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A study on key issues in Korea's pig carbon footprint and data construction for advanced calculation of domestic pig's carbon footprint

Abstract

As Korea strives for carbon neutrality by 2050, accurate quantification of greenhouse gas (GHG) emissions in the livestock sector has become a critical priority. This study conducted a cradle-to-farm gate Life Cycle Assessment (LCA) of domestic pig production to identify key issues in carbon footprint (CF) calculation and address significant data gaps regarding feed composition. The functional unit was defined as 115.26 kg of live weight per pig head. The results revealed a total CF of 993.21 kg CO_2-eqivalent (CO_2-eq.) per head, with feed production accounting for a predominant 76.31% of total emissions. This share is notably higher than global averages, primarily due to the Korea’s heavy structural reliance on carbon-intensive imported feed grains. To address the inherent opacity and information asymmetry of commercial feed data, a stochastic approach utilizing Monte Carlo simulation (1,000 iterations) was employed. While variability in dietary formulations across growth stages was relatively stable (CV = 2.30%), the geographical origin of primary feed ingredients, specifically corn, introduced substantial uncertainty. The CF of corn varied from 0.23 to 1.86 kg CO_2-eq./kg depending on its origin, leading to a 9.35% coefficient of variation (CV) in feed-related emissions and an 18.0% fluctuation in the final CF per unit of live weight. These findings demonstrate that ingredient sourcing is as critical as nutritional efficiency in determining the environmental impact of swine production. The study concludes that establishing a representative, standardized national pig feed composition database is imperative for enhancing the transparency and reliability of GHG accounting. Such a foundation will provide a robust baseline for developing effective mitigation strategies and ensuring the livestock industry’s alignment with national climate commitments.

Keywords: Carbon footprint; Pig; Feed composition; Geographical origin; Monte Carlo simulation

1. Introduction

In accordance with the recent global climate change response, Korea takes action with carbon neutral strategy to ensure that net greenhouse gas emissions (GHG) are zero. GHG generated by livestock are estimated to be 7.1 gigatonnes CO_2 equivalent (CO_2-eq.) which represents 14.5% of the total global GHG [1]. Although there are differences depending on the country and research purpose, the results of life cycle assessment (LCA) for pigs show that feed production has the highest carbon footprint (CF). The CF of Canadian pigs studied by Charron-Doucet and Léger Dionne [2] accounts for 52% of the feed production stage. Additionally, Naranjo [3] reported that feed production accounted for 42.2% of the total CF for Chinese pigs. However, Reckmann et al. [4] found that this stage contributed 67.4% for German pigs.

This study was conducted to suggest the direction to construct necessary data for more accurate CF calculation for pig. Until the mid-2010s, public awareness of the impact of livestock farming on climate change was limited [5]. Although interest in the CF of livestock products has grown in recent years, consumer understanding of the relative contribution of individual stages in pork production such as feed production, manure management, and transportation remains insufficient [5]. While many consumers are aware of GHG associated with enteric fermentation and manure treatment, they tend to focus more on tangible aspects such as food transport distances and packaging waste [5]. In contrast, awareness of emissions arising from the cultivation of feed crops used in livestock farming remains notably low [5]. However, the study analysis of the actual CF calculation for pig showed that 54.8%-78.5% of contribution came from feed cultivation as shown in Table 1 [6-9]. The large influence of CF by feed cultivation among the CF generated from other source in pig production might have high significance to the estimated value of pig CF. For instance, if the influence of feed CF highly varies, the estimated value of pig CF would also inevitably vary which can greatly affect the reliability of the result value. However, in Korea, current CF estimates for pig production are expected to be inaccurate due to significant data gaps in feed composition information. Numerous studies have proposed various feed formulations for pigs; however, in practice, farmers are often unable to access the specific formulation data of the commercial feeds they use. This data gap prevents farm operators from obtaining sufficient information for an accurate CF calculation. Such information asymmetry and opacity are anticipated to cause significant uncertainty in calculating the actual environmental impact of pig production on-site.

Given these challenges, this review focuses on identifying and addressing key factors influencing the CF of pig production in Korea, with an emphasis on feed-related parameters. Representative domestic pig feed formulation scenarios were synthesized and analyzed through a comprehensive review of existing peer-reviewed literature and technical reports [10-16]. Using LCA modeling, we demonstrate how variability in feed ingredient profiles impacts the calculated CF of pork. The analysis reveals which variables (such as the ratio of imported grains or protein meals) drive the most significant changes in emissions. By illustrating the scale of uncertainty introduced by feed composition, the results highlight the urgent need for improved data.

Ultimately, our findings underscore the importance of building a representative, standardized national pig feed composition database for Korea. Establishing such a database would greatly improve the accuracy and transparency of GHG accounting in the pig sector, providing a reliable baseline for CF calculations. This, in turn, would support more effective mitigation strategies and policy measures in line with Korea's climate change commitments. By strengthening the data foundations for pig CF assessment, Korea can better track progress toward reducing livestock emissions and ensure its climate goals are met in the livestock industry.

2. Materials and Method

2.1 The System Boundaries and Functional Unit

The function unit of this study was 115.26 kg of live weight per pig head. The live weight was calculated using live weight statistic by Korean Animal and Plant Quarantine Agency [17]. The cut-off criteria to calculate the CF was set as 95% of accumulated the amounts of raw materials and 100% of energy and water consumption. As shown in Figure 1, the system boundary to calculate pig CF was set as "cradle-to-farm", referring to "from the feed production to the shipment of pig for slaughter".

2.2. Feed Production

The feed intake parameters presented in Table 2 were synthesized from established statistic, literature and technical documentation to categorize consumption patterns by feed type and feeding phase [10-16, 18]. The CF of each feed ingredient was determined using established life cycle inventory (LCI) databases for agricultural products [19–22]. Table 3 lists the specific LCI data sources and the resulting CF (in kg CO_2-eq. per kg) for each ingredient.

To ensure the methodological rigor and international comparability of the assessment, this study utilized the LCI database sets (ecoinvent, Agri-footprint, etc.), which are globally recognized as the most authoritative and scientifically verified life cycle inventory (LCI) sources for environmental impact assessment. The ecoinvent database is distinguished by its comprehensive data quality guidelines and consistent cross-sectoral modeling, making it a standard requirement for ISO-compliant life cycle assessments [23]. Similarly, Agri-footprint provides highly transparent, peer-reviewed data specifically optimized for agricultural supply chains, widely adopted by international bodies such as the FAO for livestock environmental benchmarking [24]. The integration of these high-fidelity, licensed databases—standard in prominent journals like The International Journal of Life Cycle Assessment minimizes the uncertainty inherent in secondary data and provides a robust foundation for evaluating the carbon intensity of complex global feed supply chains [25]. The use of licensed LCI databases ensures reproducibility and adherence to international LCA standards (ISO 14040/44), which is paramount for high-impact environmental research.

Major feed components such as cereal grains, oilseed meals, and brans constitute over 85% of typical pig feed by weight. In 2021, Korea relied on imports for approximately 96.9% of its feed grains and 71.8% of its feed brans [26]. Although specific import data for bran are not available, domestic bran production statistics exist. Notably, domestic oilseed meals and brans are by-products of food industries (e.g., cooking oil extraction and flour milling) that primarily use imported crops. Hence, these by-products can be considered largely derived from imported feedstocks [26]. Consequently, we applied LCI database from the regions where the original crops were produced, since the only domestic processing was the conversion of those imported crops into by-products. All GHG emissions were characterized in terms of kg CO_2-eq. using the IPCC 2013 global warming potential method (an updated version of the IPCC 2007 method) [27].

The feed composition scenarios shown in Table 4 were derived from example formulations and survey data for pig diets in Korea [10-16]. These formulations are utilized in pig performance evaluations (pig growth and carcass certification trials) that measure criteria such as feed intake, average daily gain, backfat thickness, and dressing percentage [17,18]. Table 4 presents two example diet formulations (for grower and finisher pigs) based on these sources. These example formulas represent typical compound feeds recommended by national standards, rather than any single proprietary product. Corn, soybean meal, and wheat are the predominant ingredients in Korean pig diets, collectively accounting for roughly 47.92% to 95.70% of the total mix by weight in the scenarios shown.

2.3 Farm Operation

Comprehensive statistics on on-farm energy and water use in Korean pig operations are currently unavailable. Energy consumption data, including electricity and fossil fuels, were collected from 9 representative pig farms, with the calculated mean values utilized as input data. Although specific volumetric records for groundwater usage were unavailable at the farm level, the energy required for groundwater extraction (pumping) is inherently captured within the total electricity consumption. Consequently, the absence of direct water usage data is unlikely to result in a significant omission or underestimation of the overall CF. The combined the amount of energy use data from these sources were applied in our farm operation calculations (Table 5). Table 6 summarizes the LCI datasets and conversion factors used for the farm operation stage.

2.4. Enteric Fermentation and Manure Management

Korea is in the process of developing country-specific emission factors for GHG emissions from pig enteric fermentation and manure management. Since the National Inventory Report (NIR) currently applies the IPCC Tier 1 guidelines, we used the emission factors from the 2024 Korean NIR [27] for these sources. To estimate the environmental impact, an average production cycle of 214 days was adopted, which corresponds to the aggregate feeding duration across all growth stages (Table 2). This period served as the basis for calculating methane and nitrous oxide emissions from enteric fermentation and manure management systems [28]. Nitrous oxide (N_2O) emissions from manure were estimated based on the national distribution of manure treatment methods used on pig farms [29]. Table 7 summarizes the emission factors applied for enteric fermentation and manure management in this study.

3. Result and Discussion

The primary drivers contributing to the variability in CF estimates, as identified in previous livestock-related life cycle assessment (LCA) studies, include the following factors. As noted by previous studies, enteric emissions, manure management, and the purchase of externally sourced feed are among the primary contributors to overall environmental impacts [30,31]. Moreover, the variability is strongly influenced, feeding strategies (e.g., silage inclusion level, feed and ration quality), the degree of feed self-sufficiency, and the adoption of emission-reducing technologies during effluent storage (e.g., tank covers, anaerobic digestion plants) [30,32]. These factors collectively explain the observed differences in CF across feed types. A relevant study by Wu et al. [33] discusses the application of LCA for livestock, emphasizing that these assessments typically account for the life cycle from breeding through fattening phases, effectively capturing the environmental impacts. This assertion aligns with findings from Pedolin et al., [34] who utilized LCA in a Swiss agricultural context to evaluate the environmental efficiency of different livestock product groups, including pigs, thereby reinforcing the importance of quantifying such impacts from cradle to farm gate. Furthermore, Heidari et al., [35] offer insights on the water management aspect, although their focus on bioenergy production limits the direct applicability to pig farming water usage specifically. Gislason et al. [36] demonstrated that feed composition serves as a primary determinant of the carbon intensity associated with pig production.

The activity data for the pig production process and the corresponding emission factors for this study are summarized in Table 8. Based on these inputs, the total CF was quantified and is detailed in Table 9. The CF per pig was 993.21 kg CO_2-eq, with feed consumption accounting for 76.31% of the total emissions. This predominant contribution highlights that the precision of feed-related data is a critical determinant for the overall reliability of pig environmental assessments.

Based on the specific feed mixing ratios, the estimated CF per kilogram of diet varied between 1.64 and 2.09 kg CO_2-eq. A stochastic analysis using Monte Carlo simulation (1,000 samplings) determined that the cumulative CF of total feed intake per pig was 758.9 ± 17.42 kg CO_2-eq. The low coefficient of variation (CV = 2.30%) indicates a high level of stability in the CF estimates across the feeding stages. Details of the above results are shown in Table 10. Admittedly, a limitation of this study is that the variability in the formulation of the Grower II diet, the phase accounting for the largest share of total feed intake was markedly lower than that observed in other feeding stages. This discrepancy suggests that the overall uncertainty in the CF might be primarily influenced by stages with lower consumption volumes, which warrants cautious interpretation of the aggregate results.

However, the CF outcomes shifted significantly when considering the geographical origin of feed ingredients. Using corn the primary component by mass in pig diets as a benchmark, the sensitivity of the total emission profile was evaluated based on origin-specific fluctuations. The emission coefficients for corn from various regions, which served as the basis for this variability analysis, are summarized in Table 11. As shown in Table 11, the CF of corn varies significantly by origin, ranging from 0.23 to 1.86 kg CO_2-eq/kg. To evaluate the impact of this geographical variability, a Monte Carlo simulation (1,000 samplings) was performed using the average dietary formulations for each production phase. This approach maintains methodological consistency with the prior assessment of formulation-induced variability.

The CF of the diets was highly sensitive to the origin of corn, with values ranging from 1.22 to 2.63 kgCO_2-eq./kg feed. A stochastic assessment using Monte Carlo simulation (1,000 iterations) determined that the cumulative CF of total feed intake per pig was 533.87 ± 49.93 kgCO_2-eq. The resulting coefficient of variation (CV) of 9.35% reflects a substantial degree of geographical variability, as detailed in Table 12.

Assuming the feed CF values are normally distributed (Table 12), we can estimate a confidence interval for the feed-related emissions. At a 95% confidence level, the feed portion of CF per pig ranged from about 432.3 to 647.8 kgCO2-eq.. This feed uncertainty propagates to the total CF per pig, yielding approximately 667.6 to 883.1 kgCO2-eq. per head (95% confidence interval), which corresponds to roughly a 18.00% variation in the total CF per unit of live weight due to feed composition differences. In other words, variability in corn source can cause nearly one-fifth difference in the CF of pork production [37].

This study was conducted in accordance with ISO 14044 and ISO 14067 standards for LCA and CF, ensuring that our methodology is robust and internationally comparable. Our findings regarding the dominance of feed in the CF are in line with broader literature. Previous analyses have reported that feed cultivation and processing contribute roughly 60%–62% of the total GHG emissions in pig production systems on average [38]. In our Korean context, we found the feed contribution to be even higher at about 76.31% of total emissions. This higher share can be largely attributed to the structural dependence of the Korean livestock sector on imported feed ingredients [18]. Korean produces only a minor fraction of the grains used for feed (e.g. <1% of corn is grown domestically), resulting in a heavy reliance on carbon-intensive imported feed. The contrast between our result and those from other regions underlines how supply chain structure can affect the CF [26].

Although the feed-related emission share in Korea is higher than reported in many other countries, it is important to note that feed production is generally the single largest GHG source in pig farming everywhere. Literature reviews of pig LCA studies show that feed supply typically accounts for a significant portion of emissions (ranging from about one-third up to three-quarters of total GHG emissions) [39].

This consistently indicates that feed cultivation and feed use are the predominant drivers of carbon impacts in pork production systems. Consequently, improving feed production efficiency and supply chain management emerges as a critical mitigation strategy for reducing emissions from pig farming. For instance, optimizing feed processing techniques can lower energy use and thus mitigate emissions in feed production, and enhancing feed conversion efficiency (through nutritional innovations or additives) is identified as a key approach to curbing GHG emissions in the pig industry [37]. Focusing on feed-related measures such as sourcing lower-carbon feed ingredients, improving feed quality, and better feed conversion ratios should therefore yield substantial reductions in the overall CF of pork.

At present, a major challenge in precisely assessing and comparing livestock CF is the lack of transparent feed composition and source data in Korea. Feed manufacturers often treat ingredient formulations and source as confidential business information, which means researchers and breeding farms have limited access to representative feed data. This opacity introduces significant uncertainty into CF calculations. To address these data limitations, a stochastic approach was employed to estimate the probability distribution of the feed-related

CF. This involved Monte Carlo simulation, a sampling technique utilizing random number generation to account for variability in both dietary formulations and ingredient origins, with input parameters derived from an extensive review of pig nutrition literature [10-16]. Our analysis revealed that the choice of corn origin resulted in a fluctuation of approximately 18.0% in the CF per kilogram of live weight. This suggests that the geographical source of primary feed components is a critical factor in the precision of life cycle assessments. These findings are in line with observations from other studies [36,37,40-43] that many LCA analyses do not report detailed feed formulas or ingredient-level impacts, making it difficult to pinpoint emission differences. Without clearly established emission factors that reflect actual feed compositions and source, it is challenging to accurately track improvements in emission reduction or to make robust comparisons across different production systems.

4. Conclusion

This study quantified the life cycle carbon footprint (CF) of Korean pig production, identifying a total emission of 993.21 kg CO_2-eq. per pig. Feed consumption emerged as the dominant contributor, accounting for 76.31% of emissions—significantly higher than global averages due to Korea’s heavy reliance on carbon-intensive imported grains. Sensitivity analysis revealed that the geographical origin of ingredients is a critical uncertainty driver; Monte Carlo simulations showed that corn sourcing alone can induce an 18.0% variation in total CF. By utilizing stochastic modeling with 1,000 iterations, this study established a realistic 95% confidence interval (667.6–883.1 kg CO_2-eq.), providing a more transparent baseline for policy-making than traditional deterministic estimates.A key finding is the urgent necessity for a standardized national pig feed database to overcome current information asymmetries and proprietary data barriers. Such a foundation is essential for tracking environmental performance and implementing mitigation strategies, such as sourcing low-carbon ingredients and optimizing feed conversion ratios. Ultimately, improving data transparency and robustness is vital for Korea’s transition toward precise, site-specific environmental management, supporting the nation’s 2050 carbon-neutral commitments.

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Table 1. The carbon footprint contribution based on previous pig carbon footprint studies

Farm categories in references		Total (kg CO_2eq.)	The contribution of the pig production system to total carbon footprint per kg pig (%)	
			Crop growth for feed	On farm
Canada farms [2]		4.43	52.2	47.8
China farms [3]		2.66	42.2	57.8
Northern German farm [4]		3.01	67.4	32.6
Ireland average farm [6]		3.20	63.4	36.6
Herd size top 25% farm [6]		3.00	62.0	38.0
Herd size top 10% farm [6]		2.99	61.9	38.1
Farm in the Edinburgh [7] (21 synthetic fertilizer scenario case)	Highest	2.86	78.5	21.5
	Lowest	1.85	67.4	32.6
Farm in the Edinburgh [7] (21 slurry fertilizer scenario case)	Highest	3.07	71.2	28.8
	Lowest	2.29	63.9	36.1
Weaning farm in the Galicia [8]		0.40	54.8	45.3
Fattening farm in the Galicia [8]		3.02	58.7	41.3
Typical Austrian pork production [9]		4.38	66.7	33.3

Table 2. Contribution to mass of feed types in Korean pig

Stage	Days in stage	Avg feed intake (kg/day)	Feed per head per stage (kg)
Wean	5	3	15.0
Nursery	56	0.55	30.8
Grower I	63	1.6	100.8
Grower II	56	2.4	134.4
Finisher	34	3	102.0
Total feed amount (kg)	-	-	383.0

Table 3. Carbon footprint of crop feed for feed composition and LCI database

Ingredients	GWP (kgCO$_2$-eq./kg)	LCI Database	Source	Note
Corn	1.31	Maize, at farm {BR} Economic	Agri footprint 6.3 [19]	
Whey	0.13	Whey {GLO}| cheese production, soft, from cow milk | Cut-off	Ecoinvent 3 [20]	
Fish meal	1.2	Fish meal, at processing {CN} Economic	Agri footprint 6.3 [19]	
Dehulled soybean meal	4.25	Soybean meal (solvent), at processing {BR} Economic	Agri footprint 6.3 [19]	Proxy
Whey powder	1.38	Whey powder dried, at processing {US} Economic	Agri footprint 6.3 [19]	
Wheat	0.506	Wheat grain, at farm {US} Economic	Agri footprint 6.3 [19]	
Wheat bran	0.319	Wheat bran, from dry milling, at processing {US} Economic	Agri footprint 6.3 [19]	
Oats-dehulled	0.529	Oat grain, dried, at storage {PL} Economic	Agri footprint 6.3 [19]	
Soy hull	0.15	Soybean hull (solvent), at processing {US} Economic	Agri footprint 6.3 [19]	
Sucrose	0.625	Sugar, from sugar cane, at processing {TH} Economic	Agri footprint 6.3 [19]	Proxy
Soybean meal	4.25	Soybean meal (solvent), at processing {BR} Economic	Agri footprint 6.3 [19]	

Molasses	0.193	Molasses, market mix, at regional storage {DE} Economic	Agri footprint 6.3 [19]	
Sugar beet pulp	0	Sugar beet pulp wet, at processing {PL} Economic	Agri footprint 6.3 [19]	
DDGS	0.647	Maize distillers grains dried, at processing {US} Economic	Agri footprint 6.3 [19]	
Animal fat	1.44	Fat from animals, at processing {US} Economic	Agri footprint 6.3 [19]	
Blood meal	1.86	Blood meal, at processing {NL} Economic	Agri footprint 6.3 [19]	
Spray dried plasma protein	0.00412	Protein feed, 100% crude {CH}| meat and bone meal to generic market for protein feed | Cut-off	Ecoinvent 3 [20]	
Bakery byproduct	0	Groundnut shells, at processing {VN} Economic	Agri footprint 6.3 [19]	Proxy
Sugar	0.625	Sugar, from sugar cane, at processing {TH} Economic	Agri footprint 6.3 [19]	
Soybean oil	8.07	Crude soybean oil (pressing), at processing {BR} Economic	Agri footprint 6.3 [19]	
Monocalcium phosphate	1.27	Dicalcium phosphate, processing/FR	agribalyse v3.0.1 [21]	Proxy
Limestone	0.00207	Limestone, unprocessed {RoW}| limestone quarry operation | Cut-off	Ecoinvent 3 [20]	
Salt	0.278	Salt/FR	agribalyse v3.0.1 [21]	
DL-Methionine	3.13	DL-Methionine, processing/RER	agribalyse v3.0.1 [21]	

L-Lysine	3.07	L-Lysine HCl, processing/FR	agribalyse v3.0.1 [21]	
L-Threonine	3.82	ThreAMINO? 98.5% L-Threonine, at Evonik plant {HU} Economic	Agri footprint 6.3 [19]	
L-Tryptophan	18.4	TrypAMINO? 98.0% L-Tryptophan, at Evonik plant {SK} Economic	Agri footprint 6.3 [19]	
Arginine	3.07	L-Lysine HCl, processing/FR	agribalyse v3.0.1 [21]	Proxy
Vitamin premix	0.44	Vitamin and oligo-element complement, for weaned piglet, at feed plant/FR	agribalyse v3.0.1 [21]	
Mineral premix	0.364	Mineral supplement, for beef cattle {GLO}| mineral supplement production, for beef cattle | Cut-off	Ecoinvent 3 [20]	
Lactose	0.518	Lactose, delactosed whey <210dried 96% DM, at processing {NL} Economic	Agri footprint 6.3 [19]	
Choline chloride	0.872	Total minerals, additives, vitamins, at plant {RER} Economic	Agri footprint 6.3 [19]	Proxy
Phytase	12.4	Enzymes {RoW}| enzymes production | Cut-off	Ecoinvent 3 [20]	Proxy
Dicalcium phosphate	1.27	Dicalcium phosphate, processing/FR	agribalyse v3.0.1 [21]	
Prohacid advance	1.27	Dicalcium phosphate, processing/FR	agribalyse v3.0.1 [21]	Proxy
ZnO	0.726	Zinc oxide {RoW}| zinc oxide production | Cut-off	Ecoinvent 3 [20]	
Valine	18.4	TrypAMINO? 98.0% L-Tryptophan, at Evonik plant {SK} Economic	Agri footprint 6.3 [19]	Proxy

Enzymes	12.4	Enzymes {RoW}| enzymes production | Cut-off	Ecoinvent 3 [20]	
Organic acid	3.87	Fatty acid {GLO}| market for fatty acid | Cut-off	Ecoinvent 3 [20]	
Mold inhibitor	9.27	Fungicide, at plant {RER} Economic, S	Agri footprint 6.3 [19]	
Probiotic	0.00412	Protein feed, 100% crude {CH}| meat and bone meal to generic market for protein feed | Cut-off	Ecoinvent 3 [20]	Proxy
SDPP	0.00412	Protein feed, 100% crude {CH}| meat and bone meal to generic market for protein feed | Cut-off	Ecoinvent 3 [20]	
TCP	1.27	Dicalcium phosphate, processing/FR	agribalyse v3.0.1 [21]	Proxy
Na_2CO_3	1.24	Sodium bicarbonate {RoW}| soda production, solvay process | Cut-off	Ecoinvent 3 [20]	

GWP= Global warming potential
US = United States of America
BR = Brazil
CH= Switzerland
DE = Germany
RoW = Rest of World
GLO=Global
FR = France
TH = Thailand
IN = India
CN = China
RER = Europe
NL = Netherlands
SK= Slovakia
HU=Hungary
VN=Vietnam
PL=Poland

LCI= Life cycle inventory

Table 4. Feed formula of pig feeds

Feed ingredients	**Ratio of each ingredient in each feed for each pig (%)**																											
	Feed for Wean						**Feed for Nursery**						**Feed for Grower I**								**Feed for Grower II**				**Feed for Finisher**			
	A [10]	B [11]	C [12]	D [12]	E [12]	F [13]	G [10]	H [11]	I [12]	J [12]	K [12]	L [13]	M [14]	N [14]	O [14]	P [14]	Q [15]	R [15]	S [15]	T [15]	U [16]	V [16]	W [16]	X [16]	Y [15]	Z [15]	AA [15]	AB [15]
Corn	40.61	38.07	44.12	43.81	43.49	37.78	55.33	46.57	53.73	53.31	52.88	49.83	56.72	60.55	60.52	60.51	70.93	66.68	68.20	63.95	72.44	72.34	72.24	72.14	74.84	70.59	72.11	67.86
Whey	8.00	0.00																										
Fish meal	3.00	5.00	2.50	2.50	2.50	4.00	-	3.00				4.00	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Dehulled soybean meal	-	24.49	-	-	-	-	-	29.49	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Whey powder	-	17.00	7.50	7.50 0.	7.50	15.00	-	15.38	-	-	-	10.00	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Wheat	6.00	0.00	-	-	-	-	6.00	-	-	-	-	-	-	-	-	-	5.00	5.00	5.00	5.00	-	-	-	-	5.00	5.00	5.00	5.00
Wheat bran	-	-	7.50	7.50	7.50	3.50	-	-	7.00	7.00	7.00	4.00	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Oats-dehulled	-	-	-	-	-	5.00	-	-	-	-	-	5.00	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Soy hull	-	-	-	-	-	2.00	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Sucrose	-	-	-	-	-	4.00	-	-	-	-	-	4.00	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Soybean meal	18.00	5.00	20.22	20.22	20.22	10.14	24.43	-	24.31	24.31	24.31	12.75	22.75	18.40	18.09	17.81	19.38	19.42	19.70	19.74	20.20	20.20	20.20	20.20	15.86	15.90	16.18	16.22
Molasses	-	-	-	-	-	-	-	-	-	-	-	-	2.00	2.00	2.00	2.00	-	-	-	-	-	-	-	-	-	-	-	-
Sugar beet	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	4.00	-	4.00	-	-	-	-	-	4.00	-	4.00

pulp																												
DDGS	-	-	-	-	-	-	-	-	-	-	-	-	7.00	7.00	7.00	7.00	-	-	-	-	-	-	-	-	-	-	-	-
Animal fat	-	-	-	-	-	-	-	-	-	-	-	-	3.65	3.68	3.71	3.74	-	-	-	-	-	-	-	-	-	-	-	-
Blood meal	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	3.00	3.00	3.00	3.00	-	-	-	-
Spray dried plasma protein	4.00	0.00	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Bakery byproduct	5.00	0.00	9.00	9.00	9.00	3.00	5.00	-	7.00	7.00 0.	7.00	2.00	5.00	5.00	5.00	5.00	-	-	-	-	-	-	-	-	-	-	-	-
Sugar	4.00	0.00	3.00	3.00	3.00	-	4.00	-	1.00	1.00	1.00	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Soybean oil	2.50	3.38	2.40	2.40	2.40	3.00	2.50	2.60	3.47	3.47	3.47	3.00	-	-	-	-	1.71	2.03	4.13	4.45	2.22	2.22	2.22	2.22	1.60	1.92	4.02	4.34
Monocalcium phosphate	0.87	0.40	-	-	-	0.97	1.13	0.36	-	-	-	1.12	-	-	-	-	-	-	-	-	0.52	0.52	0.52	0.52	-	-	-	-
Limestone	1.15	0.77	0.37	0.69	1.01	1.25	1.09	0.83	0.40	0.82	1.25	1.25	0.62	0.60	0.60	0.60	0.72	0.62	0.72	0.62	1.30	1.30	1.30	1.30	0.67	0.57	0.67	0.57
Salt	0.30	0.30	0.30	0.30	0.30	0.20	0.30	0.30	0.45	0.45	0.45	0.25	0.40	0.40	0.40	0.40	0.20	0.20	0.20	0.20	-	-	-	-	0.20	0.20	0.20	0.20
DL-Methionine	0.05	0.14	0.32	0.32	0.32	0.42	0.09	0.08	0.24	0.24	0.24	0.34	0.08	0.12	0.16	0.20	0.03	0.04	0.03	0.04	-	-	-	-	0.02	0.03	0.02	0.03
L-Lysine	0.22	0.33	0.59	0.59	0.59	0.98	0.41	0.28	0.47	0.47	0.47	0.84	0.34	0.49	0.56	0.64	0.22	0.20	0.21	0.19	0.02	0.02	0.02	0.02	0.21	0.19	0.20	0.18
L-Threonine	-	0.14	0.31	0.31	0.31	0.41	0.07	0.13	0.19	0.19	0.19	0.37	0.09	0.15	0.20	0.24	0.03	0.02	0.03	0.02	-	-	-	-	0.01	-	0.01	-
L-Tryptophan	-	0.22	0.11	0.11	0.11	0.10	0.04	0.17	0.06	0.06	0.06	0.10	0.15	0.37	0.50	0.61	-	-	-	-	-	-	-	-	-	-	-	-
Arginine	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0.00	0.10	0.20	0.30	-	-	-	-
Vitamin premix	0.10	0.25	0.10	0.10	0.10	0.15	0.10	0.25	0.10	0.10	0.10	0.15	0.10	0.10	0.10	0.10	0.15	0.15	0.15	0.15	0.10	0.10	0.10	0.10	0.15	0.15	0.15	0.15
Mineral	0.20	0.25	0.28	0.28	0.28	0.20	0.20	0.25	0.28	0.28	0.28	0.20	0.10	0.10	0.10	0.10	0.15	0.15	0.15	0.15	0.20	0.20	0.20	0.20	0.15	0.15	0.15	0.15

premix																												
Lactose	6.00	3.95	-	-	-	5.10	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Choline chloride	-	0.05	0.06	0.06	0.06	0.10	-	0.05	0.15	0.15	0.15	-	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	-	-	-	-	0.05	0.05	0.05	0.05
Phytase	-	0.01	0.05	0.05	0.05	-	-	0.01	0.05	0.05	0.05	-	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	-	-	-	-	0.05	0.05	0.05	0.05
Dicalcium phosphate	-	-	0.70	0.70	0.70	-	-	-	0.91	0.91	0.91	-	-	-	-	-	1.22	1.23	1.22	1.23	-	-	-	-	1.03	1.04	1.03	1.04
Prohacid advance	-	-	0.20	0.20	0.20	-	-	-	0.20	0.20	0.20	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
ZnO	-	-	0.25	0.25	0.25	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Valine	-	-	0.13	0.13	0.13	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Enzymes	-	-	-	-	-	0.05	-	-	-	-	-	0.05	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Organic acid	-	-	-	-	-	0.30	-	-	-	-	-	0.30	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Mold inhibitor	-	-	-	-	-	0.15	-	-	-	-	-	0.15	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Probiotic	-	-	-	-	-	0.20	-	-	-	-	-	0.20	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
SDPP	-	-	-	-	-	2.00	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
TCP	-	-	-	-	-	-	-	-	-	-	-	-	0.90	0.94	0.95	0.95	-	-	-	-	-	-	-	-	-	-	-	-
$NaCO_3$	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0.16	0.16	0.16	0.16	-	-	-	-	0.16	0.16	0.16	0.16

Table 5. "Piglets, sow-piglet system, at farm Mass/NL" and "Pigs to slaughter, pig fattening, at farm Mass/NL" merged Gate-to-Gate data

Direction	Flow	Farm A	Farm B	Farm C	Farm D	Farm E	Farm F	Farm G	Farm H	Farm I	Total Amount	Unit	Amount /head	Unit
Input	Electricity	1,446.86	126.60	422.48	2,080.84	9,572.74	57.85	1,260.76	2,080.84	1,638.31	18,687.28	MWh	116.13	kWh/head
	Diesel		1,920		7,030	76,759	400	16,060			103,779	L	0.645	L/head
	Kerosene			2,700							2,700	L	0.017	L/head
Output	Number of pigs shipped	15,622	3,883	2,732	15,475	65,274	3,654	31,473	6,937	15,866	160,916	Heads	1.00	Head

Table 6. Estimation of electricity, fuel use and life cycle inventory database

Items		Life cycle inventory database	Source
Electricity		Electricity, medium voltage {KR} market for electricity, medium voltage	Ecoinvent 3 [20]
Fossil	Diesel	Diesel {RoW} market for diesel	Ecoinvent 3 [20]
	Kerosene	Kerosene {RoW}market for kerosene	Ecoinvent 3 [20]

KR= Korea
RoW=Rest of World

Table 7. Emission from enteric fermentation and manure management from pig

Contents	**Activity data**	
	Value	**Unit**
Enteric fermentation (CH_4)	0.314	kg/head
Manure management (CH_4)	4.690	kg/head
Manure management (N_2O)	0.057	kg/head

Table 8. Estimation of gate-to-gate data and emission factor for pig

Contents		Activity data		Average Emission factor	
		Value	Unit	Value	Unit
Feed	Wean	15.0	kg/head	1.90	kgCO$_2$-eq./kg
	Nursery	30.8	kg/head	2.09	kgCO$_2$-eq./kg
	Grower I	100.8	kg/head	1.92	kgCO$_2$-eq./kg
	Grower II	134.4	kg/head	2.05	kgCO$_2$-eq./kg
	Finisher	102.0	kg/head	1.91	kgCO$_2$-eq./kg
Electricity		116.13	kWh/head	0.683	kgCO$_2$-eq./kWh
Diesel (production)		0.645	L/head	1.04	kgCO$_2$-eq./L
Diesel (combustion)			L/head	3.85	kgCO$_2$-eq./L
Kerosene (production)		0.017	L/head	1.09	kgCO$_2$-eq./L
Kerosene (combustion)			L/head	3.99	kgCO$_2$-eq./L
Product	Pig	1	head		
	Live weight	115.26	kg/head		
Enteric fermentation (CH_4)		0.314	kg/head	27.5	kgCO$_2$-eq./kg
Manure management (CH_4)		3.945	kg/head	27.5	kgCO$_2$-eq./kg
Manure management (N_2O)		0.048	kg/head	265	kgCO$_2$-eq./kg

Table 9. The result and contribution of carbon footprint per head of pig (from average emission factor**)**

Contents		**Carbon footprint**		**Contribution of carbon footprint (%)**
		Value	**Unit**	
Feed	Wean	28.57	kgCO_2-eq./head	2.88%
	Nursery	64.47	kgCO_2-eq./head	6.49%
	Grower I	193.85	kgCO_2-eq./head	19.52%
	Grower II	275.99	kgCO_2-eq./head	27.79%
	Finisher	195.01	kgCO_2-eq./head	19.63%
	Total	**757.89**	**kgCO_2-eq./head**	**76.31%**
Electricity		79.32	kgCO_2-eq./head	7.99%
Diesel	Production	0.67	kgCO_2-eq./head	0.07%
	Combustion	2.48	kgCO_2-eq./head	0.25%
Kerosene	Production	0.02	kgCO_2-eq./head	0.00%
	Combustion	0.07	kgCO_2-eq./head	0.01%
Enteric fermentation (CH_4)		8.63	kgCO_2-eq./head	0.87%
Manure management (CH_4)		128.99	kgCO_2-eq./head	12.99%
Manure management (N_2O)		15.15	kgCO_2-eq./head	1.53%
Carbon footprint of pig		993.21	kgCO_2-eq./head	100.00%

Table 10. CF of pig feed in Korea (depends on mixed ratio)

Feed ingredients	**Average GWP (kgCO_2-eq.)**	**Minimum GWP – F (kgCO_2-eq.)**	**Maximum GWP – L (kgCO_2-eq.)**	**Standard deviation**	**Coefficient of variation (%)**
Feed for Wean (1kg)	1.90	1.64	2.41	0.28	14.6
Feed for Nursery (1kg)	2.09	1.80	2.38	0.18	8.7
Feed for Grower I (1kg)	1.92	1.79	2.12	0.13	6.6
Feed for Grower II (1kg)	2.05	2.05	2.06	0.00	0.1
Feed for Finisher (1kg)	1.91	1.81	2.01	0.10	5.3
Total feed for pig (383 kg)	757.89			17.43	2.30

GWP= Global warming potential

Table 11. Carbon footprint of corn from LCI database

Country	**GWP (kgCO$_2$-eq./kg)**	**LCI Database**	**Source**
Argentina	1.50	Maize, at farm {AR} Economic	Agri footprint 6.3 [19]
Austria	0.23	Maize, at farm {AT} Economic	Agri footprint 6.3 [19]
Belgium	0.25	Maize, at farm {BE} Economic	Agri footprint 6.3 [19]
Bulgaria	0.26	Maize, at farm {BG} Economic	Agri footprint 6.3 [19]
Brazil	1.31	Maize, at farm {BR} Economic	Agri footprint 6.3 [19]
Belarus	1.86	Maize, at farm {BY} Economic	Agri footprint 6.3 [19]
Canada	0.36	Maize, at farm {CA} Economic	Agri footprint 6.3 [19]
Switzerland	0.31	Maize, at farm {CH} Economic	Agri footprint 6.3 [19]
China	0.40	Maize, at farm {CN} Economic	Agri footprint 6.3 [19]
Czechia	0.37	Maize, at farm {CZ} Economic	Agri footprint 6.3 [19]
Germany	0.27	Maize, at farm {DE} Economic	Agri footprint 6.3 [19]

Spain	0.40	Maize, at farm {ES} Economic	Agri footprint 6.3 [19]
France	0.30	Maize, at farm {FR} Economic	Agri footprint 6.3 [19]
Greece	0.39	Maize, at farm {GR} Economic	Agri footprint 6.3 [19]
Hungary	0.27	Maize, at farm {HU} Economic	Agri footprint 6.3 [19]
Indonesia	1.37	Maize, at farm {ID} Economic	Agri footprint 6.3 [19]
India	0.76	Maize, at farm {IN} Economic	Agri footprint 6.3 [19]
Italy	0.34	Maize, at farm {IT} Economic	Agri footprint 6.3 [19]
Japan	0.43	Maize, at farm {JP} Economic	Agri footprint 6.3 [19]
Lithuania	0.34	Maize, at farm {LT} Economic	Agri footprint 6.3 [19]
Mexico	0.61	Maize, at farm {MX} Economic	Agri footprint 6.3 [19]
Netherlands	0.26	Maize, at farm {NL} Economic	Agri footprint 6.3 [19]
Philippines	0.40	Maize, at farm {PH} Economic	Agri footprint 6.3 [19]
Pakistan	0.80	Maize, at farm {PK} Economic	Agri footprint 6.3 [19]

Poland	0.42	Maize, at farm {PL} Economic	Agri footprint 6.3 [19]
Portugal	0.56	Maize, at farm {PT} Economic	Agri footprint 6.3 [19]
Romania	0.29	Maize, at farm {RO} Economic	Agri footprint 6.3 [19]
Russia	0.41	Maize, at farm {RU} Economic	Agri footprint 6.3 [19]
Slovenia	0.28	Maize, at farm {SI} Economic	Agri footprint 6.3 [19]
Slovakia	0.31	Maize, at farm {SK} Economic	Agri footprint 6.3 [19]
Thailand	0.34	Maize, at farm {TH} Economic	Agri footprint 6.3 [19]
Türkiye	0.42	Maize, at farm {TR} Economic	Agri footprint 6.3 [19]
Ukraine	0.35	Maize, at farm {UA} Economic	Agri footprint 6.3 [19]
United States of America	0.26	Maize, at farm {US} Economic	Agri footprint 6.3 [19]
Viet Nam	0.76	Maize, at farm {VN} Economic	Agri footprint 6.3 [19]
South Africa	0.35	Maize, at farm {ZA} Economic	Agri footprint 6.3 [19]

Table 12. Carbon footprint of pig feed in Korea (depends on corn origin)

Feed ingredients	**Average GWP (kgCO$_2$-eq.)**	**Minimum GWP – F (kgCO$_2$-eq.)**	**Maximum GWP – L (kgCO$_2$-eq.)**	**Standard deviation**	**Coefficient of variation (%)**
Feed for Wean (1kg)	1.57	1.22	2.62	0.30	19.1
Feed for Nursery (1kg)	1.67	1.27	2.63	0.26	15.5
Feed for Grower I (1kg)	1.41	1.14	2.50	0.25	18.0
Feed for Grower II (1kg)	1.47	1.27	2.45	0.26	18.0
Feed for Finisher (1kg)	1.33	1.03	2.41	0.28	20.9
Total feed for pig (383 kg)	533.87			49.93	9.35

GWP= Global warming potential

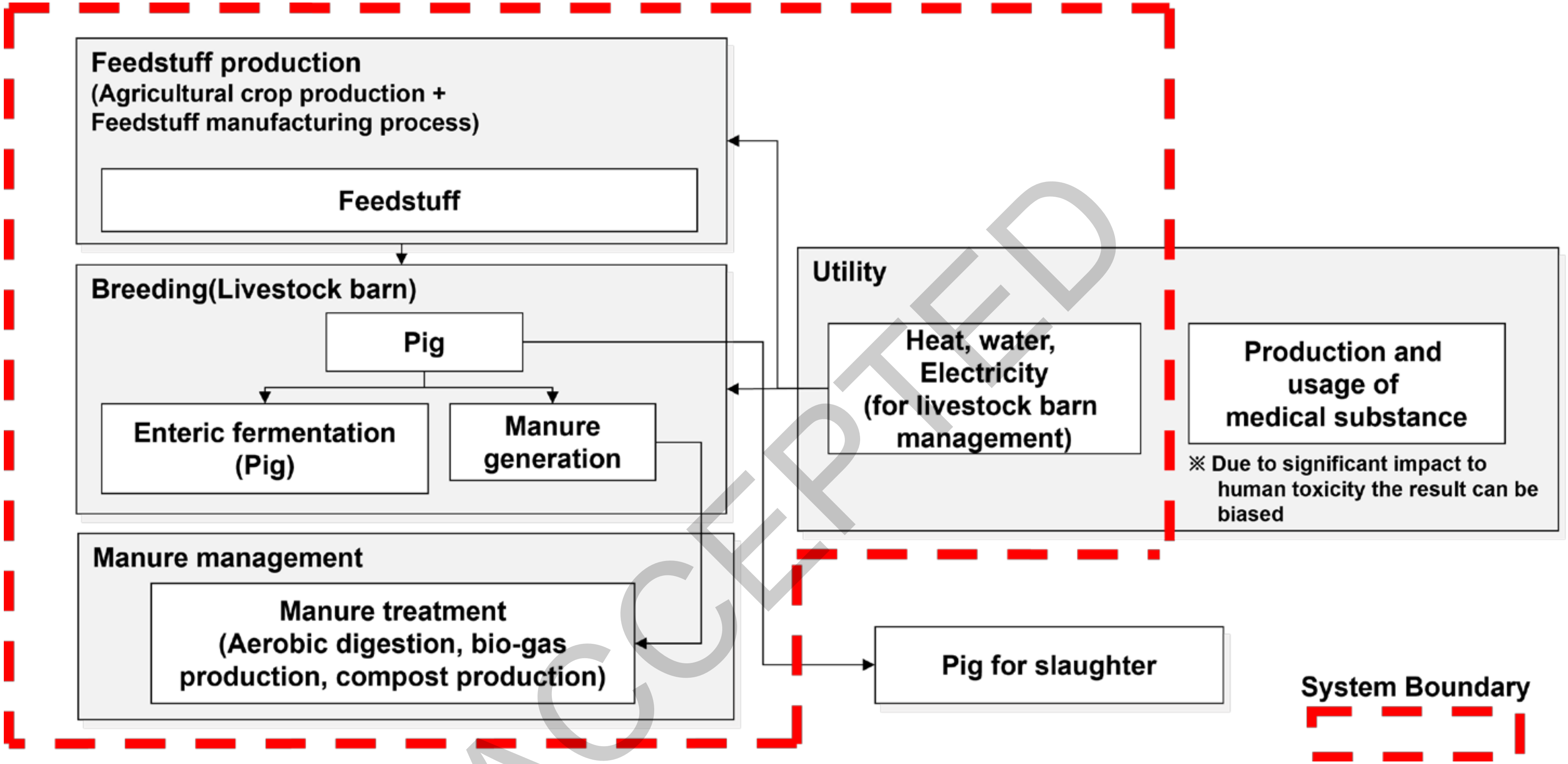

Fig. 1. System boundaries for carbon footprint calculation for pig