Project initiated by Mandy Nevel

and coordinated by Derek Armstrong, Miranda Bowden-Doyle, AHDB

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The Burden of Animal Diseases in UK pork production

By

Beat Thomann

With

Jonathan Rushton, Gemma Chaters, William Gilbert, K. Marie McIntyre and Ben Huntington

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University of Liverpool
Institute of Infection, Veterinary and Ecological Sciences
IC2 Building
146 Brownlow Hill
Liverpool
L3 5RF

United Kingdom
j.rushton@liverpool.ac.uk
www.animalhealthmetrics.org

Executive Summary

Livestock in The United Kingdom (UK) are a significant part of the rural economy contributing towards livelihoods, business and employment. They also provide important exports and of course products in the UK food system with impacts on the health and wellbeing of millions of UK consumers. Animal diseases and health problems constrain the livestock sector in the UK (and worldwide) in its ability to contribute to the social, economic and cultural outcomes of society. Understanding how to effectively and efficiently address these impacts requires systematic data collection and analysis in order to quantify and understand the burden of animal diseases (in terms of production loss caused and expenditure on mitigation). This report, commissioned by the Agriculture and Horticulture Development Board (AHDB), presents a six month project to initiate the estimation of the Burden of Animal Diseases in UK pork production. The project is supported by the Global Burden of Animal Diseases (GBADs) programme, which is funded by the Bill and Melinda Gates Foundation and The UK's Foreign, Commonwealth and Development Office (FCDO) and led by the University of Liverpool with the World Organisation for Animal Health (WOAH). The project is led in partnership by the University of Liverpool (UoL) and Scotland's Rural College (SRUC), benefitting from the SRUC's considerable links with the UK pork industry and UoL's leadership of the GBADs programme, to provide a local case study that is conducted using a framework that is being applied globally. In addition, a research collaboration was established with the University of Bern, Switzerland, which contributed significant experience in animal health economics. The project provides a basis for future work to understand resource allocation for animal health and welfare in the UK pork sector. It provides opportunities for decision makers to critically assess the balance of net production losses and expenditure on critical health issues that are limiting animal productivity, welfare, compromising human health (i.e. zoonoses and antimicrobial resistance) and contributing to inefficient use of land and water resources.

Key outcomes:

1. UK pork production systems are very diverse but can be classified in three main production types: breeding, rearing and finishing. Pig farms often comprise more than one production type (stage). Various additional characterization criteria (e.g. indoor/outdoor farrowing, slaughter weight, rearing system or production standard) can be added for sub-classification.
2. Data on population size is available from various national and international sources (e.g. DEFRA, AHDB, FAOSTAT, EUROSTAT). However, the granularity of the data varies, as does the actual pig population size during the year. The estimated biomass of the breeding population was 98,692 tonnes and 175,091 tonnes for the fattening pig population, respectively. The biomass of the entire UK pig population was estimated at a median of 273,949 tonnes. The mean capital value of the entire UK pig population was estimated at £381.2 million.
3. Diseased farms (current state) showed substantially lower output (animals and revenue) than the healthy farms free from all possible causes of animal disease burden (utopia state). Furthermore, diseased farms also showed lower animal input, mainly caused by the decreased efficiency and throughput. Overall, 188,536 fewer working sows, 937,316 fewer weaners and 448,330 fewer feeders would be required in a disease-free utopia scenario to achieve the current production output (pigs slaughtered per year) with disease.
4. The annual Animal Health Loss Envelope (AHLE) for a medium-sized breeding farm (500 working sows) was estimated at £394,000, for a rearing farm (2,500 nursery spaces) at £156,000 and for a fattening farm (2,000 fattening spaces) at £246,000. Estimates for an entire production stage were £343million, £140million and £375million for the breeding stage, rearing stage and fattening stage, respectively. For the overall UK pork production system, the AHLE was estimated at £858million per year.

Further work is required with the industry in setting the ideal health state and its parameterisation. There is also work needed on the current levels of animal health expenditure in the industry that needs

to include the costs of pharmaceuticals and veterinary services at farm-level plus the investment by the industry and government on research, education and coordination. This information will be critical in indicating weaknesses in animal health resource allocation.

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Introduction

Livestock are part of an economic system therefore the evaluation of the burden of animal disease must be placed in an economic context that captures livelihood and wider economy impacts as well as externalities related to the environment and human health.

The Global Burden of Animal Diseases (GBADs) programme will move animal health decision making away from a partial assessment basis to an evidence-based process. Economics in animal health has traditionally been used as an adjunct to advocacy for reduction of a specific pathogen in a population *(Figure 1: An animal health approach)*. GBADs will add value by searching for optimality in resource allocation in order to improve productivity and human wellbeing (*Figure 1: An economic approach).* This approach will confirm that control of specific pathogens is not the only priority activity in many circumstances, and instead will describe the need to invest in fundamental husbandry, nutrition and genetic improvements in parallel.

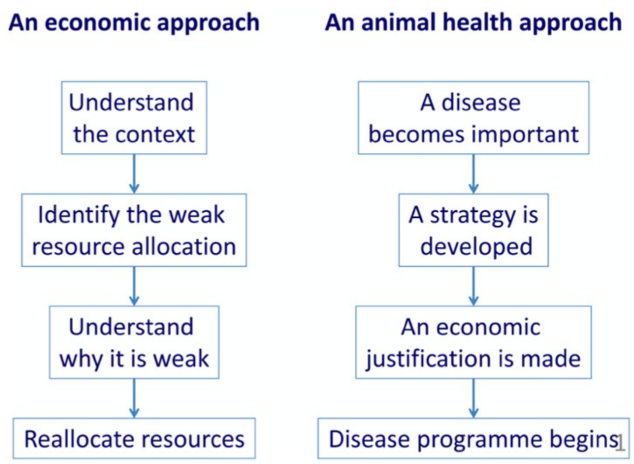

Figure 1: Different approaches to resource allocation in animal health

GBADs will challenge the current status quo whereby investments related to animal health are made through: (1) cost benefit analyses based on assumptions or weak data; (2) rules of thumb (heuristics) of whether a problem needs to be addressed; or, (3) reactions to outrage-generating crises. GBADs will analyse the livestock and aquatic sectors in order to generate information on: animal biomass; capital investment in animals; health loss envelope that captures production loss and expenditure; attribution of that envelope to animal health causes and risk factors; and the wider economy impacts. This information will be systematically assessed to understand who is most affected by the burden of animal diseases and health issues, where there are weaknesses in animal health technology and resource allocations to alleviate burdens and indicate priority areas to improve farmers' livelihoods.

Project milestones:

The Burden of Animal Diseases in UK pork production project will provide:

1. Classification of the UK pork production systems
2. Estimation of the biomass and capital investment in animals and the infrastructure needed to manage them in each system
3. Description of the current level of inputs and outputs in each system
4. Estimation of the animal health loss envelope by system, regional and national level
5. Preparation of articles for farming and industry press; present results to AHDB Pork sector council and to a farmer/vet meeting

The report covers points 1 to 4 and the presentations made at meetings are available on request.

Budget

The total budget for the work was £50,000.

Sustainability

The collaborators will use outputs and combine learnings from this and other current AHDB funded projects in the pig sector to scope a joint application for future research funding. In addition, they will continue to seek additional support in terms of finance, expertise and data from government veterinary services, academia, NGOs and the private sector.

The output generated will be of value for each of these components in society and overall will have an impact on the sustainability of pork production in a UK context. The added value of these products will be such that each organisation will begin to institutionalise the data collection and analysis methods developed.

Results 1: Classification of the United Kingdom pork production systems

Pork production systems vary widely around the world and often consist of country-specific production types reflected by their value chains. This document aims to provide a qualitative overview of the pork production systems in the United Kingdom (UK). This report draws on the GBADs programme work on classification of livestock production systems and consultations of experts in the pig sector, particular thanks to the AHDB team – Derek Armstrong, Carol Davis, Jennifer Newman and Matthew Harris and Georgina Crawford of Red Tractor Farm Assurance.

Introduction

The classification consists of three main categorisations: (i) Production type, (ii) Management system and (iii) Enterprise type (Figure 2). This classification overview is qualitative only and reflects a simplified version of the multifaceted systems in place. The overview was designed in the perspective of future analyses in the context of animal health economics. Various additional characterization criteria (e.g. indoor/outdoor farrowing, slaughter weight, rearing system or production standard) could be added to the classification. However, not all of these criteria apply to all farm types and for some parameters, only little or no data is available. The individual categories are described in detail below.

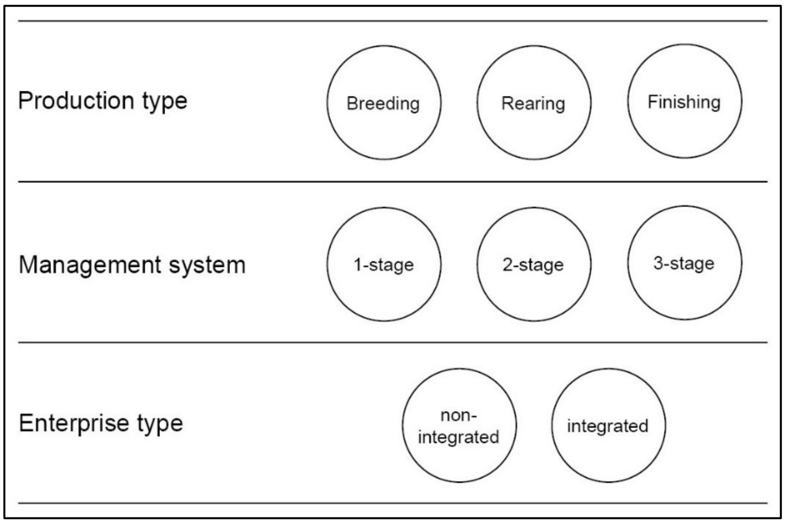

Figure 2: Classification of pork production systems in the United Kingdom.

Production type

Breeding: The breeding stage can be further divided into several subtypes, which have different terms depending on their purpose. One common distinction is the subdivision into nucleus breeding with pure lines, multiplication with gilt production and terminal crossing with offspring used for fattening. Data on the specific breeding type of a farm are sparse and subdivision is therefore not included in the classification overview. However, based on the available data, a distinction can be made between indoor and outdoor breeding for the majority of commercial farms.

Rearing: The rearing phase, also called nursery, describes the stage between weaning and finishing. Piglets are usually weaned at around 7kg with an average weaning age of 27 days (Nix, 2020)[1]. However, in the literature different thresholds are used for the reporting of the individual stages. AHDB publishes GB average ex-farm prices paid for 7kg and 30kg weaners each week (AHDB, 2022b) and in the Defra Pig and Poultry Farm Practices Surveys (FPS) (DEFRA, 2010) weaners were classed as pigs weighing between 7kg and 30kg. Even though 30kg is considered the norm, 35kg values can occasionally be found (Nix, 2020). In the FPS, growers were classed as weighing between 30kg and 65kg and finishers as pigs weighing over 65kg. In general, various terms are used to describe the different stages of production and the respective animals. The difference between "grower" and "finisher" stages is usually because of rations as compounders supply producers with weaner, grower and finishing rations.

Finishing: Finishers can typically be further divided into three different weight classes: Pork (average liveweight 87kg; deadweight 64kg), Cutter (100kg; 75kg) and Bacon (112kg; 84kg) (Nix, 2020). The vast majority of UK pigs are taken to baconer weight, around 1/5 to cutter weight and less than 5% to pork weight (AHDB, personal communication).

Management system

The different production types described are often combined in multi-stage systems. All combinations are prevalent: 1-stage, 2-stage and 3-stage integration. One-stage management systems are farms that do either breeding, rearing or finishing only. Two-stage systems are found in both variations, farms that combine breeding and rearing (with finishing taking place on another farm) or farms that combine rearing and finishing. Three-stage management systems that include all production stages are often referred to as farrow-to-finish farms. Farrow-to-finish farms are frequently used for models in animal health economics as they facilitate capturing disease impacts across all production stages. There are different practices regarding the ownership. Any of these stages, 1, 2 or 3, can be carried out on different farms but the breeder (Stage1) may retain ownership at the 2 and/or 3 stage and pigs are therefore reared/finished under contract. Furthermore, the owner may 'sell' the pigs to the contractor under a guarantee to purchase them back for slaughter. This is important as far as disease management is concerned as under the first situation some of the risk of disease impact is shared between owner and contractor. Under the second situation, all of the disease risk for that 'contractor' period is carried by the contractor.

Enterprise type

The enterprise type describes the ownership structure and the degree of vertical integration. Various types of ownership are present. In the classification overview, a simplified binary distinction is applied: non-integrated and integrated. Non-integrated pig farms are often privately owned and family run, while integrated farms are mostly owned by a larger company/integrator. However, also privately owned and family run farms may act as integrators in the sense that they use contractors to rear/finish a proportion or all of their pigs, as described above. Large vertical integrators are abattoirs controlling the entire production process (even if they sell pigs to contractors on a buy-back contract). The degree of integration can have an effect on market access, feed and slaughter prices. Furthermore, considering animal diseases, some of the larger integrators have in-house veterinary teams and dispensaries.

[1] The main data source for published margins within the Pigs section of *The John Nix Farm Management Pocketbook 2021* is the AHDB Pork performance data

Additional characterisation criteria

Deadweight prices

Deadweight prices are typically reported as Standard Pig Price (SPP) and All Pig Price (APP) (AHDB, 2022a) on a weekly basis. The SPP is the average price for GB standard pigs with no explicit premium, other than weight and grade. The APP is the GB average deadweight pig price achieved by producers each week for standard and non-standard pigs. A non-standard pig is a pig on which premiums are paid for certain production systems, feed regimes or breeds (including RSPCA Assured, rare breed, outdoor reared and outdoor bred). Price or weight does not determine whether a pig is standard or non-standard. Both prices do not include vertically integrated pigs (e.g. owned by abattoirs) that are not traded. Achieved deadweight prices are important criteria for economic analyses of disease burden.

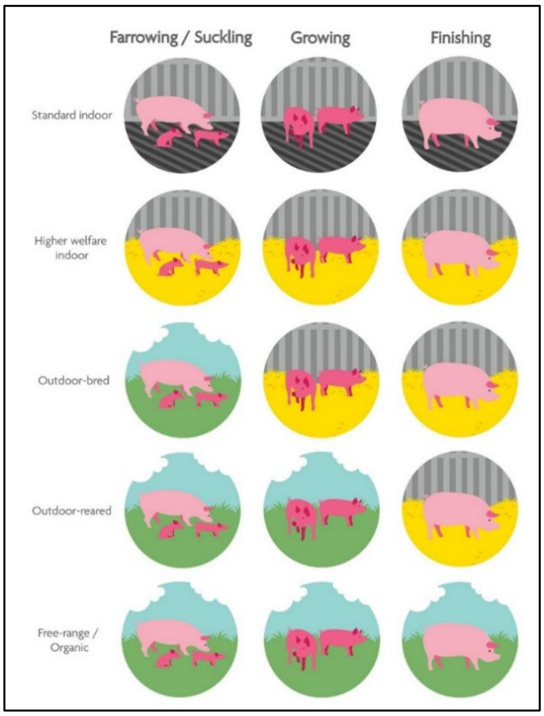

Figure 3: Pig rearing systems in the UK. (Source: www.rspcaassured.org.uk)

Rearing systems

There are various pig rearing systems in place in the UK (Figure 3). The different types of rearing systems mostly cannot be retrieved from publicly available data sources and are therefore not included in the classification overview. However, information on the rearing system can provide valuable additional information for a given farm.

Common rearing systems are the following (ADAS; RSPCA):

Standard indoor: Pigs raised indoors without higher welfare certification are not required to have access to bedding, and may be raised on fully slatted or bare concrete flooring. Sows may be confined to farrowing crates when giving birth and nursing their young.

Higher welfare Indoor: Pigs raised to higher welfare indoor standards will be kept in barns with straw or other suitable enrichment materials and a lying area of solid construction with sufficient bedding. Higher welfare indoor systems also use free farrowing accommodation such as individual pens or indoor arcs.

Outdoor-bred: Outdoor bred means the pigs are born in outdoor systems with access to bedded arks and outdoor paddocks. Shortly after weaning, the piglets are brought indoors for growing and finishing, normally on straw bedding.

Outdoor-reared: Outdoor reared pigs are born and reared in outdoor systems for about half of their lives. While outdoor-reared pigs may not necessarily have access to pasture, they will have access to an outside pen and a bedded tent or arc.

Free-range: Free-range pigs are born and raised outside where they and the sows spend their entire lives with permanent outdoor access.

Organic: There are various different organic standards/labels. In general, the pigs must have permanent access to the outdoors (whenever weather conditions and the state of the ground allow) and are fed organic non-GM feed. They also have access to bedded huts or tents and a paddock.

40% of sows (female pigs) in England are kept outdoors – although their offspring, which are reared for meat, will typically be brought inside for some of their growing period. Most (60%) of these will be housed in straw-based indoor systems. 3 to 4% of meat pigs are reared entirely outdoors either as free-range or organic (ADAS).

Production standard and labels

In addition to the different rearing systems, there are also various pork labels in the UK. Both rearing system and pork label can have an effect on consumer prices. Common labels are shown in Table 1.

Table 1: A selection of common pork labels in the United Kingdom (adapted from: RSPCA).

Label	Description
	Organic labels such as The Organic Food Federation, Welsh Organic, Soil Association and OF&G require that the animals have been fed an organic diet. There are also strict rules regarding the use of antibiotics and other medicines. Pigs in organic systems have access to the outdoors throughout their production cycle. A list with UK approved control bodies with links to their specific standards can be found on the DEFRA website (DEFRA, 2020)
	The RSPCA Assured label indicates that the farms have been monitored and assessed against the RSCPA welfare standards for pigs.
	The Red Tractor label indicates that the pork has been farmed processed and packed in the UK. Its animal welfare standards are above UK legal minimum standard.
	In Scotland, the QMS Specially Selected Pork label indicates the pork is Scottish, and that the farms may have been checked by the Scottish SPCA.
	There is not an official UK pork label but the Union Jack, or the words "British Pork" are often used on packaging. The UK legal standard allows tail docking or farrowing crates only under specific circumstances.
	EU legal standards are similar to those in the UK but also allow the use of sow stalls for the first four weeks in a sow's pregnancy, which have been illegal in the UK for over 20 years.

Summary

UK pork production systems are very diverse but can be classified in three main production types: breeding, rearing and finishing. Pig farms often comprise more than one production type (stage). Various additional characterization criteria (e.g. indoor/outdoor farrowing, slaughter weight, rearing system or production standard) can be added for sub-classification.

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Results 2: Demographics, biomass and capital value of the UK pig population

The GBADs programme aims to estimate the burden of animal disease in different regions and production systems (Rushton *et al.*, 2018). Detailed information on the population, biomass and capital value are key elements in this process. Animal biomass can be used as a common denominator and scale to compare disease burden or other quantitative data to relevant animal populations, which vary in size and composition between regions and over time. For example, animal biomass is used by WOAH and several surveillance groups as a denominator for the analysis of antimicrobial use data and to compare between different animal species and/or countries (Góchez *et al.*, 2019). For the estimation of the biomass, data availability and granularity are crucial. On a global level, detailed data are not yet available for many countries and therefore the WOAH mainly uses globally available datasets from the WOAH World Animal Health Information System (WAHIS) and the United Nations Food and Agriculture Organization Statistics (FAOSTAT) (Góchez *et al.*, 2019). On the other hand, if detailed data on livestock populations, including age or weight classes, are available from national statistics, the estimates are likely to be more accurate and reliable. In the framework of GBADs, a manual to estimate global domestic livestock biomass is being developed that describes the different methods available to calculate biomass and addresses the issues of data availability, parameter estimation and uncertainty to ensure the use of consistent methods within the GBADs programme.

Population demographics

Population size

Pig population data for the UK is available from multiple sources (Table 2). However, reported pig population size varies between the different data sources. DEFRA report the most detailed public data with population estimates from surveys in June and December (December surveys comprise a smaller sample). These population estimates are then made available to other reporting bodies. Pig numbers published by AHDB correspond to DEFRA data. EUROSTAT reports specific values for the four categories "Live swine", "Piglets, live weight of under 20 kg", "Breeding sows, live weight 50 kg or over" and "Other pigs". However, the latest data is for 2016 and the UK no longer reports to EUROSTAT. FAOSTAT reports annual stock numbers without further subcategorization. These numbers are higher than from other data sources and generally are closer to June survey data than to December data reported by DEFRA, which suggests that the UK provides June census data for international statistics.

Table 2: Overview of data sources for the UK pig population.

Data source	Year*	Total no. of pigs	Comment	Reference
DEFRA	2020 (DEC)	4,757,594	Published twice per year (June and December surveys), most detailed public data; multiple subcategories	DEFRA
AHDB	2020 (DEC)	4,758,000	Same data as DEFRA	AHDB
EUROSTAT	2016	4,544,900	No annual publication cycle; subcategorization into "total pigs, piglets, breeding sows and other pigs"	EUROstat
FAOSTAT	2020	5,148,000	Published annually; no subcategories	FAOstat

* Latest available data

The data sets from DEFRA include annual statistics on the number of pigs (and other livestock) in England and the UK as at 1 June and 1 December each year (DEFRA, 2022a). June surveys include the categories listed in Table 3. The total pig population was estimated at 5,055,000 heads in June 2020 and at 4,758,000 in December 2020 (Table 4), with 4.5% (n=227,057) fewer pigs in December than in June of the same year.

Table 3: UK pig numbers (thousand head) reported by DEFRA, June survey

	2015	2016	2017	2018	2019	2020
Sows in pig	285	295	297	289	295	295
Gilts in pig	56	55	55	58	57	57
Other sows	66	65	64	63	61	50
Gilts for breeding	85	79	81	81	84	88
Boars for service	15	15	14	13	12	11
Feeding pigs	4,232	4,356	4,457	4,509	4,569	4,553
Total pigs	**4,739**	**4,866**	**4,969**	**5,012**	**5,078**	**5,055**

The longitudinal data show that the pig population is dynamic and that the size varies throughout the year and between years, with smaller population sizes in December (Figure 4). From 2010 to 2020, the population increased by 594,000 heads (+13.3%) and in the last 5 years (2015-2020) by 316,000 heads (+6.7%) (DEFRA, June data).

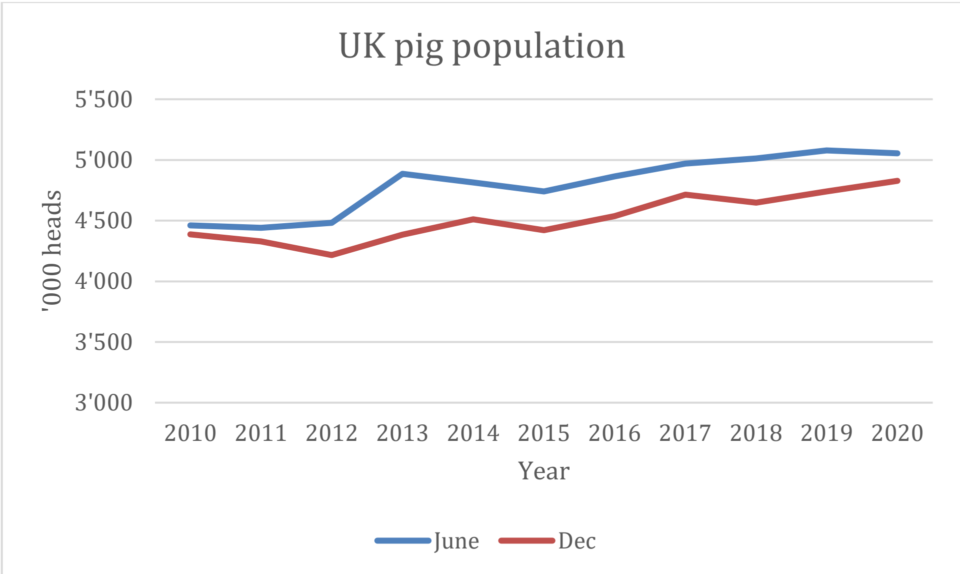


Figure 4: Variation in the UK pig population size over the last 10 years. Source: DEFRA

Data from DEFRA December surveys additionally include detailed numbers for five different weight categories in fattening pigs (Table 4). Fattening pigs accounted for 90% of the pig population and breeding pigs for 10%. Within the fattening pigs, the lighter weight classes are composed of more pigs than the heavier classes with 29% of fattening pigs being below 20kg. The reported numbers for fattening pigs 110kg and over in the December surveys have to be treated with caution, as many abattoirs are shut over the Christmas period (personal communication). Within the breeding pigs, the female breeding pigs (i.e. sows in pig, gilts in pig and other sows) accounted for 80% and other breeding pigs (gilts not yet in pig and boars for service) for the other 20%. These proportions are relatively stable over time. The difference in overall population size between June and December is mainly caused by the lower amount of fattening pigs in December (-5%), while the number of breeding pigs increased slightly during this period.

Table 4: UK pig numbers reported by DEFRA, comparison between June and December surveys.

	JUN 2020	DEC 2020			CHANGE DEC20/JUN20	
Category	***head***	***head***	***%-total***	***%-cat***	***head***	***%***
Total breeding pigs	***501,621***	***504,056***	***10%***	***100%***	***2,435***	***0.5%***
Sows in pig	295,309	296,088	6%	59%	779	0.3%
Gilts in pig	56,741	57,601	1%	11%	860	1.5%
Other sows	50,147	51,426	1%	10%	1,279	2.5%
Female breeding herd	*402,197*	*405,115*	*8%*	*80%*	*2,918*	*0.7%*
Gilts not yet in pig	88,064	87,563	1.8%	17%	-501	-0.6%
Boars for service	11,360	11,378	0.2%	2%	18	0.2%
Other breeding pigs	*99,424*	*98,941*	*2%*	*20%*	*-483*	*-0.5%*
Fattening pigs	***4,553,155***	***4,323,663***	***90%***	***100%***	***-229,492***	***-5.0%***
110kg and over	-	59,073	1%	1%	-	-
80kg and <110kg	-	686,248	14%	16%	-	-
50kg and <80kg	-	1,063,247	22%	25%	-	-
20kg and <50kg	-	1,249,551	26%	29%	-	-
Under 20kg	-	1,265,544	26%	29%	-	-
Total pigs	**5,054,776**	**4,827,719**	**100%**		**-227,057**	**-4.5%**

Number and size of holdings

DEFRA also publishes detailed annual statistics on the structure of the agricultural industry (DEFRA, 2022b). These data series show livestock population (as well as land and crop areas and agricultural workforce) estimates for England and the UK as at 1 June each year. The results come from the long-running June surveys of agriculture and horticulture that are carried out each year in England, Scotland, Wales and Northern Ireland. The information includes long-term trends or detailed results for different types of farm, farm size or geographical area. The sample size for the June survey changes each year depending on UK and EU requirements. UK data collection for 2020 was disrupted by Covid-19. Therefore, the most recent data is from 2019 (Table 5). A total of 10,539 UK pig farms were reported, of which 5,451 were classified as female pig breeding farms and 8,617 as fattening pig farms (which implies that some farms were classified as both). However, many of these farms only have a very small number of pigs. 3,328 breeding farms have less than 5 sows and 3,757 fattening farms have less than 10 fattening pigs. The average number of pigs on holdings with 5 or more breeding pigs was 192 and on farms with 10 or more fattening pigs 936 pigs. Furthermore, the reported pig numbers refer to pigs found on commercial farms, where commercial holdings are defined as those with significant farming activity. These significant levels are classified as any holding with more than 5 hectares of agricultural land, 1 hectare of orchards, 0.5 hectares of vegetables or 0.1 hectares of protected crops, or more than 10 cows, 50 pigs, 20 sheep, 20 goats or 1,000 poultry.

Table 5: UK numbers of holdings and livestock numbers by size group. Data from June 2019 survey. Source: DEFRA

Livestock Type	Size band	Holdings	Pigs
Female pig breeding herd	1 to 4 breeding pigs	3,328	6,015
	5 to 24	1,001	10,674
	25 to 99	390	20,868
	100 and over	732	375,932
	Total	**5,451**	**413,489**
	Average female breeding pigs		*76*
	Average on holdings with >=5 female breeding pigs		*192*
Fattening pigs	1 to 9 fattening pigs	3,757	13,242
	10 to 49	1,805	41,141
	50 to 299	1,001	130,782
	300 to 999	728	452,571
	1 000 and over	1,326	3,931,194
	Total	**8,617**	**4,568,929**
	Average fattening pigs		*530*
	Average on holdings with >=10 fattening pigs		*937*
Total pigs	1 to 9 pigs	5,132	16,876
	10 to 49	2,181	50,258
	50 to 299	1,104	145,432
	300 to 999	720	449,845
	1 000 and over	1,402	4,415,915
	Total	**10,539**	**5,078,325**
	Average number of pigs		*482*
	Average number of pigs on holdings with >=10 pigs		*936*

Furthermore, the Animal & Plant Health Agency (APHA) and the Livestock Demographic Data Group (LDDG) report estimates for the size and distribution of pig holdings at GB level. The most recent report is from 2019 and is based on information on pig movements for the 24-month period 2016-2017 held in eAML2 and ScotEID (APHA, 2019). Holdings were classed into five holding size categories depending on the number of pigs moved (Table 6). The pig density maps are based on weighted values of these categories. A pig holding was defined here as any holding which pigs are moved to and from during the period of interest. This definition includes markets, abattoir and other non pig-keeping premises, although these are estimated to be a small proportion compared to the pig-keeping holdings.

Table 6: Description of size of holding according to number of pigs moved (incoming and outgoing) in 24-month period (APHA, 2019).

Size category of holding	Numbers of pigs moved in 24-month period	Description
1	1-25	Pet pig owner or small holdings
2	26-300	Small holdings
3	301-2,000	Small commercial holdings
4	2.001-8,000	Medium commercial holdings
5	8,000+	Large commercial holdings

The highest densities in pig population (Figure 5) are in Yorkshire and Humber, the East of England and a small area within North-East Scotland, where the majority of large commercial farms are known to exist. A higher density of pig holdings can be seen in several areas, particularly in South-West England and the Midlands. Interestingly, both Wales and South-East England are shown to have areas of higher holding density but a lower pig density. This points to a lower number of pigs per holding, and may reflect a greater proportion of smallholder premises with pigs in these areas (APHA, 2019).

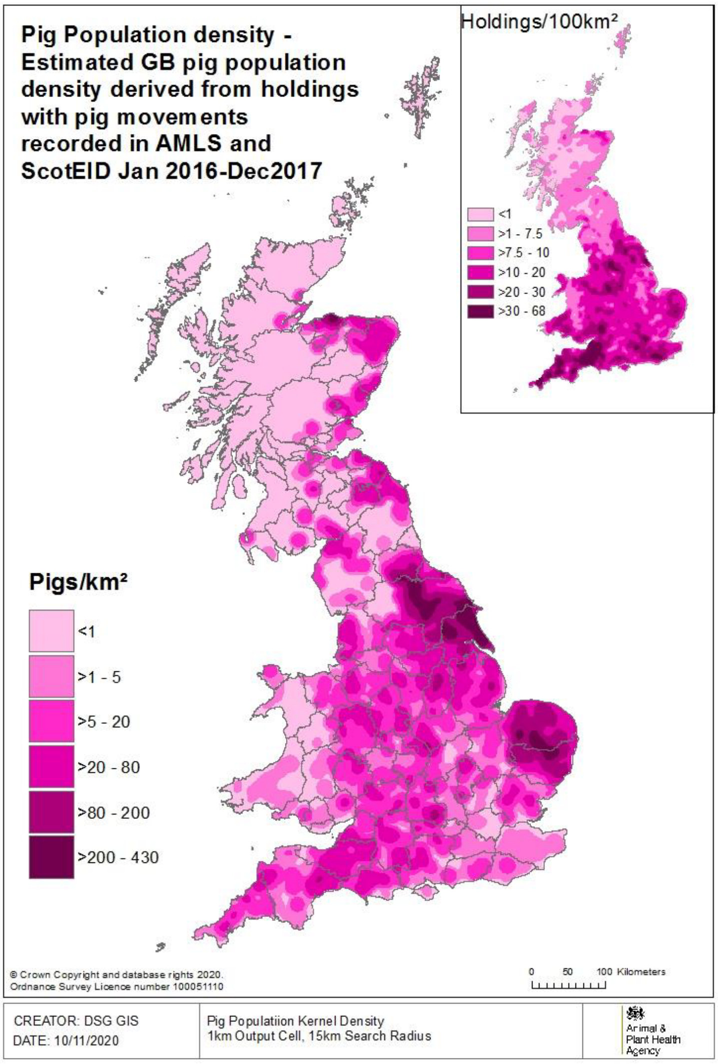


Figure 5: Pig population and holding density in GB. (APHA, 2019)

A total of 27,956 holdings were identified and could be allocated to a county. However, the dataset used may contain holdings which no longer have pigs. This is also indicated by the high discrepancy compared to the numbers reported by DEFRA (Table 5) which are based on a different methodology (APHA capture all pig movements/registered premises with pigs, whereas Defra only captures commercial holdings where pigs are kept). Table 7 and Table 8 show breakdowns of holdings by estimated size category and country respectively. The majority of holdings (73.3%) were within size category 1, and are likely pet pig owners and small holdings. There were 3,442 (12.3%) holdings classes in categories 3 to 5, which are suggested to be "commercial holdings". England has the greatest number of holdings of each size category. Scotland has the greatest proportion of size category 3 to 5 holdings, with Wales having very few holdings of categories 3 to 5.

Table 7: The number of pig holdings in each country, by estimated herd size category (2016-2017). Source: APHA

County	Size Category (No. of holdings)					Total
	1	2	3	4	5	
England	16,423	3,350	732	970	1,294	22,769
Scotland	1,607	223	123	121	130	2,204
Wales	2,455	456	46	18	8	2,983
GB total	**20,485**	**4,029**	**901**	**1,109**	**1,432**	**27,956**

Table 8: Distribution of pig holdings in each country, by estimated herd size category (2016-2017). Source: APHA

County	% of Country total					% of Total
	1	2	3	4	5	
England	72.1	14.7	3.2	4.3	5.7	81.4
Scotland	72.9	10.1	5.6	5.5	5.9	7.9
Wales	82.3	15.3	1.5	0.6	0.3	10.7
GB total	**73.3**	**14.4**	**3.2**	**4.0**	**5.1**	**100**

Farm type

Data on farm type is available from the "Pig Enhanced Demographic Report", which is also based on pig movement data from eAML2 and ScotEID, but for the period 2014-2015 (APHA, 2020). All holdings that were size category 3 or above (see Table 6), indicating that they moved at least 300 pigs in the 24-month period and were likely to be commercial holdings, were selected for analysis. The total number of holdings within the movement dataset from 2014-2015, which were estimated to be commercial-sized pig farms, was 3,252. The majority of farms were allocated as feeders (40.4%), whereas the combination of high and low intake breeding farms represented over a quarter (27.7%) of all farms (Table 9).

Table 9: Number of commercial-sized pig farms by estimated holding type, based upon pig movement data characteristics (APHA, 2020).

Holding Type	Number of farms	% of total farms
Feeder	1,315	40.4
Breeder-Finisher	811	24.9
High intake breeding or nursery	456	14.0
Low intake breeding	447	13.7
Unknown	223	7.0

Details on the analysis of the entire data set, including non-commercial holdings and holdings not classified as "farm", are reported in Smith et al. (2020). In Table 10, the number and proportion of all holding types are listed. In total, 4.45% were classified as "non-farm holding", 71.07% as "pet pig owner or smallest small-scale holdings" and 14.33% as "Small-scale holdings".

Table 10: Number of each estimated holding type by category determined by analysis of pig movements (Smith *et al.*, 2020)**.**

Estimated holding type	No. holdings	% of total
AI Centre	6	0.02%
Abattoir	116	0.36%
Butcher	38	0.12%
Butcher/farm	15	0.05%
Market	53	0.17%
Show	139	0.43%
Port	17	0.05%
Vets	6	0.02%
Other	1,034	3.23%
Farm		
Pet pig owners or smallest small-scale holdings	22,766	71.07%
Small-scale holdings	4,590	14.33%
Feeders	1,315	4.11%
Breeder-finisher	811	2.53%
High-intake breeding or nursery	456	1.42%
Low-intake breeding	447	1.40%
Unknown	223	0.70%

Figure 6 shows the distribution of the holding types in GB. The Yorkshire and Humber region contained a large proportion of the total high-intake breeding/nursery farms (46%), breeder-finisher farms (26%) and feeder farms (39%), whereas the low-intake breeding units were mainly located in the East of England (29%). Scotland contained 44% of all the holdings with an unknown type, possibly due to less information being supplied within the Scottish movement dataset (APHA, 2020).

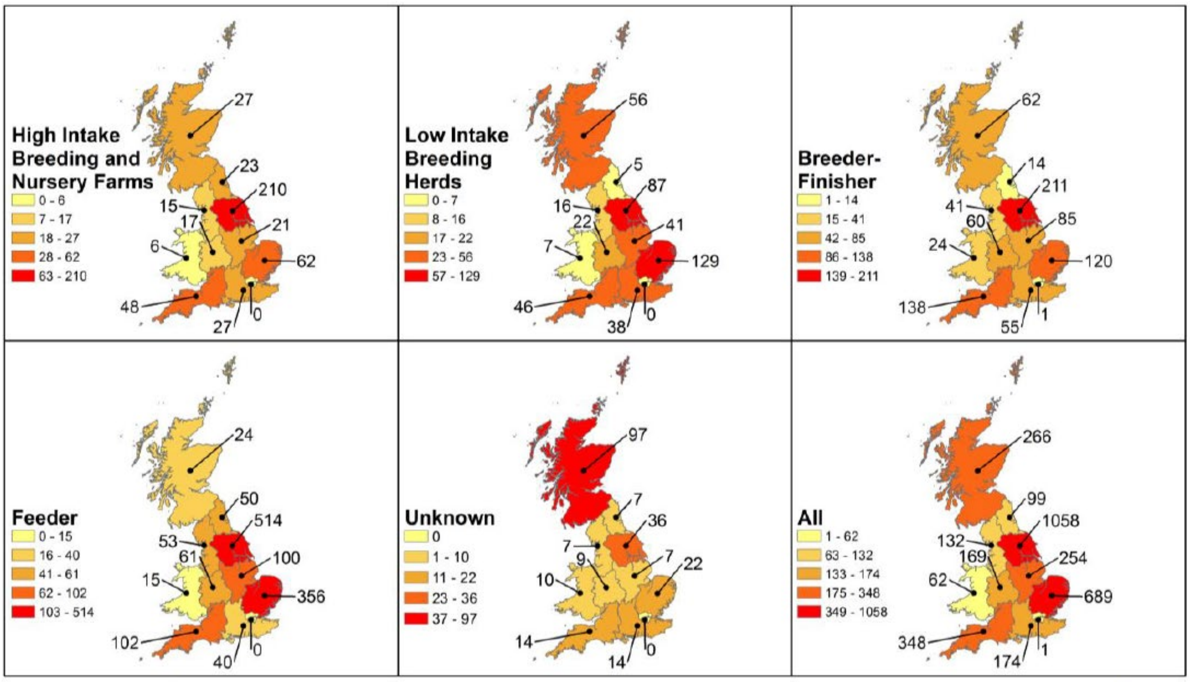


Figure 6: "Commercial" pig holding locations (n=3,252) aggregated to NUTS1 regions and separated by holding type. (APHA, 2020)

Biomass estimation

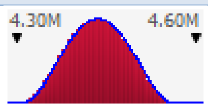
The livestock biomass, which is the sum of individual live weights for a given population can be calculated using the formula:

$$Biomass\ (kg) = N * W$$

In which N refers to the total number of animals and W refers to the average live body weight. In order to obtain more accurate estimates, the population and live weight data can be separated by different production types or stages and the biomass calculated accordingly.

To account for variability in population size and body weight, a stochastic model was developed and estimates are based on 10,000 iterations. Population data were based on DEFRA numbers reported for 2020 (Table 4; DEFRA, 2022a). PERT probability distributions were applied to the number of animals in each animal category, with June and December values serving as minimum and maximum values and the arithmetic mean as most likely values of the distributions. For example, the number of fattening pigs was defined as described in Table 11.

Table 11: Values of the PERT distribution for the fattening pig population size used as input variable.

Parameter	Value
Minimum	4,323,663
Most likely	4,438,409
Maximum	4,553,155
Chart	

For live weight, different approaches were applied for breeding and fattening pigs due to the different dynamics of the weight of these animals. For breeding pigs, values were defined for the subcategories and then weighted according to the proportion of the population size to estimate the average body weight of the main category. Finally, a PERT distribution was defined for the weight of a breeding pig, using the calculated average as most likely value. This resulted in an estimated median weight of a breeding pig across all subcategories of 196.3 kg (90% central range: 153.2 kg to 232.9 kg).

Table 12: Parameters for the probability distribution of live weight of fattening pigs used as input variable.

Parameter	Value
Distribution	Beta General
α1	0.87823
α2	1.6947
Minimum	1.5
Maximum	130

For fattening pigs, body weight was defined based on weight categories and number of animals per category as reported by DEFRA (Table 4). A probability distribution was fitted around these values. Beta general was found to best fit the distribution of live weight of fattening pigs. The probability distribution for the live weight of fattening pigs was defined as described in Table 12, which resulted in an estimated mean live weight of 45.4 kg and a median live weight of 39.5 kg (Figure 7).

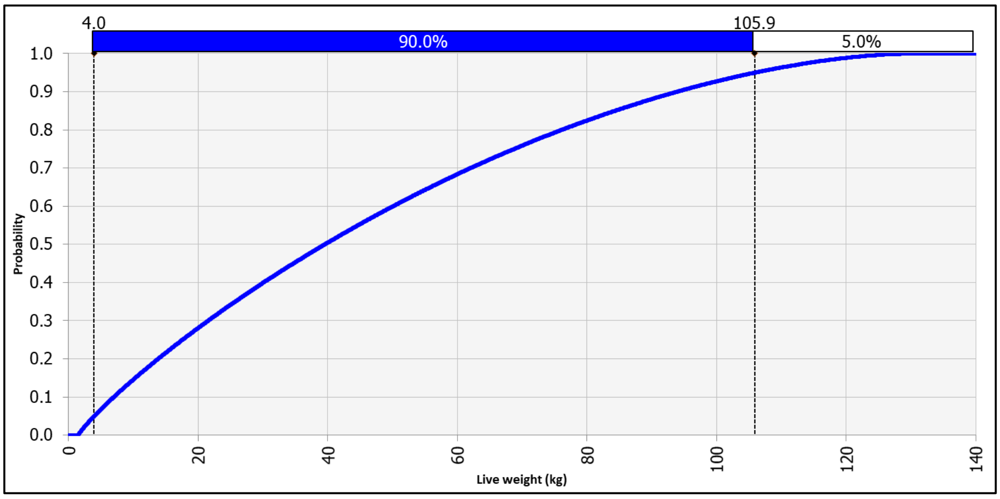


Figure 7: Probability distribution of the live weight of fattening pigs.

The estimated median biomass of the breeding pig population was 98,692 tonnes (mean 98,116 tonnes) and 175,091 tonnes (mean 201,334 tonnes) for the fattening pig population, respectively. The median biomass of the entire UK pig population was estimated at 273,949 tonnes (mean 299,450 tonnes).

As described above, these estimates are based on a stochastic model and therefore vary for each simulation and sub-numbers do not necessarily sum up for the reported median and mean of the total. This applies for all stochastic outcomes presented in this report. Furthermore, the biomass of a population is a dynamic figure and is constantly changing. The reported estimates are based on population data from June and December 2020 and describe the apparent biomass for this period.

Capital investment

When estimating the capital value of the UK pig population, it has to be considered that many pigs are at a stage of production where they are not usually traded and that no figures are reported on the market value (either per head or per kg) of these pigs. Thus, several input parameters are based on assumptions and then extrapolated on the entire population. Therefore, the capital value estimates should be treated with caution.

For the estimation, the fattening pig population was subdivided based on weight categories reported by DEFRA (DEFRA, 2022a). For pigs weighting less than 20kg, an average price per head of £41.86 was assumed. This value is based on the average GB weaner prices for 7kg weaners for 2020 (AHDB, 2022b). For pigs weighing between 20kg and under 50kg, the average 30kg weaner price was used (£58.41/head). For fattening pigs weighing 50kg and more, the average All Pig Price (APP) for 2020 (£1.64) was used (AHDB, 2022a). For the calculation of the carcass weight, 75% killing out was assumed and multiplied by the average live weight of the corresponding category. An alternative (simplified) approach for a scenario where data on weight categories of fattening pigs is scarce would be multiplying the median live weight of fattening pigs (39.5kg) with the average APP and population size. This value has been calculated for illustrative purposes. For the breeding pigs, a value of £145.95 per head was assumed, which is the average between the replacement gilt price (£195) and the average cull sow price (£96.90) for 2020. The price for replacement gilts represents the average commercial price for gilts used in the cost of production (COP) model from AHDB (personal communication from AHDB Market Intelligence). The financial values were then multiplied by the number of animals in each category, using the population distribution described above.

For fattening pigs, the mean capital value was estimated at £307.8 million and for breeding pigs at £73.4 million, respectively. The mean capital value of the entire UK pig population was estimated at £381.2 million. The alternative simplified approach to estimate the capital value of fattening pigs resulted in a total of £287.5 million.

As a comparison, the reported value of all pig slaughterings in the UK for 2020 was £1,557 million (Figure 8). However, this value refers to a period of one year in which farms send multiple batches of fattening pigs for slaughter (total 11.2 million head) at an average dressed carcass weight of 86.9 kg. In contrast, the estimated capital values of this study are based on a cross-sectional study approach with population estimates for a specific time point. At this point in time, the population consists of 10% breeding pigs and 90% fattening pigs, with the vast majority of fattening pigs weighing significantly less than at the time of slaughter.

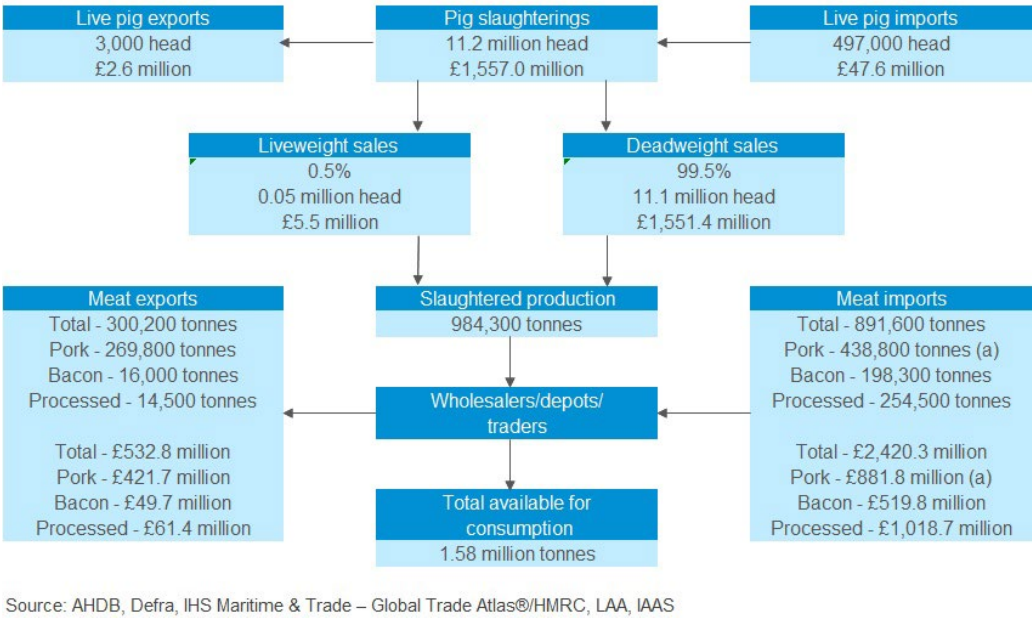


Figure 8: UK pig meat marketing chain 2021 (Image source: AHDB).

Since 2020, significant variations in slaughter weights and pig prices have been observed, which are largely driven by external factors (such as abattoir labour shortages, Brexit, COVID-19, war in Ukraine). These effects were not taken into account in the estimation of the biomass and capital values, as on the one hand most of the data on which the estimates are based come from the time before these events and on the other hand some of these effects are considered to be temporary.

Summary

Data on population size is available from various national and international sources (e.g. DEFRA, AHDB, FAOSTAT, EUROSTAT), whereby DEFRA collects the original data and makes it available to the other bodies. However, the granularity of the data varies widely, as does the actual pig population size during the year. The estimated biomass of the breeding population was 98,692 tonnes and 175,091 tonnes for the fattening pig population, respectively. The biomass of the entire UK pig population was estimated at 273,949 tonnes. The mean capital value of the entire UK pig population was estimated at £381.2 million.

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Results 3 and 4: Description of input and output levels and the estimation of the animal health loss envelope (AHLE)

In milestone 3 and 4, the levels of input and output were assessed and the Animal Health Loss Envelope (AHLE) was estimated. By collating data on input and output relationships, the animal health losses for specified production systems can be compared with a defined, transparent, and consistently applied utopian situation, which need not necessarily be based on empirical data. The AHLE is the difference between net production loss and expenditure in the current state against net production loss and expenditure in a state of ideal health in a utopian situation (Figure 9). In future work the AHLE can be attributed to provide information on the absolute and relative burden by syndrome or disease (depending on health data available).

Within the framework of the Global Burden of Animal Diseases (GBADs) approach, all possible causes of the animal disease burden should be considered – not only notifiable/transboundary diseases or those historically viewed as 'important', but also including (and not limited to) endemic and non-communicable diseases, nutritional issues, injuries and accidents, as well as the impacts of poor animal husbandry practices (Huntington *et al.*, 2021). The "utopia" scenario applied in the analyses thus comprises the GBADs definition of a state free from all possible causes of animal disease burden.

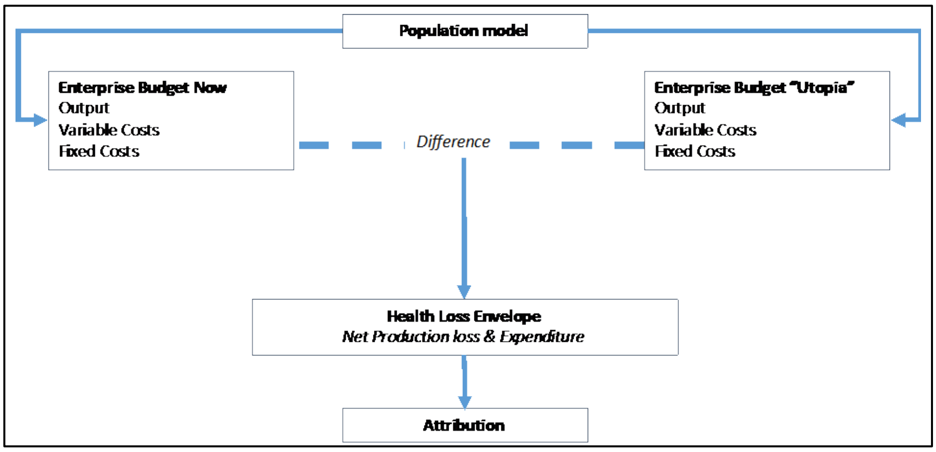

Figure 9: Framework to estimate the Animal Health Loss Envelope (AHLE).

Methods and model description

Levels of input and output were estimated for the diseased farm (baseline) and compared to the estimates of the "utopia" scenario (state of production free from all possible disease burden).

Three different production stages were assessed independently: (i) breeding, (ii) rearing and (iii) fattening. The production model (see Figure 10 and Figure 11) was based on a previously developed model used to estimate reproductive and respiratory disease effects in pig production (Nathues *et al.*, 2017) and were adapted and expanded accordingly. The model was built in Excel (Microsoft Corporation, Redmont, Washington, USA) and the Excel Add-on @Risk was used (Palisade Corporation, Newfield, New York, USA) to account for uncertainty and variability of parameters. The model consisted of several sub-models, which were linked with each other. The production model simulated the production dynamics within a timeframe of one year and the epidemiological flow model simulated disease impact according to defined disease status and incorporated these effects into the production model. The baseline production parameters were mostly obtained from production data provided by AHDB and supplemented by other literature (Nix, 2020; DEFRA, 2021).

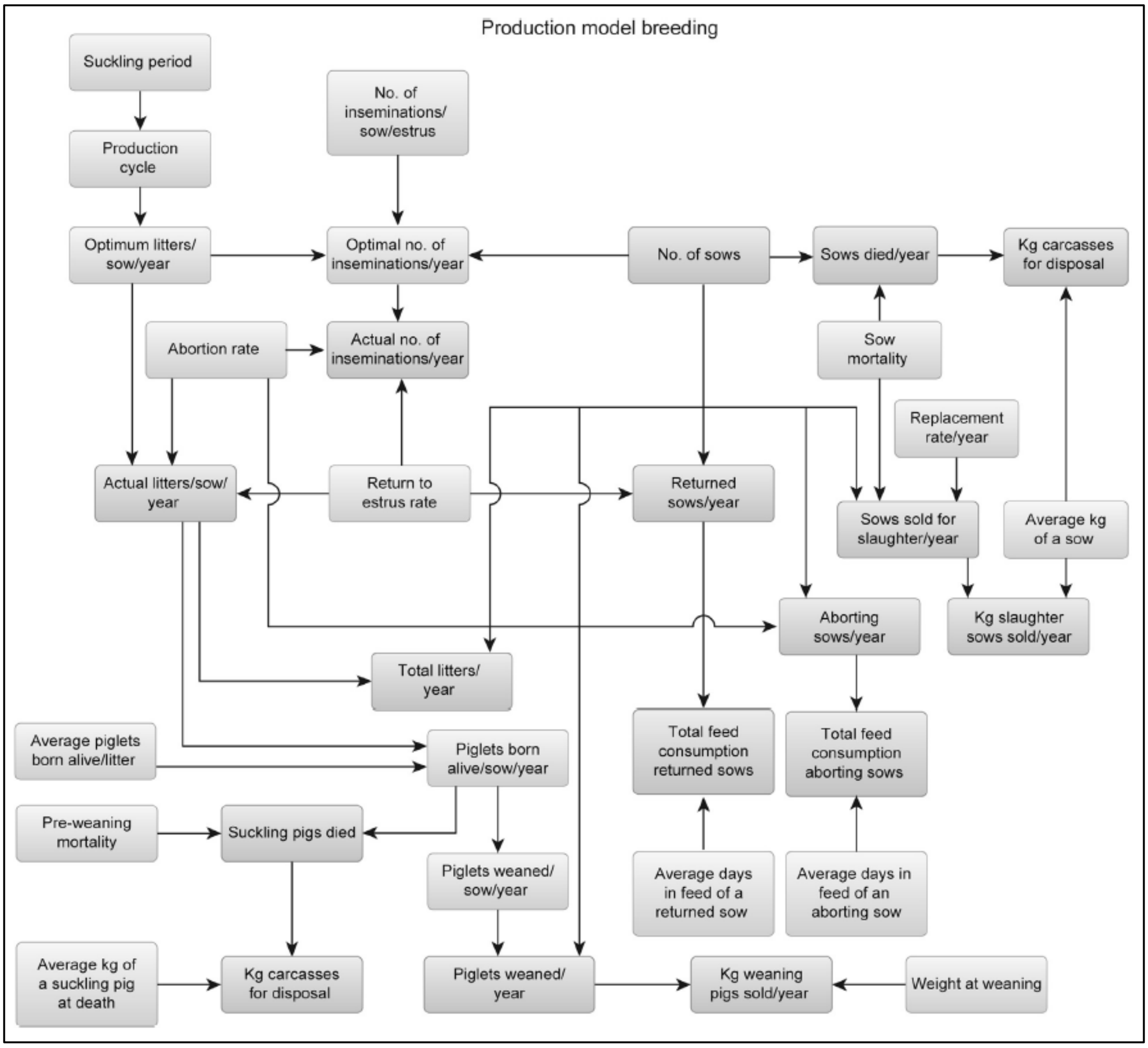

Figure 10: Schematic production model of the breeding stage (Nathues *et al.*, 2017).

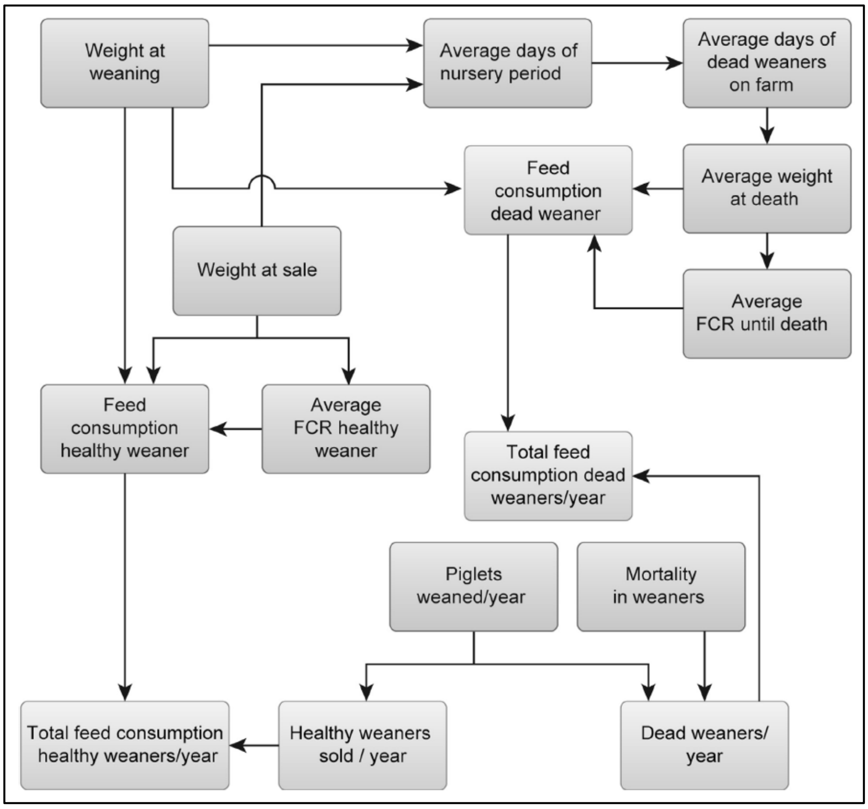

Figure 11: Schematic production model of the rearing stage, which also applies for the fattening stage (Nathues *et al.*, 2017).

For each production stage, two production levels were modelled: "Average" and "Top10" according to the Agrovision performance data for the year 2021 provided by AHDB. In this dataset, the ranking (average or Top10) for the traits is based on pigs weaned per sow per year for breeding sows and feed conversion ratio (FCR) for rearing and fattening with all the other traits being the performance for the same herds based on that ranking. For the breeding stage, input values were based on indoor herd values, as these data were considered more suitable for international benchmarking (predominant production type and higher data availability) compared to values from outdoor breeding. For the utopia scenario, performance parameters were derived either from regression models fitted to the baseline data or maximum values of an individual parameter in the baseline datasets. For example, the FCR of rearing pigs in the utopia scenario was estimated based on FCR reported in the Agrovision dataset, with a linear regression fitted to these data taking into account the average weight at the end of the rearing stage. To model high performance in a scenario without disease, the 95% lower limit of the beta coefficient was selected. This regression was validated against reported FCRs for the Top10 farms in comparative literature (Nix, 2020) and the single best value for FCR from the Agrovision data and is valid for the lower end of rearing weight (Figure 12).

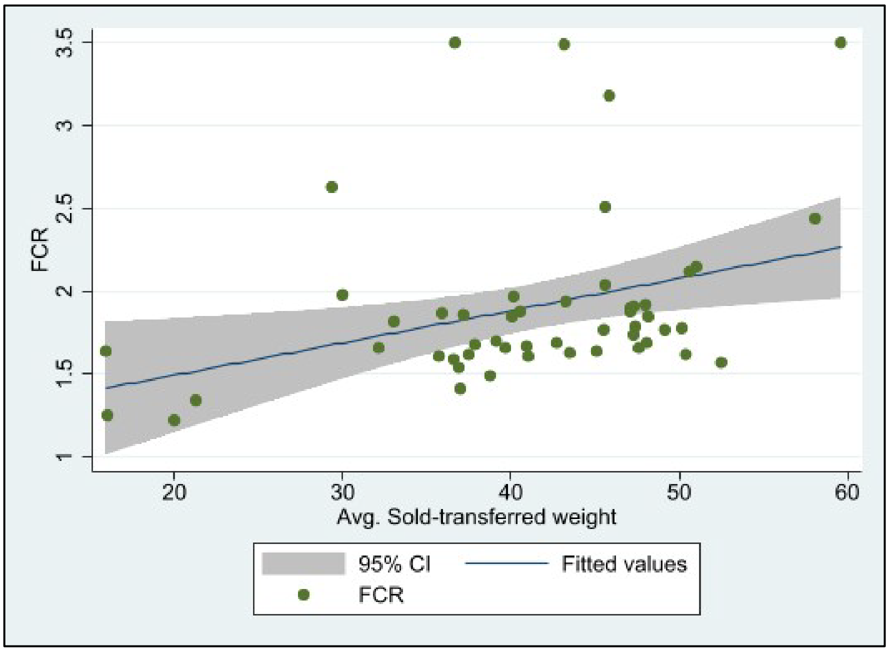

Figure 12: Linear regression to estimate the feed conversion ratio (FCR) for rearing pigs in the utopia scenario.

Similar regression models were applied to estimate the FCR of fattening pigs and feeding days for rearing pigs as well as for fattening pigs. The regression equations are noted below Table 14 and Table 15. These tables (along with Table 13) contain information on input variables (rounded values) used for the production models. The average daily weight gain (ADG) was calculated based on the total weight gain in the rearing or fattening stage and the corresponding feeding days. "Dynamic" input parameters (e.g. weight of pigs produced) of the utopia scenario were adjusted based on critical values of the baseline (i.e. average scenario). For example, the weight of pigs at the start and at the end of the rearing and fattening stage in the utopia scenario were identical to the weights in the average scenario, as other production parameters (FCR, feeding days or ADG) depend on these factors. On the other hand, critical input variables of the average and Top10 scenario were not necessarily identical (e.g. weight at the end of the rearing stage, average: 40kg; Top10: 30kg), which implies that outcomes from the comparison between these two scenarios (especially for the rearing and fattening stage, which strongly depend on start and end weights) need to be treated with caution. In the utopia scenario, all disease effects as well as disease associated expenditures were set to zero.

Table 13: Selected input variables for the three different scenarios (Average, Top10, Utopia) used for the model to estimate the Animal Health Loss Envelope (AHLE) for the breeding stage.

BREEDING STAGE	Average herds (diseased)	Top10 herds (diseased)	Utopia (without disease)
Production rhythm (weeks)	3	3	3
Length of suckling period (weeks)	3	3	3
Replacement rate per year (%)	54	53	50
Return-to-oestrus rate (%)	14.5	8.8	0
Sow mortality (%)	8.3	7.4	0
Abortion rate (%)	2.9	1.8	0
Average piglets born alive per sow per litter	14.3	15.8	17.4*
Pre-weaning mortality (%)	12.3	9.5	0
Weight at weaning (kg)	7.3	6.9	7.3
Litters/sow/year	2.21	2.34	2.61*
Pigs weaned per sow per year	27.8	33.6	45.3*

* values used for the utopia scenario are not restricted by legal standards of production labels (e.g. Red Tractor) and are driven by biological feasibility.

Table 14: Selected input variables for the three different scenarios (Average, Top10, Utopia) used for the model to estimate the Animal Health Loss Envelope (AHLE) for in the rearing stage.

REARING STAGE	Average herds (diseased)	Top10 herds (diseased)	Utopia (without disease)
*Weight of pigs at start (kg)**	7.5	7.2	7.5
*Weight of pigs produced (kg)**	40	30	40
Days in nursery	66	51	61[1]
Mortality of rearing pigs (%)	4.05	3.86	0
Pigs with respiratory symptoms (%)	20	10	0
Feed conversion ratio	1.85	1.41	1.29[2]
Average daily weight gain (g)	485	415	537

[1] fitted linear regression: 52.00014-.822723*start_weight+1.200184*end_weight+3.130972*FCR

[2] fitted linear regression: 1.105162+0.0045896*end_weight

Table 15: Selected input variables for the three different scenarios (Average, Top10, Utopia) used for the model to estimate the Animal Health Loss Envelope (AHLE) for in the fattening stage.

FATTENING STAGE	Average herds (diseased)	Top10 herds (diseased)	Utopia (without disease)
Weight of pigs at start (kg)	41	35	41
Weight of pigs produced (kg)	115	116	115
Feeding days	91	77	68[1]
Mortality of fattening pigs (%)	3.87	3.55	0
Pigs with respiratory symptoms (%)	20	10	0
Feed conversion ratio	2.82	2.22	2.02[2]
Average daily weight gain (g)	850	945	1088

[1] fitted linear regression: 120.8883-1.6603*start_weight+0.1319*slaughter_weight

[2] fitted linear regression: 1.5414-0.0074*start_weight+0.0068*slaughter_weight

To estimate the Animal Health Loss Envelope (AHLE) the gross margin, defined as revenue minus variable costs, between the diseased farm and the utopia farm was compared. Farm level fixed costs (e.g. for building, equipment) were considered as unaffected and were not taken into account when assessing the difference in gross margin. Animal-level fixed costs (e.g. per piglet weaned), on the other hand, would decrease as more piglets are produced. However, these estimates were not relevant for the gross margin estimation at farm level. Nevertheless, as diseased herds have extra labour cost to manage ill pigs (in addition to the veterinary costs) labour costs were not considered as fixed costs in this analysis and treated as variable costs. The AHLE was estimated by calculation the difference in gross margin between the average production level (baseline) and the utopia scenario. Farm-level estimates were calculated for different farm sizes, based on the distribution of the sizes in the Agrovision and DEFRA data. The breeding stage was modelled for 250, 500 and 1,000 working sows, the rearing stage for 1,000, 2,500 and 5,000 nursery pig spaces and the fattening stage for 1,000, 2,000 and 3,000 pig spaces. For the estimation of the AHLE on the population level, the AHLE of the average baseline farm with the medium herd size (i.e. 500 breeding sows, 2,500 nursery spaces and 2,000 fattening spaces) were assumed and extrapolated with the corresponding number of farms per production stage that are required reach the target value of slaughtering pigs. In addition to the AHLE estimation, the two diseased production levels (average and Top10) were also compared against each other. These estimates provide a benchmark for farmers, in contrast to the utopia scenario which represents an idealised situation that may seem unachievable to the producer. However, the primary purpose of the utopia scenario is to facilitate the methodological framework, creating a total boundary on losses that cannot be exceeded at a future attribution stage (which is not part of this study). The analyses were conducted as stochastic simulations with 1,000 iterations. For the most part, stochastic model outputs were not normally distributed and estimates are, unless stated otherwise, reported as medians. This also leads to the fact that comparing or sum of individual values from different simulations will not necessarily correspond to the results of another simulation.

Levels of input and output

Farm-level estimates of inputs and outputs for medium-sized farms/production stage (500 working sows, 2,500 nursery spaces and 2,000 fattening spaces) are displayed in Figure 13. Given that the capacity of the building and thus herd size is fixed, and farmers most likely fill up all spaces independently of disease status, an average breeding farm with disease had an increased input of £17,000 and reduced output of £378,000 per year, along with 8,760 fewer weaner pigs as output. To achieve the same level of output in animals, a healthy farm would only need 307 working sows instead of the 500 in a diseased farm. For the rearing and fattening stages, also the number of input animals changed with a fixed amount of animal spaces. A diseased rearing farm had a reduction in input of 1,137 animals and increased costs of £28,000 along with a reduced revenue of £128,000 and 1,680 fewer pigs sold. Diseased fattening farms had 2,377 lower animal input and reduced costs of £118,000 along with 2,672 fewer animal output and £364,000 reduced revenue. The larger outputs in the utopia scenario in the rearing and fattening stages were not only caused by better performance of a batch but also the overall increased number of batches per year going through the given number of pig spaces. The same concept applies for the breeding stage with an increased number of litters per sow and year. The substantially lower costs of a diseased fattening herd is mainly cause by the lower total amount of feed needed per farm per year based on the lower number of animals coming in.

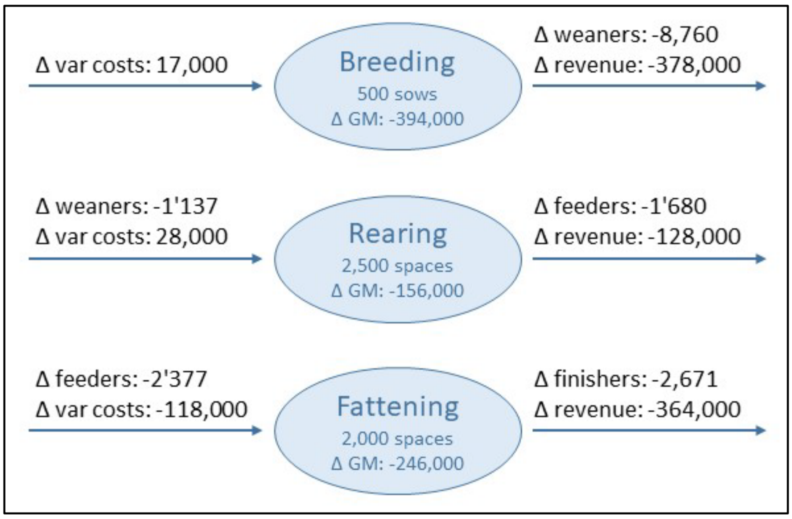

Figure 13: Differences of input and output (in number of animals and monetary values) between diseased and healthy production systems. Values are reported in the perspective of a diseased farm.

To estimate the reduction in input needed on the population level to achieve the same level of output in a scenario without disease, a backward calculation approach was applied. The number of clean pig slaughterings in 2021 (n=11,136,415) was used as target value (DEFRA, 2021). Required numbers of farms and animals to achieve the current production output are listed in Table 16. The number of farms per production stage does not imply that these will be separate farms but the number of farms comprising these production stages. For example, when disease is removed (utopia scenario) 765 farms with nursery stages and the size of 2,500 spaces are required to produce a total of 11,136,415 feeding pigs as output to supply the required amount of the fattening stage. As a comparison, 900 diseased nursery farms (n=135 more) from the same size are required to reach the required level of output (n=12,073,731) in the diseased scenario. In these calculations, farm size was considered as a fixed value while the number of required farms would reduce as the output per farm increases in the utopia scenario. The two variables "farm size" and "number of farms required" are strongly correlated and in reality, structural changes would likely affect both of them with the number of farms decreasing and average farm size increasing.

Table 16: Estimation of number of farms and number of animals for inputs and outputs required to achieve current production output on population level.

	Without disease (utopia)	With disease (average)	Difference
BREEDING STAGE			
Working sows	500	500	-
Piglets weaned per farm and year	22,656	13,896	-8,760
Number of farms required	492	869	377
Piglets weaned in population	11,136,415	12,073,731	937,316
Input needed for breeding (sows)	245,771	434,307	188,536
NURSERY STAGE			
Nursery spaces	2,500	2,500	-
Weaners in per farm/year	14,556	13,419	-1,137
Feeders out per farm/year	14,556	12,876	-1,680
Input needed for nursery stage	11,136,415	12,073,731	937,316
Number of farms required	765	900	135
FATTENING STAGE			
Number of fattening spaces	2,000	2,000	-
Fatteners in per farm/year	9,981	7,604	-2,377
Fatteners out per farm/year	9,981	7,310	-2,671
Input needed for fattening stage	11,136,415	11,584,745	448,330
Number of farms required	1,116	1,523	408

* Reference value: UK annual numbers of livestock slaughtered: Clean pigs: 11136.4 thousand head (DEFRA, 2021)

In Figure 14, the required number of animals and the difference in input of each production stage are displayed, to eventually produce the current population output (i.e. number of slaughter pigs). Overall, 188,536 fewer working sows, 937,316 fewer weaners and 448,330 fewer feeders are required in the disease-free utopia scenario compared to the baseline with disease.

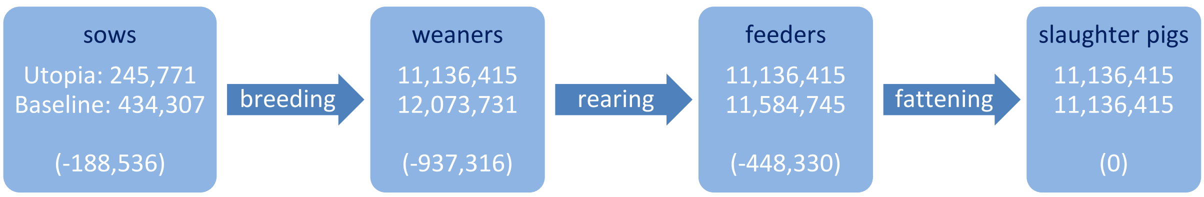

Figure 14: Number of animals required per production stage to achieve the target values of pigs slaughtered per year. The top values refer to the utopia scenario, the middle values to the average production (baseline) and the bottom values to the difference between utopia and average production.

Animal Health Loss Envelope (AHLE)

Farm-level estimates for the breeding stage are listed in Table 17. A medium-sized "Top10" breeding farm with 500 working sows achieved a gross margin that is £94,826 higher than the gross margin of an average farm. The difference in gross margin obtained from the comparison of an average farm with a farm without disease effects is £-394,369. The annual gross margin per sow was reduced by £166 and £765 compared to the Top10 and utopia scenarios, respectively. As described previously, miscellaneous costs largely comprise of additional costs generated by handling sick animals. Overall, the AHLE in the breeding stage was larger than in the rearing and fattening stage.

Table 17: Differences in performance and economic farm-level estimates in the "Average vs. Top10" and "Average vs. Utopia" scenarios comparisons of breeding herds/stage producing weaners with a weight of 7kg. Values are reported in the perspective of the "Average farm".

BREEDING	Average vs. Top10			Average vs. Utopia		
Number of working sows	250	500	1000	250	500	1000
Performance parameters						
Total number of piglets born alive per year	-1,421	-2,842	-5,684	-2,766	-5,533	-11,065
Total number of piglets weaned per year	-1,439	-2,879	-5,757	-4,380	-8,760	-17,520
Total number of litters per year	-33	-65	-130	-99	-199	-397
Total number of returns	47	93	187	110	219	438
Total number of abortions	9	19	37	22	44	88
Economic parameters (in £)						
Revenue	-42,002	-84,003	-168,007	-188,804	-377,609	-755,218
Replacement costs	626	1,252	2,504	3,095	6,191	12,382
Feeding costs	-3,083	-6,153	-12,304	-10,327	-20,665	-41,364
Veterinary costs	1,911	3,822	7,641	9,250	18,500	37,000
Miscellaneous costs	5,829	11,659	23,316	6,291	12,573	25,139
Total variable costs	5,292	10,762	21,022	8,328	16,748	33,045
Gross margin	**-47,307**	**-94,826**	**-189,042**	**-197,150**	**-394,369**	**-788,298**

Estimates for the rearing stage are listed in Table 18. In the comparison between the average and the Top10 farm, the average farm showed better economic values than the Top10 farm. However, in contrast to the comparison between the average and the utopia scenario, the start and end weights of the nursery stage was not adapted in the average vs Top10 comparison. Even though starting weight was similar (7.5kg in the average vs 7.2 kg in the Top10 farm) in both scenarios, the weight of pigs produced varied greatly (40kg vs 30kg) which resulted in higher revenues and feeding costs for the average. However, the main driver for the better economic performance of the average farm in this comparison was the substantially reduced replacement costs caused by reduced number of batches per year as a result of the increased feeding days. This implies that a ranking solely based on FCR is not representative enough to identify Top10 farms. The estimated AHLE of a medium-sized rearing farm was £155,626. The difference in gross margin per nursery pig produced was £-11 and £-9 compared to Top10 and utopia, respectively. Overall, the annual losses in the rearing stage were smaller than in the breeding and fattening stage (based on medium farm size in all stages).

Table 18: Differences in performance and economic farm-level estimates in the "Average vs. Top10" and "Average vs. Utopia" scenarios comparisons of rearing herds/nursery stage producing feeders with a weight of 40kg (Average) and 30kg (Top10).

REARING	Average vs. Top10			Average vs. Utopia		
Number of nursery spaces	**1,000**	**2,500**	**5,000**	**1,000**	**2,500**	**5,000**
Performance parameters						
Total number of batches per year	-8	-8	-8	-2	-2	-2
Total number of weaners in per year	-1,519	-3,798	-7,596	-455	-1,137	-2,273
Total number of feeders sold for fattening per year	-1,471	-3,677	-7,354	-672	-1,680	-3,360
Economic parameters (in £)						
Revenue	15,590	38,976	77,951	-51,164	-127,911	-255,822
Replacement costs	-62,710	-156,776	-313,552	-18,768	-46,920	-93,840
Feeding costs	26,533	66,333	132,665	18,767	46,918	93,836
Veterinary costs	1,639	4,096	8,189	8,755	21,889	43,777
Miscellaneous costs	4,516	3,961	3,049	5,270	5,862	6,837
Total variable costs	-30,076	-82,315	-169,374	14,008	27,713	50,556
Gross margin	**45,647**	**121,272**	**247,301**	**-65,175**	**-155,626**	**-306,389**

Values are reported in the perspective of the "Average farm".

Estimates for the fattening stage are listed in Table 19. The estimated AHLE of a medium-sized fattening farm was £246,127. The difference in gross margin per pig sold for slaughter was £-10 and £-21 compared to the Top10 and utopia farm, respectively. The average diseased farm had lower revenue and lower replacement costs for all farm sizes. The comparison toward the utopia farm showed higher feeding costs, despite the lower number of animals per year.

Table 19: Differences in performance and economic farm-level estimates in the "Average vs. Top10" and "Average vs. Utopia" scenarios comparisons of fattening herds/stage producing fattening pigs sold for slaughter at a live weight of 115kg.

FATTENING	Average vs. Top10			Average vs. Utopia		
Number of fattening spaces	**1,000**	**2,000**	**3,000**	**1,000**	**2,000**	**3,000**
Performance parameters						
Total number of batches per year	-0.6	-0.6	-0.6	-1.2	-1.2	-1.2
Total number of fatteners in per year	-649	-1,298	-1,947	-1,189	-2,377	-3,566
Total number of fatteners sold for slaughter per year	-638	-1,277	-1,915	-1,336	-2,671	-4,007
Economic parameters (in £)						
Revenue	-89,805	-179,610	-269,415	-182,057	-364,114	-546,171
Replacement costs	-37,072	-74,144	-111,217	-67,880	-135,760	-203,639
Feeding costs	-689	-1,377	-2,066	6,371	12,741	19,112
Veterinary costs	-105	-210	-316	4,039	8,077	12,116
Miscellaneous costs	4,266	1,437	-1,392	2,023	-3,039	-8,106
Total variable costs	-33,598	-74,206	-114,945	-55,447	-118,004	-180,554
Gross margin	**-56,211**	**-105,406**	**-154,473**	**-126,614**	**-246,127**	**-365,619**

Values are reported in the perspective of the "Average farm".

To estimate AHLE for the entire UK pork production, farm-level estimates of the AHLE were extrapolated to the population level. The number of farms per production stage was derived from the hypothetical number of farms (with medium farm sizes) that are producing under diseased conditions to reach the current UK production output (i.e. annual number of slaughter pigs produced). The median annual AHLE for the breeding stage was estimated at £343million. The AHLE for the rearing and fattening stages were estimated at £140million and £375million, respectively. This resulted in an AHLE of £858million per year for the UK pork production overall production stages Table 20.

Table 20: Estimates for the Animal Health Loss Envelope (AHLE) for the different production stages and on the population level for the total pig production in the UK (in £). Estimates are based on farm-level outcomes and average performance levels used as baseline.

Production stage	Number of farms	AHLE median	AHLE 5% percentile	AHLE 95% percentile
Breeding	869	342,600,078	337,034,341	350,100,221
Rearing	900	140,045,233	136,906,492	143,900,927
Fattening	1,523	374,947,195	366,912,266	385,410,123
TOTAL		**857,592,506**	**840,853,099**	**879,411,272**

Sensitivity Analysis:

Sensitivity analysis was conducted to identify critical input parameters that contribute most to the variance of the output (i.e. the difference in gross margin between diseased and non-diseased scenarios). For this purpose, input parameters of the "Utopia" scenario were defined as uniform distribution, varying from "Average" value to the "Utopia" value of the specific variable. For example, in the sensitivity analysis, the abortion rate in breeding sows varied from 0% to 2.9%.

In the breeding stage, the most sensitive input variables were: Number of piglets born alive per sow per litter, litters per sow per year and extra labour to handle sick animals (Figure 15). Sow mortality, return-to-oestrus rate, replacement rate or abortion rate had substantially fewer impacts compared to the dominating effect of the number of piglets weaned per year (as a result of piglets born alive, number of litters and pre-weaning mortality). In the nursery stage, the most sensitive input variables were: feed conversion ratio (regression coefficient: 0.82), mortality of rearing pigs (0.46) and feeding days (0.25). In the fattening stage, the difference in gross margin was most sensitive to the variation of the feed conversion ratio (0.91), feeding days (0.32) and mortality of fattening pigs (0.24).

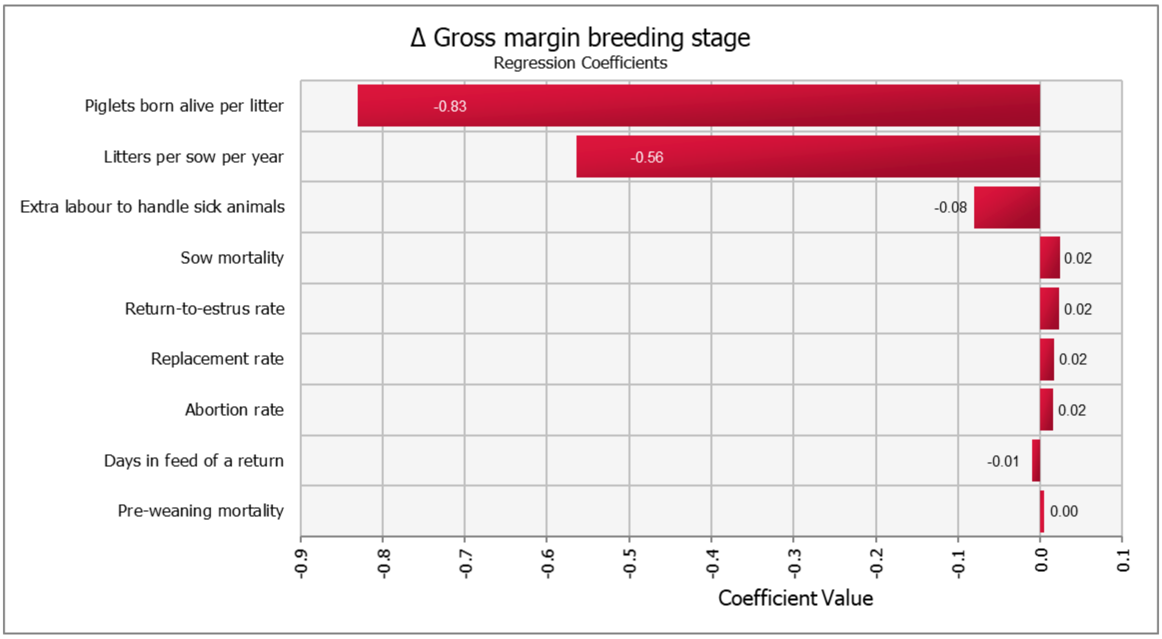

Figure 15: Regression coefficients for the sensitivity analysis for the breeding stage

Summary

Diseased farms (current state) showed substantially lower output (animals and revenue) than the healthy farms free from all possible causes of animal disease burden. Furthermore, diseased farms also showed lower animal input, mainly caused by the decreased efficiency and throughput. Overall, 188,536 fewer working sows, 937,316 fewer weaners and 448,330 fewer feeders would be required in a disease-free utopia scenario to achieve the current production output (pigs slaughtered per year) with disease.

The annual Animal Health Loss Envelope (AHLE) for a medium-sized breeding farm was estimated at £394,000, for a rearing farm at £156,000 and for a fattening farm at £246,000. Estimates for an entire production stage were £343million, £140million and £375million for the breeding stage, rearing stage and fattening stage, respectively. For the overall UK pork production system, the AHLE was estimated at £858million per year.

Implications

The results indicate that the estimated annual AHLE (£858m) corresponds to 55% of the total annual value of pig slaughterings (£1,557m). Compared to the mean capital value of the entire UK pig population (£381m), the estimated AHLE is 2.25 larger. This implies that there is significant disease burden in the UK pork production and understanding what the causes of this loss and the potential mitigation actions would be beneficial.

Further work is required with the industry in setting the ideal health state and its parameterisation. Possible approaches could be the analysis of production data from environments (almost) free from common endemic diseases or the continuous evaluation of data over time to identify biological feasible maximum production levels. There is also work needed on the current levels of animal health expenditure in the industry that needs to include the costs of pharmaceuticals and veterinary services at farm-level plus the investment by the industry and government on research, education and coordination. This information will be critical in indicating weaknesses in animal health resource allocation. The analytical structure of GBADs foresees, in addition to the description of the (i) livestock population (i.e. estimation of biomass and value of input and output) and the estimation of the total (ii) animal health loss envelope (AHLE) conducted in this study, as next steps the (iii) attribution of disease burden by pathogen, disease or disease complex and (iv) the impact across the economy. The attribution by disease will quantify the absolute burden due to each disease but also the relative burden compared to total burden. This will be indicative for decisions on disease and intervention priorities for public authorities as well as private organizations and farmers. Finally, the impact estimation across the economy will give insights on how different stakeholder groups across the society are affected.

From the producer's perspective, the results show that in a healthy environment, the same output can be achieved with a significantly lower input. Production parameters are often influenced in a multifactorial way, with good management practices and the level of biosecurity and hygiene influencing the condition of the animals. Furthermore, the animal health status also affects factors that at first glance are typically not primarily attributed to animal health, such as piglets born alive, FCR or feeding days, which were driving factors of the estimated animal health loss envelope.

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