Sustainability of Broiler Production

Contents

Summary

This report explores a comprehensive approach to developing a sustainable model for broiler production by integrating environmental, social, and animal welfare considerations - framed under the themes of Poultry, Planet, and People. Sustainability is defined as a holistic concept, requiring a balance between environmental responsibility, economic viability, and social equity. In the context of broiler production, this involves minimizing resource use and emissions but also promoting human and animal health and welfare.

The poultry sector has a relatively low environmental footprint compared to other livestock production systems, largely due to intensive genetic selection aimed at maximizing growth rate and high stocking densities. However, this efficiency has come at a significant cost to animal welfare.

Adopting the Better Chicken Commitment (BCC) criteria offers the potential to substantially improve the welfare of billions of chickens worldwide. Nevertheless, this shift is expected to result in an increase in greenhouse gas emissions. The extent of this environmental impact remains uncertain, as current assessment tools are not yet fully validated and only partially capture the complex, multi-dimensional nature of sustainability.

In BCC-compliant systems, like in any system, the environmental impact of broiler production can be mitigated through a range of individual practices. Feed production, which contributes to the majority of greenhouse gas emissions in the broiler sector, represents a key area for intervention. Strategies such as reformulating feed with alternative protein sources and selecting more sustainable ingredients are discussed as promising ways to reduce emissions. Using renewable energy and improving manure management can further decrease environmental impact. Beyond the farm, changes in processing practices and consumer-facing interventions - such as sustainable menu offerings and reducing food waste - offer further opportunities to reduce environmental impact across the value chain.

BCC-aligned systems also present additional advantages that must be taken into account when assessing their environmental impact and overall sustainability, such as lower mortality and fewer carcass downgrades, which contribute to reduce food and feed waste and a decreased need for antibiotics.

In conclusion, achieving a truly sustainable broiler production model requires an integrated approach over the entire production lifecycle, that addresses all components of sustainability, while ensuring ethical treatment of both people and animals.

1. Poultry, Planet, People: Defining a sustainable model of broiler production

1.1. Definition of sustainability

In 1987, the United Nations Brundtland Commission[1] defined sustainability as "*meeting the needs of the present without compromising the ability of future generations to meet their own needs*". Today, there is not a single universal definition of sustainability, but it has often been based on three pillars since the late 80's: people (social sustainability), planet (environmental sustainability) and profit (economic sustainability)[2].

Sustainable development is also one of the most widespread terms used to describe sustainability goals aimed to address global inequality in economic prosperity and the climate crisis. In this framework, the United Nations Environmental Assembly proposed 17 sustainable development goals (SDGs) to transform the world by "ending poverty, protecting the planet and improving the lives and prospects of everyone, everywhere". These goals were adopted by all United Nations Member States in September 2015 as part of the 2030 Agenda for Sustainable Development with the objective of ending poverty, protecting the planet and improving people's lives (Figure 1)[3].

Figure 1: Sustainable development goals (SDGs) (United Nations Environmental Assembly, 2015[3]).

The lives of animals are strongly linked to the life of people, as animals play various roles in our societies and the environment. Concepts like One Health[4] and One Welfare[5] suggest that the health and welfare of people and that of animals are interdependent. This interconnectedness highlights the importance of considering both human and animal health and welfare in a holistic manner to ensure a balanced and healthy ecosystem. However, animal welfare is not explicitly included in any of the SDGs, which have been criticized for being "anthropocentric"[6]. Despite of this, several experts have analysed the goals and concluded that working towards fulfilling these goals is compatible with the improvement of animal welfare[7,8]. For example, experts have acknowledged that animal welfare can contribute to addressing environmental challenges and have promoted a One Health/One Welfare approach to achieve the SDGs[8,9] . Additionally, there have been recent calls for non-human animals to be explicitly included in the SDGs[6].

The need to broaden the scope of sustainability to encompass animal welfare is being increasingly supported, as a growing body of research is highlighting the interconnectedness of environmental, social, and economic dimensions of sustainability with the humane treatment of animals. Numerous studies emphasize the significant negative impact of industrial farming practices on animal welfare, not only raising ethical concerns but also highlighting the potential repercussions on the overall sustainability of food systems[9].

It is now widely recognized that animals are sentient beings, capable of suffering and experiencing positive emotions[10]. A growing body of scientific evidence also demonstrates how animals suffer in intensive farming systems which do not meet their physical and behavioural needs. Authors like Drury and colleagues[6] called sustainability "an ethical construct in which animal welfare must always be included". Other authors, like Boyle and colleagues[7] state that animal welfare is a common good that entails a shared responsibility and an ethical obligation.

Moreover, explicitly acknowledging animal welfare as an integral part of sustainability is better aligned with expectations from the general public. When consumers are asked about sustainability in the context of food, ethical production - with a particular emphasis on animal welfare- consistently appears as one of the main considerations[11].

By including animal welfare in the sustainability discourse, we can aim for more comprehensive and ethically sound production models that promote long-term ecological balance, social equity and economic resilience.

1.2. Sustainability of broiler production

DEFINITIONS

- **Green House Gases (GHG):** Group of gases contributing to global warming and climate change[12]. Currently covers seven greenhouse gases:
  - the non-fluorinated gases:
    - carbon dioxide (CO_2)
    - methane (CH_4)
    - nitrous oxide (N_2O)
  - the fluorinated gases:
    - hydrofluorocarbons (HFCs)
    - perfluorocarbons (PFCs)
    - sulphur hexafluoride (SF_6)
    - nitrogen trifluoride (NF_3)
- **Global Warming Potential (GWP):** Term used to describe the relative potency, molecule for molecule, of a greenhouse gas (carbon dioxide, methane, nitrous oxide), This term takes into account how long it remains active in the atmosphere, which is currently calculated over 100 years. Carbon dioxide is taken as the gas of reference and given a 100-year GWP of 1[13].
- **Land Use Change (LUC):** Change over time of the distribution of land uses within a country. A land use can be defined as a series of human activities undertaken to produce one or more goods or services. According to this definition, land use provides a basis for analysing social, economic and environmental characteristics, and allows to differentiate various land use types, where required[14]. In this context, LUC is considered a process where human activities transform the natural landscape, from one land use category to another because of human activity. e.g. soybeans on deforested land produced in parts of South America.
- **Life Cycle Analysis (LCA):** Method used to assess the environmental impact associated with all the stages of a product's life — from raw material extraction through materials processing, manufacturing, distribution, use, repair and maintenance, and disposal or recycling.
- **Life Cycle Inventory (LCI):** Second step of a Life Cycle Analysis consisting of quantifying all the inputs (e.g., energy, water, raw materials) and outputs (e.g., emissions, waste) associated with each stage of a product's life cycle.

The livestock sector accounts for approximately 14.5% of the total anthropogenic (due to human activity) greenhouse gases (GHG) emissions. Although meat and dairy production uses 70% of all agricultural land and 40% of the arable cropland, they produce less than 20% of the global food energy requirements[15]. A high percentage of this land use is dedicated to producing animal feed. For instance, in 2019 in the European Union, 71% of the agricultural land was used to this purpose[16].

Compared with other species, broiler production is considered as one of the most sustainable livestock production systems in terms of its relatively low GHG emissions[17,18] (Figure 2). This efficiency has been enhanced by an intensification of the production practices over the past decades, using genetic selection to achieve dramatic increases in growth rates and keeping birds at high stocking densities (i.e. maximizing the number of birds that can be kept per meter square). However, these practices have been shown to have severe negative repercussions on the birds' health (e.g. impaired walking ability, sudden death syndrome, ascites), behaviour (e.g. inability to display natural behaviours, high inactivity) and mental welfare (e.g. increasing negative emotional states such as stress and fearfulness).[19]

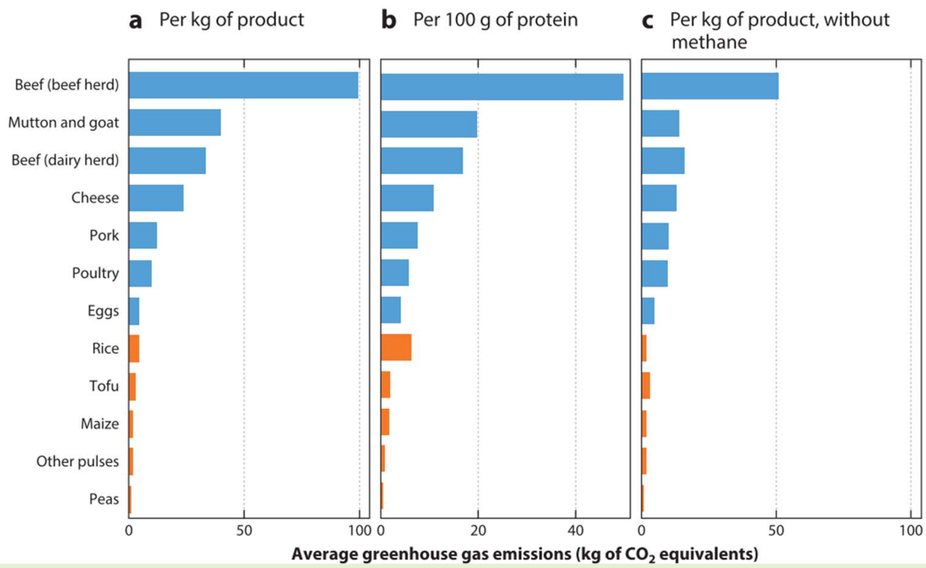


Figure 2: Average GWP for the production of animal and plant-based food (from Clark et al., 2022[17]).

With growing awareness over the impact of intensive farming on the welfare of broiler chickens, initiatives such as the Better Chicken Commitment (BCC; also called European Chicken Commitment in Europe, ECC) have been introduced to improve broiler chicken welfare in Europe, North America, and beyond. The BCC is a science-based framework, developed by a coalition of animal welfare organisations, aimed at driving meaningful welfare improvements for broilers through the adoption of a set of key criteria by industry stakeholders.

Concerns have been raised that the BCC criteria, while improving broiler welfare, could directly conflict with other environmental goals and in particular with food companies' commitments to reduce the carbon footprint of their broiler supply chain. Indeed, certain components of the BCC will reduce the efficiency achieved in current conventional broiler production systems. For instance, the BCC requires the use of higher welfare breeds, which typically have a slower growth potential and are less efficient at converting feed than the fast-growing breeds commonly used in intensive systems. The BCC also requires a lower stocking density (max 30 kg/m^2 vs max 39-42 kg/m^2 in standard systems), meaning less birds can be reared in a BCC shed. Therefore, more birds, more barns, and more feed would be needed if the aim was to produce the same amount of chicken meat. These concerns also apply and are even exacerbated in other higher welfare systems, such as extensive indoors, free-range and organic systems, where stocking densities are even lower and slow-growing breeds are often used.

Corporate sustainability policies are often directed to address the environmental impact of the company's activities and tend to focus solely on emissions. However, sustainability covers more aspects than environmental impact, which all need to be considered holistically when looking at the sustainability of broiler production. As proposed by Bist and colleagues[20], a framework for sustainable poultry production should consider the impacts of a system on the planet, people and animals (Figure 3)[20].

In this document we will use this "**Poultry, Planet, People**" framework to look at the impact, mitigation strategies and potential opportunities associated with higher welfare chicken production.

Figure 3: Holistic view of the sustainability of poultry production (from Bist et al., 2024[20]).

1.3. Assessing the sustainability of broiler production

In order to discuss the environmental impact and overall sustainability of different broiler production systems, it is important to be able first to assess their impact appropriately and consistently. However, assessing the impact of different systems is not an easy task, and attempts have been made both in the scientific literature and by industry stakeholders.

1.3.1. The Life Cycle Assessment (LCA) method

A common method used to estimate the environmental impact of a product, in this case broiler meat, is the life cycle assessment (LCA). The LCA includes all processes and related environmental impacts in the entire life cycle of the product, focusing not only on carbon footprint, but also on other issues such as eutrophication from nitrate and phosphate leaching or acidification due to ammonia. However, the LCA method is designed to emphasize the productive performance of the systems, meaning that highly productive broiler systems using fast-growing strains typically display better LCA performance than systems using slower-growing strains with longer rearing periods for example[21]. Integrating certain distinctions in environmental impact between conventional systems and higher welfare systems, such as organic, proves challenging within the confines of a LCA. This is because the LCA lacks the capacity to incorporate information regarding, for example, the impacts of a system on biodiversity or soil quality[21]. Lastly, as it has been highlighted[22], this method is highly dependent on the database used, as different effects and results can be obtained depending on the database used.

1.3.2. The need for holistic approaches when assessing sustainability

There is a need for comprehensive approaches to the assessment of the sustainability of broiler production systems, using multi-criteria analysis that account for factors not considered in the LCA, such as bird welfare and health (including antibiotic use) and meat quality[23]. Evaluating broiler production systems solely on individual aspects like socio-economic or environmental factors can lead to erroneous or superficial conclusions about the best system. Therefore, it is crucial to employ holistic methodologies that allow a comprehensive assessment of sustainability in broiler production[24].

For example, Meda and colleagues[11] (2021) developed a consensual assessment grid for the sustainability of chicken supply chains, co-constructed with various French stakeholders (including industry members, researchers, NGOs, etc.), and tested it to compare conventional chicken production systems in France and the traditional free-range Label Rouge systems. The results of the analysis showed that Label Rouge systems performed better in the three pillars of sustainability - economic (creating value on the territory or creating local jobs), social (meeting citizens' expectations, improving acceptability of the poultry sector) and environmental (optimizing management of resources, preserving natural habitats), than current conventional methods, even when the tool did not include animal welfare in the assessment[11].

1.3.3. Sources of variation in the environmental impacts of different broiler production systems

To better understand the impact of moving to higher welfare broiler systems, CIWF commissioned a report looking at the environmental impact of different broiler production systems based on the available scientific literature[25]. The objective of this report was to determine which characteristics of each system contributed most to the environmental impact, identifying them as possible targets for mitigation strategies.

The report consisted of a literature search and meta-analysis to compare production systems: conventional, higher welfare indoor, free range, and organic. The report also outlined the impact of key characteristics of higher welfare systems, such as breed, stocking density or environmental enrichment, on environmental metrics like GWP, LUC, or biodiversity (Table 1).

Production Systems	System Characteristics	Environmental Metrics
Conventional	Broiler Strain	**Global warming potential**
Higher Welfare Indoor (BCC)	**Stocking Density**	Land use
Free Range	**Slaughter Weight**	Water use
Organic	Slaughter Age	Acidification & eutrophication potential
	Natural Light	**Ammonia emissions**
	Enrichment	Biodiversity Index
	Feed Conversion Ratio (FCR)	**Energy use**

Table 1: Production systems included in the meta-analysis. Due to the limited number of studies, and the lack of detail provided by some studies, the comparison of production systems was limited to three impact metrics (in bold): GWP, Ammonia emissions, and Energy used. The analysis of system characteristics was also limited to Stocking Density, Slaughter weight, and FCR (in bold) (From Kyriazakis et al.,2024[25]).

However, the low number of papers on the environmental impact of higher welfare systems, particularly higher welfare indoors systems, limited the analysis. Additionally, even within a broiler production system, there was a large variation in the values reported for the different environmental metrics (Figure 4). It was also difficult to separate certain systems and system features. For example, higher welfare systems almost exclusively used slower-growing breeds.

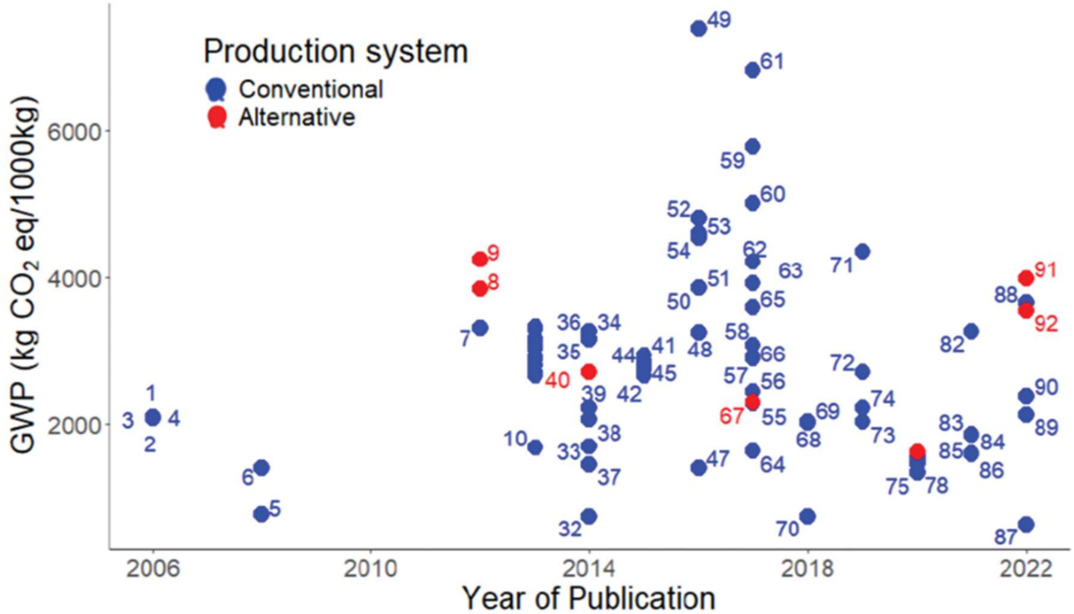


Figure 4: Global warming potential (GWP) measurement variation between different studies. Conventional systems are in blue, and higher welfare systems in red (from Kyriazakis et al., 2024[25]).

After reviewing the available literature, the report identified significant variation in the metrics used across the studies analysed. The choice of database and methodological approach plays a critical role in shaping the outcomes of environmental impact assessments. This variability has also been observed on the environmental impact of feed. For example, an experimental study by Alkhtib and colleages[26] showed that the choice of Life Cycle Inventory (LCI) database would condition the results when analysing the environmental impact of several broiler diets.

The report found that the GWP & Water use associated with feed production activities accounted for over 75% of the total environmental impact, making it the main contributor to the environmental impact of broiler production. Most of the GWP impact is associated with Land Use Change (LUC), especially that associated with unsustainable soybean production.

The report concluded that there were no statistical differences in the Global Warming Potential (GWP) between production systems. However, higher welfare systems were associated with a higher energy use. This is probably due to longer production cycles, higher heating needs as stocking density decreases, and the higher number of animals needed to produce the same amount of meat[27].

Additionally, the report highlighted that there is insufficient evidence available to fully evaluate the environmental impact of broiler production systems and the individual characteristics of each system:

- There is a lack of studies on the environmental impact of higher welfare systems.
- Better reporting on environmental metrics is needed across systems, especially regarding feed production activities.
- Validated environmental metrics not focused exclusively on GWP are needed.
- Future calculations should include aspects of higher welfare systems which can contribute to a sustainable model of production, such a lower antibiotic use or food waste.

Finally, the authors of the report pointed out that comparing systems may not be the most relevant approach. For instance, the high variation in environmental impact within conventional systems indicates there are better and worse practices within a system. Instead of comparing systems, it is more useful to improve key characteristics or practices within a system that can reduce environmental impact without compromising animal welfare.

2. Poultry

Chickens are the most widely farmed land animals, with over 76 billion slaughtered globally in 2023[28]. Consumption of chicken meat has doubled since the 90's [29]and it is estimated to grow by 15% in the next decade[30], driven in part by its affordability and the perception that it is the most "sustainable" meat option.

Most of these chickens reared for meat are farmed in intensive systems, unable to express most of their natural behaviours and suffering from a range of welfare and health issues. Given both the scale of suffering and the vast number of animals affected, improving chicken welfare must be a top priority[19,31,32].

The poor welfare of broiler chickens in intensive systems is partly due to the use of fast-growing breeds, selected to reach slaughter weight in only 35-40 days[19]. These birds have a high basal metabolic rate, and a high energy demand which can create oxygen deficits. This results in a high incidence of heart and pulmonary conditions, ascites, and even sudden death. Fast-growing broilers are also prone to leg and foot disorders. These conditions influence their locomotion and general activity, causing a poor walking ability, difficulty to access feed and water, pain, and inability to perform natural behaviours[19]. Additionally, there is abundant evidence regarding the prevalence of breast muscle myopathies and skin lesions related to fast growth and high breast yield[33].

Fast-growing broilers, due to their body conformation and poor health, have difficulties walking and expressing natural behaviours such as perching, preening, or foraging. This often translates in an increase in the percentage of time that the birds spend inactive and has a negative effect on their mental welfare[34]. Slower-growing breeds demonstrate a better response to stress than fast-growing ones, are more active and display a larger range of natural behaviours, resulting in a better mental wellbeing overall[35].

In conventional systems, chickens are reared at high stocking densities (typically 39-42 kg/m^2), which limits their behavioural expression and their ability to rest undisturbed. This low space allowance per bird, coupled with the walking difficulties of fast-growing breeds, increase the time birds spend in contact with litter, which can become too wet and cause injuries to the chickens' legs and skin[19].

Conventional production also often lacks enrichment (such as perching surfaces and pecking substrates) and natural light, and typically provides low light intensity – all of which increase the inactivity levels of the birds. Chickens prefer to perform some actions under high light intensities, while a source of natural light (e.g. windows) also helps behavioural synchronization and undisturbed resting[36–38]. The provision of appropriate perching surfaces and pecking substrates provide opportunities to express highly motivated perching and pecking behaviours[39,40].

In 2025, Karlsson and colleagues published a study using a literature review and an emissions model aiming to quantify the trade-offs between animal welfare and environmental sustainability in broiler production in Sweden[32]. Their findings indicated that the welfare gains achieved by transitioning to two slower-growing broiler breeds (Ranger Classic and JA757) and reducing stocking density from 36 kg/m^2 to 25 kg/m^2 significantly outweighed the associated increase in greenhouse gas emissions.

Reducing the stocking density was associated with a low increase in emissions and a moderate improvement in welfare indicators. Using slower-growing breeds had a large impact on both welfare and emissions. Notably, the trade-off was smaller when both measures were implemented together, suggesting that combining slower-growing breeds with lower stocking densities maximizes welfare improvements relative to the rise in emissions. Moreover, the study did not account for any potential mitigation strategies, implying that the actual trade-off between welfare and environmental impact may be even less substantial than reported.

3. Planet

Higher welfare systems should form the basis of sustainable broiler production. Significant welfare improvements can be associated with a higher environmental impact. However, higher welfare systems also offer significant benefits that need to be quantified when evaluating the environmental impact of transitioning to such systems. In addition, there is a number of best practices that can help to mitigate these impacts (see Table 4 for summary).

When analysing the source of emissions from chicken production (Figure 5), feed production appears as the highest contributor, indicating that the most effective strategies to mitigate the environmental impact of broiler production will relate to feed[41]. Addressing the remaining sources of emissions, such as energy use or manure production, can help to further mitigate the environmental impact.

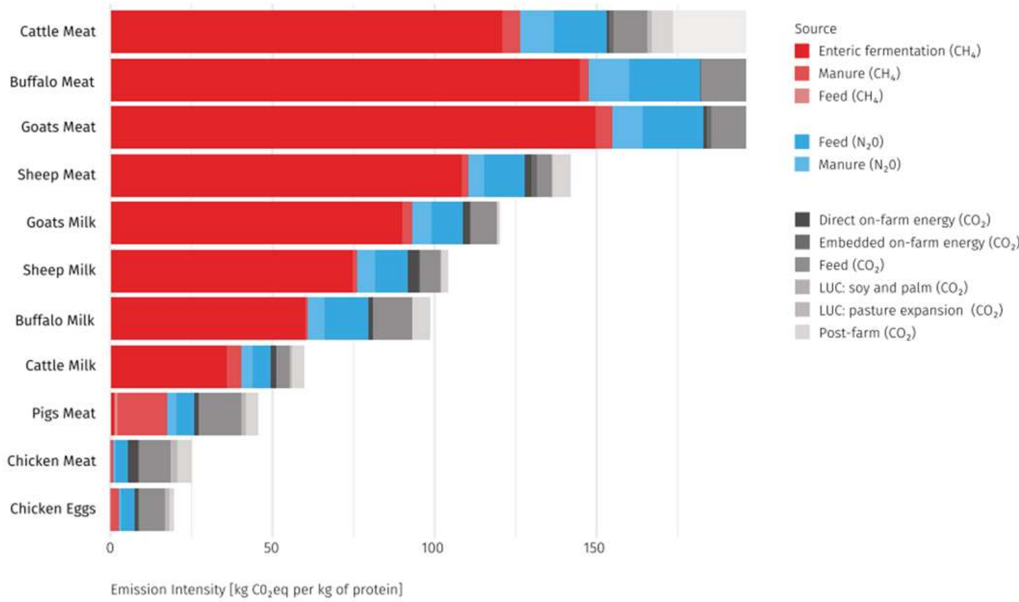


Figure 5: Emissions per unit of product, showing the source of emissions by species and food type (from FAO, 2023[42]).

3.1. Feed interventions

3.1.1. Challenges associated with BCC production

As previously mentioned, feed-associated activities are the largest contributor to the environmental impact of broiler production. More than 75% of the GWP in broiler production is due to feed production. This is mainly due to land use change and the production of unsustainable soya (linked with deforestation and biodiversity loss), which is widely used as a protein source for broiler feed in Europe.

Higher welfare systems require switching to slower-growing breeds with better welfare outcomes.[34] Slower growing breeds have a higher feed conversion rate (FCR), meaning that those birds need more feed to reach the same weight than fast-growing breeds. These breeds also have a lower breast meat yield as they have a more natural conformation[43]. Some authors have also raised the issue that in higher welfare systems, birds are either slaughtered at lower weights or at the same weights but with longer rearing times. In both cases more feed would be needed to produce the same amount of meat[44].

3.1.2. Mitigation strategies

Depending on the geographical source of feed ingredients, it may be important to include land us change (LUC) in the environmental impact calculations. Whether or not LUC is taken into account can greatly modify the results of an environmental assessment in broiler production. For example, most of the soya used as feed ingredient for the European chicken production comes from recently deforested areas of South America[25,45].

Some higher welfare broiler breeds can accommodate diets with lower digestibility, protein, and amino acids content[46,47]. For example, in 2022, the US producer Perdue reported that the environmental impact of moving from a conventional fast-growing breed to the BCC-approved Hubbard Redbro breed decreased from 9% to 1.5% when birds were fed a "low protein diet"[48]. Additionally, BCC parental stocks are more productive and require less feed, leading to advantages before the start of the production phase on FCR and carbon footprint against conventional broiler chicks[49].

Sourcing feed from local sources and/or with low LUC can significantly help reducing the environmental impact of broiler production. Using a model, Mostert and colleagues[49] (2022) estimated the GHG emissions from three different production systems in the Netherlands (conventional, Dutch retail standards, Beter Leven one star) looking at all production stages (breeder and broiler stages). Results illustrate how the GHG emissions related to feed production increase considerably when considering land use change, at all production stages and for all system types (Figure 6). This study also found that at broiler farm level, the higher welfare Beter Leven one Star (BLS) system had lower emissions compared to the conventional system. This was due to the inclusion of LUC from feed production, as the BLS breeds had lower nutritional recommendations compared to the other systems and therefore had a lower amount of soybean products in their diet.

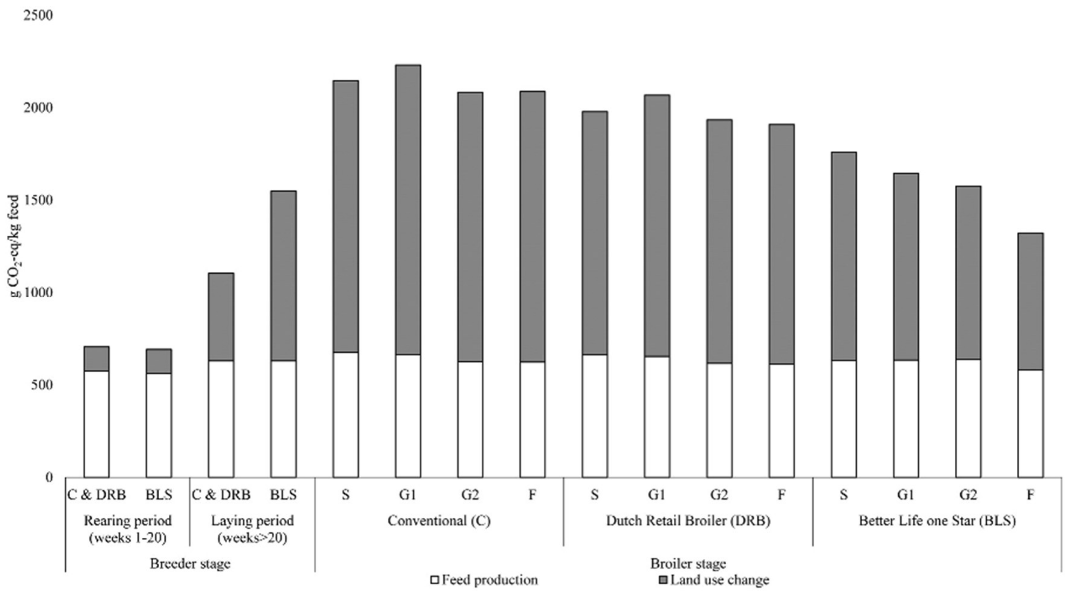


Figure 6: GHG (g CO2-eq /kg feed) of feed production and land use change emissions from feed production for the broiler breeder generation (rearing and laying) and broiler generation (starter, grower and finisher) for the conventional, Dutch Retail Broiler, and Beter Leven one Star broiler production systems. (From Mostert et al, 2022[49]).

Additional measures should be implemented to optimize the diet according to the breed-specific nutritional requirements. For example, the BCC-approved Redbro breed could decrease its GWP, including LUC, by moving from a conventional feed (3.5 kg CO2eq per kg broiler) to the feed recommended by Hubbard for the Redbro (2.55 kg CO2eq per kg broiler). The resulting GWP could be reduced even further by moving to a lower soya and lower nutrient density strategy (2.15 kg CO2eq per kg broiler). This could bring the GWP of the Redbro to a lower level than a conventional breed on a conventional diet (2.62 kg CO2eq per kg broiler). (Hubbard presentation at CIWF Broiler Forum, 2023).

The addition of enzymes to enhance the digestibility of proteins can also be a promising way to mitigate the environmental impact of slower growing breeds[20] (Burton presentation at CIWF BCBN webinar, 2025). Alternative feed ingredients, such as seaweed, can also reduce GHG emissions and ease the competition with human food (Table 2)[18,50]. Locally available by-products of the agricultural industry can also be introduced in the diets[51]. For example, alternative plant-based ingredients such as sunflower meal, corn gluten meal, faba beans with low tannins, and dried distillers' grains with soluble or DDGS (the dried residue remaining after the starch fraction of maize), can be used to substitute soybean meal[52,53].

A 2018 model by Tallentire and colleagues proposed that the environmental impact of transitioning to a slower-growing (38.6 g/day) breed could be partially mitigated by replacing soy with novel ingredients such as microalgae, yeast protein concentrate, bacterial protein meal, leaf protein concentrate, and insect meal[41]. This study found, based on a model using a LCA, a 55% reduction in greenhouse gas emissions and a 32% reduction in agricultural land use with a novel formulated diet for slower-growing birds including novel ingredients such as micro and macroalgae, duckweed, yeast protein concentrate, bacterial protein meal, leaf protein concentrate or insect meal. However, this diet was associated with an increase in Nitrogen (99%) and Phosphorus (29%) in the excreta, highlighting the need of an adequate manure management.

Using treated human food waste, previously sterilised using heat, in broiler feed can reduce carbon emissions by displacing food in landfills, reducing quantities of traditional feed ingredients, with a positive or neutral effect on growth performance indicators[54]. For example, types of food waste currently used as feed ingredients are bakery goods, dried tomato puree, dried and ground carrot, cornflakes waste and oyster mushroom waste. Additionally, by-products derived from the oilseed industry (soybean, sunflower, canola, cotton seed and cocoa seed meal or cake) can supply valuable components such as protein, amino acids, fatty acids and minerals[55]. Several studies have reported that incorporating food waste at different percentages resulted in similar or improved performance measures in chickens[54,56]. However more research is needed and there may be logistic difficulties to implement this solution at a large scale, related to the collection, transportation, storage, and handling of such materials[20].

Further steps to mitigate the environmental impact of feed production could be increasing the feed mill efficiency or moving to regenerative agriculture practices to grow feed ingredients.

	Description	Pros	Challenges
Insect-Based	Insects like black soldier fly larvae and mealworms, are rich in protein (35–53%), essential amino acids, and minerals, with a high digestibility rate	Lower greenhouse gas emissions and water footprints Can efficiently be reared on organic waste, aligning with circular economy principles Aligns with birds' natural insect-eating behaviour Potential performance benefits such as faster growth, better FCR	Ethical considerations (number of individuals, rearing conditions, lack of knowledge of welfare needs) Cost-effectiveness Different regulatory frameworks Consumer acceptance
Single Cell	Single-cell protein (SCP) derived from various microorganisms such as yeast, bacteria, and fungi	Sustainable protein production with protein content ranging from 12% to 76.4% Improvements in body weight gain and FCR at 5% and 10% inclusion levels	Cautioning against the use of 15% SCP in poultry diets as it may be harmful for the birds
Algal and seaweeds	A wide variety of algae and seaweeds including Chlorella, Spirulina, Ulva, Ascophyllum, Laminaria, and Sargassum	Requires minimal land and no freshwater. Can contribute to carbon dioxide mitigation through photosynthesis Some species contain unique bioactive compounds that can positively benefit poultry health	Scaling up production, maintaining consistent nutritional profiles, and addressing potential environmental impacts associated with large-scale seaweed farming High production and processing costs Potential toxicity or allergenicity Further research is needed to evaluate the effects of algae and seaweed on poultry health and performance under various conditions
By-Product and Food Waste	Waste coming from human food production, processing, distribution, and consumption chain	Reduction of greenhouse gas emissions, water consumption, land utilization, and waste Reduces reliance on expensive conventional feed ingredients Provided functional components such as protein, amino acids or fatty acids	Regulatory restrictions exist for certain types of food waste due to concerns about stability, disease transmission and contamination Logistical complexities related to the collection, transportation, storage, and handling of such materials

Table 2: Potential novel feed ingredients for broiler production (based on Bist et al., 2024[20]).

3.1.3. Advantages of BCC production

It has been suggested that slower-growing breeds have lower nutritional requirements[49] and adapt better to low-protein diets [57,58] than fast growing breeds, although further research is needed. Additionally, slower-growing breeds used in BCC-compliant production have other benefits that are often unaccounted for, including lower mortality rates and lower carcass downgrade. It has been estimated that 1 in every 20 chickens reared for meat in the UK and the US die before slaughter and never reach consumers[59]. In 2022, only in the UK, the mortality rate in broiler production was the highest in a decade, reaching nearly 7%[60]. That means that resources, specifically feed, were invested in growing more than 80 million chickens that were ultimately wasted. Several studies have reported that the total mortality of fast-growing breeds is significantly higher than slower-growing breeds[61,62]. For example, a 2020 study[62] reported that the mortality of a fast-growing breed on a UK conventional farm over four production cycles was 6.2% versus 2.6% for a slower-growing BCC approved breed.

Additionally, the difference in meat yield between conventional breeds and some BCC-approved breeds is not as large as it is often portraited. For instance, the Hubbard Redbro (a BCC approved breed) at a final live weight of approximately 2.2 kg had a breast meat yield percentage only 4.7 lower than the Ross 308 at the same weight[63].

Carcass downgrade is an additional problem of today's fast-growing broiler breeds. Achieving a large final body weight and high muscle yield in such a short amount of time often has detrimental consequences on the composition of the carcass of commercial broilers. Fast-growing breeds have higher rates of post-mortem rejections at slaughter due to different carcass quality issues, including ascites, discolouration, cellulitis, and perihepatitis[61,62]. A 2023 commercial study comparing the carcass condemnation rates of Ross 308 (fast growing) and JA787 (slower growing) chickens showed that the prevalence of ascites and discoloration was 6.5 and 2 times higher in the Ross 308, respectively[64].

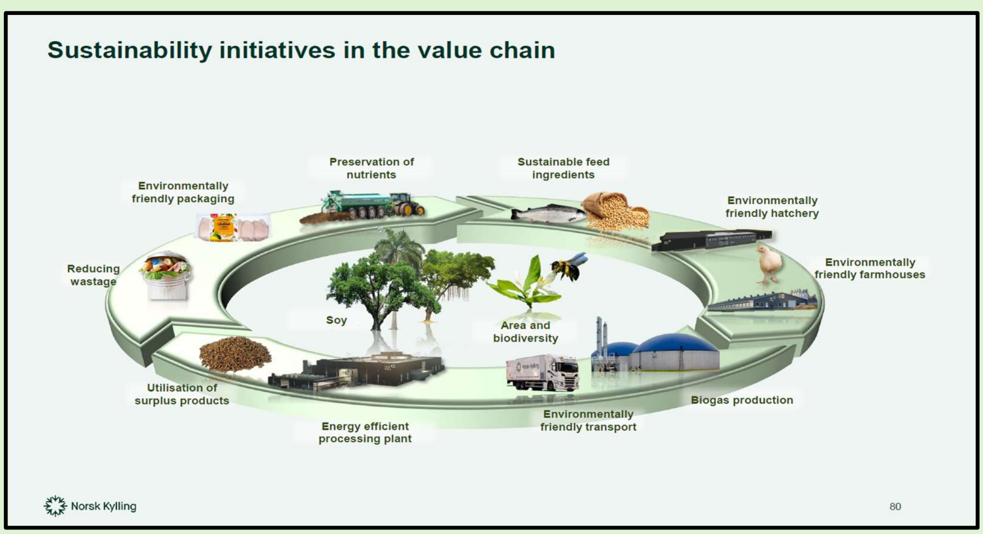
The most frequent issue affecting carcass integrity in fast-growing breeds are breast muscle myopathies, such as white striping or wooden breast[65]. White striping is reported to affect up to 50% of chicken breasts in Italy, Spain, France and Brazil[66], while an assessment by Kuttappan and colleagues found that 98% of breasts from nine-week-old broilers in the US showed some degree of white striping[67]. Slower-growing breeds have a lower incidence of breast myopathies. For example, a 2020 study showed that that while 99% of slow-growing birds were free of white stripping, only 72-96% of birds belonging to three conventional breeds[33] had no white striping. Therefore reducing mortality, carcass downgrades, and breast myopathies through the use of slower-growing chickens not only improves animal welfare but also benefits the environment by minimizing waste.

In Norway, producer Norsk Kylling transitioned from Ross 308 to the BCC-approved JA787 without an increase in emissions[68]. This was achieved thanks to re-formulating the diet, lower feed consumption at breeder stage, and lower transport emissions as a result of lower bird losses (mortalities) during grow out and transport (see Box 1 and Case study).

Box 1: An example of sustainable higher welfare broiler production: Norsk Kylling

Norwegian broiler producer Norsk Kylling is achieving higher welfare outcomes without an associated increase in GHG emissions. They managed to successfully switch from the conventional Ross 308 breed to the slower-growing breed JA787, while decreasing their GWP by 1%, thanks to a range of best practices:

- They are investigating alternative, locally sourced, and sustainable feed ingredients that require less land use.
- Norsk Kylling has targets of using 100% soy-free feed by 2030, along with a 50% reduction in the feed's carbon footprint, a 40% reduction in feed-related emissions and a 30% reduction in land use for feed production. The soy content in their feed in 2022 was 10%.
- They use renewable energy through the value chain, including a new environmentally friendly hatchery and an energy efficient processing plant.
- Transportation: 21% of their freight already relies on renewable fuel. The ambition is to increase this figure to 30% by 2025 and make a full transition to 100% renewable fuel by 2030.
- Less feed is wasted thanks to 27% lower daily mortality and 79% lower bird mortality during transport.
- Due to the lower percentage of meat downgrades and carcass condemnations, food wastage has decreased by 36%.
- They have developed environmentally friendly packaging solutions.
- They have created pollinator zones on farm, with wild vegetation around their farms, creating an area equivalent to 15 football pitches.
- They have a project aimed at converting manure into biogas.



3.2. Production phase

3.2.1. Challenges associated with BCC production

A) Energy

After feed production, energy use is the second largest contributor to greenhouse gas emissions in the poultry production sector[42]. GHG emissions from energy use account for approximately 11.4% of the GWP[63] in the US poultry production and for 4.2 to 7.3% of the GWP in Dutch broiler production[49]. Industrial farming is still highly reliant on fossil fuels. Additionally, the demand for electricity, mainly for ventilation and heating, has increased due to intensification and automatisation of broiler farms[69].

The energy needed per kg of meat produced is likely to be higher in indoor higher welfare systems[25]. This is due to the reduced stocking density and longer grow-out periods for higher welfare breeds, which may require more houses and energy for heating.

B) Manure and waste production

Additionally, the solid waste produced on farm (such as manure and litter) or in slaughterhouses (such as feathers or blood), often in large quantities, is a significant source of GHG emissions.

Many farmers spread chicken manure on fields as an alternative to synthetic fertilizers. However, the production of litter may exceed the need for fertilizers. Chicken manure production and storage is linked to ammonia (NH3), nitrous oxide (N2O) and methane (CH4) emissions. Ammonia emissions are a particularly important issue as they have a negative effect over the ecosystems and human health. For instance, volatilisation of ammonia used on agricultural land results in a loss of nitrogen, reducing its availability for plant growth. Ammonia reacts with moisture in the air to form ammonium (NH4), the deposition of which contributes to the acidification of soil and water. Additionally, the deposition of ammonia can cause an excess of nutrients, leading to, for example, algal blooms, a process known as eutrophication. And when combined with other air pollutants such as sulphuric acid and nitric acid, it forms secondary particulate matter (PM10) which can remains in the air for several days and travels long distances causing and respiratory problems in humans[70].

Poultry manure can also contain pesticide residues, antibiotics (and potentially drug-resistance pathogens), hormones (in countries where they are allowed), and other pollutants that contaminate air, soil, and water[71].

It is often argued that slower-growing chickens used in higher welfare systems produce more manure[72] as they live longer and have a higher FCR compared with conventional breeds [72]. Therefore, adequate manure management strategies need to be in place.

3.2.2. Mitigation strategies

A) Energy use

Overall inputs in the form of electricity use and fuel are low in the poultry industry compared to other livestock species, such as beef cattle. Nevertheless, even small percentages, when combined, can lead to significant outcomes.

The use of renewable energy systems can reduce emissions from heating and electricity use on broiler farms. For example, between 1990-2005, GHG emissions per kilogram of broiler meat produced in Sweden decreased by 24%. This was mostly achieved by switching from petrol to biofuels for heating the barns[73]. Solar panels can also be installed on the roof of barns. Depending on the location and size of the farm, surplus energy can be sold, providing an extra economic advantage[74].

B) Manure and waste management

Despite ECC birds living longer and producing more manure per kg of meat, the lower number of chickens per barn due to a reduced stocking density can compensate for that increase. Additionally, slower-growing breeds can be fed diets with lower protein content, which can contribute to decrease ammonia emissions, although this needs to be further researched[46]. Ammonia produced in the barns can be also captured and repurposed as a potential source of energy[20]. Additionally, many farmers already spread chicken manure on fields as an alternative to synthetic fertilizers, but the amount of manure produced may exceed local needs. Manure needs to be used as fertilizer in a responsible way. Proper manure storage, controlled application rates, and monitoring the nutrient levels of the soil, is essential to avoid a negative environmental impact[75].

The extraction of value-added products from the solid waste produced at slaughterhouse level, such as keratin from feathers or protein hydrolysate, could reduce the amount of waste that needs to be managed. The remaining waste could be sold for biofuel use, such as biogas/biodiesel through thermo-chemical, and biological treatment[76].

Alternatively, litter can be incinerated to obtain energy. A Japanese study showed that this process could reduce the acidification potential and emissions from chicken production while decreasing the need for fuel and the electricity consumption[77].

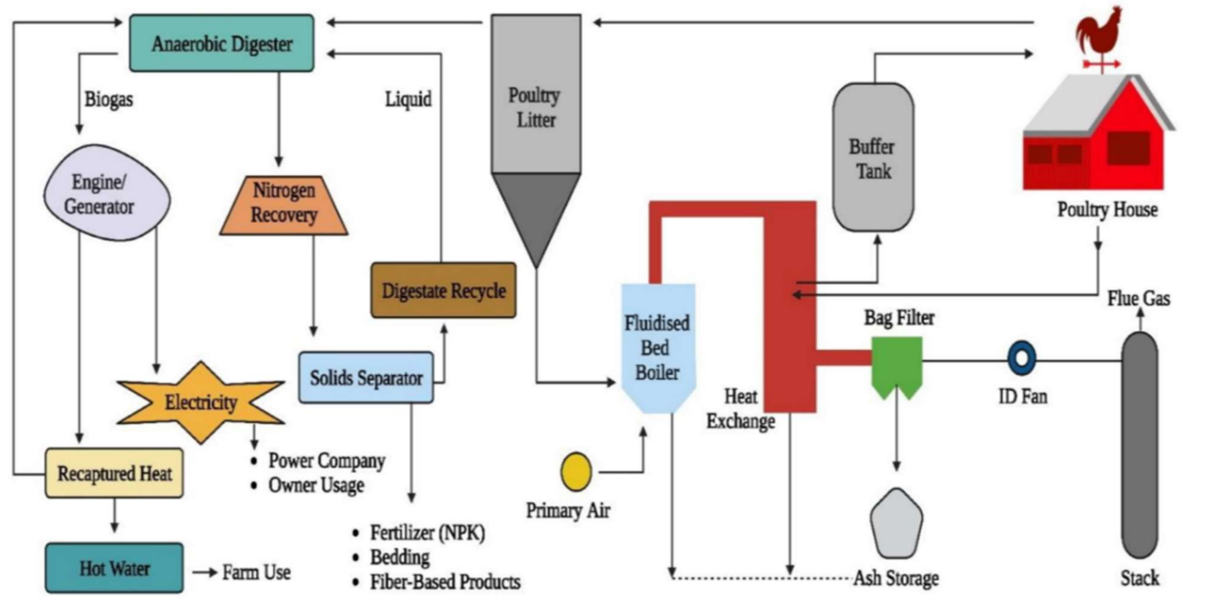


Figure 7: Potential use of waste poultry products to generate sustainable energy and biogas (From Bist et al., 2024[20]).

3.2.3. Advantages of BCC production

Regarding energy use, the presence of windows on the sides of broiler barns that let in natural light can decrease the need for artificial lighting during the day.

Slower-growing breeds have a higher FCR compared with conventional breeds, resulting in more manure / kg of meat produced. On the other hand, a reduction in stocking density would translate to less manure produced per farm.

The use of slower-growing breeds has been linked to a lower use of antibiotics. In 2022, antibiotic usage in Dutch farms was nine times lower where slower-growing breeds were used[78]. The use of animal manure for soil fertilization represents a route for the spread of pharmaceuticals in the environment, including aquatic contamination[71]. This means that higher welfare systems have a lower risk of spreading antibiotics – and antibiotic resistance genes, into the environment through manure[71].

3.3. Addressing the demand: Processing and menu offering interventions

3.3.1. Challenges associated with BCC production

Poultry meat is the most consumed meat worldwide, and second in the EU (after pig meat). The demand for chicken meat has largely increased in the past years (Figure 8)[18].

In Europe, the average poultry meat consumption was 24.2 kg retail weight per capita in 2021. In the US, the average consumption is even higher reaching 49.4 kg per capita[79]. Between 1960 and 2004, the consumer price index for poultry products in the US increased at half the rate of all other animal protein products, making chicken meat increasingly more affordable in comparison with other animal proteins[43].

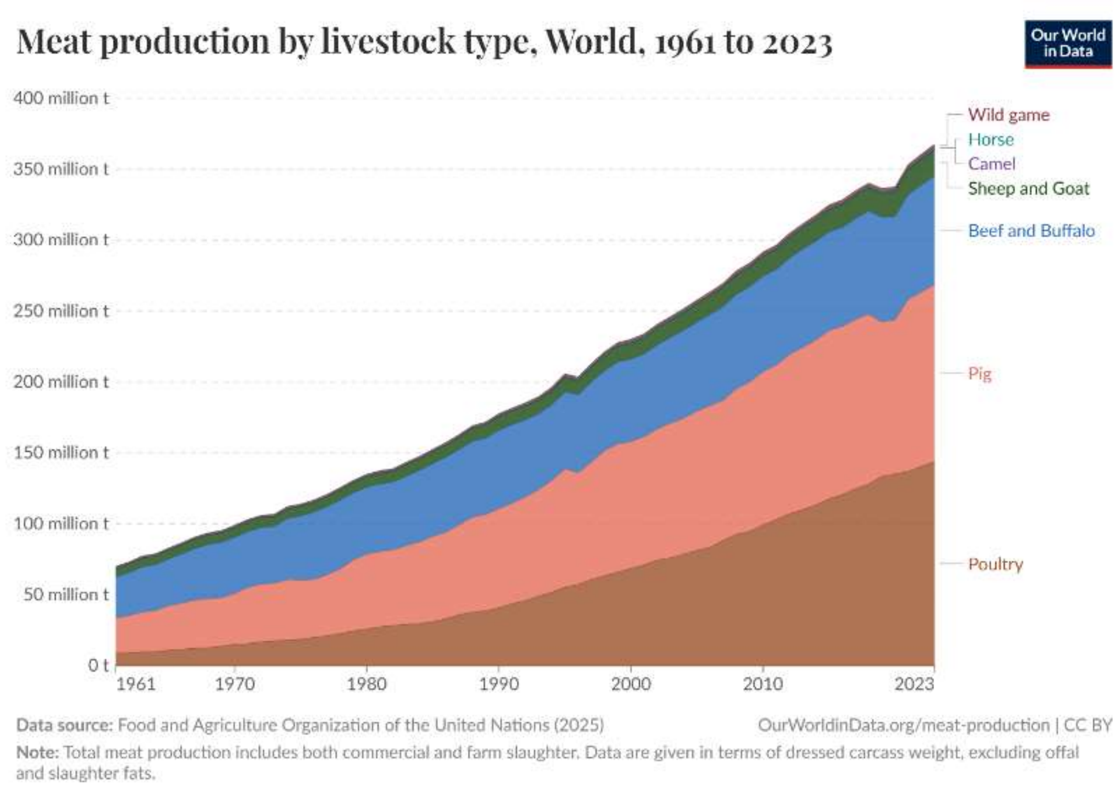


Figure 8: Evolution of global meat consumption from 1961-2023 (Our World in Data[29]).

The poultry industry often raises concerns about meeting the increasing demand for chicken meat while simultaneously transitioning to higher welfare standards. Additionally, western consumers' preference for breast meat[80] can present a challenge for higher welfare production, as higher welfare breeds often present a lower breast meat yield and higher thigh yield, compared to conventional ones.

3.3.2. Mitigation strategies

The difference in breast meat yields between BCC-approved breeds with an intermediate growth and fast-growing breeds is less pronounced than between slow-growing breeds and fast-growing breeds. For example, the difference in breast meat yield between the Hubbard Redbro (a BCC-approved breed that has a cumulative growth rate of 51.5 grams per day) and the Ross 308 (one of the most widely used fast-growing broiler breeds with a cumulative growth rate of 64 grams per day) narrows to 4.7 percentage points (20.6% for the Hubbard Redbro versus 25.3% for the Ross 308)[63].

Full utilization of the carcass (for example allowing thigh meat and leg meat to be taken from the same bird) allows to increase efficiency while also reducing costs. This can be done by developing new products or new recipes that use the whole chicken carcass, including the promotion of the darker meat (i.e. thighs) over breast meat. In recent decades, breast meat has been promoted as the healthiest cut of chicken. Efforts should also be made to promote the qualities of dark meat and incorporate it into recipes and menus. An example of this can be found in the Netherlands and Norway, where consumption of thighs is promoted equally alongside breast meat[63] (Norsk Kylling pers. communication).

Additionally, reducing meat consumption has been identified as an essential strategy for mitigating environmental challenges[18,44]. This can be achieved by intervening in the processing phase and by introducing changes in the menu offerings. For example, offering more meals which treat animal protein as a side rather than centre of the plate option can also reduce portion sizes while maintaining the nutritional density of meals. Blended proteins that mix chicken with plant-based ingredients such as cauliflower, chickpeas and other plant proteins can also reduce the amount of chicken in a given product. This process has already been adopted by food services and supermarkets[81] and has the potential to be accepted by consumers when presented as healthier and more sustainable, given that the taste is acceptable[82].

3.3.3. Advantages of BCC production

While less chickens are produced per shed in BCC production compared to conventional systems, as a result of the lower stocking density and the longer rearing period, the lower mortality and carcass downgrades in slower-growing breeds can mitigate that reduction.

In both the US and the EU, recent consumer surveys indicate that a significant proportion of consumers support stronger animal welfare legislation[83], are willing to pay a premium for higher welfare products[84], and express a desire for greater transparency through on-pack labelling related to animal welfare or production methods[84,85].

Additionally, there is a marketing advantage for chicken produced in higher welfare systems. Consumers, especially from Western countries and the EU, believe that low input, extensive systems are more sustainable, better for animal welfare, and provide better product quality[33].

	Environmental Impact issues	Mitigation strategies	Advantages
Feed	• Over 70% of poultry emissions come from feed, mainly due to unsustainable soy and land use change • Slower-growing BCC breeds need more feed as they take longer to reach slaughter weight	• Optimize diets for the system and breed. Feed-related emissions can be considerably decreased by using a low soy-low nutrient density diet • Use local and sustainable protein sources	• BCC breeds adapt better to more sustainable diets • The parent stocks of some BCC breeds are more productive and consume less feed
Production	• Lower stocking density in BCC systems leads to higher land use and energy use • Longer living birds produce more manure	• Overall, inputs in the form of electricity use and fuel are low in the poultry industry • Use renewable energy • Treat manure for biofuel or biogas	• Lower mortality rates and lower carcass downgrades lead to less food and feed waste • Lower stocking density/ fewer birds lead to less manure produced per barn • Natural light decreases the need for artificial lighting • Eggs of BCC parent breeds have better survivability
Consumer demand	• Increasing poultry demand conflicts with fewer chickens produced per shed in BCC systems • Consumer preference for breast meat conflicts with lower breast yield in BCC breeds	• Promote different parts of the chicken and use the full carcass to reduce waste • Develop new recipes, reduce meat portions and use blended meat products	• Lower mortality and carcass downgrades decrease the meat yield gap with conventional production • Meet consumer demand for higher welfare products • Less breast myopathies leads to better meat quality • Using slower growing breeds leads to lower antibiotic use

Table 4: Summary of the environmental impact, potential mitigation strategies and advantages of higher welfare BCC broiler production.

4. People

4.1. Social benefits

When assessing the sustainability of broiler production, the most overlooked pillar is the social pillar. When social aspects are included, some higher welfare systems can rank higher in the sustainability index than conventional systems[21,24].

4.1.1. Public health

The slower-growing breeds used in higher welfare systems have better natural immunity & lower disease susceptibility. On the other hand, fast-growing breeds experience more chronic stress which has negative repercussions on their immune system[86]. Some studies have reported that fast-growing breeds suffer from prolonged inflammatory response and disseminate more pathogens when infected with *Campylobacter*[87] and *Eimeria*[88] , both of which cause foodborne diseases.

Antibiotic resistance (AMR) is a critical global health threat, with resistant pathogens causing an estimated 5 million deaths in 2019 and projections indicating this could rise to 10 million by 2050 if left unaddressed[89]. The misuse and overuse of antibiotics in healthcare, agriculture, and animal husbandry accelerate the development of resistant bacteria, rendering common infections increasingly difficult to treat[90]. Conventional systems use more antibiotics to compensate for a higher risk of pathogen dissemination associated with higher numbers of animals in a reduced space. In 2022, antibiotic usage in Dutch farms was nine times lower where slower-growing breeds were used[78].

Poultry farmers and their families face risks like exposure to antibiotic-resistant bacteria and developing allergies to antibiotics[91]. Since 2012, poultry farmers in The Netherlands are classified as people needing quarantine and special treatment due to these conditions [85]. But these hazards not only affect the farm workers and their surrounding environments; the higher stocking densities in those systems increase the risks of zoonotic diseases outbreaks, which is a broader human health risk for the entire society. For instance, Rocchi and colleagues' multifactorial assessment reported that two organic systems performed better in terms of health risks, antibiotic resistance and income for the workers compared to conventional systems[21].

4.1.2. Attractivity of the sector

Staff workers in higher welfare systems take more pride in growing chickens that are healthier, "happier" and behave more naturally, and are often more eager to show their farm transparently to the public. This can improve consumer trust and can help to recruit farm workers and to motivate the next generation to take over the farm (Norsk Kylling, personal communication). For example, higher welfare Label Rouge systems performed better in terms of meeting citizens' expectations and improving the acceptability of the

poultry sector compared with conventional systems in Méda and colleagues' assessment (2021)[11].

4.2. Economic viability

4.2.1. Cost mitigation strategies

The transition to higher welfare systems, such as BCC compliant farms, is not without a cost. The increase in production costs must be absorbed across the entire food chain, not just by producers or consumers, while transition periods are also crucial when modelling the economic impact of a move to BCC production. Companies need to align their strategy within the business and cohesively pull in the same direction. It is important to remain fair, set the price of chicken responsibly without increasing margins on higher welfare products, ensuring they remain accessible to consumers while supporting farmers who adopt improved welfare standards.

There is a range of cost-reduction strategies that exist to offset some of the cost increase associated with BCC production - such as better carcass utilisation, menu reformulation and innovative product development. In addition, it is important to take into account some advantages of BCC systems when modelling production costs, as BCC systems can outperform conventional systems in some areas, such as a better productivity of the parent stock, lower rejection rates in slaughterhouses and fewer carcass downgrades due to meat quality issues [61], leading to a reduction in food waste. In addition, ECC flocks typically report much lower mortality rates [61].

4.2.1. Meeting consumer demand

There is a growing consumer demand for higher welfare products. Consumers tend to perceive higher welfare products as healthier, safer, tastier, authentic, environmentally friendly, and traditional.[92] Compared with chicken meat produced in conventional highly intensive production systems, many consumers are willing to pay more for chicken meat from higher welfare systems, including indoor systems with more space and enrichment, free-range and organic systems. Consumers in Denmark, France, the Netherlands and the UK were generally willing to pay between 5% and 30% more, with some consumers willing to pay 50-100% more for chicken breast produced to higher welfare standards[93]. Belgium consumers were willing to pay an average of 43% more for chicken breast labelled as 'free range', 50% more for 'traditional free range', and 63% more for 'free range total freedom[94]'. US consumers were willing to pay an average 48% premium for chicken breast with a trustworthy welfare certification[95].

While investing in higher welfare chicken production bears a cost, signatory companies will often benefit from improved brand reputation, stronger marketing and consumer loyalty due to their higher welfare standards.

Conclusion

Sustainability is a broad concept focused on ensuring a viable future for humans, animals, and the planet. While minimizing environmental impact is an essential aspect, true sustainability encompasses more. Broiler production has an advantage over other livestock species in terms of lower emissions; however, this has often come at the expense of bird welfare. To move forward and transition towards a truly sustainable model of broiler production, we must strike a balance to enhance broiler welfare and address environmental concerns, while considering all other components of sustainability. There is a range of efficient mitigation strategies that can be explored to reduce the environmental impact of broiler production systems and, in many cases, higher welfare systems may even outperform conventional systems in advancing a more holistic model of sustainable broiler production.

Going further: Regenerative poultry farming

Innovative regenerative agriculture systems embrace a holistic approach that seeks to restore and enhance the health of ecosystems. Regenerative principles aim to actively rebuild soil health, increase biodiversity, and promote ecological balance. In broiler production, regenerative practices include rotational grazing, cover cropping, and minimal chemical inputs.

Rotational grazing is a key component, allowing chicken flocks to move across different sections of pasture. This mimics the natural patterns of wild birds, preventing overgrazing and allowing the land to recover and regenerate. The integration of cover cropping involves planting diverse vegetation that not only provides a natural foraging environment for the chickens, but also helps prevent soil erosion, enhances nutrient cycling, and attracts beneficial insects. Additionally, minimal reliance on chemical fertilizers and antibiotics helps prioritising natural processes and facilitates the development of resilient ecosystems.

From an animal welfare point of view, regenerative chicken production systems encourage the display of natural behaviours by allowing the birds to roam freely on pasture, engaging in activities such as scratching, dust bathing, and pecking. This not only enhances the overall welfare of the chickens but also contributes to the sustainability of the farming model by promoting a more natural and balanced ecosystem. As a result, consumers are not only offered ethically produced and high-quality chicken meat but also the assurance that the animals are living in a manner that aligns with their innate behaviours.

In agroforestry or silvopastoral systems, chickens are allowed to graze on woody lands like orchards or forests, thus incorporating the production of vegetation and livestock. These chickens spend more time grazing, ingesting larger amounts of forage and bioactive compounds. They will also perform natural weeding and fertilize the trees, thus reducing the environmental impact of the orchard and chicken production, except for the land use[96].

In regenerative systems, dual-purpose chickens should be used, where hens are reared for egg production and males are kept for meat production, and small groups of chickens may be raised on pasture and fed a diverse diet from circular of food waste[97].

For a poultry system to truly be regenerative, the feed must also come from regenerative sources. Achieving full self-sufficiency in feed at a commercial scale is challenging. Therefore, the most practical and impactful approach is to ensure that any supplemental feed is sourced from other regenerative systems, maintaining alignment with regenerative principles throughout the entire supply chain

As the demand for ethically produced and sustainable food continues to grow, regenerative agriculture emerges as a promising solution that balances the needs of chicken, ecosystems, and consumers alike.

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