. To achieve globally sustainability, management of these cycles at all levels is essential. Narrowing the scope in this review on agricultural livestock farms and industrial like livestock operations, the most important and most frequently mentioned critical challenges from the market (consumers and retailers), the general public [media, non governmental organisations (NGOs)], and politics (regulatory authorities) are the impact of livestock on the different elements of the ecological footprint like climate change, land use and degradation, water footprint and biodiversity as well as the social elements food safety and security, animal welfare and workforce health and safety. In 2006 the FAO report ''Livestock's long shadow'' (Steinfeld et al., 2006) came as a shockwave. It stated, that the global animal industry contributed more than traffic to global warming, i.e., 18% of the global warming potential (GWP) expressed in CO_2e. It also stated, that damage to environment occurred at both the high and low end of the intensity of livestock production systems and that it should be a major policy focus dealing with problems of land degradation, climate change and air pollution and loss of biodiversity. In the report ''The state of food and agriculture – Livestock in the balance'' (FAO, 2009) the positive social aspects of the livestock sector in contributing to food security and poverty reduction especially in developing countries is underlined. However, the livestock sector must improve its environmental performance at one hand, but can play a key role in mitigating climate change through adoption of improved technologies. To do this, feed conversion efficacy and feed quality are key tools to reduce GHG emissions. The most recent publication (Gerber et al., 2013) points out specific mitigation opportunities in tackling climate change through livestock like improving production efficiency, improving breeding and animal health, using manure management practices to recycle and recover nutrients and energy contained in manure, sourcing low emission inputs such as feed and use of feed additives like amino acids, enzymes and gut modulating products such as pre- and probiotics, organic acids and phytobiotics. Due to its substantial environmental impact, more and more the livestock industry comes under scrutiny of strict legal framework in an effort to reduce this impact. As in the case of the European Union (EU), there are significant reduction targets to be achieved by 2030 compared to the 2009 level. For the EU 28, theses targets are 27% for ammonia (NH_3) and 33% for methane (CH_4) (Agrarzeitung, 2014). These ambitious reduction targets can not be achieved by a single measure only, they call for an intelligent combination of several mitigation technologies like precision animal feeding and handling concepts, improved manure storage, -handling, -treatment and -application technologies to optimize the animal feed to food chain with regard to its environmental impact. On the other hand, there are also examples, where companies do not wait for the legal framework to tighten, but try to proactively create niche markets for their more sustainable produce. Australian Pork, a producer-owned company delivering integrated services that enhance the viability of Australia's pig producers, is aiming for zero-carbon pig farms by applying new feeding concepts, effective effluent management, reduction of GHG emissions through fertilizer applications and most efficient recovery of emissions (CH_4) from the manure for use as ''green energy'' (Pig International, 2013).

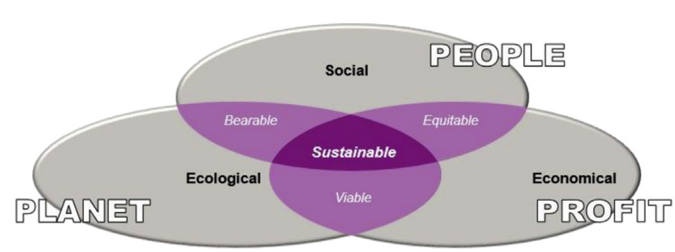

Fig. 1. 3-dimensions model of sustainability.

3. Sustainability – a topic for China?

The fast industrial development of China since the commercial liberation in 1978 leads to severe environmental damages which have been published the first time (The Guardian, 2014). The 16% of soil are said to be polluted, 20% of farmland unusable and 60% of groundwater not suitable for consumption. This situation leads to a revision of China's 25-year-old country's environmental law with concrete environmental standards and strict penalties as important principle. In case of hurting the law, companies will be published, responsibles will be prisoned, officials can be fired and high fines for polluters will be issued. In parallel, for example, pig production in China underwent a dramatic structural change from almost only backyard farms in 1985 to about 60% of pigs produced by specialized household farms raising up to 500 pigs per year and 22% of pigs produced by large-scale commercial farms producing from 500 to 50,000 pigs per year (INFORMA, 2009) in 2007 with a clear tendency for further concentration in the following years. Not surprisingly, if not accompanied by best management practises, these development leads to more frequent cases like the threatening of closing water polluting poultry and pig farms around Lake Tai by environmental protection authorities (The Dairy Site, 2015) or the 16,000 dead pigs floating down the Huangpu river into China's affluent financial centre Shanghai (Reuters, 2013). The Ministry of Environmental Protection, State Statistics Bureau and Ministry of Agriculture jointly released the Bulletin on the First National Census on Pollution Sources on February 9, 2010 (China.org 2010). The most striking result of this investigation was that agriculture today is a bigger source of pollution in China than industry. Researchers found that farming was responsible for 44% of chemical oxygen demand (the main measure of organic compounds in water), 67% of phosphorus discharges, and 57% of nitrogen discharges into bodies of water. Manure from industrial livestock farms is the most important source of this pollution—in 2008 China's livestock produced 4.8 billion tons of waste. As the livestock industry grows, so too will the amount and problems of manure.

The most critical factors for sustainable development are population growth, consumption level and technology. Ehrlich and Holdren (1971) brought together these factors in to a simple equation: $I = P \times A \times T$, where I is the environmental impact, P is the population, A is the affluence and thus the consumption level of life style and T is the technology level. Using this principle two scenarios of pig meat production for China can be envisaged; a baseline scenario and a growth scenario. Within each scenario is a high protein and a low protein pig feed diet (see Table 1). In the base case a 35 kg consumption level is assumed, in the growth scenario 45 kg have been projected. Keeping the affluence level constant, lowering the protein level of the diet by 3%-points reduced the nitrogen load by almost 25%. The reduced protein regime could even allow an increase of the meat consumption by 10 kg per capita and year and still reduce the nitrogen output by more than 3%, whereas the standard protein regime would lead to a 28% higher nitrogen load compare with the baseline scenario.

Gerber et al. (2013) estimated, that the livestock sector produces GHG emissions of 7.1 Gt CO_2e or 14.5% of total human-induced GHG emissions. The pig meat sector, producing globally 110.2 million tons of pork carcass weight, emitted 0.668 Gt CO_2e or 9.4% of the total livestock emissions (MacLeod et al., 2013). It can be estimated, that China with its production of >50 million tons of pork stands for about 45% or about 0.3 Gt CO_2e. Over all production systems (backyard, intermediate, industrial) feed production stood for 60% and manure management for 27% of the GHG emissions. Comparing this global estimation with data for single countries, Reckmann et al. (2013) for German and Dalgaard (2007) for Danish pig farms found with 63% similar contributions of feed. Thus, in an effort to mitigate the environmental impact of pig production, these two sectors offer the best lever for improvement. This is also true for the two other environmental impact categories most frequently mentioned in LCA studies (deVries and de Boer, 2010; Dalgaard, 2007; Reckmann et al., 2013; Kebreab et al., 2015), namely the eutrophication potential (EP) and the acidification potential (AP) normally expressed in PO_4e and SO_2e, respectively. Eutrophication potential and AP are closely connected to air, soil and water quality and capture the environmental impact associated with commonly regulated emissions. Acidification potential is causing the blue-green algae bloom frequently envisaged in lakes and rivers close to regions with a dense livestock population, EP acid rain and smog.

4. The third dimension in feed formulation

Optimizing the nutritional and economic aspects of feed formulation and feeding concepts is established best practice of all advanced premixers, compounders and integrated feed companies. However, the ecological aspect has been given only low consideration due to missing tools and low legal and public pressure. The latter aspect most likely is going to change quickly in most regions, and in parallel more and more software tools are available for free from consulting services (Holos, 2015), universities (FeedPrint, 2015) or feed additive suppliers (Evonik, 2015a). AMINOFootprint 2.0 is a web-based app which can be used with desktop and laptop PCs or tablets. It focuses on calculation the GWP, EP and AP values of individual compound feed types for pig or poultry with 1 t of feed as the functional unit as well as whole feeding cycles with the feed conversion ratio and the relative share of the single feed stages (i.e., starter, grower, finisher) as variables and on metric ton of live weight as functional unit. The database consists of certified feed ingredients from the main production regions of the world (GaBi, 2014) and covers all relevant stages of feed ingredient production. The user can further simulate different transport and supply chain scenarios and see their environmental impact. The system boundaries are cradle to gate, so not including logistics of finished feed, meat processing and the retailing phase. The user can finally compare the environmental impact categories of a standard feed with those of an ecologically optimized feeding concept. This is a net comparison not only taking into account the effects of the different feed composition, but including the effects of the NH_3 emissions in the animal house and during manure storage and field application as well as the nitrous oxide (N_2O) and nitrate (NO_3-) emissions during manure spreading. As the nitrogen content in the feed is directly but inversely related to these emissions occurring in the stable and during manure storage and application, an efficient approach to reducing emissions is the reduction of the protein content in the diet (Dourmad et al., 1992; Canh et al., 1998; Eriksson et al., 2005; Jongbloed et al., 2007; Le et al., 2009; Spring

Table 1
Case study on the impact of a reduced protein level in pig feeding on the nitrogen load.

Item	Baseline		Growth	
Feeding strategy, % CP	18	15	18	15
People, bn	1.3	1.3	1.3	1.3
Affluence, kg meat/capita	3	35.0	45.0	45.0
Technology (N-output), g/kg meat	6.12	4.62	6.12	4.62
Impact, kt N	279	211	358	270
Relative, %	100	75.6	128	96.7

Sources: FAOSTAT, 2009, CIA World Factbook, 2009, own calculations.

and Bracher, 2014; Li et al., 2015). It is generally accepted that reducing the protein level in a diet reduces the nitrogen content in the manure by 10%, the NH_3 emission into the ambient air by 10%, the water consumption of the animals by 3% and the manure volume by 5% (Peisker et al., 2009). As up to 4% of the N in fertilizer or manure can be omitted as N_2O (Woitowitz, 2007), reducing N-content in manure trough low protein diets contributes to reduced N_2O emissions, which is formed by bacterial nitrification and denitrification processes in soil mainly from nitrate.

5. Case study: potential of low protein diets in lowering the environmental impact of Chinese pig production

In order to demonstrate the potential of a lower protein content compared to the Chinese Feeding Standard (Dong, 2015) in lowering the most critical environmental impact categories GWP, AP and EP, a case study using AMINOFootprint 2.0 has been conducted. First, diets with a minimum CP-level according to the Chinese standard have been optimized using price levels for the ingredients in June 2015 using Brill software. Then, the CP-level has been reduced by 1 to 2.5% points for the different stages of the growing pig feeds, by 1% point for the gestating sow and by 2% points for the lactating sow. For the growing pig, Table 2 shows the nutrient composition, the environmental impact and the cost of the different diets, whereas.

Table 3 contains the ingredient composition. Tables 4 and 5 show the respective data for the breeding sow. The environmental impact has been calculated for the different diets in AMINOFootprint 2.0 setting Shandong province as the feed production site and individual local, regional or overseas transport scenarios for the different ingredients. For SBM, Brazilian source originating from soy plantations having undergone land use change (LUC) was set. As mentioned before, comparing different diets with regard to their environmental impacts takes not only the feeding regime, but also the impact of the nitrogen content on the gaseous emissions during manure storage and spreading into account. These results are shown in Table 6.

The assumed scenario leads to significantly environmental savings. Global warming potential is reduced by about 40,000 kt, AP by about 750 kt and EP by about 170 kt. To put this in perspective, this means more than a 13% reduction for GWP in relation to the 0.3 Gt estimated above for the Chinese pig industry. It also means the equivalent CO_2 output of 17 million middle class cars driving 20,000 km per year each. For growing pigs alone, taking average literature values (de Vries and de Boer, 2010) for GWP, AP and EP as reference a reduction potential can be calculated (Table 7). The calculated savings for the lower protein diets are 11.2, 27.5 and 11.3% for GWP, AP and EP, respectively. Due to different scenarios for the compared protein levels and whether feed ingredients with or without LUC with its detrimental impact especially for GWP have been used, it is quite difficult to compare these savings with other trials where lower protein diets have been evaluated for their mitigation potential versus conventional diets. However, reductions shown by Eriksson et al. (2005), Mosnier at al. (2011), Osada et al. (2011), Ogino et al. (2013), Tsujimoto et al. (2013), and Garcia-Launay et al. (2014) are in a similar order of magnitude or even higher.

Generally one can say, that in most cases the mitigation potential by lowering the protein content is larger for AP and EP compared with GWP. For GWP, a much more significant factor than the CP-level as such is whether ingredients from LUC regions are being used or exchanged in the different scenarios. Even replacing an ingredient, like for example SBM from Brazil originating from LUC-areas with Brazilian SBM from an area not being debited with LUC without reducing the CP-level, shows a significant lowering of the GWP. The most significant improvements always can be shown by exchanging a LUC-ingredient with an non-LUC ingredient and in parallel lowering the CP-level of the diet by using more supplemental amino acids. In the last few years, there is more and more scientific evidence (Evonik, 2013; Gallo et al., 2014; Garcia-Launay et al., 2014; Gloaguen et al., 2014) that the CP level of pig diets can be lowered much more than current practice in pig farming without losing performance when formulating diets at the right ideal protein ratio, optimized levels of standardized ileal digestible amino acids and using the net energy (NE) system instead of metabolizable energy (ME). A further reduction might be possible when additional feed amino acids like isoleucine or arginine on top of the established ones (methionine, lysine, threonine, tryptophan, valine) become available. However, at extremely low protein levels N or non-essential amino acids like glycine or glutamine might become limiting. Wu (2014) proposes in consequence to enlarge the ideal protein pattern by those amino acids, which have been traditionally named as being non-essential.

Table 2
Nutrient composition, environmental impact and cost of growing pig diets formulated according to Chinese standard or with reduced protein level.[1]

Calculated nutrients	Piglet prestarter	Piglet prestarter, low CP	Starter	Starter, low CP	Grower 1	Grower 1, low CP	Grower 2	Grower 2, low CP	Finisher	Finisher, low CP
Weight range, kg	3 to 8	3 to 8	8 to 20	8 to 20	20 to 35	20 to 35	35 to 60	35 to 60	60 to 100	60 to 100
% CP	21.00	20.00	19.00	18.00	17.80	15.50	16.40	14.44	14.50	12.00
kcal ME	3,238	3,238	3,120	3,120	3,070	3,070	3,070	3,070	3,070	3,070
Lys	1.29	1.29	1.04	1.04	0.79	0.79	0.72	0.72	0.61	0.61
Met	0.37	0.39	0.35	0.36	0.29	0.26	0.27	0.25	0.25	0.21
Met + Cys	0.73	0.73	0.60	0.60	0.55	0.48	0.52	0.46	0.47	0.39
Thr	0.81	0.81	0.65	0.65	0.51	0.50	0.47	0.45	0.41	0.40
Trp	0.24	0.24	0.18	0.18	0.14	0.14	0.13	0.13	0.11	0.11
Arg	1.10	1.01	1.07	1.08	0.90	0.82	0.83	0.75	0.75	0.65
Ile	0.70	0.70	0.62	0.60	0.54	0.47	0.49	0.42	0.43	0.36
Leu	1.73	1.65	1.40	1.26	1.31	1.19	1.24	1.13	1.14	0.93
Val	0.88	0.88	0.73	0.71	0.67	0.59	0.62	0.54	0.55	0.46
His	0.50	0.47	0.41	0.39	0.39	0.33	0.35	0.30	0.31	0.26
kg CO_2e/t feed	904.4	654.5	357.8	390.8	−60.2	−460.2	−382.6	−710.0	−691.5	−674.5
kg SO_2e/t feed	9.78	9.48	8.85	9.16	9.33	8.23	8.36	8.09	8.12	8.89
kg PO_4e/t feed	3.72	3.65	3.36	3.52	3.95	3.10	3.54	3.05	3.14	3.44
Cost, Euro/kg	267.58	277.85	232.47	235.50	216.75	212.10	210.50	207.39	201.73	206.74

CO_2e = CO_2-equivalents; SO_2e = SO_2e-equivalents; PO_4e = PO_4e-equivalents.

[1] Amino acids in % standardized ileal digestibility (SID).

Table 3
Ingredient composition of growing pig diets formulated according to Chinese standard or with reduced protein level.

Ingredients, %	Piglet prestarter	Piglet prestarter, low CP	Starter	Starter, low CP	Grower 1	Grower 1, low CP	Grower 2	Grower 2, low CP	Finisher	Finisher, low CP
Weight range, kg	3 to 8	3 to 8	8 to 20	8 to 20	20 to 35	20 to 35	35 to 60	35 to 60	60 to 100	60 to 100
Corn	60.21	62.73	58.76	63.34	58.73	64.81	62.19	67.25	66.93	77.93
Soybean meal (48%)	17.68	14.67	13.09	13.23	4.05	3.03	2.12	–	–	–
Sunflowermeal	–	–	15.66	18.20	8.89	17.49	12.18	18.10	16.97	16.32
Rapeseed meal	–	–	–	–	15.00	–	9.89	–	1.96	–
DDGS corn	10.00	10.00	8.79	–	10.00	10.00	10.00	10.00	10.00	–
Blood plasma	5.00	5.00	–	–	–	–	–	–	–	–
Whey powder	2.50	2.50	–	–	–	–	–	–	–	–
MCP	0.84	0.86	0.73	0.77	0.61	0.77	0.57	0.69	0.48	0.57
Limestone	2.30	2.44	1.11	2.46	1.26	2.17	1.85	2.44	2.54	3.72
Salt	0.12	0.12	0.39	0.43	0.39	0.38	0.16	0.17	0.10	0.23
Premix	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50
MetAMINO	0.10	0.13	0.05	0.08	–	–	–	–	–	–
Biolys	0.65	0.79	0.81	0.83	0.49	0.77	0.52	0.77	0.52	0.64
ThreAMINO	0.08	0.12	0.10	0.12	–	0.07	–	0.05	–	0.07
TrypAMINO	0.03	0.05	0.01	0.01	–	0.02	–	0.02	–	0.02
ValAMINO	–	0.05	–	0.02	–	–	–	–	–	–
L-Isoleucine	–	0.05	–	–	–	–	–	–	–	–

DDGS = distillers dried grains with solubles; MCP = monocalciumphosphate.

6. Low emission farm (LEF)

To reach the full potential of mitigating the environmental impact of livestock production, several best practices must be combined (Gerber et al., 2013). These best practices are optimized breeding and husbandry management for best performance and health, efficient nutrient management to reduce feed resources consumption and nutrient excretion, waste management to reduce waste volumes and finally emission management to reduce environmental impacts. All three are followed by efficient energy use and nutrient recycling. The combination of all these elements leads to more efficient and sustainable reduction of emissions and

Table 4
Nutrient composition, environmental impact and cost of breeding sow diets formulated according to Chinese standard or with reduced protein level[1].

Calculated nutrients	Sow, gestating	Sow, gestating low CP	Sow, lactating	Sow, lactating low CP
% CP	13.00	12.00	18.00	16.00
kcal ME	2,880	2,880	3,170	3,170
Lys	0.42	0.42	0.79	0.79
Met	0.19	0.16	0.25	0.22
Met + Cys	0.39	0.35	0.53	0.48
Thr	0.34	0.33	0.51	0.49
Trp	0.13	0.12	0.20	0.17
Arg	0.65	0.56	1.00	0.83
Ile	0.37	0.32	0.61	0.50
Leu	0.68	0.62	1.08	0.92
Val	0.49	0.44	0.70	0.67
His	0.25	0.22	0.39	0.33
kg CO_2e/t feed	−901.1	−906.7	413.6	−225.8
kg SO_2e/t feed	3.27	3.23	4.68	3.89
kg PO_4e/t feed	1.34	1.36	2.63	2.38
Cost, Euro/t	166.60	166.88	206.38	207.05

CO_2e = CO_2-equivalents; SO_2e = SO_2e-equivalents; PO_4e = PO_4e-equivalents.

[1] Amino acids in % standardized ileal digestibility (SID).

Table 5
Ingredient composition of breeding sow diets formulated according to Chinese standard or with reduced protein level.

Ingredients, %	Sow, gestating	Sow, gestating low CP	Sow, lactating	Sow, lactating low CP
Wheat	–	–	75.33	81.39
Barley	79.39	80.20	–	–
Wheat bran	8.65	13.82	–	–
Soybean meal (48% CP)	–	–	15.19	7.39
Sunflowermeal	9.31	3.20	6.49	7.70
Dicalcium phosphate	0.70	0.75	1.51	1.55
Limestone	0.81	0.81	0.29	0.31
Salt	0.62	0.62	0.48	0.49
Premix	0.50	0.40	0.40	0.50
Biolys	0.13	0.19	0.31	0.62
ThreAMINO	–	0.03	–	0.07
ValAMINO	–	–	–	0.07

Table 6
Potential reduction of environmental footprint in Chinese pig production.

Parameter	Fattening pigs	Gestating sows	Lactating sows	Total
% CP standard/low	15.9/13.8	13.0/12.0	18.0/16.0	
GWP, t CO_2e	29,093,350	445,500	10,075,050	39,613,900
AP, t SO_2e	624,624	56,430	69,309	750,363
EP, t PO_4e	146,861	10,395	15,147	172,403

GWP = global warming potential; AP = acidification potential; EP = eutrophication potential; CO_2e = CO_2-equivalents; SO_2e = SO_2e-equivalents; PO_4e = PO_4e-equivalents.

Table 7
Relative savings for GWP, AP and EP by lowering the average CP-level from 16 to 14% for growing pigs.

Parameter	Per kg live weight[1]	Per pig 100 kg final weight[1]	650 million pigs in China per year	Savings by low protein diets, t/yr	Savings, %
GWP, t CO_2e	4	400	260,000,000	29,093,350	11.2
AP, t SO_2e	0.035	3.5	2,275,000	624,624	27.5
EP, t PO_4e	0.02	2	1,300,000	146,861	11.3

GWP = global warming potential; AP = acidification potential; EP = eutrophication potential; CO_2e = CO_2-equivalents; SO_2e = SO_2e-equivalents; PO_4e = PO_4e-equivalents.
[1]GWP, AP and EP in kg.

waste and creates new business opportunities and thus increases profitability in animal production and could be abbreviated as LEF or low emission farming. Fig. 2 schematically describes the concept.

In this concept animal manure is used as feedstock for an anaerobic digester (AD) producing biogas. According to Masse et al. (2011) adoption of AD is an alternative which could substantially reduce the environmental footprint of housed livestock operations, but inadequate regulatory polices and incentives would be obstacles to widespread implementation of AD in developed and developing countries. Depending on the infrastructure, co-ferments like fat-rich slaughter offals or starch containing sources like flour- or feed mill offall could improve the CH_4 yield in the biogas plant. The raw biogas contains about 60% CH_4 gas as the main energy containing element which can be transformed in a combined heat and power (CHP) plant to heat and electricity being used on the farm or being sold to the public. Depending on the local infrastructure, the conditions for costs and prices for energy (heat, electricity, gas, fuel, diesel) and the different regulation for taxes or subsidies for renewable energies an upgrading of the raw biogas in a two step process via purification and compressing to almost pure CH_4 gas very similar to natural gas can be feasible. Technically this upgrading is well established. As for biomethane the most significant technologies are: 1) water scrubbing (WATS), 2) pressure swing adsorption (PSA), 3) chemical scrubbing (CHEMS), 4) physical scrubbing (PHYS) and 5) membrane separation (MEMS) (Niesner et al., 2013). According to the same authors, MEMS appears to be a very promising technology. The great asset of the membrane technology is ease of operation, no employment of chemicals or other consumables, the easy process configuration and the low spatial footprint. Suitable applications for MEMS appear to be at medium and small plants (100 to 500 m^3/h) which are typical for farm operations. Here the membrane technology has comparably low investment and

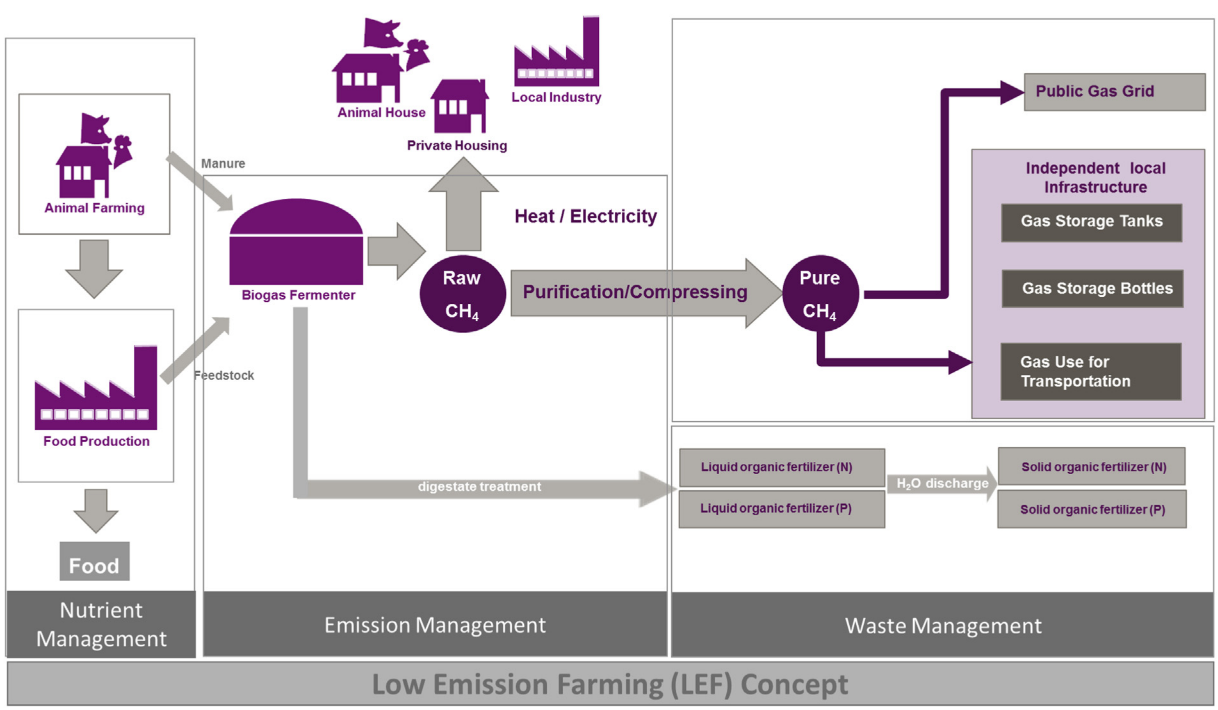

Fig. 2. Elements of the integrated low emission farm concept.

operational costs (TUV, 2012) and when run with a multistage process only a very low methan slip of $<1\%$ occurs (Evonik, 2015b). Due to its high GHG potential of about 23 times CO_2 a low CH_4 slip from a biogas plant is most critical for the mitigation performance. Especially for rural areas this decentral, local energy setup offers additional business opportunities in storing, using and selling the gas in bottles or tanks or even for fueling trucks after having adapted the engine to replace diesel. Similar like untreated manure, the so called digestate or fermentation rest out of the anaerobic digester is used as valuable organic fertilizer with nitrogen and phosphor as the most valuable nutrients. However, again depending of the given set-up of the farm (cash-crop fields available or not in close distance) and the local fertilizer greulations, there might be either a nitrogen or phosphorus surplus or deficiency. Further treatment of the digestate can optimize the picture economically and ecologically. A liquid–solid separation of the digestate leads to a more N-rich liquid and a more P-rich solid fraction. As an additional extension step, the liquid components could be brought into another chemical nutrient recycling step with clearly defined fertilizers like liquid ammonium sulfate (8% N and 9% H_2SO_4) or magnesium ammonium phosphate (MAP, also known as Struvit) and a concentrated PK-fertilizer (4% P and 7% K) as well as almost nutrient free water as output. Schultz (2015) presented a total nutrient balance calculation for such a biogas plant including nutrient recycling and production of defined fertilizer with 200,000 t each of cattle and pig manure as coferment-input and 24,241 t/yr liquid Amsul, 25,714 t liquid PK (4/7%) and 4,235 t dry fertilizer as output which can be sold and makes this set-up commercially feasible. The high energy and heat demand of the nutrient recycling plant is covered by the CHP plant of the biogas plant.

In summary, the anaerobic manure digester is a recommended GHG mitigation strategy that has a significant potential to capture and destroy most CH_4 from manure and generates renewable energy. Management of digestion systems is important, so that they do not become net emitters of CH_4. There might also be a potential for mitigating N_2O emissions following land application of the digested manure, although results are contradictory (Hristov et al., 2013; Moeller, 2015). For a detailed review of the current literature on the effects of the anaerobic digestion process on soil carbon and nitrogen turnover, N emissions during storing and application and soil biological activity see Moeller (2015).

On larger farms, biogas systems may require large initial capital investments and their economic feasibility must be shown with longer term business case calculations. To proof the ecological benefit of the LEF, more data based on the LCA method need to be created. For individual elements (i.e., nutrient-, emission-, waste- and fertilizer management). The mitigation potential of the nutrient management by lowering protein has been discussed above. If the pig manure was anaerobically digested and the biogas used for energy production, the GHG emission per pig could be reduced by 16% in a Danish investigation (Dalgaard, 2007). Greenhouse gas emissions emissions of mixed farming systems are reduced with implementation of biogas plants by reduced net emissions and after applying credits for the produced renewable energy (Michel et al., 2010; Battini et al., 2014). The design and type of the storing facilities have a major influence whether there are differences for undigested manure in comparison to digestate. Wang et al. (2014) showed for open pig manure stores similar total GHG emissions for undigested and digested manure. However, whereas CH_4 emissions represented the major part of GHG for the undigested manure, this was the case in the digested manure for N_2O. First still provisional results of an LCA evaluation simulating European feeding conditions (Haasken et al., 2015) show that increasing feed efficiency and digestibility through advanced nutrient management reduces significantly the impact of feed, farm application and manure due to reduced volumes, and yields in a reduction of GWP by about 8% compared with the base case. Another 14.3% reduction of GWP is the result of implementing emission management via biogas production due to lower CH_4 losses during manure storing and CO_2 credits for replacing fossil energy. A small further reduction of the GWP by about 1% was possible by the biogas upgrading to biomethane and giving credits for replacing diesel with biofuel. Comparable results are expected for the other impact categories AP and EP, for which the assessment is still in progress. life cycle assessment calculations should be done with an even wider scope to also integrate best practice for digestate storage and field application which seem to be advantageous compared with untreated manure (Moeller, 2015). Finally, the mitigation potential producing fertilizers as described above in an integrated LEF concept by nutrient recycling using renewable energy produced by a biogas plant fed with manure as feedstock should be researched with the comparable LCA method.

7. Conclusion and outlook

Livestock must improve its environmental footprint given the fact its resource consumption and contribution to GWP, AP and EP are substantial (Steinfeld et al., 2006; Gerber et al., 2013). Pigs are historically and culturally the most important farm animals in China. Therefore, focus in this paper is on the mitigation potential for pigs, however, in principal each element discussed is applicable for cattle and poultry, too. Advanced nutrition concepts applying the latest scientific knowledge offer great improvement potential in lowering the ecological nutrient management performance compared with current industrial practice. Combining best practice with some or all of the described further elements (anaerobic biogas production using manure as feedstock, biogas upgrading, digestate treatment and best application practices of digestate on the field or even nutrient recycling producing different types of fertilizers) under the LEF concept results in even a higher improvement potential. Under the LEF concept the biogas industry will completely change in the future from energy production based on energy crops as feedstock as a core target to effectively manage organic waste and related emissions with energy production as a side effect. Environmental savings as a license to safeguard current business and enable future growth of livestock farms under more strict environmental regulations will predominate renewable energy production under subsidize schemes. The economic and ecological feasibility of this concept is currently being evaluated in an Evonik project analyzing the return of investment and calculating the ecological benefit using the LCA methodology for different scenarios combining the individual modules of the LEF concept.

The following recommendations could be given to policy makers and regulatory authorities who want to speed up the development toward sustainable livestock operations:

1) Assess the full environmental costs of current livestock production systems which are externalized in below,
   - costs of cleaning up environmental pollution (water, soil, air), including manure and agrochemical runoff and contamination, and livelihood losses;
   - costs associated with GHG emissions from all stages of industrial livestock production;
   - loss of manure as a source of nutrients and organic matter on croplands, and increased costs of manufacturing and using commercial fertilizers.
2) Exploit the full potential of lowering the protein content of livestock feed as follows,

- the biggest potential in pigs (grower-finisher, lactating and gestating sows), chicken (layer and breeders, broiler finisher) and dairy cows;
- formulation based on standardized ileal digestibility (SID) combined with NE;
- use of protected amino acids in high performance dairy cows.

3) Continue to promote household methane digesters for biogas production in China,
   - 35 of 140 million rural households use digesters to produce cooking gas and fertilizer.
4) Require large-scale commercial farms and integrated meat complexes to build biogas plants with manure as main feedstock,
   - less than 1% of the 4.2 million large-scale livestock farms in China employ this method.

In the longer run, using insect protein as protein source for livestock could contribute a lot to securing the rising protein feed demand with an even reduced environmental footprint, as insect protein production in first LCA studies (Oonincx et al., 2010; Oonincx and de Boer, 2012; Muys and Roffeis, 2014) offers advantages in different environmental impact categories like agricultural land occupation and GWP, but more data are needed. The feeding quality of insect meals is regarded as very high (Rumpold and Schlueter, 2013; Sanchez-Muros et al., 2013; Makkar et al., 2014). In case the high energy demand of an insect protein plant which needs constant temperature of 28 to 30 °C (Muys and Roffeis, 2014) could be delivered by the CHP of a biogas plant and livestock manure being used as feedstock for the biogas as well for the insect plant, by theory this could have great mitigation potential. However, this must still be proven in concise LCA studies. Another obstacle still is the regulatory situation especially in the EU, but EFSA regulatory authorities are supposed to come out with an evaluation still in 2015. Social acceptance for insects in animal feed among farmers, the agriculture sector stakeholders and citizens or consumers has recently been investigated by Verbeke et al. (2015). The overall findings of this study indicate a positive atmosphere and momentum for change towards the adoption of insects as new ingredient in animal feed.

In conclusion it can be stated, that there is still a big potential to be lifted to improve the environmental performance of livestock operations to a more sustainable future considering all three dimensions of the sustainability model. All the needed elements for the proposed LEF concept are there already. To converge currently still frequently separated value chains of animal husbandry, energy and waste management in a closed loop approach is a complex task and needs well managed business models like private-public-partnerships and good political and social governance.

The implementation of LEF should be actively driven by the livestock operation stakeholders and proactively communicated in an effort also to increase the social aspect of sustainability.

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