UNIVERSIDADE DE LISBOA

FACULDADE DE MEDICINA VETERINÁRIA

COLLATING, PROCESSING AND ANALYSING PIG CARCASE QUALITY AND CONDEMNATION DATA TO MONITOR AND CONTROL HEALTH AND WELFARE IN THE SCOTTISH PIG INDUSTRY

MAFALDA VIEGAS DIAS GOMES

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2023

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"If you decide to become a veterinary surgeon you will never grow rich, but you will have a life of endless interest and variety."

James Herriot, *All Creatures Great and Small*

Recolha, processamento e análise de dados de qualidade e de reprovações de carcaças em matadouro para monitorizar e controlar a saúde e o bem-estar animal no setor suinícola escocês

Resumo

A literatura disponível sobre reprovações em suínos é escassa, pois esta pesquisa concentrou-se historicamente noutras espécies animais, apesar da sua importância do ponto de vista de vigilância de doenças, saúde animal, segurança alimentar e saúde pública veterinária. Este estudo teve como objetivo descrever e analisar dados relativos a reprovações parciais, totais e de qualidade de carcaça em porcos de engorda, recolhidos durante um período de quatro anos, de 2018 a 2021, num matadouro de suínos na Escócia, Reino Unido. De forma a estudar o impacto destes dados e a sua utilidade para a monitorização da saúde e bem-estar em explorações de suínos, os seguintes objetivos foram definidos: 1) realizar uma análise exploratória e descritiva, com recurso a diversas ferramentas estatísticas; 2) identificar e descrever as reprovações parciais e totais registadas neste matadouro e avaliar se estas diferiam ou apresentavam alguma semelhança com as ocorrências noutros países europeus. Por último, no decorrer do primeiro objetivo definido, três hipóteses em estudo foram formuladas: 1) analisar de que forma o número de reprovações parciais influenciava o valor médio da sonda (qualidade da carcaça); 2) avaliar se uma maior variabilidade no peso ao abate estava associada uma maior probabilidade de ter pelo menos uma reprovação parcial num lote; 3) analisar se o tipo de reprovação parcial estava associado a uma exploração específica ou se era de carácter mais abrangente.

A percentagem de reprovações parciais foi de 12,89%, sendo que as principais causas foram “Pleurisia” (61,01%), “Abscessos” (12,18%), “Artrites” (11,61%) e “Hematomas” (6,18%), com as restantes entradas a representarem menos de 2% cada. A percentagem de reprovações totais teve um valor médio de 0,36%, com “Casos suspeitos de piémia e abcessos múltiplos” responsáveis por 57,47% das ocorrências, seguidos de “Poliartrite” (26,40%), com os restantes registando um valor inferior a 4% cada. Os resultados das hipóteses em estudo demostraram que carcaças com valores médios de sonda superiores tiveram um menor número de reprovações registadas; que numericamente lotes mais heterogéneos em termos de peso registaram uma maior probabilidade de terem pelo menos uma reprovação parcial, ainda que esta diferença não tenha sido estatisticamente significativa; que as categorias de reprovação parcial não estavam associadas a marcas de explorações específicas.

Palavras-chave: análise de dados; matadouro; qualidade da carcaça; reprovação; setor suinícola escocês.

Collating, processing and analysing pig carcase quality and condemnation data to monitor and control health and welfare in the Scottish pig industry

Abstract

Despite its importance from a disease surveillance, animal health, food safety and public health point of view, the literature and information available on pig carcase condemnations is limited, as research on carcase condemnations has for long been focused on other species.

This study aimed to describe, analyse, and take meaning out of data regarding finisher pigs, collected from 2018 to 2021, in a pig slaughterhouse located in Scotland, UK. To assess how this data could be used to monitor and control pig health and welfare on-farm, the following objectives were set: to perform an exploratory and descriptive analysis; to identify and delve into the most common partial and total condemnations registered in this slaughterhouse and whether these differed or were correlated with those found in other European countries. Lastly, following the first objective, three study hypotheses were formulated: 1) to analyse whether the number of partial condemnations dictated a difference in carcase quality (probe average); 2) to assess whether a higher variability in the weight at slaughter was associated with more partial condemnations, at batch level; 3) to examine whether the type of condemnation was associated with a specific farm or if it was broader in scope.

The percentage of partial condemnations was of 12.89%, with the main causes being "Pleurisy" (61.01%), followed by "Abscesses" (12.18%), "Arthritis" (11.61%) and "Bruising" (6.18%), with the rest of the entries representing less than 2% each. Total condemnations had an overall value of 0.36%, with "Suspect cases of pyaemia and multi abscesses" being responsible for 57.47% of cases, then "Polyarthritis" with 26.40%, and the rest of the entries amounting to less than 4% each. The study hypotheses showed that carcases with a lower probe average had a higher number of partial condemnations; that numerically, more heterogeneous batches in weight were more likely to have at least one partial condemnation recorded, even though this was not statistically significant; that categories of partial condemnations were broader in scope and not associated with a particular farm.

Key words: carcase quality; condemnation; data analysis; Scottish pig production; slaughterhouse.

Recolha, processamento e análise de dados de qualidade e de reprovações de carcaças em matadouro para monitorizar e controlar a saúde e o bem-estar animal no setor suinícola escocês

Resumo alargado

Na Escócia, a suinicultura representa uma quota reduzida da produção animal em território nacional. Em 2021, esta atividade económica representou 2,1% da produção agrícola escocesa, gerando 56,5 milhões de libras. Contudo, apesar da sua pequena dimensão, o sector suinícola escocês é extremamente organizado e centrado numa produção de elevada qualidade em sistemas multisítio, com um número considerável de explorações em regime intensivo e porcas reprodutoras ao ar livre. De acordo com os dados mais recentes, existiam 4.758.000 porcos no Reino Unido em 2020, sendo que 337.000 destes animais se encontravam registados na Escócia. Considerando que a maioria dos animais de produção se destina ao consumo humano, os matadouros são considerados elementos-chave na cadeia de produção. A literatura disponível sobre reprovações em suínos é escassa, pois esta pesquisa concentrou-se historicamente noutras espécies animais, apesar da sua importância do ponto de vista de vigilância de doenças, saúde animal, segurança alimentar e saúde pública veterinária.

Este estudo teve como objetivo descrever e analisar dados relativos a reprovações parciais, totais e de qualidade de carcaça em porcos de engorda, recolhidos durante um período de quatro anos, de 2018 a 2021, num matadouro de suínos na Escócia, Reino Unido. O conjunto de dados abrangeu porcos de engorda, criados ao ar livre e em recinto fechado, abatidos e submetidos a inspeção sanitária por médicos veterinários oficiais.

Na primeira etapa deste estudo, foi necessário proceder à limpeza e análise de duas bases de dados distintas: “Quality” e “Parts”. A base de dados “Quality” continha dados relativos a qualidade de carcaça, com 992.110 registos individuais, em que cada registo (linha) correspondia a um porco. Por outro lado, a base de dados “Parts” continha 152.814 registos de reprovações parciais e totais, na qual cada registo (linha) correspondia a uma reprovação, isto é, um porco poderia ter vários registos (linhas) se o mesmo tivesse várias reprovações. Para a junção das bases de dados, “Parts” foi reduzida a nível individual (um registo por porco), surgindo assim a base de dados “Parts2_individualpigs”, após terem sido retiradas as reprovações totais. De seguida, os dados de “Quality” e “Parts2_individualpigs” foram unidos e foi criada a base de dados final “Db”. “Db” continha 992.101 entradas e 24 variáveis. Por último, procedeu-se à criação de uma base de dados a nível de lote (todos os animais da mesma exploração abatidos num dia), denominado “Db_batch>10”. Apenas lotes com mais de 10 porcos abatidos num dia foram incluídos. As variáveis existentes em “Db”

foram transformadas para resumir informações de cada lote. A título ilustrativo, o peso da carcaça foi transformado em peso médio, desvio padrão, e coeficiente de variação do peso das carcaças em cada lote. “Db_batch>10” continha 8.330 registos (lotes).

De forma a estudar o impacto destes dados e a sua utilidade para a monitorização da saúde e bem-estar em explorações de suínos, os seguintes objetivos foram definidos: 1) realizar uma análise exploratória e descritiva, com recurso a diversas ferramentas estatísticas; 2) identificar e descrever as reprovações parciais e totais registadas neste matadouro e avaliar se estas diferiam ou apresentavam alguma semelhança com as ocorrências noutros países europeus. Por último, no decorrer do primeiro objetivo definido, três hipóteses em estudo foram formuladas: 1) analisar de que forma o número de reprovações parciais influenciava o valor médio da sonda (qualidade da carcaça); 2) avaliar se uma maior variabilidade no peso ao abate estava associada uma maior probabilidade de ter pelo menos uma reprovação parcial num lote; 3) analisar se o tipo de reprovação parcial estava associado a uma exploração específica ou se era de carácter mais abrangente.

O período de estudo compreendeu 48 meses, com 938 dias incluídos. Os dados deste estudo representam 72,67% do total de porcos abatidos por ano na Escócia, de 2018 a 2021, oriundos de 118 explorações distintas. Assim sendo, possíveis conclusões deste estudo poderão ser extrapoladas a nível nacional e servir de indicador para análises futuras. Em relação à qualidade da carcaça, os valores médios da classificação das carcaças aumentaram 1mm de 2020 para 2021, de 11,5mm para 12,5mm. No entanto, mesmo com este acréscimo, as carcaças continuaram incluídas na categoria S (que corresponde a um conteúdo de carne magra de 60% ou mais do peso em carcaça) da grelha SEUROP. A percentagem de reprovações parciais oscilou entre 2018 e 2021, com o valor geral de 12,89%. Em relação às principais causas de reprovação parcial, “Pleurisia” representou 61,01% das ocorrências, seguida de “Abscessos” (12,18%), “Artrites” (11,61%) e “Hematomas” (6,18%), sendo que as restantes representaram menos de 2% cada. Os valores registados para “Pleurisia” são idênticos aos relatados por Alban et al. (2022) para a Alemanha (63,2%), todavia superiores aos descritos para Itália (38,0%), Dinamarca (26,7%) e Portugal (12,9%) em 2019. A percentagem de reprovações totais teve um valor médio de 0,36%. A maior percentagem (0,53%) foi registada em 2021, ano marcado pela crise da suinicultura e da indústria das carnes. Os efeitos combinados do Brexit e da pandemia culminaram no abate de um menor número de porcos, instigando a sobrelotação ao nível das explorações. Quanto às causas de reprovação total, “Casos suspeitos de piémia e abcessos múltiplos” foram responsáveis por 57,47% das ocorrências, “Poliartrite” em segunda posição (26,40%), com os restantes registando um valor inferior a 4% cada. A percentagem de “Casos suspeitos de piemia e abscessos múltiplos” é superior à relatada por Alban et al. (2022) para

a Noruega (33,3%), Alemanha (31,9%), Espanha (28,5%), Itália (21,6%), Dinamarca (11,6%) e Portugal (8,5%) em 2019. Da mesma forma, “Poliartrite e Artrite” representaram apenas 10,3% das reprovações totais em Portugal, 6,3% na Noruega e 2,5% em Espanha. Em relação a ocorrências com elevada relevância para a saúde pública, apenas 0,37% das 3.541 carcaças que sofreram reprovação total foram reprovadas devido a formas generalizadas de tuberculose (n=9) ou mal rubro (n=4).

Com o objetivo de analisar se o valor médio da espessura da gordura subcutânea da carcaça diferia com o número de reprovações parciais da carcaça, um modelo linear misto foi concebido. Os resultados demostraram que carcaças com valores médios de sonda superiores tiveram um menor número de reprovações registadas e que o valor médio da sonda aumentou ao longo dos anos e trimestres. Para avaliar se uma maior variabilidade do peso por lote estava associada a uma probabilidade superior deste ter pelo menos uma reprovação parcial, um modelo de regressão logística foi criado. Apesar de em termos numéricos os resultados demonstrarem que lotes mais heterogéneos registaram uma maior probabilidade de terem pelo menos uma reprovação parcial, esta diferença não foi estatisticamente significativa. Por último, das 20 principais marcas de exploração, 2 registaram uma percentagem de “Pleurisia” acima de 30%; 7 marcas registaram uma percentagem entre 20-30%; 11 marcas entre 10-20%. Nas categorias, “Indicadores de bem-estar” e “Abscessos”, todas as explorações apresentaram valores abaixo de 4%. Para “Artrite”, apenas 1 exploração registou 7,91% de ocorrências, 2 entre 2-3%, 10 entre 1-2% e as restantes com registos inferiores a 1%.

O presente estudo consistiu no primeiro relatório abrangente de registos de qualidade e reprovações em suínos, na Escócia. Tratou-se assim da primeira tentativa de sumarização e análise de um vastíssimo conjunto de dados de matadouro, com perto de um milhão de entradas. Sistemas de recolha de dados, tal como o analisado, apresentam inúmeras potencialidades e deverão servir de base para a criação de programas nacionais de controlo e erradicação de doenças e, acima de tudo, atuar na garantia do bem-estar animal, saúde animal e humana.

Palavras-chave: análise de dados; matadouro; qualidade da carcaça; reprovação; setor suinícola escocês.

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List of Acronyms and Abbreviations

AHDB - Agriculture and Horticulture Development Board

APHA - Animal and Plant Health Agency

CEPH - Centre for Epidemiology and Planetary Health of Scotland´s Rural College

CV – Coefficient of Variation

DEFRA - Department for Environment, Food and Rural Affairs

DGAV - Direção Geral de Alimentação e de Veterinária

FAO - Food and Agricultural Organization

FSS - Food Standards Scotland

LMP – Lean Meat Percentage

OECD - Organisation for Economic Co-operation Development

OR – Odds Ratio

OVI - Official Veterinary Inspector

PC – Partial Condemnation

PLF - Precision livestock farming

PRDC - Porcine Respiratory Disease Complex

PRRS - Porcine Reproductive and Respiratory Syndrome

RESAS - Rural & Environment Science & Analytical Services Division of the Scottish Government

SE - Standard Error

SD - Standard Deviation

SRUC - Scotland´s Rural College

TB - Tuberculosis

TC - Total Condemnation

UK - United Kingdom

USDA - United States Department of Agriculture

1. Internship report

The curricular internship took place in Scotland at the Centre for Epidemiology and Planetary Health (CEPH; previously known as Epidemiology Research Unit) of Scotland´s Rural College – SRUC, from January 10th to April 29th 2022, with a total of 700 hours completed. Financial support was provided through the Erasmus+ programme. An internship first took place in the Faculty of Veterinary Medicine of the University of Lisbon, from September 20th to December 17th 2021, to develop the necessary competences required for this project. During this time, data handling and data analysis techniques were developed through the completion of tasks that were assigned to the students, using R software as a tool, with the supervision of Professor Telmo Nunes. These tasks consisted, firstly, of analysing COVID-19 related data and a database provided by the *Direção Geral de Alimentação e Veterinária* (DGAV), referent to tuberculosis (TB) testing in cattle in Portugal.

During the curricular traineeship, working skills related to pig health and management, both on farm and at slaughter, were acquired by working in a research institute, under the supervision of Dr Maria Costa. This included farm and slaughterhouse visits, farmer´s meetings, interviews with farmers and vets, discussion of clinical cases and participation in ongoing investigation projects. While focusing on pig health, the student learned how to collate data from different sources (i.e., merging carcase quality and carcase condemnations data), perform descriptive and exploratory analysis, including data visualisation, and retrieve meaningful information from it to monitor varied areas such as important pig diseases, food safety and compliance with legislation. Relevant pieces of work developed by the student include a descriptive analysis of antimicrobial resistance data in Scottish pigs, and a report on the associations between antimicrobial use and herd health status for Porcine Reproductive and Respiratory Syndrome Virus and Enzootic Pneumonia. The student also had the opportunity to join the seminars taking place at the CEPH, and therefore was exposed to the broad range of research subjects being developed there. Moreover, the student had the opportunity to spend three days (26th, 27th and 28th of April) in a pig slaughterhouse where she became familiarised with different steps of the slaughter process, including *ante-mortem* and *post-mortem* inspection practices and legal requirements for European Union (EU) imports from third countries (i.e., *Trichinella spiralis* testing). In addition, scientific papers with relevance to the dissertation were presented and other pig related scientific articles were discussed on a Journal Club.

The student had the opportunity to attend the conference "Outbreak and Pandemic Preparedness: Bridging the Gap Between Animal and Human Health", held in Edinburgh on March 1st, 2022, and organized by EPIC Scotland - Centre of Expertise on Animal Disease Outbreaks. Furthermore, the student also took part in the Pig Veterinary Society Spring

Meeting, held in Edinburgh from the 24-25th March 2022, where topics such as the application of pro-active biosecurity approaches to effect changes at herd and national levels, successful strategies for managing weaners reared without zinc oxide and advances in *Streptococcus suis* research and control were discussed.

The student submitted an abstract and prepared a poster entitled "Making the most out of *Escherichia coli* Antimicrobial Resistance annual reporting data from Scottish Pigs: what else can we find?" for the 4th International Conference on Animal Health Surveillance, which was held from the 3rd to the 5th of May 2022 in Copenhagen.

The student collaborated in a research project entitled "Farmer-centric networks to control endemic pig disease in the United Kingdom (UK): using pleurisy as a case study", through participation in farmers 'meetings, farm visits and interviews with farmers and vets. The information collected was used to understand the best ways to develop and establish fruitful networks with pig farmers, understand the barriers to implementing strategies to control endemic diseases and support individual farmers and the industry when addressing endemic diseases. The student took part in informal conversations with visiting vet students from the University of Edinburgh and the University of Glasgow about possible career paths in Veterinary Medicine. Her perspective as a vet student from Portugal was shared with others. Within the "vet student visits to SRUC", the student also participated in a visit to the SRUC Vet Services on April 21st, under the topic "A Day working in a veterinary investigation centre with Dr Franz Brulisauer, Dr Fi Munro and Dr Ruth Fraser". In April 2022, the student joined the programme "Lambing Work Experience", organised by the British National Sheep Association, aimed at supporting the next generation of farm vets. The student assisted the farm Mains of Leask, in Ellon, Scotland, for two weeks, during the busy lambing season.

In addition, between May 2022 and August 2022, a three-month extracurricular traineeship was undertaken with the farm practice *Hospital Veterinário Muralha de Évora*, in Portugal. Through this, the student had the possibility of gaining a wide experience of a typical large animal vet's caseload of both routine and emergency work. The services offered included herd and flock health planning, routine fertility visits, lameness investigation and foot trimming, on-farm surgeries (mostly C-sections, abomasal surgeries, castrations, dehornings) and necropsies. In September 2022, the student attended the 31st World Buiatrics Congress, held in Madrid, and completed a two-day practical workshop on Bovine Reproductive Ultrasound, from *Universidade de Trás-os-Montes e Alto Douro*. In November 2022, a one-month extracurricular traineeship was completed in the archipelago of Azores, with *Associação dos Jovens Agricultores Micaelenses*, where there was the opportunity of gaining practical hands-on experience in the field, by accompanying the daily lives of a dairy farm vets and the most common clinical cases encountered in a rural setting.

2. Introduction

Economic development and human progress have been conventionally linked to increased meat consumption. The 2021 edition of the Agricultural Outlook, a collaborative effort of the Organisation for Economic Co-operation Development (OECD) and the Food and Agricultural Organization (FAO) predicts global meat supply to expand over the projection period, reaching 374 million tonnes by 2030. At the same time, the world is facing an intensive development of pork production and trade on a global scale. From 2005 to 2015, pork production increased by 14.6% worldwide and amounted to more than 110.3 million tonnes in carcase weight, which accounted for 42.8% of the total volume of produced meat (USDA 2022).

This ongoing growth in meat production has dictated the emergence of other equally demanding challenges, such as the urgency to prevent and detect potential public health hazards derived from foodborne pathogens or chemical contaminants in meat, the necessity to enforce disease surveillance programmes and the demand to guarantee the compliance with animal welfare standards. Slaughterhouses act as a pivotal early control point, since these structures are considered the bottle neck for production animals destined for human consumption. To ensure the continuity of this cycle, veterinary surgeons stand on the front line of the necessary inspection tasks: checking food chain information, laboratory testing, specified risk material, by-products, advocating for animal welfare and conducting *ante-mortem* and *post-mortem* examinations.

In abattoirs, data collection systems can be used for several means, such as the reduction of losses due to disease through feedback to livestock producers and private veterinary practitioners, helping in the implementation of preventive herd health programmes, study of trends and variations in animal disease incidence, setting up national disease control programmes, benchmarking and improving animal welfare and biosecurity on farm, establishment of research investigations and quality control checks on inspection standards. With the latter goals in mind, this study aimed to describe, analyse, and take meaning of data regarding Scottish finisher pigs, collected during a four-year period, from 2018 to 2021, in a pig slaughterhouse located in Scotland, UK.

2.1. Objectives

The literature on pig carcase condemnation is limited and research has been focused on other species for long, even though the analysis of this data is extremely important from a disease surveillance and public health perspective (Garcia-Diez and Coelho 2014). This study was based on slaughterhouse data regarding Scottish finisher pigs, from 2018 to 2021. To study the impact of this varied data and how this data could be used to monitor and control pig health and welfare on-farm, the following objectives were set:

- To perform an exploratory and descriptive analysis of the data and further investigate hypothesis generated in the previous step using different statistical tools.
    - To analyse whether the number of partial condemnations dictated a difference in carcase quality (probe average).
    - To assess whether a higher variability in the weight at slaughter was associated with more partial condemnations, at batch level.
    - To examine whether the type of condemnation was associated with a specific farm or if it was broader in scope.
- To identify and delve into the most common partial and total condemnations encountered at this specific slaughterhouse and whether these differed or were somehow correlated with those found in other European countries.

3. Literature Review

3.1. Pig Production

3.1.1. Global Overview of the pig production cycle

Once the sow or gilt have been bred successfully, it will farrow an average of at least 10 piglets in approximately 16 weeks (3 months, 3 weeks, and 3 days). In a farrow-to-finish operation, 22-26 weeks are required to grow a pig to slaughter weight (Haley 2021), though age at slaughter will depend on the targeted slaughter weight. Piglets are weaned at 28 days of age and weaners spend 4 to 5 weeks in the nursery until 20-25kg live weight (weaner stage). Pigs spend 4 to 5 weeks in the grower stage and then they are moved to the finisher accommodation (at 35 to 50 kg of live weight). There, pigs spend approximately 12 weeks until slaughter (finisher stage)(Rodrigues da Costa 2018). Once market weight is achieved, pigs are transported to the abattoir (Haley 2021).

In Europe, the usual live weight range falls around 90 -120 kg for industrial processing. In Ireland and the UK, most male pigs are sold entire and used for fresh meat production and bacon curing (Whittemore and Kyriazakis 2006). As a result, slaughter weights are traditionally lower, to avoid boar taint, an unpleasant odour that is released during the cooking of meat from entire male pigs. Nevertheless, only a proportion of boars produce this odour, not all consumers are sensitive to it, and its incidence is more dependent on age rather than weight (Lawlor 2010).

3.1.2. Pig Production in Scotland

According to the most recent annual census data, there were 4,758,000 pigs in the UK in December 2020 (AHDB 2022). Outdoor pig production accounts for over 40% of the total UK sow herd, but many more additional pigs are reared and finished outdoors (AHDB 2022). The UK pig industry is worth £1.6 billion at the farm-gate, £5 billion at retail and, considering foodservice, external sales, and export values, over £14 billion in total (Dewhirst 2021). In 2020, 328,212,545 pigs were slaughtered for meat production in Europe, with the UK killing around 11,165,000 of these pigs (FAO 2020).

In Scotland, around June 2020, 337,000 pigs were registered (RESAS 2020). The pig industry in Scotland is a small, but very well organised sector which focuses on assured production of high-quality pigs in multi-site systems, with a large proportion of outdoor herds. In addition to commercial producers, Scotland has relatively few small pig producers, including "backyard" producers, crofters, and small holdings (Porphyre et al. 2014). In 2021, the Scottish pig sector accounted for 2.1% of Scottish agricultural output, generating £56.5 million (Macdonald 2022). In Scotland, 21 red meat abattoirs operated in 2020, with only 11 of these killing pigs. Government slaughter reports illustrate that 2.05 million cattle, sheep and pigs were handled by these abattoirs in the 52 weeks until the 2nd of January 2021. Pig slaughter has less of a seasonal trend at Scottish abattoirs than in the whole of the UK, where production falls in the summer. Pig carcase weights have a seasonal profile, with the highest levels being registered over the winter months (except for December when the holiday season dictates early slaughter), and lowest during the summer period (Macdonald 2021).

Tables 1, 2 and 3 show the number of abattoirs killing pigs, the number of pigs slaughtered, and the number of breeder and finisher pigs in Scotland, respectively. In Table 3, the breeding herd is defined as breeding sows and pregnant gilts and prime pigs excludes barren sows, boars, and gilts over 50kg to be used for future breeding.

Table 1 - Scottish Abattoir Sector Scale in Pig meat (adapted from Macdonald, 2022).

	2018	2019	2020	2021
Abattoirs slaughtering stock (n)	14	12	11	11
Proportion of slaughter in five largest abattoirs	95.3%	97.7%	97.8%	98.2%
Proportion of slaughter in the smallest abattoirs	0.4%	0.5%	1.1%	0.7%

Table 2 - Scottish abattoir output for pig meat (adapted from Macdonald, 2022).

	2018	2019	2020	2021
Number of pigs	344,850	357,410	371,350	291,625
Volume of Meat (t)	29,185	31,105	32,840	26,305
Estimated Value (£m)	47	51	57	43

Table 3 - Scottish pig population, from 2018 till 2021 (adapted from Macdonald, 2022).

	2018	2019	2020	2021
Breeding Pig Herds	33,200	35,300	37,500	34,125
Prime Pigs	284,600	273,500	303,300	309,366

Pig production in Scotland is spread regionally, with most farms concentrated in eastern Scotland (87% of Scottish pigs), as illustrated in Figure 1. The Northeast and Tayside jointly represent 69% of the sow herd and 63% of non-breeding pigs. There are movement of weaner pigs for fattening from Northeast to Southeast and an outflow of weaners from Dumfries & Galloway.

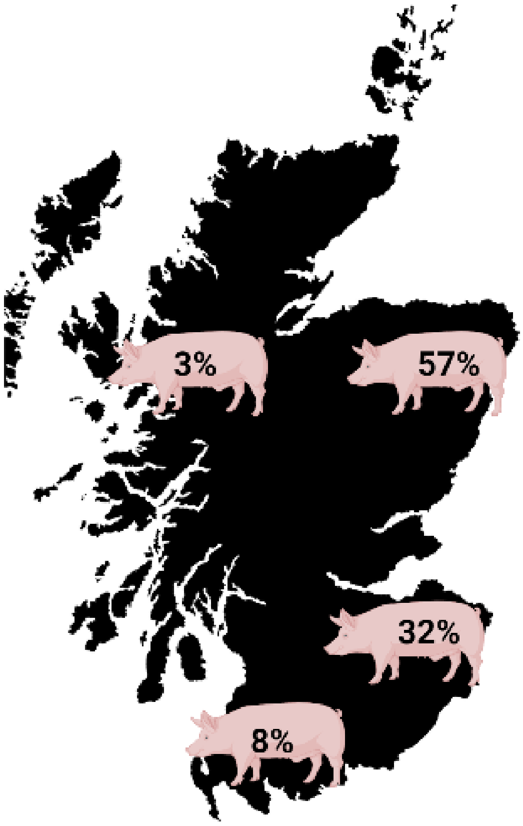


Figure 1 - Regional variation of pig production in Scotland, for fattening pigs, based on data collected on the June 2021 census commissioned by the Scottish Government (adapted from Macdonald, 2022).

Pig production is heavily concentrated into a relatively small number of herds, with 44 of these holdings having at least 250 sows and being home to more than 89% of the herd. These large holdings keep an average 666 sows (whereas the national average is of only 68). In June 2021, there were 131 Scottish holdings with at least 100 fattening pigs, and they accounted for 98% of the national total (Macdonald 2021).

3.2. The Slaughter Process

The sanitary inspection of products of animal origin is an official control whose main purpose is to ensure that only food that meets adequate hygienic-sanitary and nutritional characteristics reach the consumer. Meaning, therefore, that the protection of public health is one of the main objectives of the inspection process, constituting one of the noblest tasks for a vet. Furthermore, this official activity must also cover all aspects that are important for the protection of the health and welfare of animals, as well as for the protection of the environment, through a correct and careful control of the management of by-products (Vieira-Pinto et al. 2013).

Currently, the health inspection activity is governed by the European Regulation (EU) 2017/625, which was transposed by the UK Government, before Brexit. This regulation establishes specific rules for the organization of official controls on products of animal origin intended for human consumption. According to this regulation, the inspection of pigs must be carried out by an Official Veterinary Inspector (OVI), who performs different tasks, that are the guarantor for the attribution of a sustained final decision in terms of health safety of the inspected food and application of a health mark in foods that are fit for human consumption (Vieira-Pinto et al. 2013).

Succinctly, the process of pig slaughtering consists of pig transportation from farm to slaughter, unloading to the lairage, veterinary *ante mortem* inspection, stunning, dressing, *post mortem* inspection, stamping and delivering. At the slaughterhouse, the pigs must go through an *ante mortem* inspection by the OVI, and all the documents regarding pig identification, drivers and vehicle approval and transport authorisation must be checked. Pigs suspected to be diseased or injured are put aside. Pigs approved at *ante mortem* inspection are slaughtered. After the dressing of the carcase, the entirety of the carcase and offal are inspected by the OVI. Only the meat and offal that are fit for human consumption will be approved by the OVI, whereas unfit meat, offal or parts of the carcase will be condemned (Garcia-Diez and Coelho 2014).

The records of *ante mortem* and *post mortem* causes of pig carcase condemnation might function as a database for studies regarding swine diseases and conditions responsible for total or partial carcase and/or offal condemnations (Collins and Huey 2015). Moreover, a*nte mortem* inspection might be useful as an indicator of pig health and welfare on farm, during transportation, at unloading, and during rest in pens (Shimshony and Chaudry 2005). The *ante mortem* inspection consists of the “examination of live animals to be slaughtered, with the fundamental objective of detecting whether they have a disease or condition which may be transmitted to animals or humans through handling or consuming the meat of such animals, or whether they are behaving, individually or collectively, in a manner indicating that such a disease has occurred” (Eur-Lex 2017). The *ante mortem* inspection must also make it possible to verify that the animals are properly identified, clean, don’t show signs that their welfare requirements have been compromised or signs of any other factor that could have negative consequences for human or animal health (Vieira-Pinto et al. 2013).

Until an animal is slaughtered, three stages must be completed. The first stage consists of arrival, unloading of animals from the truck to the lairage, handling and moving these to the stunning area. Phase two covers stunning and phase three bleeding. Stunning is any intentionally induced process which causes loss of consciousness and sensibility without pain, including any process resulting in instantaneous death. The stunning phase includes both the restraint and the stunning processes. In this perspective, restraint stands for the application to an animal of any procedure designed to restrict its movements sparing any avoidable pain and minimising fear, as to facilitate effective stunning and killing. Animals must be rendered unconscious and insensible by the stunning method, and they must remain so until death occurs through bleeding (Nielsen et al. 2020). The main stunning methods employed in the slaughter of pigs are the following: electrical, exposure to controlled atmospheres, and mechanical.

Electrical stunning works by the application of sufficient current through the brain to induce generalised epileptiform activity, so that the animal becomes immediately unconscious and unable to feel pain. Electrical stunning is widely used for stunning of pigs at slaughter worldwide, particularly in small and medium-sized slaughterhouses (Sindhøj et al. 2021). If too high a voltage is employed, carcase quality may be compromised by the display of muscle haemorrhages and broken bones. Contrarily, if too low a voltage is utilized, the pig may be paralysed but still experiencing pain (Collins and Huey 2015).

Controlled atmosphere stunning methods are based on exposure to CO_2 at high concentration, CO_2 mixed with inert gases, or simply inert gases (Nielsen et al. 2020). CO_2 at high concentrations usually involves the direct exposure of conscious animals to a gas concentration of more than 80% (Atkinson et al. 2012). Exposure of pigs to CO_2 leads to metabolic acidosis and, as a result, reduction in the pH of the cerebrospinal fluid and a gradual loss of consciousness and sensibility (Mota-Rojas et al. 2012; Rodríguez et al. 2008). The survival time of different regions of the brain and the spinal cord following exposure to CO_2 varies. Therefore, a prolonged exposure to high concentration of CO_2 (> 80% by volume in air) is necessary to avoid recovery of consciousness and sensibility during hoisting, sticking, and bleeding (Llonch et al. 2012). Bolaños-López et al. (2014) recommend bleeding to be performed as soon as possible after pigs exiting the gas. The rate of induction, depth and duration of unconsciousness induced with gas mixtures depends on both exposure time and gas concentration (Verhoeven et al. 2016).

Mechanical stunning is done through the impact of a penetrative captive bolt, free projectile or hard object used to deliver a percussive blow to the head (Nielsen et al. 2020). Many different types of percussive stunning pistol are in use worldwide and were introduced at the end of the nineteenth century (Collins and Huey 2015). The effectiveness of any mechanical stunning device is dependent on the selection of the proper anatomical site, the directional aim of the device and the adequate restraining of the animal (Riaz et al. 2021)

3.3. Traditional *Post-mortem* Inspection of Pigs

Post mortem examination of pigs follows the same overall procedure as for cattle. Skin lesions are an important diagnostic feature of swine erysipelas, swine fever and urticaria. The tail should be examined for necrosis and the feet for abscess formation. The viscera require a detailed inspection, with particular attention to pneumonia and eventual secondary complications, mainly pleurisy, pericarditis, and peritonitis (Collins and Huey 2015). The mandibular lymph nodes are routinely incised and examined for TB (Hill et al. 2013). Traditionally, when *Trichinella* is known or suspected, appropriate examination and muscle sampling is carried out. In the UK, all breeding pigs (sows and boars) or at least 10 % of carcases of animals sent in for slaughter each year from each holding that is officially recognised as applying controlled housing conditions must be tested for *Trichinella*. Additionally, all pigs reared in non-controlled housing should be systematically examined (Food Standards Agency 2020). The terminology “controlled housing” stands for a type of animal husbandry where pigs are always under conditions controlled by the food business operator regarding feeding and housing (Eur-Lex 2022).

3.3.1. Common Post-mortem findings

The interpretation of common *post-mortem* findings is often a polemic topic among inspectors. Decisions require the detailed examination of suspect animals, including all parts of the carcase and viscera, as to assess whether the lesions are localised or generalised, acute, or chronic, and consequently the extent of condemnation necessary (Collins and Huey 2015). In the following section, the most common *post-mortem* findings, its causes, and implications are revised.

3.3.1.1. Abscesses

An abscess is a circumscribed collection of pus, which is separated from the surrounding tissues by a fibrous capsule. Its size is variable, being microscopic or large. Pus usually contains many bacteria and toxic products of their metabolism, acting as a source of absorption of toxic substances and microorganisms into the circulation and ultimately being responsible for the appearance of pyaemia (Ringler 1997). Abscesses are one of the most common lesions routinely encountered in pigs (Collins and Huey 2015).

Evans and Pratt (1978), Blamire et al. (1980) and Hill and Jones (1984a) have all indicated that the presence of visible abscesses is one of the most important reasons for the condemnation of the whole or part of the carcase of finisher pigs in the UK. Moreover, in another survey of 79 million pigs slaughtered in the United States during 1988, pyaemia and abscessation were the greatest single cause of the total (13.7%), and partial (20.8%), condemnation of pig carcases (Collins and Huey 2015).

In 1996, Huey carried out a study to map the position of abscesses in 75,130 pigs slaughtered in Northern Ireland. The author detected abscesses at one site only in 2.87% of the carcases examined, and at more than one site in 0.26% of the carcases. Tail biting was the cause of the infection in 61.7% of all the carcases with lesions at more than one site. In almost all cases there was a statistically significant interrelationship between the visible abscesses at different sites. Nearly all the lesions registered were small and multiple, and the bacteriology previously carried out indicated that the most prevalent causative organism was *Actinobacillus pleuropneumoniae* (Huey 1996).

Tail biting behaviour occurs when one pig takes the tail of another pig into its mouth and causes damage to the appendage (Schrøder-Petersen and Simonsen 2001). In addition to causing pain and distress, tail biting is associated with reduced feed intake and weight gain (Johnson et al. 2019). It can give rise to infection, spinal abscess, disease transmission, carcase damage, and, in some cases, cannibalism and death (Kritas and Morrison 2007); (Schrøder-Petersen and Simonsen 2001). Recommended as an animal-based measure for on-farm welfare audits, the frequency of tail biting is a serious welfare and production issue (Johnson et al. 2019). Tail biting represents an important source of financial loss because it is associated with a reduction in animal performance (Sinisalo et al. 2012).

If an abscess is accompanied by systemic changes, it will usually be necessary to totally condemn the carcase and viscera (Collins and Huey 2015).

3.3.1.2. Arthritis

The term arthritis applies to inflammation of intra-articular structures and can represent a serious threat to the welfare of animals, because it is often a painful that can lead to permanent deformations (Carlton et al. 2000). Arthritis is common in livestock species, and, on *ante-mortem* examination, animals may present varying degrees of lameness, difficulties in standing still and the affected joints hot, swollen, and painful (Constable et al. 2016). However, arthritis is also commonly seen at the abattoir in clinically normal animals (Carr et al. 2018). This can happen due to the release of endogenous endorphins, after the stress of transportation and loading/unloading the animals (Vieira-Pinto et al. 2013). If detected in the finishing herd the condition is often severe, with pigs presenting locomotor difficulties and structural deformities (Carr et al. 2018).

Arthritis can be classified according to the cause as non-infectious and infectious. In farm animals, arthritis of infectious origin is often hematogenous, affects several joints and mainly young animals. Routes for bacterial infection are via the tonsil, small intestine, navel ill, or abrasions of the integument. The identified risk factors for this condition are traumatic lesions, abrasions, clipping of teeth, tail docking or ear notching. *Streptococcus spp.*, particularly *S. suis* and *S. equisimilis*, have been reported to cause 63% of the cases, but *Trueperella pyogenes*, *Staphylococcus sp*., and *Escherichia coli* are also frequent causes (Constable et al. 2016). Other agents involved include *Mycoplasma hyorhinis*, most commonly causing polyserositis and arthritis in nursery-age pigs, and *Mycoplasma hyosynoviae*, causative agent of arthritis in finisher pigs (Pieters and Maes 2019).

Floor abrasiveness increases the chance of skin lesions and the opportunity for the invasion of microorganisms. Non-infectious arthritis results from immune-mediated processes or crystal deposition (Constable et al. 2016).

Polyarthritis is defined as inflammation of the intra-articular tissue of two or more joints (Salogni et al. 2022). Joints involved in polyarthritis are often swollen and contain fibrinous exudates. The most affected areas are usually the carpal, elbow, and hock joints (Madson et al. 2019). On the other hand, arthritis can also be classified according to the duration (acute or chronic) and type of exudate (serous, fibrinous, and purulent)(Carlton et al. 2000).

Animals showing acute arthritis lesions should be subjected to total rejection. In cases of polyarthritis, the carcase and its viscera must also be completely rejected. In non-infectious or chronic arthritis, without any systemic effect, only the parts of the affected carcase should be rejected (Vieira-Pinto et al. 2013).

3.3.1.3. Bursitis

Bursae are naturally occurring fluid-filled sacs that decrease friction at points where muscles and tendons glide over bones. Bursitis is a pathological response to trauma and its prevalence and severity is influenced by the degree of pressure exerted on the limbs by flooring systems (McFarland et al. 2000 Mar). Bursitis has implications for animal welfare due to its associations with lameness (Heinonen et al. 2013) and represents sub-optimal environmental conditions on farms (Gillman et al. 2008).

The prevalence of bursitis, affecting at least one limb, has been stated in different studies to be very high: 41.2% on farm recorded on the four limbs (Gillman et al. 2008); 44% at abattoir recorded on the hind legs (Harley et al. 2014). The risk of bursitis increases with age and body weight, as weight applies additional pressure on the limbs. Consequently, older and heavier pigs spend a greater proportion of time lying (Ekkel et al. 2003). Another study detected a maximum batch value of only 10%, but the authors only examined the forelimbs (Teixeira and Boyle 2014), while bursitis is reported to occur more frequently on the hind legs (Gillman et al. 2008).

3.3.1.4. Pneumonia and Pleurisy

One of the most frequent problems in pig production is the control of respiratory diseases. When pigs are raised in closed settings, particularly with high stocking densities, the transmission of airborne pathogens is facilitated. Respiratory disorders can range from mild clinical signs (where only the feed intake lowers) to very severe forms associated with high mortality rates. As a result, the economic losses can also fluctuate, but are mainly caused by increased mortality, decreased weight gain, increased condemnation at slaughter and increased cost for treatments, vaccinations, and increased labour costs (Carr et al. 2018). Respiratory pathologies are responsible for important losses to the producer and abattoir, attributable to higher rejection rates and lower carcase weight (Vieira-Pinto et al. 2013).Two large surveys identified pneumonia lesions in an average of 55.9–59.6% of slaughtered pigs (Hillen et al. 2014 ; Ostanello et al. 2007).

Pig lungs are pale pink in colour and have well-marked margins. The left lung possesses two lobes: a cranial lobe, divided by a cardiac notch, and a diaphragmatic lobe. The right lung is divided into four lobes in total: cranial, middle, caudal, and accessory lobes (Dyce et al. 2010). The lesions most frequently found in *post mortem* inspections of porcine lungs are pneumonias (associated or not with pleurisy) and technopathies (agonic aspiration of blood and presence of scalding water). Lesions produced by airborne agents are predominantly located in the cranioventral region of the lungs, except for *Actinobacillus pleuropneumoniae*, which mainly affects the caudal lobes. Lesions resulting from septicaemia are widespread (Vieira-Pinto et al. 2013).

Respiratory disease arises when the respiratory system is jeopardised by contact with fine particulates, for instance dust and volatile chemicals, such as ammonia from animal waste (Michiels et al. 2015). Pig respiratory pathogens can be classified as either primary or opportunistic (secondary) pathogens. Even though primary respiratory infectious agents can cause serious disease on their own, uncomplicated infections with these agents are more commonly mild and brief. More serious and economically important chronic respiratory disease arise when these primary infections become complicated by concurrent infection with multiple agents, including opportunistic bacterial infections (Yaeger and Van Alstine 2019). The terminology Porcine Respiratory Disease Complex (PRDC) was created to emphasize the complexity of events leading to the development of pneumonia, including the involvement of viral and bacterial pathogens together with the environmental, management, and genetic factors (Brockmeier et al. 2002). Four or more infectious agents are generally detected in cases of PRDC, resulting in complex interactions that can increase the severity and duration of respiratory disease and lesions. It is acknowledged that severe disease is usually polymicrobial, opportunistic bacterial infections increase the severity of the primary disease, and opportunistic bacteria are present in association with primary pathogens (M.J. Yaeger and Van Alstine 2019). Figure 2 highlights the complexity of events leading up to PRDC.

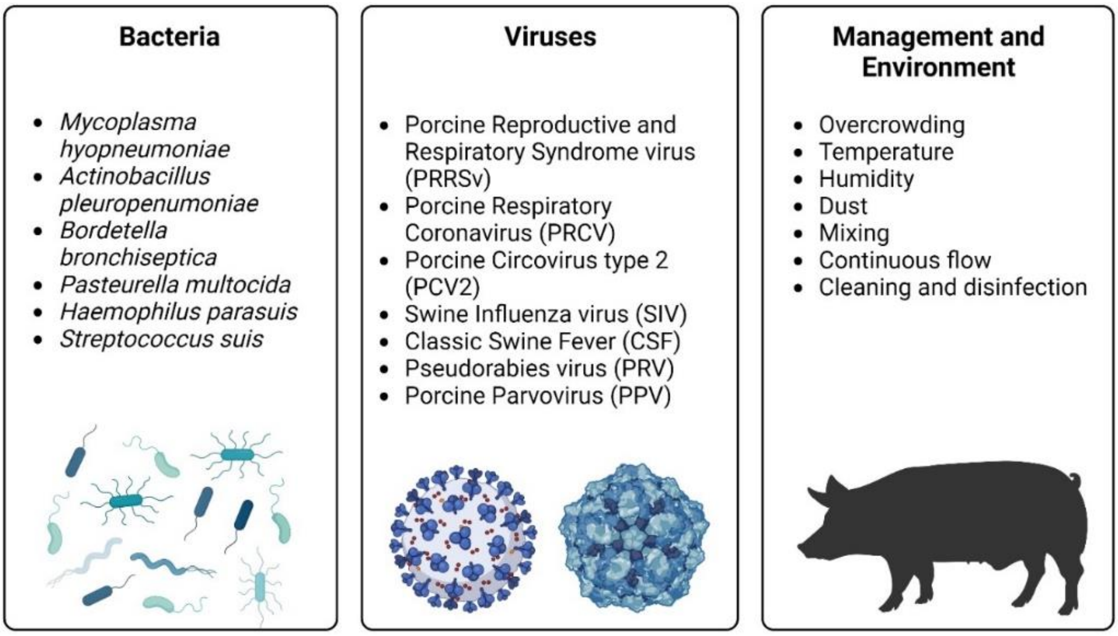


Figure 2 - Different agents playing a role in the development of Porcine Respiratory Disease Complex (PRDC) (adapted from Brockmeier et al., 2002).

The agents most frequently described as responsible for pneumonia in pigs at the time of slaughter are *Mycoplasma hyopneumoniae* (agent of enzootic pneumonia) and *Actinobacillus pleuropneumoniae* (agent of pleuropneumonia). These infections may occur alone or in association with *Pasteurella multocida*, as a secondary agent (Vieira-Pinto et al. 2013). Evidence of complications from secondary infections may arise in the form of purulent lesions. These are the main causes of total rejection of carcases due to lung lesions, as demonstrated in several studies carried out in Portuguese slaughterhouses. Fontes (2001) and Gonçalves (2001), cited by Vieira-Pinto et al. (2013) refer to purulent pneumonia as the only pneumonia that caused the total rejection of carcases at the abattoir. Nonetheless, Coelho (2003), mentioned by Vieira-Pinto et al. (2013) refers to acute pleurisy and pleuropneumonia as a cause of total rejection.

Through macroscopic evaluation alone, it is not possible to identify the etiological agent involved in the lung lesions during a *post mortem* examination. Several authors sustain there are no pathognomonic lesions for any disease, considering that pathogens can produce different lesions according to their virulence, route of infection and degree of evolution of the condition at the time of slaughter. However, according to Vieira-Pinto (2013), lesions suggestive of the presence of a certain pathological process can still be identified, such as: exclusive presence of cranioventral consolidation zones, of a reddish-gray color (suggestive of Enzootic Pneumonia) or presence of circumscribed necrosis foci in the diaphragmatic lobes, associated or not with pleurisy (potential indicator of pleuropneumonia).

In pigs, pleurisy (also referred as pleuritis) is mostly associated with hematogenous dissemination of bacteria to serosal surfaces or an extension from an underlying bacterial bronchopneumonia or abscess. The infectious agents involved are typically *Glaesserella parasuis, Streptococcus suis, or Mycoplasma hyorhinis*. The dissemination of bacteria to serosal surfaces can result in acute diffuse fibrinous pleuritis, as well as polyserositis. Often, this can occur without a concomitant pneumonia and may result in acute mortality. If the animal survives, fibrin attached to serosal surfaces will lead to the development of chronic fibrous adhesions between the visceral and parietal pleura, notably one of the most frequent lesions observed at the slaughterhouse (Yaeger and Van Alstine 2019). The differentiation of the causative agent for pleurisy by gross examination of the carcase at the slaughterhouse is unattainable, considering that the observed lesions consist of sterile healing scar tissue. Moreover, pleurisy can be present for several months before resolution, therefore the disease may have occurred at any time in the previous six months (Carr et al. 2018). The pulmonary pleura is usually the first to be affected, but infection or inflammation can quickly spread to contiguous areas of the parietal pleura. In an initial phase, hyperaemia, and an increase in the thickness of the pleura may occur, resulting in a red velvety appearance. These adhesions, which compromise lung expansion, are the most common sequelae of chronic pleurisy and can even cause the lung to rupture during evisceration, leaving fragments of the lung attached to the costal cavity of the carcase (Collins and Huey 2015).

Pleurisy is a common finding in slaughtered pigs in the UK, as evidenced by data from the systematic abattoir pathology recording under the British Pig Executive's Health Scheme. According to a case-control study to determine management and health related factors associated with pleurisy in slaughter pigs in England and Wales, out of 15,237 slaughter consignments, 80% were affected by pleurisy, whereas at the individual pig level 12.5% of 641,763 pigs were affected (Jäger et al. 2012).

During *post mortem* assessments, it is also equally important to identify and record the severity of the lesions, for the attribution of a correct sanitary decision. Knowledge of the severity of lesions is extremely important for producers, since the most serious lesions are usually involved in greater economic losses, resulting from a worse productive performance, a reduction in carcase weight and a greater number of rejections at the slaughterhouse (Vieira-Pinto et al. 2013). Pleurisy is associated with increased costs to the abattoir, due to the adhesion of lungs to the thoracic wall and the necessity of trimming the carcases, which in turn, is only possible by decreasing the line speed. Moreover, there is also an increase in waste from the slaughterhouse (Jäger et al. 2012). The severity can be influenced by the extent/exuberance of the lesions in the lung, systemic involvement, involvement by contiguity of other organs or parts of the carcass, evolution stage of the lesions (acute or chronic), type of exudate present (purulent or fibrinous) and presence of mixed infections (Vieira-Pinto et al. 2013; Vieira 2002).

3.3.1.5. Oedema

Oedema consists in an atypical collection of transudates in the interstitium and/or intercellular spaces due to fluid loss from the vascular system. It originates from increased vascular permeability, increased intravascular hydrostatic pressure, decreased intravascular osmotic pressure, or decreased lymphatic drainage (Robinson and Loynachan 2019). Oedema fluid contains low protein content and is often designated transudate, contrary to an exudate of inflammation, which is rich in protein, leukocytes, and fibrin. Oedema can be localised, resulting from acute inflammation, photosensitisation, and cerebral and pulmonary oedema, generalised due to severe malnutrition, parasitic gastroenteritis, and fascioliasis. In cases of malnutrition and starvation where there is severe protein deficiency, oedema is evident in a generalised form, being designated as nutritional oedema (Collins and Huey 2015).

3.3.1.6. Anaemia

Anaemic pigs present whiter/paler than normal with a possible yellowish skin, even though it can be difficult to appreciate in white breed pigs. Pigs can become anaemic due to loss of blood through haemorrhage, loss of haemoglobin due to dietary insufficiencies (such as inadequate iron) or reduced number of red blood cells due to disease, infection or toxaemia of the bone marrow or erythrocytes. Anaemic pigs have more diarrhoea, especially post-weaning, and laboured breathing. At *post-mortem* examination, the muscles appear pale, and the blood may not clot and look watery (Carr et al. 2018).

3.3.1.7. Jaundice

Jaundice, or icterus, is an increase of biliary salts in the blood that takes one of three forms: pre-hepatic, hepatocellular and post-hepatic jaundice. Pre-hepatic jaundice, or haemolytic icterus, occurs after massive blood destruction that surpasses the detoxifying capacity of the liver. Hepatocellular icterus derives from direct liver injury, and post-hepatic icterus is caused by obstruction of biliary drainage. Several infections can directly affect the blood or the liver: *Leptospira*, *Mycoplasma*, *E. coli* and *Salmonella*. *Ascaris suum* can also cause icterus through direct parasitosis of the liver with later migration to the lungs. Toxicoses such as copper excess and mycotoxins that primarily target the liver can lead to jaundice (Padoan [date unknown]). The yellow discolouration of the tissues may be seen *ante-mortem* in the white of the eyes or the mucosal surface of the vulva but is often diagnosed *post-mortem* (Carr et al. 2018).

3.3.1.8. *Mycobacterium avium* complex (MAC)

Even though its impact in commercial swine production has been reduced in recent years, tuberculous lesions continue to be reported in the cervical and mesenteric lymph nodes of pigs during *post mortem* inspection, mainly due to the pervasive nature of the *Mycobacterium avium* complex (MAC) (Robbe-Austerman and Thoen 2019). Mycobacterial infections in pigs are caused primarily by MAC, with these opportunistic pathogens causing localized lymphadenitis to disseminated infections (Hulinova and Faldyna 2018).

In general, these lesions are limited to small foci in a few lymph nodes associated with the digestive tract, in conjunction with nonspecific clinical signs (Wellenberg et al. 2010). In a study of lesion distribution in 81 pigs with granulomatous lesions at slaughter in Czech Republic, 31% had lesions in lymph nodes in 1 of 3 sites (head, mesenteric, or inguinal), 65% in 2 of these sites, and 4% in all 3 sites (Matlova et al. 2005).

Gross lesions of granulomatous lymphadenitis or disseminated granulomas are suggestive of but are not sufficiently specific for a definitive diagnosis. *Rhodococcus equi* and *Trueperella pyogenes* can also cause disseminated encapsulated abscesses that can easily be confused with generalized form. A definitive diagnosis demands confirmation of the *Mycobacterium spp*. in tissues with lesions by bacterial isolation or by direct PCR (Miller et al. 1999).

3.3.1.9. Generalized Tumours

A tumour or neoplasm is an abnormal growth of new cells, which have become unresponsive to standard growth control mechanisms. A careful examination of the lesions along with general carcase signs (poor condition and oedema), may give some idea as to identification, beingness or malignancy, to provide a basis for provisional judgement. However, an accurate diagnosis can only be made by histopathological examination of samples of suspect lesions, a procedure that should be carried out when suspect neoplastic lesions arise. A single or a few localised benign tumours result in partial condemnation of the affected part or organ if no other adverse signs are present (Collins and Huey 2015).

3.3.1.10. Skin Conditions

Skin diseases can only involve the skin or can be cutaneous manifestations of internal disease. Examples of diseases restricted to the skin include ear necrosis, *pityriasis rosea*, and swinepox, whereas skin lesions symptomatic of a general pathophysiological condition are erysipelas, classical swine fever, salmonellosis, dermatitis, and nephropathy syndrome. In intensive indoor systems, there is a predisposition to conditions such as pressure sores in sows, ear necrosis in pigs, or bacterial diseases. Diseases such as exudative epidermitis or erysipelas tend to spread more rapidly, whereas congenital and hereditary conditions such as *pityriasis rosea* usually occur at a constant rate within a herd. The response to therapy can aid in differentiating viral, bacterial, and fungal infections (Torrison and Cameron 2019). Many skin lesions detected at abattoir inspection are of traumatic origin, regularly caused by fights, which occur when different pig groups are mixed, as it happens before or after loading for transport to the slaughterhouse (Bottacini et al. 2018).

3.3.1.10.1. Dermatitis

Dermatitis consists of an inflammation of the skin, caused by several factors, such as external irritants, burns, allergens, trauma, and infectious agents (bacterial, viral, parasitic, or fungal). The skin's response to insult is shown by a combination of pruritus, scaling, erythema, thickening or lichenification of the skin, hyperpigmentation, oily seborrhoea, odour, and hair loss. Secondary bacterial and yeast infections commonly develop because of skin inflammation. Resolution of dermatitis requires identification of the underlying cause and treatment of secondary infections or other complications (Moriello 2020 Jan).

3.3.1.10.2. Erysipelas

Erysipelas is an infectious disease mostly of growing or adult pigs, caused by *Erysipelothrix rhusiopathiae*, a Gram-positive aerobic bacillus (Opriessnig and Coutinho 2019). This is an opportunistic zoonotic disease on the rise and reports of human cases are related to occupational exposure placing meat and fish industry workers at higher risk of exposure (Ugochukwu et al. 2019). The domestic pig is the primary reservoir of *E. rhusiopathiae*, and probably 30–50% of pigs are carriers (Opriessnig et al. 2020). These animals harbour the bacteria in lymphoid tissues and shed it in nasal secretions, saliva, and faeces. *E. rhusiopathiae* has 28 serotypes, but most isolates from swine are serotypes 1 and 2 (Helke et al. 2015). In a study conducted with 128 *Erysipelothrix* spp. isolates from British pigs (collected from 1987 to 2015), the most prevalent serotype was number 2, followed by serotypes 1a and 1b, representing 88.3% of isolates (McNeil et al. 2017).

Three different presentations are possible: acute, subacute, and chronic (Ramirez and Schwartz 2020). The chronic form results in joint lesions (arthritis), vegetative endocarditis, alopecia, dermatitis and can also manifest as respiratory distress, lethargy, cyanosis, or sudden death due to vegetative valvular endocarditis (causing cardiac insufficiency and pulmonary oedema). The acute form corresponds to a septicaemic disease that causes a sudden onset of acute death, abortions, depression, lethargy, pyrexia, withdrawal, lying down, painful joints, reluctance to move and/or vocalization during movement, partial or complete inappetence, and characteristic pink, red, or purple rhomboid or squared "diamond skin" lesions. The subacute form is clinically less severe than the acute form, and animals do not appear as sick, skin lesions may be few or absent, mortality will be lower, and animals will recover more rapidly (Torrison and Cameron 2019). The most effective way of preventing the spread of the infection is through adequate hygiene and herd management practices. In chronic cases, culling and isolation of the affected animals should be carried out, whereas vaccination is a forceful ally in preventing more serious forms of the disease (Ugochukwu et al. 2019). Erysipelas vaccines are regularly used in pigs and most breeding herds are routinely vaccinated, as protective immunity after vaccination is generally thought to range between 4 and 6 months. Nonetheless, growing pigs are not commonly vaccinated (only in high-risk situations), as they are expected to have passively acquired antibodies before being sent to the abattoir (White 2010).

Swine erysipelas is economically significant and can affect all stages of pork production. The greatest losses can be attributed to cases of sudden death and acute septicaemia in finisher pigs, even though economic losses associated with treatment and vaccinations costs, higher number of abattoir condemnations or lesion trimmings should be borne in mind (Yaeger and Van Alstine 2019; Torrison and Cameron 2019). The U.S. Department of Agriculture (USDA) and USDA Food Safety Inspection Service collects data related to swine abattoir condemnations on an annual basis and swine erysipelas continues to be ranked as one of the top ten causes for swine carcase condemnations (Bender et al. 2011). Total rejection of the carcase and its viscera must be carried out whenever the carcase presents acute lesions with erythema, diffuse skin lesions with erythema and in cases of arthritis or skin lesions accompanied by necrosis or systemic signs. When skin lesions are mild or in cases of chronic arthritis or localized verrucous endocarditis, without signs of septicaemia, the carcases may be marketed (Vieira-Pinto et al. 2013).

3.3.1.10.3. Bruising

A bruise consists of visible extravasation of erythrocytes in the subcutis, and surrounding tissue caused by trauma. The impact leaves the skin surface intact while the walls of veins, venules and small arteries are torn, leaking blood into the surrounding tissue (Saukko and Knight 2004). Skin bruises in live pigs, if visible at all, appear vaguely because of the thick epidermis of the porcine skin. However, the removal of the epidermal layer during the slaughter process makes the bruises easily identifiable at *post-mortem* inspection (Barington and Jensen 2013). The fact that 90.6% of bruises in pigs are estimated to be aged eight hours or less show that most bruises are inflicted shortly before slaughter (Barington and Jensen 2013).

3.3.1.10.4. Sarcoptic mange

Sarcoptic mange is a serious external parasitic infection caused by *Sarcoptes scabiei* var. *suis*, a species adapted to the pig. The pathogen is spread through direct contact with infected animals or infested buildings (Carr et al. 2018). This disease has high economic significance, due to its impacts on morbidity, mortality, decreased fertility and feed conversion ratio (Laha 2015). On average, sarcoptic mange reduces the average daily gain by 11% and the feed conversion ratio by 6% for fattening pigs (Ózsvári 2018). The visual inspection of the skin of finisher pigs in the slaughterhouse can be useful tool for surveillance (Davies 1995). British pig producers have put in place measures to eradicate sarcoptic mange from their herds, with these efforts resulting in decreasing yearly trends (Correia-Gomes et al. 2017). This affection should be considered a welfare problem and future breeding stock should be purchased from sarcoptic mange-free farms (Carr et al. 2018).

3.4. Utilization of ***Post-mortem*** data

The collection of data and information from several farms is achieved using slaughterhouse checks, whilst minimising the resources required for this. Moreover, slaughter checks are a good indicator of animal health and welfare, and pivotal to assure food safety (Rodrigues da Costa 2018). The data collected can be used for several means, such as reduction of losses due to disease through feedback to livestock producers and private veterinary practitioners, aiding in the implementation of preventive herd health programmes, study of trends and variations in animal disease incidence, setting up national disease control programmes, benchmarking and improving animal welfare and biosecurity on farm, establishment of research investigations and quality control checks on inspection standards. The data collection system in the abattoir must include full details of the carcase and species, disease condition, part of carcase affected, weight of meat and offal condemned and, if necessary, be supplemented by the results of laboratory examinations (Collins and Huey 2015). Usually, acute, and generalised conditions demand the total condemnation of the carcase and the viscera, whereas the chronic and localised require only partial condemnation or no condemnation at all. This is the motive why it is crucial to ensure that viscera follow the carcase on to the detained rail, as there may be significant lesions in both (Collins and Huey 2015).

The main goals of meat inspection are to contribute to food safety, animal health and welfare, as well as identifying noncompliance with the current animal welfare rules. Since the abattoir is the bottle neck of production animals destined for consumption, many diseases and conditions can be detected at *ante* and *post-mortem* inspection. The study of carcase condemnations may prove to be a valuable control tool to assess the emergence and evolution of swine diseases. In fact, it may assist producers and veterinary authorities in improving and adjusting health programmes depending on the epidemiological context (Alban et al. 2022). The health assessment of pigs in the slaughterhouse is of great value in identifying diseases that are immediately observed clinically or that are suspected to be present in their subclinical or chronic form. In addition, these assessments have also proved to be of great value in monitoring the health profile of a herd (Vieira-Pinto et al. 2013).

In a study that investigated the causes for *ante-mortem* and *post-mortem* condemnations of pigs intended for human consumption, during a 78-month period in Portugal, of the 15 identifiable causes of total carcase condemnation, osteomyelitis (38.5%), granulomatous lymphadenitis (22.7%), pleurisy/pneumonia (21.2%), abscesses (8.4%), peritonitis (2.6%) and generalised melanosis (1.8%) were the most prevalent, whereas other causes accounted for under 1% of condemnations. The authors concluded that *post-mortem* condemnations were higher than *ante-mortem* condemnations and lower than observed in a previous article by Martínez et al. (2007). In the previous article by Martínez et al. (2007), based on a study conducted in a Spanish abattoir, the main reasons for total condemnations were abscesses, cachexia, catarrhal bronchopneumonia, vertebral osteomyelitis, arthritis, pleuritis, peritonitis and pleuropneumonia (Martínez et al. 2007).

As reported by Flesja and Ulvesaeter, in an extended disease recording programme in Norwegian pigs between 1975 and 1977, about 39% of the pigs included in the study had lesions. The most reported lesions were scabies (12%), parasitic hepatitis of severe and moderate degrees (11 %), pleurisy (7%), pneumonia - severe and moderate (5.4%), pericarditis (4.3%), pyaemia and abscesses (2.5%), tail lesions (2.3%), peri- hepatitis and other non-parasitic liver lesions (2.2%), polyarthritis and arthritis (1.7%), tuberculous lesions in the cervical lymph nodes (0.9%), peritonitis (0.9%) and atrophic rhinitis (0.8%) (Baconers et al. 1979). However, certain factors should be taken into consideration: diseases, such as sarcoptic mange or TB, have been subjected to control programmes and its incidence reduced. Moreover, variations in the causes and prevalence of carcase condemnations reported in different studies may be associated with the geographical area, climatological conditions, farm management and health herd status (Martínez et al. 2007).

An investigation of the causes and cost of rejection of pig carcases and viscera was undertaken in a population of 1.3 million pigs slaughtered at seven abattoirs in England, in 1980. In this population, 0.2% of whole carcases and parts of 2.0% of the carcases were rejected. The main causes of total condemnations were pneumonia, pleurisy, peritonitis, and fever, and for partial condemnations, abscesses, and arthritis (Hill and Jones 1984b). Another study by Huey, conducted in 1996, dealt with data from a centralised meat inspection system in Northern Ireland. Out of 75,130 pigs slaughtered, 0.7% of all carcases were totally condemned, with abscesses or pyaemia recorded as the cause in 0.28% of these cases (Huey 1996). Though this data is outdated, it provides a useful background to the carcase condemnation data presented in this work.

A study conducted by Alban et al. (2022) dealt with the differences in code terminology and frequency of findings in meat inspection of finisher pigs in seven European countries.

Several conclusions were reached in terms of the differences in the percentage of total condemnations, when compared to the number of pigs slaughtered, as highlighted in Table 4.

Table 4 - Percentage of total condemnations (TCs), according to the number of pigs slaughtered during 2019, in seven different European countries (adapted from Alban et al., 2022).

	Total number of pigs slaughtered on a national level in 2019	Number of pigs slaughtered in 2019 included in the study	Percentage (%) of pigs slaughtered in 2019 included in the study	Percentage (%) of TCs in the pigs included in the study
Denmark	16,839,000	4,000,000	23.75%	0.15%
Finland	1,816,000	1,800,000	99.12%	0.51%
Germany	55,131,000	53,600,000	97.22%	0.20%
Italy	11,500,000	11,500,000	100.00%	0.21%
Norway	1,600,000	196,773	12.30%	0.26%
Portugal	5,558,000	4,200,000	75.57%	0.38%
Spain	52,982,000	3,500,000	6.61%	0.11%

In terms of TCs, Alban et al. (2022) showed that the predominant causes of total condemnation of pig carcases stand apart according to the country where data was recorded. For instance, Italy appoints “Contamination with faeces or bile” as the number one motif for TCs, whereas less specific codes, such as “Circulatory disorders” and “Systemic disease” rank first in Denmark and Norway, correspondingly. Germany and Spain both assigned “Abscesses or multiple abscesses” first place in the list of TCs, with Portugal reporting it to be “Osteitis”. According to the same study, in Denmark, the most frequent cause of partial condemnation was “Chronic Pleuritis” (26.7%); in Finland, “Pleuritis” was the most usual finding (22.5%); in Germany, conditions in the respiratory tract (including “Pleuropneumonia”, “Pleurisy” and “Enzootic Pneumonia”) corresponded to 63.2% of all organ alterations; in Italy, respiratory diseases were most frequently registered, with “Pleuritis”, “Enzootic Pneumonia” and “Pleuropneumonia” accounting for 38.0% of partial condemnations; in Norway, the prevalence of “tail wounds/short tail” was 0.065%, whereas “Liver Parasitism” caused the partial condemnation of 0.06% of livers; in Portugal, the most frequent cause of partial condemnation was “Liver Parasitism” (34.0%); in Spain, the two abattoirs contributing to the study did not record partial condemnations. A more detailed list of total and partial condemnations enumerated in the article can be found in Appendix 1 and 2.

The causes for total condemnation for swine carcases between 2018 and 2019, in Portugal, by pathology group, with a few occurrences higher than 100, are listed in Table 5:

Table 5 - Causes for total condemnation for swine carcases, between 2014 and 2019 by pathology group, in Portugal (adapted from DGAV, 2020).

Main Causes of TCs by Pathology Group	Nº of occurrences in 2018	Nº of occurrences in 2019	Percentage (%) of TCs in the pigs slaughtered in 2018	Percentage (%) of TCs in the pigs slaughtered in 2019
Osteitis/Osteomyelitis	4347	6091	30.81%	33.86%
Cachexia, emaciation	1846	2314	13.08%	12.86%
Abscesses and multiple purulent lesions	922	1401	6.53%	7.79%
Pneumonia	1058	1171	7.50%	6.51%
Peritonitis	888	1155	6.29%	6.42%
Pleuropneumonia	890	1111	6.31%	6.18%
Polyarthritis	799	952	5.66%	5.29%
Arthritis	575	742	4.08%	4.12%
Multiple Lung or Pleural Abscesses	306	387	2.17%	2.15%
General Organic Reaction	283	300	2.01%	1.67%
Organoleptic anomalies	204	291	1.45%	1.62%
Enteritis	334	241	2.37%	1.34%
Technopathies	167	236	1.18%	1.31%
Pericarditis	225	188	1.59%	1.05%
Dermatitis	94	160	0.67%	0.89%
Disgusting meat	105	136	0.74%	0.76%
Pleurisy	37	130	0.26%	0.72%
Febrile Syndrome	69	116	0.49%	0.64%

According to a report published by the Portuguese Official Veterinary Authorities, in 2018, the average percentage of total condemnations for swine carcases was 0.32% (out of 4,349,799 pigs slaughtered), whereas in 2019 it rose to 0.42% (out of 4, 296,926 pigs slaughtered) (DGAV 2020).

3.5. Carcase Quality and Grading

According to the European Union (EU) specification for carcase dressing, a pig carcase corresponds to the body of a slaughtered pig, bled, whole or separated in halves, eviscerated, without tongue, bristles (hair), nails, genital organs, flare fat, kidneys, and diaphragm (Ianniciello et al. 2014). However, the UK specification allows the abattoirs to leave the kidneys, flare fat, diaphragm, and tongue (GOV.UK 2022b).

Carcase characteristics as fat thickness, muscle depth and lean meat percentage (LMP) are important parameters to assess carcase quality and to determine an appropriate market price (Lucas et al. 2017). The classification is done by estimation of the content of lean meat in the carcase, measuring instrumentally the thickness of muscular and adipose tissue in one or more parts (Ianniciello et al. 2014). This needs to be carried out in the slaughterhouse by properly trained staff and it follows a simple structure:

- Calibration and confirmation of the functionality of equipment used for the measurement;
- Presentation of the carcase at the weighing station of the slaughter line;
- Weighing the dressed carcase for its warm weight;
    - To calculate the cold weight, deduct 2% from the warm weight, to allow for moisture loss from the carcase after slaughter (Meat and Livestock Commercial Services Limited 2020) .
- Use of a measuring instrument for the classification;
- Identification of the carcase;
- Chilling of the carcase.

These procedures may vary according to national requirements, and such variations should be considered when doing the calculation of the percentage of fat. According to the EU standards, the carcases must be weighed as soon as possible after slaughter and not later than 45 minutes after the animal has been stuck. The measure of the thickness of the fat should be made at the time of weighing. The combination of two measured values allows the determination of LMP and grants the categorization of the carcase according to a commercial class provided by the SEUROP framework (Ianniciello et al. 2014). Six commercial categories are set depending on the proportion of detected fleshiness or the percentage of lean meat measured in the carcase, as highlighted in Table 6. In the EU, LMP is determined using the SEUROP classification, which is based on fat thickness (Ianniciello et al. 2014). The SEUROP grid ensures objective payments for pig producers, as it is dependent on the LMP and weight (Sprysl et al. 2007).

Table 6 - Categories of the SEUROP grid (adapted from Lucas et al., 2017).

SEUROP grid	
Categories	**Lean Meat as a percentage of recorded carcase cold weight**
S	60% or more
E	55% or more, but less than 60%
U	50% or more, but less than 55%
R	45% or more, but less than 50%
O	40% or more, but less than 45%
P	Less than 40%

Pig classification has been used for a long time worldwide, ensuring a fair payment to the producer according to the composition of the carcase and safeguarding the transparency of commercial transactions. Several decades of investigation have culminated in the use of rulers, optical probes, manual electronic probes and lastly robots (Daumas 2001) . On the slaughter line, LMP may be estimated by means of carcase measurements taken by different types of equipment. The probes authorized in the UK are listed on Table 7.

Table 7 - Probes authorized for Pig Carcase Grading in the UK (adapted from Lucas et al., 2017).

Name of the Probe	Type of Technology	Type of Recording
Intra-scope	Optical	Non-automatic
Fat-O-Meater (FOM)	Reflectance	Automatic
Hennessy Grading Probe (HGP II)	Reflectance	Automatic
CBS Ultra-Meater	Ultrasound	Automatic
AutoFom	Ultrasound	Automatic

The probe used in this study was an optical probe, also known as *Intra-scope*, sold by *MLC Services Ltd*. The *Intra-scope* measures lateral tissue thicknesses by probing. The source of light at the end of the probe detects the change in light reflectance at the boundary of fat and muscle. Fat depth can be measured from about 5 to 50 mm (Figure 3) and is visualized by means of a mirror system on an engraved sliding barrel (marked in mm). The errors of the *Intra-scope* are around 10 % higher than those of the electronic probes and this method suffers biases between sexes and breeds (Daumas 2001).

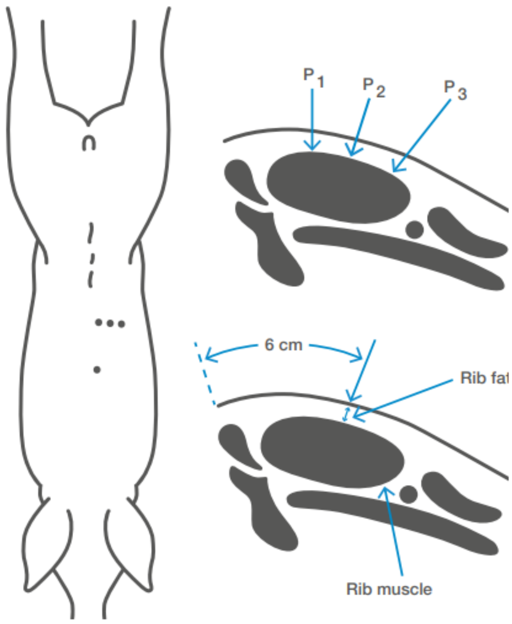


Figure 3 - Locations of probing sites on a pig carcase (adapted from AHDB, 2021).

For each carcase, the following values should be recorded: dead weight, LMP, fat cover thickness, thickness of the loin and class of fleshiness. After the classification, the carcases should be labelled, and the label should provide information on the weight category. The mark or label should contain information about the classification. The mark can be applied by stamping on the skin at the level of the hindquarter with heat resistant and non-toxic indelible ink (Ianniciello et al. 2014).

The lean meat content (Ŷ) in pig carcass can be predicted by *Intra-scope* based on the equation, where F equals fat thickness (Jansons et al. 2016):

$$\hat{Y} = 66.6708 - 0.3493 \times F$$

4. Materials and Methods

4.1. Slaughterhouse Management Aspects

The slaughterhouse included in this study had a line speed of around 260 pigs per hour. The number of pigs killed per week was approximately of 4,000 animals in April 2022, even though this value varied over the last few years. In 2021 it decreased due to COVID-19 related issues (fewer working days and disease outbreaks within the working force) and the purchase of the factory by another company.

During loading and unloading at the abattoir, the handling of pigs was low stress, as the animals were herded into a CO_2 chamber gently and with no shouting. Immediately after stunning, the pigs were bled.

Meat inspection was performed by a team of one OVI, who managed the overall process and examined the carcases retained for possible total condemnations, and between three or four assistants from Food Standards Scotland (FSS) who performed the first inspection of the carcases and organs. Each carcase was identified by a slap mark - specific combination of letters and numbers which is unique to each pig unit and allows clear identification of pigs and carcases at slaughter for traceability purposes - and a kill number. The slap mark used was attributed by the Department for Environment, Food and Rural Affairs (DEFRA), by the local Animal Health Divisional Office. Figure 4 illustrates the slaughter process and its various steps.

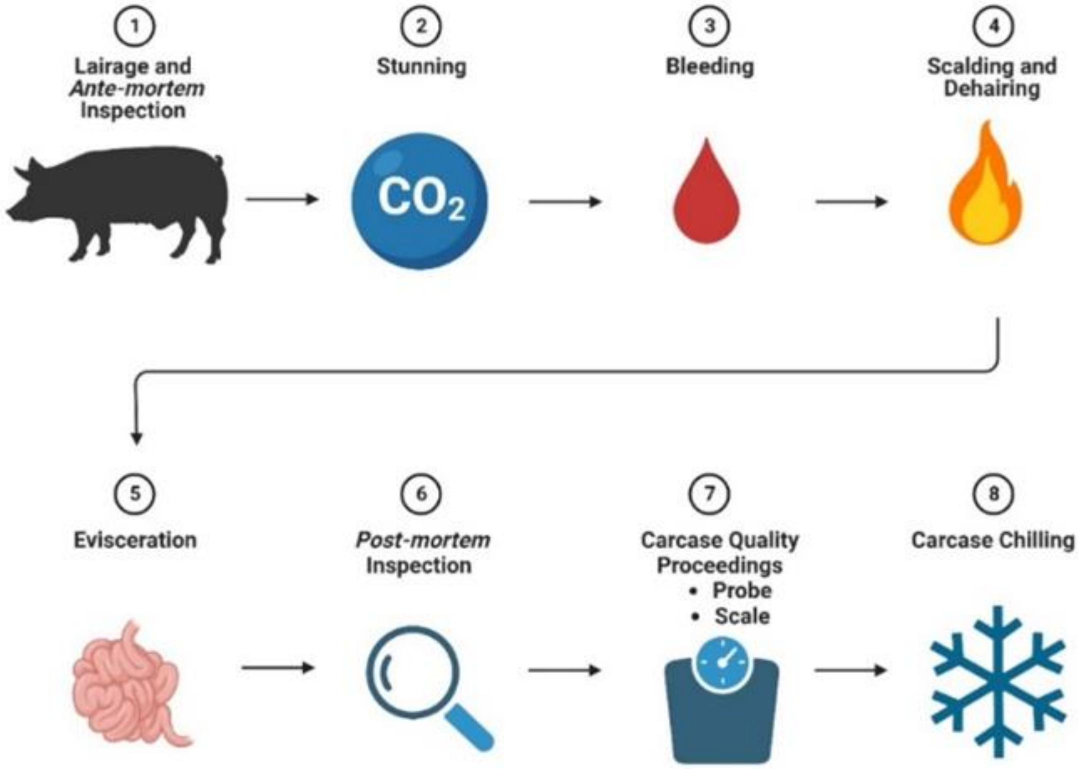


Figure 4 - Flow chart illustrating the slaughter process at the studied slaughterhouse.

In this slaughterhouse, data registration was carried out in multiple sites along the process. Data regarding *ante-mortem* inspection was recorded in the lairage, after an initial visual examination of the batch by the OVI. As for partial and total condemnations, the carcases and offal were firstly examined by the FSS staff and then data was documented. In dubious or possible total condemnation cases, the final decision had to be validated by the OVI and it was only recorded in the system afterwards. The computer system employed made it possible to record various conditions for partial or total condemnations per animal. Looking back at Figure 4, data collection was done in stage 1 (to register any pigs condemned on the *ante-mortem* inspection or any other relevant information), 6 (to insert partial or total condemnations in the system) and 7 (for carcase quality purposes, where the value of the

Intra-scope probe and the total weight of the carcase were measured) of the picture. The data gathered in stages 1 and 6 was then put together in a database called “Parts” and the data from stage 7 was compiled in another database named “Quality”.

4.2. Dataset and Data pre-processing

All data regarding condemnations was obtained directly by the author in February 2022, from a pig slaughterhouse plant in Scotland, UK, targeting 118 Scottish pig farms. The dataset covered finishing pigs, raised both outdoors and indoors, slaughtered, and inspected by official veterinarians (OVI’s) over a 48-month period, from January 2018 to December 2021.

In the first stage of this analysis, two different datasets were available, containing information about carcase quality and carcase condemnations. The “Quality” database contained carcase quality data with 992,110 entries with individual pig records, such as cold weight, probe average, slap mark, kill number and date. In the former dataset, one row corresponded to one pig. On the other hand, the “Parts” dataset contained 152,814 individual carcase condemnation records, where one row corresponded to one condemnation, which meant that one pig could have multiple conditions recorded. This dataset had information regarding the producer, slap mark, part, condition, kgs condemned, kill number and date.

Before data analysis, various data handling procedures were necessary on the “Quality” and “Parts” dataset. Data was checked and existing errors in the different datasets were corrected, allowing the merge of the datasets. A list of some of those corrections follows below:

- A total of 3,501 pigs across the four years of study from the data frame “Quality” had total weight of 0. Firstly, the possibility of these animals being condemned at the *ante-mortem* inspection was considered. However, after a meeting with the slaughterhouse team, this value was deemed too high, and these pigs were removed from the dataset.
- In both datasets, some pigs were attributed a slap mark called “EXTRA”, which did not correspond to a real slap mark. These pigs and others from similar slaps exist to balance between extra pigs sent in from the farm and missing pigs in other batches. In the dataset “Parts”, sows from the slap mark “EXTRA SOWS” were removed, as these were included in the data extraction by mistake.
- A unique indicator was created in both datasets called “PigID”, that worked as an individual identifier for the pigs slaughtered on a specific date (date_killnumber), and “PigID2” that acted was an identifier for the pigs slaughtered in a specific date, with a specific slap mark (date_kill_slapmark).

- In the data frame "Quality", there were two lines with the same "PigID" that belonged to different slaps. This was considered and error and these two occurrences were eliminated from the database.

- In the "Parts" data frame, there were 10 days across the 4 years of data without condemnations. After a meeting with the slaughterhouse team, it was established that these were due to technical problems or system failure. In the end, these dates were removed from the dataset.
- In the "Parts" data set, there were pigs with a partial condemnation caused by "Mastitis" (n=2), on day 11/11/2021 and 15/11/2021. These entries were taken out, as this study is solely focused on finisher pigs.
- The entries "Badly Bled" (n=72), "Contamination Hair" (n=18010), "Fallen (Skinned)" (n=3) and "Over scald" (n=229) were removed from the dataset "Parts", as these were erroneously included when was transferring the data from the server and therefore did not represent health conditions that resulted in condemnations.
- A total of 3,917 pigs did not have a direct match, which meant that these existed in the "Parts" dataset but not in the "Quality" dataset. The motives to justify this were unknown, as a complete match was expected. The pigs without a direct match between the two datasets were not included in the study.
- The "Parts" dataset contained 152,814 rows, in which one pig could appear multiple times, depending on the number of partial condemnations registered. After an initial investigation, it was found that the number of partial condemnations per pig could range from one to five.

Ultimately, the goal was to merge the datasets "Parts", which had to be reduced to individual pig level, to the dataset "Quality". To do this, another dataset called "Parts2_individualpigs" was generated from the clean dataset "Parts", the total condemnations were taken out and partial condemnations kept in. "Parts2_individualpigs" contained 122,678 entries, and 11 columns (variables). In this dataset, one line corresponded to one individual pig with one or more partial condemnations. After this, datasets "Quality" and "Parts2_individualpigs" were joined and the final dataset "Db" was created. "Db" contained 992,101 entries and 24 variables, such as: "Date", "Year_week", Year", "Week", "Month", "Quarter", "Slap", "Weight_Total" (values in Kg), "Probe_Average" (values in mm), "Kill_Number", "PigID", "PigID2", "Nº of PCs per pig", "Kgs condemned per pig" and four categories with the most relevant conditions that led to partial condemnations, such as "Pleurisy", "Arthritis", "Abscesses", "Welfare Indicators".

The process of creating the final databases "Parts 2_individualpigs" and "Db_batch>10" is explained in Figure 5 and 6.

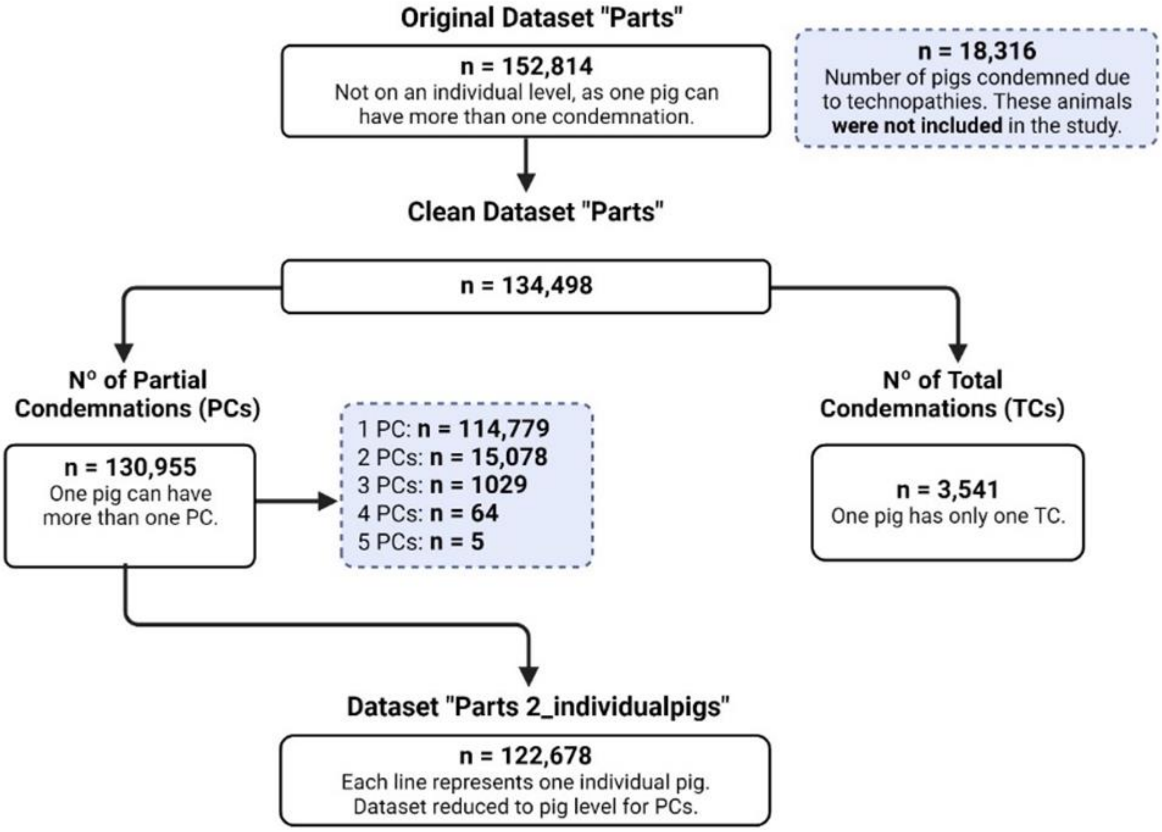


Figure 5 - Steps necessary before having the database "Parts 2_individualpigs" ready.

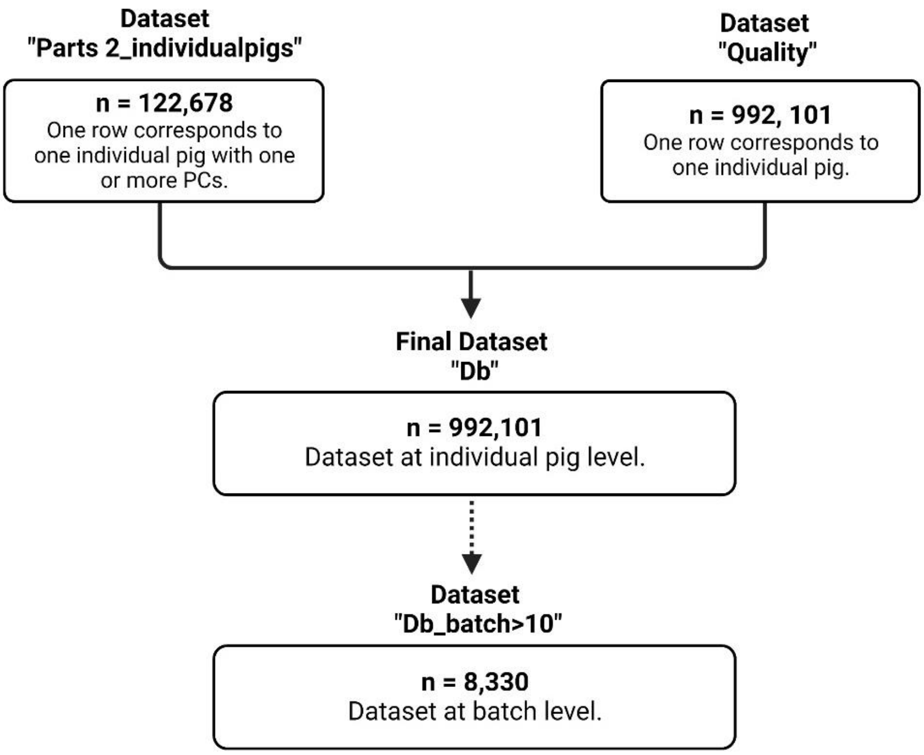


Figure 6 - Steps necessary before having the final dataset "Db" ready and the dataset "Db_batch>10" reduced at batch level.

After having the final dataset “Db” at individual pig level, another dataset was created at batch level (one batch corresponds to all pigs killed in each day from a given slapmark), called “Db_batch>10” and only batches with more than 10 pigs in one day were included. “Db_batch>10” contained 8,330 entries. All the indicators that were already present in the dataset “Db” were retained and the following columns added: “BatchID” (that corresponds to the total number of pigs slaughtered in a specific day, from a specific slap mark), “Nº of pigs with PCs per batch”, “Nº of PCs per batch”, “Kgs of PCs per batch”, “Nº of pigs per day” and “HasPC”.

4.3. Descriptive and statistical analysis

All data was processed using Microsoft Excel® and further analysis were performed in (RStudio Team 2021), including R packages Dplyr, Ggplot2, Lme4 and Lmer. All levels of statistical significance were determined for $P < 0.05$. Data handling was divided into descriptive and inferential statistical analyses and was made in RStudio™ 3.6.1 and Microsoft Excel™ 2021.

4.4. Study Hypotheses

Besides the descriptive and exploratory analysis of the dataset “Db”, a few hypotheses were put into consideration. The first aimed to assert how the probe average value varied with an increasing number of partial condemnations. To answer this question, a generalized linear mixed effects model was created, with the variables “N_PCs_perpig”, “quarter” and “year” as fixed effects and “slap mark” as a random effect. The models were developed using R software (R Core Team, 2018), through the usage of packages specific for mixed models: lme4 (Bates et al. 2015) and lmerTest (Kuznetsova et al. 2017).

The second hypothesis aimed to answer whether a higher variability in the carcase weight within each batch was associated with more partial condemnations per batch. To explore this relationship, a mixed effects logistic regression model was carried out with the dependent variable being the binomial variable “PCs_batch_>1”.

Finally, the third hypothesis intended to ascertain whether the category of partial condemnation was associated with a specific farm or broader in scope. To answer this question, a table of frequencies for four partial condemnation categories (“Pleurisy”, “Arthritis”, “Abscesses”, “Welfare Indicators”) was created. All slap marks were anonymized and replaced by a letter. Finally, a Kruskal-Wallis test was used to evaluate whether differences in the categories of partial condemnations were statistically significant in different slap marks.

5. Results

5.1. "Db" Data set - Descriptive Analysis

Table 8 underlines the number of days when the slaughterhouse was operating. Considering that the study period spans from 2018 until 2021, 938 out 1,461 days (64.20%) were included, with the maximum number of days being achieved in 2019 and the minimum in 2021. Table 9 points out the number and percentage (%) of pigs slaughtered included in this study, when compared to the national Scottish abattoir output for pigs. The sample comprised (992,110 out of 1,365,235 pigs) amounts to 72,67% of the overall national population of pigs slaughtered between 2018 until 2021.

Table 8 - Overview of the slaughter days.

	2018	2019	2020	2021	TOTAL
Nº slaughter days	233	254	249	202	938
Nº slaughter days per month (mean (SD))	19.42 (2.11)	21.17 (1.40)	20.75 (1.14)	16.83 (3.64)	

Table 9 - Number and percentage (%) of pigs slaughtered included in this study, when compared to the National Scottish Abattoir output for pigs (adapted from Macdonald, 2022).

	2018	2019	2020	2021	TOTAL
Nº of pigs slaughtered per year on a national level	344,850	357,410	371,350	291,625	1,365,235
Nº pigs slaughtered per year included in the study	255,534	265,889	281,742	188,945	992,110
Percentage (%) of the Nº of pigs slaughtered per year included in the study	74.10%	74.39%	75.87%	64.79%	72.67%

A total of 118 slaps were analysed throughout the study period. The number of pigs killed per year was 992,110 in total, with the lowest number being registered in 2021, due to the pandemic impact on the staffing level and number of operating days. This resulted in pigs backing up on farms, with the number starting to increase rapidly since September 2020, as the capacity to slaughter animals was reduced. The slaughterhouse was closed for two weeks in 2021, due to the pandemic. From April/May 2021 until September 2021, the plant was open for three days a week, to take advantage of the furlough scheme put forward by the Scottish

Government, as to reduce the economic impact of the Covid-19 pandemic. A detailed descriptive analysis is shown in Table 10.

Table 10 - Descriptive Analysis of the killing output.

	2018	2019	2020	2021	TOTAL
Nº slaps	95	87	88	83	118
Nº pigs killed per year	255,534	265,889	281,742	188,945	992,110
Nº pigs killed per quarter, per year	**Q1:**64,793 **Q2:**60,115 **Q3:**60,396 **Q4:**70,227	**Q1:**63,271 **Q2:**64,693 **Q3:**68,115 **Q4:**69,810	**Q1:**67,953 **Q2:**68,567 **Q3:**74,056 **Q4:**71,162	**Q1:**59,667 **Q2:**52,540 **Q3:**41,919 **Q4:**34,817	
Average nº pigs/slap (mean (SD))	2,166 (3,222.8)	2,253 (4,144.5)	2,388 (4,270.8)	1,601 (3,013.8)	
Average nº pigs killed per quarter, per year (mean (SD))	4,583 (1,598.5)	4,747 (1,197.6)	5,017 (1,305.6)	3,371 (1,652.7)	
Average nª pigs killed per week, per year (mean (SD))	4,842 (1,192.5)	5,016 (690.3)	5,301 (835.4)	3,562 (1,577.1)	
Max nº of pigs per slap	19,992	31,867	32,219	21,524	
Min nº of pigs per slap	3	19	1	14	

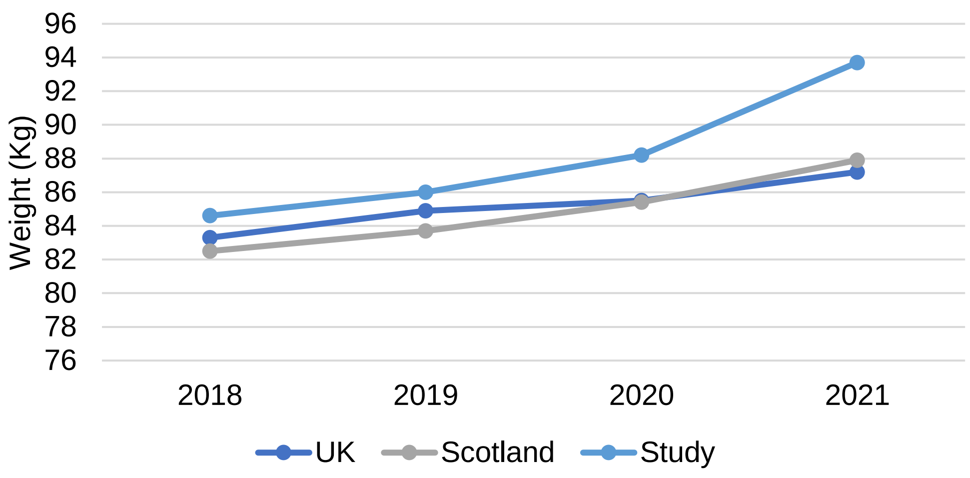
5.2. "Db" Data set - Carcase Quality

5.2.1. Carcase Weights

As delineated in Graph 1 and Table 11, carcase weights increased from 2018 onwards, possibly due to further improvements in productivity as well as attempts to boost carcase weights to generate a higher revenue per pig. The rise came despite higher feed costs. In the UK, carcase weights have a seasonal profile, generally falling in the summer months.

Table 11 - Average carcase weights in Scotland, in terms of kg per head (adapted from Macdonald, 2022).

	National Level		Study			
Year	**UK**	**Scotland**	**Mean (SD)**	**Median**	**Min**	**Max**
2018	83.3 kg	82.5 kg	84.8 (7.78) kg	84.9 kg	29 kg	176 kg
2019	84.9 kg	83.7 kg	86.3 (7.71) kg	86.3 kg	29 kg	139 kg
2020	85.5 kg	85.4 kg	88.6 (8.20) kg	88.7 kg	32 kg	141 kg
2021	87.2 kg	87.9 kg	94.2 (9.35) kg	94.0 kg	10 kg	163 kg



Graph 1 - Evolution of the average carcase weight, throughout 2018-2021, in the UK, Scotland and in the abattoir included in this study.

5.2.2. Carcase Grading

The evolution of the average probe values is displayed on Table 12 and Figure 7.

Table 12 - Average probe values registered in the study slaughterhouse by year.

Year	Mean (SD)	Average Lean Meat Content (%)	Median	Min	Max
2018	11.7 (2.24) mm	62.58%	12mm	0 mm	30 mm
2019	11.4 (2.08) mm	62.59%	11mm	4 mm	31 mm
2020	11.5 (2.37) mm	62.65%	11mm	0 mm	30 mm
2021	12.5 (2.67) mm	62.30%	12mm	0 mm	40 mm

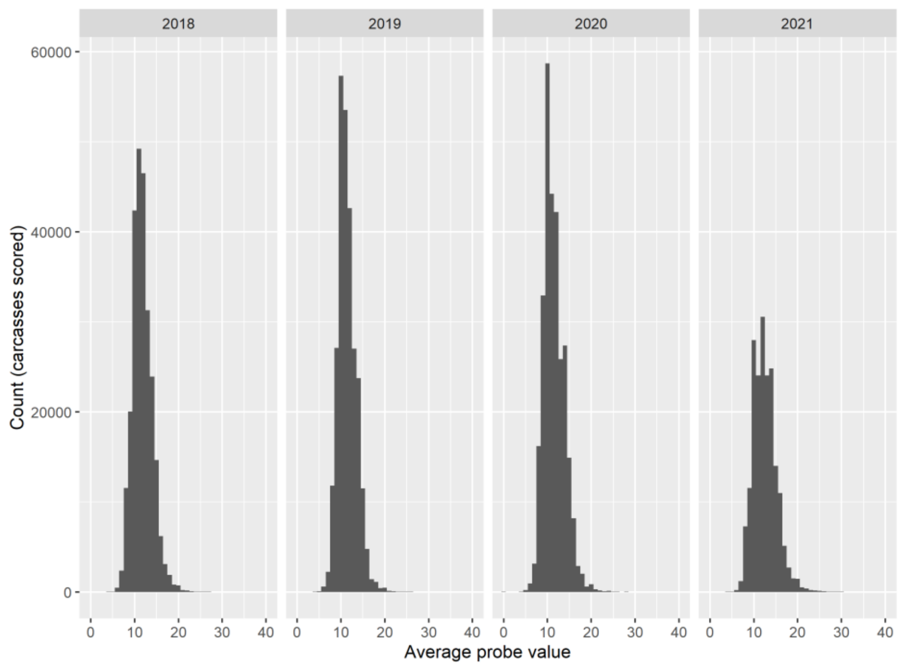


Figure 7 - Evolution of the probe average, throughout 2018-2021, in the in the abattoir included in this study.

5.3. "Db" Data set - Condemnations

5.3.1. Partial Condemnations (PCs) at individual level

Table 13 summarises the PCs, from 2018 to 2021. The conditions that resulted in partial condemnations are listed below in Table 14 in alphabetical order and in Appendix 5, as well. The most relevant conditions that led to partial condemnations were grouped together in four different categories: "Pleurisy", "Arthritis", "Abscesses" and "Welfare Indicators". Table 15 explains how the categories were constructed, the conditions included and its representativity in terms of the partial condemnations. The aim of this step was to facilitate the interpretation of the hypotheses in study, and to understand the impact of each group of partial condemnation in terms of the carcase quality at individual pig level.

Table 13 - Overview of the partial condemnations (PCs) throughout the study period.

	2018	2019	2020	2021	TOTAL
Nº of PCs	32,963	36,014	35,532	23,454	127,963
% PCs	12.90%	13.54%	12.61%	12.41%	12.89%
kgs of PCs	43,484.5 kg	51,679 kg	54,199 kg	32,924 kg	182,286 kg

Table 14 - Partial condemnations (PCs) listed in detail and its specific percentage.

Conditions	Nº of Partial Condemnations	Percentage (%) of Partial Condemnations
Pleurisy	79,898	61.01%
Abscess	15,954	12.18%
Arthritis	15,210	11.61%
Bruising	8,094	6.18%
Fight/Bite Wounds	2,777	2.12%
Skin Condition	2,504	1.91%
Peritonitis	2,474	1.89%
Tail Bite	1,409	1.08%
Erysipelas like lesions	745	0.57%
TB Like Lesions	659	0.50%
Fracture	606	0.46%
Bursitis	473	0.36%
Other	152	0.12%
Suspect Uraemia/Abnormal Smell	13	0.01%
TB Like Lesions (Generalised)	9	0.01%
TOTAL	**130,977**	**100%**

Table 15 - Categories and the different partial condemnations (PCs) included in the dataset "Db".

Name of the Group	Partial Condemnations Included	YES	NO
Pleurisy	Pleurisy	78,814	913,937
Arthritis	Arthritis	14,323	977,778
Abscesses	Abscesses	15,235	976,866
Welfare Indicators	Bruising Fight/Bite Wounds Tail Bite	11,903	980,198

The deduction in weight for each category does not represent real weighed values and varies with each type of condemnation. Table 16 contains the weight deductions for the four different groups.

Table 16 - Weight Deduction Values made by the slaughterhouse, for the four partial condemnation categories.

Name of the Category	Mean	SD	Min	Max	Total Kg Condemned
Pleurisy	0.77 kg	0.96 kg	0.0 kg	24.5 kg	60,128 kg
Arthritis	3.24 kg	2.62 kg	0.0 kg	29.0kg	46,463 kg
Abscesses	2.92 kg	3.00 kg	0.5kg	40.0kg	44,441.5 kg
Welfare Indicators	1.92 kg	2.08 kg	0.0kg	40.0kg	22,859.5 kg

5.3.2. Partial Condemnations (PCs) at batch level

As previously explained, a batch corresponds to the total number of pigs slaughtered on a particular day, from a specific slap mark. After having the final dataset "Db" at individual pig level, another dataset was created at batch level, called "Db_batch>10". Table 17 summarises the variables used to characterize the partial condemnations in the population of study, at a batch level.

Table 17 - Overview of the partial condemnations (PCs) throughout the study period at batch level.

	Nº Pigs	Nº Pigs with PCs	Nº of PCs	kg of PCs
Mean	119.0	0.4	0.4	0.6 kg
SD	67.48	3.86	4.12	5.86 kg
Min	10.0	0.0	0.0	0.0 kg
Max	440.0	94.0	101.0	205.5 kg

5.3.3. Total Condemnations (TCs)

Table 18 - Overview of total condemnations (TCs) throughout the study period.

	2018	2019	2020	2021	TOTAL
Nº of TCs	551	890	1,100	1,000	3,541
% TCs	0.22%	0.33%	0.39%	0.53%	0.36%
Kgs of TCs	49,595.4 kg	80,121.6 kg	99,009 kg	90,009 kg	318,735 kg

Table 18 summarises the TCs, from 2018 to 2021. Total condemnations were not probed or weighed. Most TCs had a standardized slaughter weight attributed to them, which for the most part corresponded to the total weight of 90 kg (n=3,710) and 91.8 kg (n=26). The conditions that originated TCs were the following: Anaemia, Erysipelas, Generalised Tumours, Jaundice, Oedema/Emaciation, Other Pathology/Condition, Polyarthritis, Septic Peritonitis and Pleurisy, Septic Peritonitis Only, Septic Pleurisy Only, Suspected Fever/Septicaemia, Suspect Pyaemia/Multi Abscesses – Other, Suspect Pyaemia/Multi Abscesses – Tail, Suspect Uraemia/Abnormal Smell, TB Like Lesions (Generalised). To facilitate the analysis, the entries "Suspect Pyaemia/Multi-Abscesses - Other" and "Suspect Pyaemia/Multi-Abscesses - Tail" were grouped together. The conditions that resulted in total condemnations from the database "Parts" are listed below in Table 19.

Table 19 - Total Condemnations (TCs) listed in detail and its specific percentage.

Conditions	Nº of TCs	Percentage (%) of TCs
Suspect Pyaemia/Multi Abscesses	2,035	57.47%
Polyarthritis	935	26.40%
Septic Peritonitis & Pleurisy	122	3.45%
Septic Peritonitis Only	110	3.11%
Jaundice	89	2.51%
Septic Pleurisy Only	80	2.26%
Oedema/Emaciation	59	1.67%
Suspected Fever/Septicaemia	46	1.30%
Other	21	0.59%
Suspected Uraemia/Abnormal Smell	13	0.37%
Anaemia	13	0.37%
TB Like Lesions (Generalised)	9	0.25%
Generalised Tumours	5	0.14%
Erysipelas	4	0.11%
TOTAL	**3,541**	**100%**

5.4. Study Hypotheses

5.4.1. Carcase Quality and Number of Partial Condemnations

Regarding the linear mixed effects model, the estimates for the "N_PCs_per pig", "year" and "quarter" are stated in table 20, with all of these being significant for the probe average values of the carcase. This means that, for one unit increase in the number of PCs per pig, the probe value was expected to decrease by 0.370 units; with one increase in year, the probe average was expected to increase by 0.189; with one increase in the quarter, the probe average value was expected to increase by 0.152. Random effects are part of the variance components of the model, explaining part of the total variance that is not explained by the fixed effects.

Table 20 – Modelling estimates for the probe average depending on the number of partial condemnations per pig, year, and quarter.

Fixed Effects	**Estimate**	**SE**	***P***
Intercept	-369.900	4.6750	<0.001
N_PCs_perpig	-0.370	0.0065	<0.001
Year	0.189	0.0023	<0.001
Quarter	0.152	0.0003	<0.001
Random Effects	**Variance**	**SE**	
Slap Mark	0.6921	0.8319	

5.4.2. Variability in the weight and number of partial condemnations, at batch level

The second hypothesis aimed to answer whether a higher variability in the weight, at batch level, was associated with a higher number of partial condemnations. To explore this relationship, the "Db_batch" data set was used, and a mixed effects logistic regression model (Table 21) was developed with the dependent variable (y-axis) being the binomial variable "PCs_batch_>1". The dependent variable had the outcomes "Yes" or "No" and represented the probability of having at least one partial condemnation in a batch. Moreover, the model also included "weight_CV_batch", quarter and month as continuous predictors of the binary outcome and "slap mark" as a random effect. The variable "weight_CV_batch" represents the coefficient of variation (CV) for the variable "weight_total", at batch level. It was calculated by dividing the standard deviation by the mean weight of a batch. This statistical measure evaluates the dispersion of data points in a data series around the mean and is dimensionless, thus allowing the comparison of data sets with different units. The higher the CV, the greater the dispersion.

Table 21 - Logistic regression estimates for the number of partial condemnations depending on the coefficient of variation for weight, month and quarter.

	Estimate	SE	*P*	OR [95% CI]
Intercept	-7.081	0.8658	<0.001	
Weight_CV_batch	0.029	0.0434	0.506	1.029 [0.944 - 1.123]
Month	-0.388	0.2924	0.184	1.474 [0.378 - 1.218]
Quarter	1.149	0.8945	0.199	3.155 [0.527 - 18.878]

5.4.3. Types of partial condemnations in different slap marks

Table 22 lists the number of pigs sent to the abattoir from the top 20 slap marks with condemnations due to “Pleurisy”, “Arthritis”, “Abscesses” and “Welfare Indicators”. Kruskal-Wallis tests showed no statistical significance: “Pleurisy” (*P*-value=0.5493), “Abscesses” (*P*-value=0.5807), “Arthritis” (*P*-value=0.5381), “Welfare Indicators” (*P*-value=0.3781).

Table 22 - List and percentage (%) of the four partial condemnation categories, for the 20 slap marks with a higher percentage of “Pleurisy” condemnations.

Slap	Total Pigs	Pleurisy (%)	Arthritis (%)	Abscesses (%)	Welfare Indicators (%)
A	120	36.67%	1.67%	1.67%	1.67%
B	417	32.13%	7.91%	2.40%	0.48%
C	7,775	29.23%	0.95%	1.32%	1.07%
D	35,433	26.72%	1.83%	3.07%	2.54%
E	3,981	26.07%	1.73%	0.33%	1.53%
F	10,491	25.95%	1.86%	2.48%	2.61%
G	634	23.97%	0.47%	0.95%	1.42%
H	2,567	21.43%	1.60%	2.69%	1.36%
I	12,274	20.91%	0.64%	1.97%	1.25%
J	3,099	16.62%	0.29%	0.71%	0.68%
K	3,272	14.91%	1.96%	0.31%	0.95%
L	43,081	14.71%	0.55%	1.17%	0.65%
M	27,689	14.53%	1.10%	1.90%	1.37%
N	9,717	13.74%	0.80%	1.14%	2.11%
O	1,444	13.23%	2.63%	1.04%	0.90%
P	4,385	12.73%	2.62%	1.14%	0.59%
Q	5,993	12.60%	1.50%	2.35%	1.95%
R	604	12.42%	1.99%	3.64%	3.81%
S	6,338	11.94%	0.46%	0.57%	0.30%
T	9,503	11.69%	1.59%	1.02%	1.21%

6. Discussion

The present study consists of the first comprehensive report of pig carcase quality and condemnation records in Scotland. As a matter of fact, this was the first attempt to carefully examine a large slaughterhouse dataset to report on its data, usefulness, and on the information to be potentially retrieved on a regular basis. The work conducted aimed to identify and understand the major challenges encountered with this kind of data and to draw the aspects in need of improvement, with the ultimate objective to increase production efficiency and sustainability of the Scottish pig sector.

In the first stage of this analysis, two different datasets were available, containing information about carcase quality and carcase condemnations. The “Quality” database contained carcase quality data with 992,110 entries with individual pig records, whereas the “Parts” dataset contained 152,814 individual carcase condemnation records. Before the data analysis, various data handling procedures were necessary on the “Quality” and “Parts” dataset, such as reducing “Parts” to individual pig level, creating the data set “Parts2_individualpigs”. Following this, datasets “Quality” and “Parts2_individualpigs” were joined and the final dataset “Db” was created with 992,101 entries and 24 variables, at pig individual level. “Db_batch>10” was designed to run some of the statistical models.

The study period spanned from 2018 till 2021, with 938 out 1,461 days included. The data included in this investigation amounted to 72.67% of the total number of pigs killed per year on a national level in Scotland, from 2018 to 2021. Indeed, 992,110 out of 1,365,235 slaughtered pigs are represented in the final database “Db”. The year of 2021 has less entries than previous years, quite possibly due to the closure of the slaughterhouse plant for several weeks, due to the Covid-19 pandemic and the factory`s purchase by another company. Even so, possible conclusions to be drawn from this study can easily be extrapolated to the Scottish pig industry level and be regarded as an indicator for future analysis.

Continuing the exploratory analysis, 118 slaps were included in this study. Traditionally, the fourth quarter, that comprises the months of October, November, and December, is the strongest one in terms of the volume of pigs slaughtered, a trend that was true for 2018 and 2019. However, in 2020 and 2021, the slaughter peak was achieved in the third and first quarter, respectively. The number of pigs slaughtered annually maxed out in 2020, with a total of 281,742, whereas the lowest value was registered in 2021 with 188,945 pigs. As for the average number of pigs per slap, it fluctuated annually, with the peak value being reached in 2020 with 5,017 pigs, a minimum value of 1 pig per slap and a maximum of 32,219 animals.

On the subject of carcase quality, the average probe values increased 1mm from 2020 to 2021, from 11.5mm to 12.5mm, with the average lean meat content decreasing too and hitting the value of 62.30%. Nonetheless, even with this decrease, the carcases were still included in the category S (60% or more of lean meat as a percentage of recorded carcase cold weight) of the SEUROP grid.

As previously highlighted by (Alban et al. 2022), the comparison of the meat inspection code systems between countries is difficult, due to lack of uniformization, as the systems vary considerably regarding terminology, number of codes available, and the way the codes can be categorised. When the data was initially collected, total and partial condemnations were gathered jointly in a single database called “Parts”. Firstly, it was necessary to understand the conditions that led to partial or total condemnations and organize the different code systems in an orderly way, so that the comparison with data from other countries would be possible.

The percentage of PCs fluctuated between 2018 to 2021, yet the overall value was of 12.89%. Surprisingly, contrary to what was initially expected, the lowest percentage of PCs (12.41%) was registered in 2021, the year of a dramatic crisis in the meat sector. The year of 2019 had the highest PCs percentage, with 13.54%, but falling behind 2020 in terms of the kgs of PCs condemned (51,679 kgs against 54,199 kgs).

In terms of PCS at an individual level, the main conditions registered belonged to the Respiratory system, with “Pleurisy” accounting for 61.01% of the occurrences, followed by “Abscesses” (12.18%), “Arthritis” (11.61%) and “Bruising” (6.18%), with the rest of the entries representing less than 2% each. The percentage for “Pleurisy” is identical to what was reported by Alban et al. (2022) for Germany (63.2%), yet lower than the values described for Italy (38.0%), Denmark (26.7%) and Portugal (12.9%) in 2019. As for the weight deduction values done by the slaughterhouse, “Pleurisy” was again the leading factor, with 60,128 kgs condemned.

Concerning PCs at batch level, the average number of pigs per batch was 119 with a minimum value of 10 animals and a maximum of 440. In these batches, on average, 0.4 pigs were partially condemned, with a standard deviation of 3.86 and the average number of PCs amounted to 0.4, with a standard deviation of 4.12. Regarding the kgs of PCs, on average per batch, 0.6 kgs were rejected, with a maximum of 205.5 kgs.

The percentage of TCs varied between 2018 to 2021, but the overall value of 0.36% is within the ranges previously described in literature. The highest percentage (0.53%) was recorded in 2021, a year tarnished by the pig farming and meat processing crisis. The combined effects of Brexit and the pandemic caused meat processors to routinely slaughter fewer pigs, instigating a backlog and overcrowding on farms, while posing problems around animal health and welfare. Another reason for concern is the low supply of CO_2 used for stunning pigs, due to the soaring price of natural gas, which further limited the capacity of abattoirs. This meant that pigs were sent to slaughter with heavier weights, an observation supported by the variation in the carcase quality parameters: in 2018 the average carcase weight was of 84.6 kg, with a standard deviation of 8.73kg, whereas in 2021 this value had increased to 93.7kg with a standard deviation of 11.4kg. Not only was this growing trend observed in this study, but also at national level, with average carcase weights of 87.2kg in the UK and 87.9 kg in Scotland (Macdonald 2022).

Alban et al. (2022) conducted a study that compared total condemnation percentages in seven different European countries, where this value ranged from 0.11% to 0.51%. Garcia-Diez and Coelho (2014) reported 0.24%, in 161,001 pigs killed in Portuguese abattoirs from March 2006 to September 2012. In another article, by J R Hill and Jones (1984), of the 1.3 million pigs slaughtered at seven abattoirs in England, 0.2% were totally condemned. Huey (1996) reported a percentage of 0.7%, in a universe of 75,130 slaughtered pigs, for Northern Ireland. Lastly, a report published by the Portuguese Official Veterinary Authorities, indicated a value of 0.32% for 2018 and 0.42% for 2019, on a national level. The differences seen in Scottish data and the literature can be attributed to the year in which some of these studies were conducted (logically, changes in pig production systems were massive from the 80s and 90s, when compared to current times), the distinct particularities of each country (for instance, the proportion of pig outdoor vs indoor herds varies within European countries), the changes in meat inspection systems and the way information is recorded and stored within these.

Regarding the causes for TCs, “Suspect cases of pyaemia and multi abscesses” were responsible for 57.47% of occurrences, “Polyarthritis” followed in second place (26.40%), with the rest of the entries amounting to less than 4% each. The percentage for “Suspect cases of pyaemia and multi abscesses” is higher than what was reported by Alban et al. (2022) for Norway (33.3%), Germany (31.9%), Spain (28.5%), Italy (21.6%), Denmark (11.6%) and Portugal (8.5%) in 2019. Similarly, “Polyarthritis and Arthritis” only accounted for 10.3% of TCs in Portugal, 6.3% in Norway and 2.5% in Spain. These disparities can possibly be explained by the use of distinct terminology and the way condemnation categories are set.

Regarding entries with high public health relevance, only 0.37% out of 3,541 pigs were totally condemned due to a generalised form of TB (n=9) or Erysipelas (n=4). On the other hand, 1.07% of pigs were partially condemned because of Erysipelas (n=745) and TB-like lesions (n=659), respectively. One limitation is the lack of information regarding the identification of causative infectious agents responsible for PCs and TCs. An important remark goes to the high percentage of TCs and PCs, due to “Polyarthritis and “Arthritis”. As stated before, Erysipelas may cause disease, often in the form of arthritis. Even though it is always important to identify the possible causative agents, in this case, due to its zoonotic nature, suspicious carcases should be sampled and selected for analysis.

After running the descriptive analysis, a few hypotheses were put into consideration. The first one consisted in analysing whether probe average values differed in carcases that were partially condemned. To this end, a linear mixed model was fitted. The outputs showed that, for one unit increase of the number of PCs per pig, the probe value was expected to decrease by 0.370; with one increase in year, the probe average values were expected to increase by 0.189; with one increase in quarter, the probe average value were expected to increase by 0.152. The increase of the probe average by year can be explained by the rise of the weight at slaughter, as with higher probe values, the LMP decreases. Due to the pandemic and the consequent backlog in farms, pigs were slaughtered at heavier weights, from 2019 onwards.

To study whether a higher variability in the weight at slaughter was associated with a higher probability of having at least one partial condemnation, a logistic regression model was fitted. Even though in numerical terms the model showed that more heterogeneous batches in terms of weight were more likely to have at least one partial recorded, this difference was not statistically significant.

Finally, one of the study goals was to assess whether the category of partial condemnation was associated with a specific slap mark or if it was broader in scope. Out of the 20 slap marks, 2 slaps had a "Pleurisy" percentage above 30%; 7 slaps between 20-30%; 11 slaps between 20-10%. For "Welfare Indicators" and "Abscesses", all slap marks had values below 4%. For "Arthritis", 1 slap was rated 7.91%, 2 slaps between 2-3%, 10 slaps between 1-2% and lastly 7 slaps with entries below 1%. When considering slap marks with a "Pleurisy" percentage above 30%: slap "A" had the highest "Pleurisy" condemnation rate (36.67%), ranked 9th place for both "Arthritis" (1.67%) and "Abscesses" (1.67%) and finally 6th place for "Welfare Indicators" (1.67%); slap "B" had the second highest "Pleurisy" condemnation rate (32.13%), ranked 1st for "Arthritis" (7.91%), 5th for "Abscesses" (2.4%) and 19th for "Welfare Indicators" (0.48%). Lastly, the Kruskal-Wallis tests showed no statistical significance. Hence, the categories of partial condemnations are broader in scope, even though a trend was identified for slap "B", which ranked 2nd for "Pleurisy" and 1st for "Arthritis".

Several difficulties were encountered when cleaning the initial datasets, especially when it came to fully understanding the many variables and their meaning. Even though the data was extracted directly from the slaughterhouse server, many entries were erroneously included, some days had no recorded condemnations, some carcase weights were generated automatically and did not represent real values, the data formats were not always the most suitable for the analysis and the amount of data, close to one million entries, increased the number of obstacles in the way. Another limitation of the data collection system that became evident with this work was that despite gathering large amounts of records, much of this information is presented to slaughterhouse management team as raw data and a considerate amount of useful information can potentially get lost in the process.

Even with these shortcomings, this data, especially condemnation data, could be used to set up surveillance networks, including syndromic surveillance systems, a relatively novel approach that relies on the detection of individual and population health indicators (for instance, behavioural patterns, signs, and symptoms) that are present before a laboratory diagnosis is achieved (Mandl et al. 2004). The assumption behind any syndromic surveillance system is that these changes can be noticed if routinely collected data are analysed continuously (Dórea et al. 2011). In a scientific study conducted by Merca et al. (2022), production data recorded routinely in Swedish breeding pig farms were used to detect early signals of reproduction failure and identify potential PRRS outbreaks. Similarly, condemnation data of public health relevance, such as Erysipelas, can be monitored over time to identify outbreaks or problematic farms. Complementary data, like meat sanitary inspectors' ID and Food Chain Information records should be used too. The setting up of an automated system to process these data regularly (i.e., weekly) would provide useful feedback for farms and for food safety authorities.

With the increasing societal concerns around animal welfare, the need for more reliable welfare indicators is becoming increasingly more evident. Precision livestock farming (PLF) systems, which make use of sensors, have been developed to gather data on tail length and tail biting lesions at slaughter and can provide additional sources of information to consumers and the industry about the welfare of pigs. According to D'Eath et al. (2014), early warning signs, namely pigs holding their tails tucked under, could be automatically detected using PLF methods, allowing earlier reaction and prevention of further tail damage on farm. Systems of these sort implemented at the slaughterhouse could systematically assess tail lesions of all pigs slaughtered and generate the necessary data to support the phasing out of routine tail docking on farm. Highlighting the need for this, the EU has recently launched a call to support the development of PLF systems to, in an automated fashion, measure tail length and tail lesions of pigs at the slaughter line (HaDEA 2022).

Post-mortem meat inspection is traditionally based on visual observations of lesions, which is a subjective parameter and sometimes not a true reflection of the actual infection status of the carcase. Visual inspection of slaughtered carcases for pathological changes should ideally be supported by bacteriological analysis (Alfifi et al. 2022). For this analysis, this type of data was not available, but it should be considered for potential future studies, especially since the main public health hazards arising from meat consumption nowadays are not detected via traditional meat inspection (Blagojevic et al. 2021). Another study limitation relates to the probe used to assess carcase quality. As stated before, this type of equipment is outdated, with the values measured varying with sexes, breeds, and originating errors around 10 % higher than those of the electronic probes (Daumas 2001). Therefore, caution should be taken when interpreting some of these results.

7. Conclusion

Prior to this study, an exploratory analysis of pig carcase quality and the most common partial and total condemnations in the Scottish pig industry had not yet been conducted. The exploratory analysis showed results for partial and total condemnations consistent with previous findings for other European countries. The study hypotheses showed that carcases with a higher number of PCs registered, had a lower probe average value; that numerically, more heterogeneous batches in weight were more likely to have at least one partial condemnation recorded, even though this was not statistically significant; that categories of partial condemnations were broader in scope and not associated with a particular farm.

The type of data presented in this work can be used to assess carcase quality parameters, monitor the evolution of the most common partial and total condemnations, and serve as a basis to set up disease surveillance systems for the Scottish pig industry. The objective of such a system would be two-fold: to safeguard public and animal health, and to promote the sustainability and efficiency of the Scottish pig sector. Disease surveillance acts as an essential communication point and can be defined as an information-based activity involving the collection, analysis, and interpretation of large volumes of data (Nsubuga et al. 2006). The information collated can then be used to assess the effectiveness of control and preventive health measures, monitor changes in infectious agents and disease patterns, identify high risk populations or areas to target interventions and act a valuable archive for future references. However, the collection of data must be standardised and provided at local, regional, and national level.

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Appendices

Appendix 1- Main Causes of total condemnations (TCs), according to the number of pigs slaughtered during 2019 in seven European countries (adapted from Alban et al., 2022).

Countries	Main Causes of TCs	Percentage
Denmark	Circulatory disorders	43.3%
	Osteomyelitis including related soft abscesses	11.6%
	Acute Pleuritis	10.9%
	Icterus	10.4%
	Gastric Ulcer	8.3%
	Rectal Stricture	6.9%
	Dead on arrival	6.0%
	Acute Erysipelas	5.6%
	Acute Peritonitis	4.6%
	Septicaemia	4.2%
Germany	Multiple Abscesses	31.9%
	Organoleptic Changes	17.2%
	Errors due to slaughter process	11.1%
Italy	Contamination with faeces or bile	19.7%
	Spinal, neck and thigh abscesses	21.6%
	Erysipelas	12.9%
	Pleuritis	11.9%
	Peritonitis	
Norway	Systemic Disease	57.3%
	Abscesses	33.3%
	Phlegmons	33.3%
	Peritonitis	26.6%
	Pericarditis/Pleuritis	19.7%
	Gastrointestinal Disease	13.2%
	Abnormal Colour	7.5%
	Arthritis	6.3%
	Pneumonia	5.5%
	Urinary Tract Diseases	5.1%
	Skin Diseases	4.7%
Portugal	Osteitis	36.3%
	Polyarthritis and Arthritis	10.3%
	Multiple Abscesses	8.5%
	Peritonitis	7.1%
	Pneumonia	7.2%
	Pleuropneumonia	6.9%
	Cachexia	5.9%
	Multiple lung or pleural abscesses	2.4%
	Traumatised, bloody, or organoleptic changed meat	1.8%
Spain	Abscesses or Multiple Abscesses	28.5%
	Icterus	20.5%
	Suppurative Osteitis	17.8%
	Erysipelas	4.4%
	Cachexia	4.0%
	Septicaemia	2.6%
	Polyarthritis	2.5%
	Delayed evisceration	1.9%
	Organoleptic alterations	1.7%
	Over scalding	1.7%

Appendix 2 - Main Causes of partial condemnations (PCs), according to the number of pigs slaughtered during 2019 in seven different European countries (adapted from Alban et al., 2022).

Countries	Main Causes of Partial Condemnations	Percentage
Denmark	Chronic Pleuritis	26.7%
	Mechanical errors related to slaughter	24.3%
	Contamination with bile	8.5%
	Scar/ Contusion/Bursitis	5.7%
Finland	Pleuritis	22.5%
	Ascariasis	5.0%
	Pericarditis	4.3%
	Abscess(s)	3.0%
	Arthritis	2.8%
	Pneumonia	2.7%
	Tail Biting	1.0%
Germany	Conditions in the Respiratory Tract	63.2%
	Ascariasis	27.4%
	Alterations of the Kidney	13.9%
	Pericarditis	11.8%
Italy	Respiratory Diseases*	38.0%
	Ascariasis	4.5%
Norway	Tail wounds/short tail	0.07%
	Liver Parasitism	0.06%
Portugal	Liver Parasitism	34.0%
	Lung Emphysema	18.7%
	Lung Pneumonia, Pleuritis, Pleuropneumonia	12.9%
	Liver Degeneration	7.5%
	Stomach/Intestines-Enteritis	5.8%
	Lung-slaughter bleeding	4.3%
	Liver-hepatitis	3.0%
	Stomach/Intestines-parasitism	2.6%
	Lung–congestion	1.4%
	Claws–arthritis	1.2%
	Heart-uncomplicated infectious pericarditis	1.2%
Spain	No available record	No available record

*Including “Pleuritis”, “Enzootic Pneumonia” and “Pleuropneumonia”.

Appendix 3 - Probe average values and its relationship with the average LMP and SEUROP category.

Year	Probe Average Category	Nº Entries	Interval Average LMP (%)	SEUROP CATEGORY	(Nº Entries/Total Year) %
2018	**[0-5]**	48	66.67-64.92	S	0.02%
	]5-10]	76,762	64.58-63.18	S	30.04%
	]10-15]	165,567	62.83-61.43	S	64.79%
	]15-20]	12,644	61.08-59.68	E/S	4.95%
	]20-25]	485	59.34-57.94	E	0.19%
	]25-30]	25	57.59-56.19	E	0.01%
	]30-35]	0	55.84-54.45	E/U	0.00%
	]35-40]	0	54.10-52.70	U	0.00%
2019	**[0-5]**	87	66.67-64.92	S	0.03%
	]5-10]	99,051	64.58-63.18	S	38.76%
	]10-15]	158,353	62.83-61.43	S	61.97%
	]15-20]	8,113	61.08-59.68	E/S	3.17%
	]20-25]	268	59.34-57.94	E	0.10%
	]25-30]	16	57.59-56.19	E	0.01%
	]30-35]	1	55.84-54.45	E/U	0.00%
	]35-40]	0	54.10-52.70	U	0.00%
2020	**[0-5]**	220	66.67-64.92	S	0.09%
	]5-10]	111,832	64.58-63.18	S	43.76%
	]10-15]	154,524	62.83-61.43	S	60.47%
	]15-20]	14,493	61.08-59.68	E/S	5.67%
	]20-25]	631	59.34-57.94	E	0.25%
	]25-30]	38	57.59-56.19	E	0.01%
	]30-35]	0	55.84-54.45	E/U	0.00%
	]35-40]	0	54.10-52.70	U	0.00%
2021	**[0-5]**	45	66.67-64.92	S	0.02%
	]5-10]	48,154	64.58-63.18	S	18.84%
	]10-15]	117,488	62.83-61.43	S	45.98%
	]15-20]	21,789	61.08-59.68	E/S	8.53%
	]20-25]	1,298	59.34-57.94	E	0.51%
	]25-30]	159	57.59-56.19	E	0.06%
	]30-35]	8	55.84-54.45	E/U	0.00%
	]35-40]	2	54.10-52.70	U	0.00%

Appendix 4 - List of the parts partially condemned, and its percentage (%).

Parts Condemned	Nª of Parts Condemned	Percentage (%) of Parts Condemned
Pleura	78,231	59.74%
Trim	17,988	13.74%
Hock (Hind)	8,818	6.73%
Leg	6,437	4.92%
Skin	5,152	3.93%
Hock (Fore)	3,831	2.93%
Head	3,516	2.68%
Trotter	2,182	1.67%
Tail	1,534	1.17%
Belly	1,285	0.98%
Ribs, including Pleura	1,168	0.89%
Chump	536	0.41%
Loin	87	0.07%
Shoulder	79	0.06%
Hind 1/4	68	0.05%
Hand	22	0.02%
Fore 1/4	16	0.01%
Half Carcase	5	0.00%
TOTAL	130,957	100%

Appendix 5 - List of the conditions that led to partial condemnations (PCs) and its percentage (%).