

Cage-Free x Climate

The case for compatibility



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Asia Research & Engagement (ARE)

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Part A: Framing and Shared Findings

Executive Summary

Emissions, animal welfare, and cage-free practices and commitments increasingly feature in the sustainability disclosure frameworks shaping the agri-food industry.

The central question this series addresses is whether cage-free housing systems for broilers, laying hens, and gestating sows are compatible with climate action. The answer in every case is the same: compatibility is achievable, costs are manageable, and management of key system inputs determines the outcome rather than the housing system itself. For each of the three industries, the series offers a specific recommendation for transition to climate-efficient cage-free systems.

The shared finding.

For broilers, layers, and sows alike, feed production is the dominant source of greenhouse gas emissions. That share rises further for Asian producers reliant on imported, carbon-intensive feed grains. The primary source of welfare–climate tension is the same in all cases: cage-free systems give animals more space and freedom of movement, which raises energy expenditure slightly and, in some configurations, the amount of feed required per unit of output. This is a genuine trade-off but in every case the series identifies management levers that contain or reverse it.

The cross-cutting levers.

Four management levers consistently have far greater impact on emissions than higher-welfare housing — and the first of them matters far more than the rest. **Feed sourcing is the single largest determinant of climate outcomes in all three cases.** Feed production accounts for roughly 60–84% of total emissions, so avoiding high-deforestation supply chains and reducing soy dependence delivers climate gains that dwarf any difference between housing systems.

The practical implication is that a producer moving to higher-welfare farming while avoiding deforestation-linked feed can improve welfare and cut emissions at the same time.

- **Manure and litter management** — through moisture control, short-storage handling, and downstream abatement — reduce

Recommended Pathways for New Investment

The climate-compatible higher-welfare configuration for each species, and its enabling conditions

Gestating Sows	Broilers	Laying Hens
RECOMMENDED SYSTEM Full group housing — electronic sow feeders (ESF) or free-access stalls, with precision feeding Enabling conditions • Precision feeding cuts N/P excretion & feed GHG • Stable grouping + parity-matching + adequate space • Short-storage manure handling; composting / biochar	RECOMMENDED SYSTEM Cage-free floor system, moderately slower-growing (BCC) genetics at reduced stocking density Enabling conditions • Low- or no-deforestation feed sourcing • Environmental enrichment + appropriate lighting • Housing-energy mitigation (e.g. heat exchange) • Captures most welfare gain at moderate climate cost	RECOMMENDED SYSTEM Cage-free — barn or aviary (co-equal; choose on management capability & local conditions) Enabling conditions • Deforestation-free feed / lower-impact protein • Manure & litter management (low-CP diet, belt, moisture) • Mortality control: rearing, aviary design, stockmanship • Enriched cage is a transitional step, not the destination

Source: ARE synthesis of cited LCA and welfare literature.

greenhouse gas and ammonia emissions regardless of which housing system is operated.

- **Reproductive and production performance** — through stable grouping, appropriate genetics, and active management of mortality and culling — is where cage-free systems earn their climate offset.
- **Housing-energy design** — ventilation, heating, and cooling — determines whether the infrastructure of higher-welfare housing adds to or contains the energy footprint.

Recommendations

Each part of the report sets out a full recommendation:

Gestating sows: full group housing with electronic sow feeders (ESF). ESF feeds each sow to her own requirement and lowers dietary crude protein and soy inclusion. That cuts nitrogen excretion by up to 17% and phosphorus by up to 15%, which reduces the ammonia and nitrous oxide arising from manure, while optimised precision feeding can cut system-wide emissions by up to 6%. Because feed is the largest source of emissions in pig production — between 70% and 77% in import-reliant Asian systems — precision feeding is an integrated component of group sow housing.

Broilers: cage-free floor systems, moderately slower-growing birds at reduced stocking density, with enrichment and a suitable lighting regime. Slower-growing breeds at lower density are not the highest-welfare option available but they capture most of the welfare gain at a moderate climate cost. They also reduce antibiotic use, mortality and leg problems, and help with food safety in hot climates. Feed sourcing affects the climate result more than housing choice.

“This series addresses the common assumption that higher-welfare systems are a luxury the industry cannot afford and finds it substantially overstated.”

Laying hens: cage-free, barn-raised single or multitier (aviary).

Both enable hens to exhibit the behaviours on which the welfare case rests: nesting, perching, dustbathing, foraging, and free movement. The conventional cage provides none of those and the enriched cage only offers partial benefits. Single-tier systems carry less keel-fracture risk and are simpler to run. Aviaries allow the fullest range of behaviour and hold more birds per square metre of floor. Producers should choose between them on the basis of their own management capability, local conditions, expected demand, and economics.

Introduction

The global livestock sector faces two conflicting pressures.

1. A growing body of scientific evidence, civil society advocacy, investor scrutiny, and regulatory momentum calling for better farm-animal conditions: more space, more behavioural freedom, and an end to the most restrictive confinement systems.

2. The urgent need to reduce food-system contributions to greenhouse gas emissions, which account for roughly one-third of global anthropogenic emissions (of which animal-based foods comprise more than half).

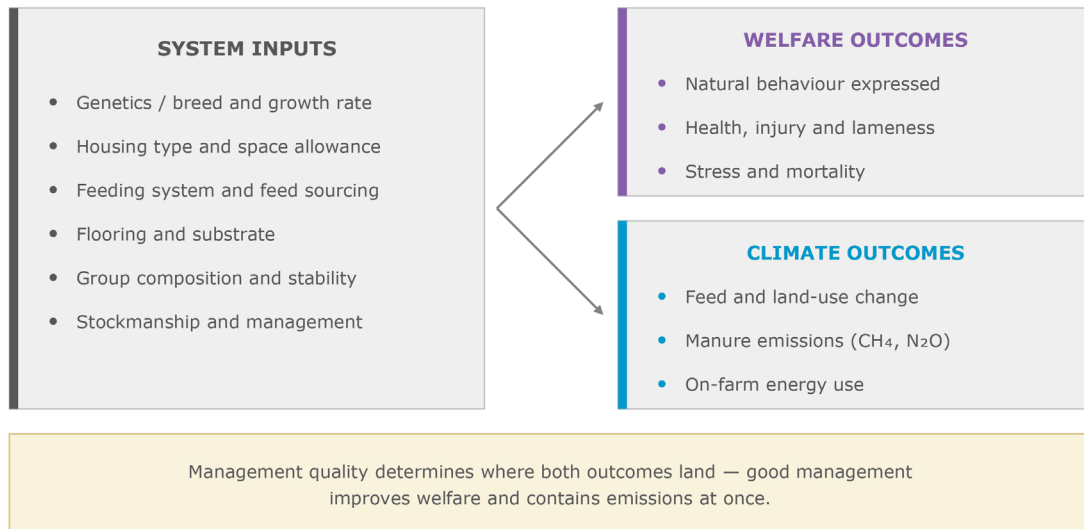
Where these two pressures meet, producers, investors, and policymakers face a question: can higher-welfare production align with climate goals?

The common assumption is that it cannot. The argument goes that higher-welfare systems use more space, more feed, more energy, and more infrastructure per unit of output and that adding these costs is a luxury the industry cannot afford. This assumption functions as a brake on cage-free welfare transitions worldwide, but it's particularly obstructive in Asia. Not only does Asia produce the majority of the world's poultry and pork, but welfare regulation is limited and the evidence base drawn from temperate, high-regulation industries does not always transfer directly.

This series directly addresses that prevailing assumption and finds it substantially overstated. Across broilers, layers, and sows, scientific literature shows that the relationship between higher-welfare housing and climate performance is not a fixed trade-off. The welfare-climate conflict is real in some cases, absent in others, and manageable across the range. What determines outcomes for producers is not primarily the housing system but the combination of management practices that

How Housing Shapes Welfare and Climate

The system inputs, and how they are managed, determine both welfare and climate outcomes — not the housing system alone.



Source: ARE analysis.

accompany the housing change: how feed is sourced and formulated, how manure is handled, how groups are composed and stabilised, and how reproductive and production performance are maintained through the transition.

The series is organised around that finding. Each of the three parts is structured identically, analysing the key welfare determinants and climate drivers for that farmed animal before bringing them together in an input-by-input assessment of where welfare and climate align, conflict, or move together conditionally. This analytical structure allows the welfare–climate relationship to be characterised precisely, at the level of decisions producers and investors actually make, rather than as a single aggregate housing-system choice. The evidence is presented as it stands, including genuine conflicts and evidence gaps.

Compatibility is achievable and the series is intended to be useful to companies, especially producers, who need to understand what that achievement actually requires.

The series is addressed primarily to producers, retailers, and investors operating in or engaging with Asian livestock markets, though the evidence base and framework apply more broadly. The Asian context receives specific attention in each part: the geographic transferability of evidence from temperate industries, the production conditions that differ materially from European and North American baselines, and the commercial and regulatory landscape that shapes the pace and form of welfare (cage-free) transitions in the region.

Parts B1 to B3 cover gestating sows, broiler chickens raised for meat, and laying hens. Each can be read independently. Together they make a case that the welfare and climate transitions facing livestock production are not diverging agendas. Where the evidence is followed carefully and management is designed accordingly, they are on the same pathway towards a sustainable and just transition.

Cross-Cutting Methodological Notes

The three parts are based on detailed analytical literature reviews, each ending with animal-specific methodological caveats. Four issues, however, apply across all cases and are summarised here to avoid repetition. Readers should treat them as applicable throughout; animal-specific details address only issues particular to broilers, layers, and sows.

Reading the comparative figures. The comparative Life Cycle Assessment (LCA) figures in each chapter depend on a small set of methodological choices. These choices have been flagged to help producers and investors interpret the evidence accurately and apply it to their own context — especially in tropical and subtropical Asian markets, where evidence drawn largely from temperate, highly regulated industries may not transfer directly.

Functional unit and system boundary. The unit chosen to express results materially affects how systems perform, because systems with higher output or larger product size appear relatively better under some units than others. System boundaries matter as well; including or excluding upstream and downstream stages can change results, especially for systems with higher mortality or shorter productive lifespans, where a narrow scope can hide the replacement burden. Cross-study comparison therefore requires close attention to both choices.

Land-use-change accounting for soy. Soybean meal is the main protein source in commercial pig and poultry rations, and how its land-use-change (LUC) burden is accounted for can move a system's footprint several times over. Three choices matter: whether LUC is counted at all, whether indirect change is included alongside direct conversion, and the amortisation period applied. The stakes are large, since soy-related land-use change can account for more than half of total climate impact in some broiler studies. Comparative figures should therefore be checked to confirm both systems were assessed on the same basis.

Geographic transferability to Asian markets. The great majority of the high-quality LCAs and welfare studies cited in this series were conducted in the EU, the UK, North America, and Australia, and several of their findings are conditioned on temperate-climate, high-input, regulated production. Four shifts recur when that evidence is applied to tropical and subtropical Asia:

- **The heating-energy penalty largely disappears.** A substantial part of the higher-welfare environmental penalty in cold-climate studies comes from heating lower-density housing in cold weather. In tropical climates, this driver is minimal.
- **Heat stress becomes the dominant production risk instead.** The binding constraint shifts from heating to cooling and ventilation. Chronic heat stress reduces feed intake, fertility, growth, and product quality. This is most relevant in caged or high livestock mass/density systems.

“The clearest shared thread is feed, which dominates the climate footprint of all three systems, while heat stress is an ever-increasing climate impact and energy demand on caged systems.”

- **Feed and LUC profiles differ.** Proximity to high-LUC South American soy means a housing comparison calibrated on lower-LUC feed will understate the feed-driven GHG profile facing many Asian producers.
- **Management maturity is earlier.** Higher-welfare and explicitly cage-free management expertise across much of Asia is at an earlier stage — so results from mature industries represent a best case rather than the expected outcome during early adoption.

Overall Conclusion

The three farmed animals in this series do not give an identical answer to the welfare–climate question, and we have not forced one.

- **For gestating sows,** the move out of crates is close to a win-win, because group housing unlocks shared precision feeding that can more than offset the cost of extra feed.
- **For broilers,** a trade-off remains — moderately slower genetics and lower densities do raise the feed needed per unit of output — though it is a manageable one.
- **For laying hens,** the picture is closer to neutral, depending on how well the system is run.

In every case, the same set of inputs — feed, manure, the animals’ productivity, and the building’s energy — decides where the balance lands, far more than the choice of housing itself.

The clearest shared thread is feed, which dominates the climate footprint of all three systems. It is through feed that giving animals more space and freedom registers as a climate cost, by modestly raising the energy and feed needed per unit of output. The same feed that drives the added climate cost is also the most powerful means of offsetting it: sourcing lower-deforestation feed and reducing soy dependence delivers climate gains that dwarf any difference between housing systems. Meanwhile several of the most welfare-significant changes — enrichment and lighting for broilers, nests and perches for hens, the feeding system itself for sows — carry little or no climate cost at all.

The decisive variables sit upstream and downstream of the housing decision: feed sourcing, manure and litter handling, the reproductive and production performance that spreads a footprint across more output, and the energy design of the building.

This is why the recommended destinations differ by industry but rest on the same handful of levers.

None of the investment pathways is recommended unconditionally. Each rests on similar terms: low-deforestation feed, sound manure handling, mortality and performance management, and appropriate housing-energy design. Across all three, the housing transition and the climate objective are better understood as a single design problem to be solved rather than as opposing goals to be traded off.

The series is deliberate about the limits of this claim. The direction of the welfare findings is robust, but the magnitude of both the welfare gains and the environmental penalties is uncertain and sensitive to local conditions. Most of the underlying evidence is temperate and the Asian evidence base in particular remains thin. These conclusions are best read as a sound basis for decisions that should be re-grounded in local transition-cost, productivity and emissions data as that evidence matures, not as precise predictions for any single market.

That caveat is also where the opportunity lies. Asia's poultry and pig capacity can be far easier to design as higher-welfare, climate-compatible systems from the outset than to retrofit later.

For the producers, buyers, banks, and investors shaping that build-out, the message of this series is simple: Higher welfare does not have to come at the expense of the climate. Systems that give animals materially better lives can also perform well on climate, as long as feed, manure, productivity, and energy are managed well.

About this series

Cage-free × Climate: The Case for Compatibility is published in four parts, with a shared annex of source tables. Each part is self-contained and can be read on its own; this document, Part A, sets out the shared framing, the methodology, and the conclusions the series draws together.

Part A: Framing and Shared Findings (this document)

The question the series addresses, the shared methodology and findings, and the recommended pathway for each category.

Part B1: Gestating Sow Housing Systems, Welfare, and Climate Impact

Group housing with electronic sow feeders improves sow welfare, and the shared precision feeding it enables offsets the climate cost of the extra feed.

Part B2: Broiler Growing Systems, Welfare, and Climate Impact

Moderately slower-growing birds at lower stocking density capture most of the welfare gain at a moderate climate cost, and feed sourcing matters more than the housing choice. Caged systems perpetuate the cost and impacts of heat stress.

Part B3: Layer Hen Housing Systems, Welfare, and Climate Impact

Barn and aviary systems restore the behaviours the welfare case rests on, usually at minor climate cost. That cost narrows where laying rate and feed efficiency are maintained, and better feed sourcing can outweigh it altogether.

Annex: Expanded Source Tables

The full evidence tables behind Parts B1–B3: every study cited, with year, type, geography, system, and welfare relevance. Shared across the series.

Endnotes

1 Crippa, M., Solazzo, E., Guizzardi, D., Monforti-Ferrario, F., Tubiello, F. N., & Leip, A. (2021). Food systems are responsible for a third of global anthropogenic GHG emissions. *Nature Food*, 2(3), 198–209. <https://doi.org/10.1038/s43016-021-00225-9>

2 Xu, X., Sharma, P., Shu, S., Lin, T.-S., Ciais, P., Tubiello, F. N., Smith, P., Campbell, N., & Jain, A. K. (2021). Global greenhouse gas emissions from animal-based foods are twice those of plant-based foods. *Nature Food*, 2(9), 724–732. <https://doi.org/10.1038/s43016-021-00358-x>

3 FAO. (2026). FAOSTAT: Crops and livestock products [Data set]. Food and Agriculture Organization of the United Nations. <https://www.fao.org/faostat/en/#data/QCL>

4 World Animal Protection. (2020). Animal Protection Index. <https://api.worldanimalprotection.org/>

Part B1: Gestating Sow Housing Systems, Welfare, Climate Impact

Recommendation: New Sow Housing Investment

Full group housing with shared electronic sow feeders (ESF). ESF feeds each sow to her own requirement and lowers dietary crude protein and soy inclusion. That cuts nitrogen excretion by up to 17% and phosphorus by up to 15%, which reduces the ammonia and nitrous oxide arising from manure, while optimised precision feeding can cut system-wide emissions by up to 6%. Because feed is the largest source of emissions in pig production — between 70% and 77% in import-reliant Asian systems — precision feeding is an integrated component of group sow housing.

Part B1 of the Cage-free x Climate series; Part A sets out the shared framing, methodology, and cross-cutting findings, and Parts B2 and B3 cover broilers and laying hens. The Annex, Expanded Source Tables, holds the full evidence tables for the studies cited here.

Key takeaways

- **The crate constrains a sow to a space she cannot turn around in for the entirety of her gestation.** The welfare consequences — stereotypies, muscle and bone deterioration, a higher claw-lesion index, infection rates, and suppressed natural behaviour — are well-documented.
- **The primary source of tension is feed:** more space and movement raise maintenance energy, and feed accounts for up to 70–77% of pig-production emissions in import-reliant systems.
- **The only direct comparative LCA finds group pens modestly better than stalls** on global-warming potential, energy, and water use, driven by the reproductive performance that stable group management supports.
- **For Asian producers in the tropics, the evidence carries a specific opportunity:** Asia's dependence on imported feed with

high deforestation risk means that precision feeding's nutrient and emissions savings are proportionally larger there than in European systems where the imported feed share is lower.

In this section

- **Terminology and Scope**
- **1. The Welfare-Climate Question in Sow Housing**
- **2. Key Welfare Determinants in Sow Housing Systems**
- **3. Main Drivers of Climate Performance in Sow Housing**
- **4. Welfare and Climate: Alignment, Conflict, Conditionality**
- **5. Methodological Issues**
- **6. Conclusion**

Terminology and Scope

Maternal behaviour in sows is biologically important and remains strong even in domesticated pigs. Basic social-structure features of the outdoor reference groups (groups of ~4 sows) were maintained in indoor sow systems. The social contacts in stable groups enhance the synchrony of heats and lactational oestrus (heat).¹ The ability of sows to express these natural behaviours is influenced by the housing environment in which they are kept, making sow housing systems a key consideration.

Against this backdrop, group housing for gestating sows is replacing individual stalls in many regions, originally for welfare reasons but increasingly as more efficient, cost-effective, and productive than conventional stall systems. It changes how pregnant sows live, eat, move, and interact, with knock-on benefits for welfare of sows and piglets, and environmental performance.

This report uses the conventional gestation crate as the baseline for comparison and examines group housing across a spectrum of feeding configurations and degrees of confinement. The systems discussed are defined below:

- **Conventional gestation crate (stall)** — the baseline: an individual stall prior to and for the entirety of pregnancy, typically about 220cm long by 72cm wide, allowing the sow to lie on her side but not to turn around, walk or select her environment or neighbours.
- **Group housing** — sows kept together in shared pens with common feeding and lying areas for sub-groups, from post weaning to insemination and throughout gestation. Group housing systems are also differentiated by:
- **Feeding systems in group pens** — modern group pens differ mainly in how long they house gestating sows and how they feed sows plus whether groups are static or dynamic (i.e. whether they do not enable new sow introductions or do, respectively). The five principal configurations are:
 - **Free-access feeding stalls** — recommended, with ESF: sows feed as needed via a limited number of shared stalls.
 - **Electronic Sow Feeders (ESF)** — recommended: the most precision feeding system; 1 unit per 40 to 50 sows max.

- **Floor feeding** — less used in higher-welfare pens; feed competition is difficult to control.
- **Trickle feeders** — less used.
- **Cafeteria (free-choice) feeding** — less used; feed is offered *ad libitum*.

Among these, ESF and floor feeding are the most widely adopted modern configurations; in commercial ESF pens, group sizes for static systems range from 10 to 50 sows, and for dynamic systems up to more than 300 sows, with dynamic management more common at large scale and experience.

- **Early mixing (EM) and late mixing (LM):** EM means grouping sows before or soon after insemination, avoiding the high-risk period of embryo implantation in the uterine wall (beginning around day 11–12). LM means grouping them several weeks later, once pregnancy is well established (commonly day 28). Both approaches share the goal of avoiding mixing during the sensitive implantation window. Grouping sows earlier, within about four days of insemination, allows them to return to stable groups sooner, without harming reproductive performance or sow welfare, provided the aggression that accompanies any mixing is well managed.²

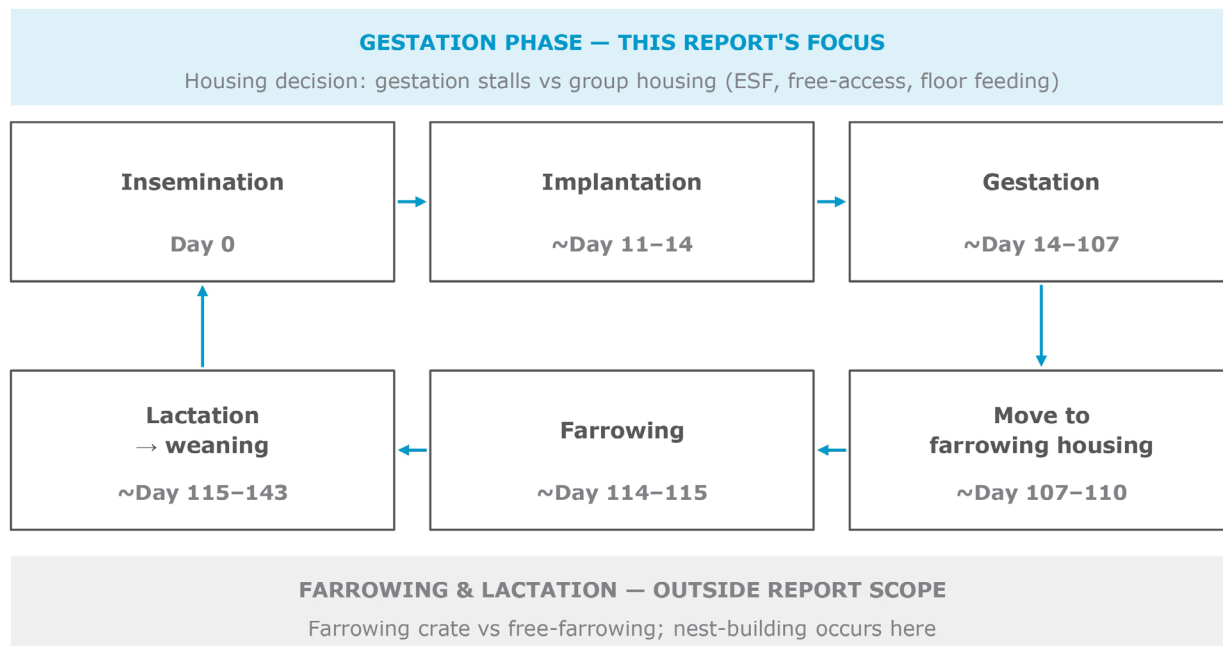
Space standards and management refinements.³ The principal regulatory benchmark for space is EU Council Directive 2008/120/EC, which requires a minimum unobstructed floor area of 2.25m² per sow and 1.64m² per gilt where animals are kept in groups, rising by 10% for groups of fewer than six and falling by 10% for groups of 40 or more. The 2022 EFSA Scientific Opinion on pig welfare endorses strengthening these requirements and recommends that regulators use animal-based measures, not only resource-based thresholds.⁴ Drawing on producer experience and industry benchmarking from Australia's transition away from gestation stalls, a 2024 industry survey identified an emerging operational standard — *ad libitum* feeding during the first week post-mixing, deliberate parity-matching at grouping, and a space preference of 1.8–2.2m² — that blends ESF and drop-feeding approaches and differentiates successful from unsuccessful transitions.

Scope note. This report confines its analysis to the gestation phase — the pre-implantation and gestation housing of breeding sows — comparing the conventional gestation crate with group pen configurations. Farrowing and lactation housing are acknowledged but not analysed in detail except where they bear directly on the welfare-climate comparison. Asia-specific housing classification remains a significant evidence gap.

We were unable to find peer-reviewed studies since 2015 documenting commercially adopted gestation pen standards specific to China, Taiwan, Japan, or South Korea comparable with EU or Australian standards. Chinese welfare research is active but remains productivity-centred rather than focused on housing-typology reform.

The Sow Reproductive Cycle

From insemination to weaning, then repeating — about 2.2–2.4 litters per sow per year.



Source: ARE analysis. Timings are standard commercial reproductive management figures.

1. The Welfare-Climate Question in Sow Housing

Within pork production, gestating sow housing has become the focal welfare issue and the one where the regulatory and commercial transition is most visibly accelerating. Gestation crates are already banned or being phased out across the EU, and major pork producers and retailers have made crate-free commitments with binding timelines. In Asia, where more than half of the world's pigs are raised, and where regulation has not necessarily followed, we see voluntary transitions in Thailand, China, Vietnam, and elsewhere; not for premium markets but because groups gestational sow housing is modern, more productive, and essentially cost-neutral.

Feed accounts for up to 70–77% of pig-production emissions in import-reliant Asian systems, and the possible tension in sow housing runs through enabling the movement that welfare demands: more movement raises maintenance energy and, if poorly managed, feed use per unit of output. But the perceived tension frequently reverses in practice. The feeding systems that group housing enables — above all ESF-based precision feeding — reduce nitrogen and phosphorus excretion substantially while cutting feed-related emissions, making the feeding system the report's strongest welfare-climate synergy rather than a source of conflict.

A direct comparative life-cycle assessment finds group pens modestly better than stalls — by around 1% on global warming potential, energy use, and water use — driven by improved reproductive performance.⁵ In certain scenarios where a resource cost remains, it is narrowest where feed efficiency and

reproductive performance are actively maintained — and widest where they are not.

The remainder of this section is organised around the production-system inputs that determine both welfare and climate outcomes — space allowance, social stability and group management, feeding system, and flooring — rather than around housing labels.

- **Section 2** establishes the welfare evidence around these inputs.
- **Section 3** establishes the climate evidence around the main drivers of environmental performance.
- **Section 4** brings the two together, tracing each input through to its welfare and climate consequence before aggregating to a system-level summary.
- **Section 5** sets out the methodological caveats specific to the sow evidence base, building on the cross-cutting notes in Part A.

Key Welfare Determinants — Gestating Sows

The design and management inputs analysed in this section, and the welfare measures each one drives

2.1 Space allowance and stocking density

How much usable floor area each sow has, and how it is distributed

WELFARE MEASURES DRIVEN

Aggression after mixing · locomotion and resting comfort · injury and skin lesions · whether subordinates can avoid dominants

2.2 Social stability and group management

Whether groups are static or dynamic, how they are composed, and when sows are mixed

WELFARE MEASURES DRIVEN

Aggression at regrouping · lameness · skin lesions · reproductive loss around implantation

2.3 Feeding system and feed access

How feed is delivered, and whether competition for it can be controlled

WELFARE MEASURES DRIVEN

Feed competition and stress · vulva-biting at feeder entrances · body-condition variation

2.4 Flooring type, maintenance and design

Surface underfoot, and the zoning of lying, dunging and drinking areas

WELFARE MEASURES DRIVEN

Claw and leg health · slipping and injury · resting comfort · stereotypies

Source: ARE analysis.

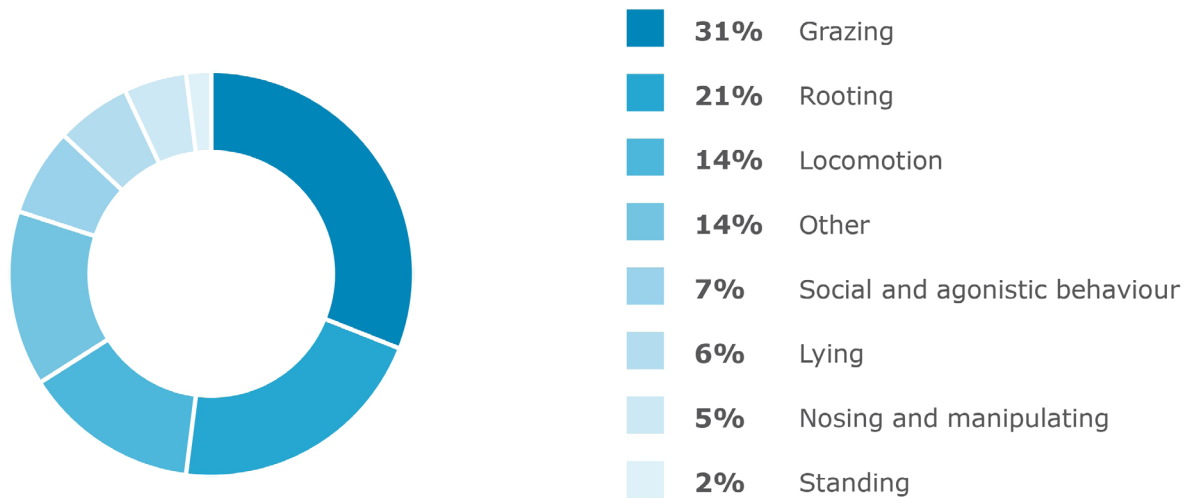
2. Welfare Determinants in Sow Housing Systems

The welfare differences between gestation crates and group pens arise from a defined set of design and management inputs — how space is designed and used, how stable and well-matched the social group is, how feed is delivered and whether competition over it can be controlled, and the type of flooring in contact with the sow.

This section is organised around those inputs rather than around welfare outcomes, because it is the inputs that producers and regulators specify. The welfare measurements that follow from them — aggression and stress physiology, lameness and skin lesions, claw and leg health, stereotypies, and affective-state proxies — are presented under the input that primarily drives them. Some outcomes, lameness and lesions, appear under more than one input because they are multi-causal.

Behaviour of Unconfined Pigs

Share of the active day spent on each behaviour when pigs are free to choose.



Source: Stolba & Wood-Gush (1989), The behaviour of pigs in a semi-natural environment.

Understanding these welfare determinants also requires consideration of the sow's behavioural biology. Sows naturally isolate before farrowing, build nests through rooting, pawing, and foraging, then stay close to the nest for several days after birth.⁶ These patterns remain biologically strong despite domestication, with reviews and comparative studies showing that domestic sows still retain much of the same nest-building and maternal repertoire seen in more natural or wild-type settings.⁷

The chart above illustrates how unconfined pigs naturally allocate their time across a range of behaviours. The largest proportion of activity is devoted to grazing (31%) and rooting (21%), meaning that more than half of a pig's time is spent exploring and foraging for food. Additional time is spent on locomotion (14%), reflecting the importance of movement and environmental exploration. Social interactions account for 7% of observed behaviour, while nosing and manipulating objects (5%) further demonstrate pigs' strong motivation to investigate their surroundings. Relatively little time is spent inactive, with lying (6%) and standing (2%) together representing less than one-tenth of total behaviour. The remaining 14% comprises other activities.

2.1 Space Allowance and Stocking Density

Space is one of the strongest determinants of welfare in group-housed sows. It influences aggression, locomotion, resting comfort, injury, and the ability of subordinate animals to avoid dominant ones. By contrast, the restricted movement of gestation crates is associated with poorer muscle condition, reduced bone strength, higher rates of urinary and vaginal infections, and stereotypies such as sham chewing and bar biting.

The most comprehensive recent synthesis is a 2022 systematic

A pregnant sow inside a bare-floored group pen.



Source: Nova Dwade/We Animals

review, which finds that the relationship between space and welfare is context-dependent rather than a simple linear dose-response.⁸ One controlled Australian study found a linear decrease in both aggression and plasma cortisol on day 2 after mixing as space increased from 1.4 to 3.0m², but these differences had disappeared by day 9, and space allowance did not consistently affect lesion counts — a finding attributed to interactions with feeding system, group size, and group composition.⁹ Furthermore, there is broad agreement that very low allowances are inadequate: 1.4m² per sow is considered insufficient, with welfare improving as space increases and further benefit likely in the 1.8–2.4m² range and above.¹⁰

Space also frames the case for grouping sows early after insemination. Better reproductive synchronicity can additionally be achieved by mixing sows directly after weaning. Either way, mixing them at least within the first week after insemination — before embryos implant — reduces the time they spend confined, and the available evidence suggests this can be done without harming reproductive performance. Early premixing, where sows are grouped into pens within roughly the first days to a week after insemination, rather than waiting until pregnancy is confirmed near day 28, has become a focus of welfare research as pressure grows to reduce time spent in gestation stalls.

On stress physiology, most studies find no difference in plasma cortisol between stall- and group-housed sows, or among groups with different space allowances.¹¹ These findings challenge simple interpretations of cortisol alone as a reliable welfare discriminator and reflect the broader point that space cannot be evaluated in isolation from feeding management. The 2022 EFSA opinion acknowledges this complexity, endorsing quantitative dose-response modelling to estimate minimum

“Frequent regrouping increases aggression because dominance hierarchies must repeatedly be re-established, whereas static groups are generally associated with calmer behaviour and less fighting.”

space requirements while noting that the empirical data remain heterogeneous. The welfare consequence of space is thus real but conditional on how feeding and grouping are managed — a theme that recurs throughout this section and is taken up against its climate consequence in Section 4.

2.2 Social Stability and Group Management

Because pigs are highly social, with natural sub-groups of around six sows, welfare is strongly influenced by how groups are structured and managed. Frequent regrouping increases aggression because dominance hierarchies must repeatedly be re-established, whereas static groups — animals kept together throughout gestation with no other introductions — are generally associated with calmer behaviour and less fighting. Partitions to enable smaller groups also assist.

The most direct post-2015 evidence is a 2016 Belgian study, which found that static groups had lower lameness scores and significantly lower skin-lesion prevalence (24.9% vs 47.3%, $P < 0.05$) at the end of gestation.¹²

Lameness prevalence peaked at 22.4% in dynamic groups against 8.9% in static groups during the group-housed phase. Claw-lesion prevalence did not differ (75.5% across both systems), suggesting that floor-related claw damage is system-independent.

The picture is not uniform, which is why social stability is best read as a conditional rather than absolute welfare lever. A 2022 review cites evidence that sows in large dynamic groups (more than 50) may adopt more tolerant, passive responses to unfamiliar animals, mitigating the aggression typical of smaller dynamic groups; a controlled Canadian study found no differences¹³ in aggression, skin injuries, or cortisol between static and dynamic ESF groups in a fully controlled comparison.

That systematic review cautions that studies comparing static and dynamic groups differ substantially in space, group size, and feeding system, making definitive conclusions premature — a controlled, adequately powered trial remains an evidence gap.

Early or preimplantation grouping may further improve welfare by allowing hierarchies to stabilise before embryo implantation, reducing both embryonic-loss risk and aggression severity. The climate relevance of group stability runs through mortality and longevity, addressed in Section 4.

(Left) Sows queueing at an ESF system in preimplantation group housing at Hartos Agropecuária, Brazil. (Right) Sows feeding in a free-access system in preimplantation housing, Canada.



Source: Humane World for Animals (2025), The business case for preimplantation group housing systems.

2.3 Feeding System and Feed Access

Feeding management is a major welfare determinant in group housing because competition over feed can increase aggression and stress. Systems such as ESF and free-access stalls improve welfare by reducing competition while feeding and allowing feeding individualised to sow condition and gestation stage — but the post-2015 evidence reveals that each configuration carries its own welfare signature.

A 2022 review identifies queuing at the ESF entrance — roughly four to six sows waiting at any time, with about one-third having already eaten their daily ration — as a welfare concern specific to ESF systems as this may specifically lead to vulva-biting when queuing around the entry to the ESF. Free-access stalls reduce aggression and plasma cortisol relative to floor feeding but are associated with elevated vulva-biting, indicating that the spatial configuration of stalls can redirect rather than eliminate aggression.

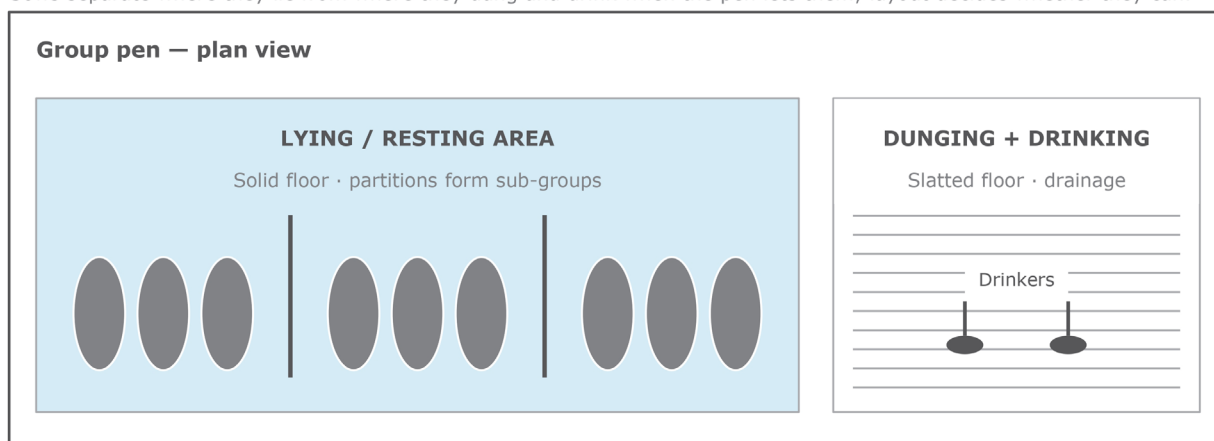
We were unable to find any systematic review or meta-analysis published post-2015 that directly compares ESF and free-access stall welfare outcomes, a noted gap for producers choosing between configurations. Because the feeding system is also the principal route to precision feeding, it is the input where welfare and climate interact most directly, as Section 4 sets out.

2.4 Flooring Type, Maintenance and Design

Flooring shapes leg and claw health, resting comfort, and injury risk. Poorly designed slatted floors increase slipping and leg problems, while partially slatted or solid resting areas can improve comfort and reduce injury. EU regulations require partial solid flooring, as supported by scientific review. Solid floors and partitions to enable sub-groups are expected in resting or lying areas, while slatted flooring can be used in areas of excretion, and drinking.

Functional Zoning in a Group Pig Pen

Sows separate where they lie from where they dung and drink when the pen lets them; layout decides whether they can.



Source: ARE analysis.

A 2023 Brazilian longitudinal study of commercial herds (2013–2023)¹⁴ found that individual housing consistently increased the claw-lesion index across all herd clusters, while group housing appeared to mitigate adverse effects on claw health — one of the first multi-year commercial datasets outside Europe or North America, strengthening the global applicability of the claw-health argument for group housing.^{15 16} Flooring choice also carries a climate consequence through nitrous oxide, which is where Section 3 begins to connect.

Taken together, Section 2 establishes the welfare side of the central claim: welfare improvement is directional and input-specific, and its reliability depends on management. Section 3 turns to the climate side.

3. Climate Performance Drivers in Sow Housing

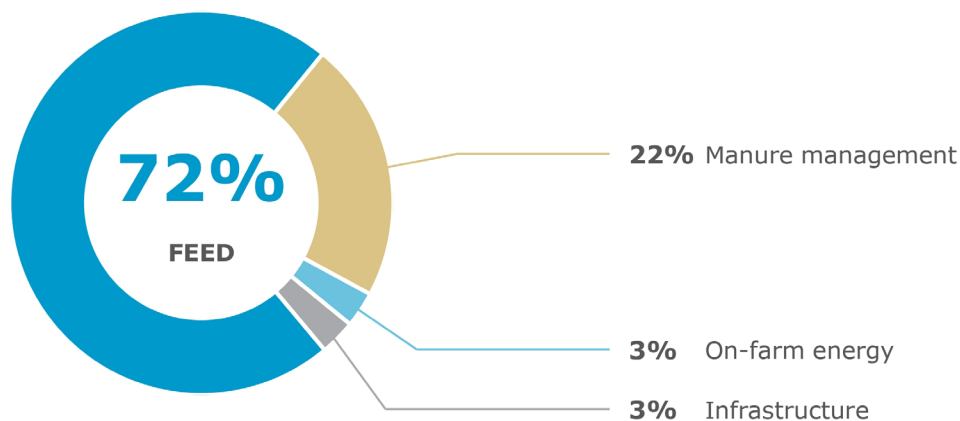
Before examining individual systems, it helps to set out the drivers of climate performance in rough order of magnitude.

Feed production dominates, accounting for the large majority of total burdens; manure management is the second largest contributor; energy use and infrastructure each have a minor share.

The sections below take each in turn. **The central message is that the largest levers — feed and manure — are largely independent of housing system**, which is why housing choice is a secondary-order driver of climate impact. The three major agricultural greenhouse gases involved are methane, nitrous oxide, and carbon dioxide.

Gestating Sows — Where Emissions Come From

Representative shares of total greenhouse-gas emissions; values vary by study, system boundary and geography.



Source: ARE analysis, based on cited LCA literature.

3.1 Feed — Volume and Composition (70–77%)

Feed production is the largest source of emissions in pig systems, arising from fertiliser application, crop cultivation, land-use change, transport, and processing. Soybean meal can substantially raise the footprint, where it is linked to deforestation or long-distance imports.

Earlier estimates placed feed-related activities at 45–65% of total emissions, but post-2015 evidence warrants extending the upper bound. A 2023 review of European pig systems finds feed accounts for about 70% of global warming potential in European pig systems.¹⁷ A 2026 South Korean LCA found feed at 76.31% of the total footprint per pig — 993.21kg of CO₂-equivalent (CO₂e) per head — its elevated intensity driven by reliance on imported corn.¹⁸ A 2025 Vietnamese LCA — the first integrated assessment from Southeast Asian pig farming — found feed digestion the primary emission source (8.26kg CO₂e per pig per month), with manure a minor share.¹⁹

This regional disaggregation carries a specific implication for Asia. For producers relying on long-haul imported feed grains, feed production is the dominant emissions lever, and the upper bound of the feed share should be extended toward 70–77%. Because feed dominates and is largely independent of the housing form, climate outcomes are shaped above all by feed volume and composition rather than by whether sows are crated or grouped — the pivotal point for the input analysis in Section 4.

3.2 Manure Management (20–40%)

Manure management is the second-largest source of emissions and a major source of both methane and nitrous oxide, contributing roughly 20–40% of total pig-production emissions, though in developing Asian contexts this share appears lower relative to feed. Emissions depend heavily on storage duration, temperature, oxygen exposure, and

treatment. Liquid slurry and open lagoons generally produce more methane than systems with frequent removal or anaerobic digestion. A 2024 validated model²⁰ quantifies the storage effect: ammonia emissions were 2.6kg per year per pig place under long-storage deep-pit systems, versus 1.4kg per year under short-storage flushing, with methane following the same pattern.

A 2025 swine sustainability review²¹ confirms that anaerobic digestion, composting, and biochar offer co-benefits of nutrient recovery and GHG reduction, while noting that integrating these technologies into group pens — if manure may contain straw bedding — presents practical engineering challenges. However, anaerobic digester systems have now been used in Europe with group housing for almost two decades, and engineers have resolved the main challenges with slurry systems for manure. As with feed, the dominant abatement lever here is the manure-handling practice, which is operationally separable from the housing configuration.

3.3 On-Farm Energy Consumption (3–8%)

Energy use in sow housing arises from ventilation, heating, cooling, lighting, automated feeding, and water infrastructure, and is generally estimated at about 3–8% of total pig-production emissions. **A 2019 US life-cycle assessment found that gestation pens reduced overall electricity and natural-gas use by 1.5% per kg live weight compared with stalls, owing to the lower maintenance energy requirements of group-housed sows.** While ESF electricity consumption is a real operational cost, energy at roughly 3% of the system's overall greenhouse-gas footprint is unlikely to be a determining factor in whole-system comparisons.

3.4 Infrastructure (2–10%)

Infrastructure — embodied carbon in building materials, retrofits, flooring, steel, concrete, and maintenance — generally contributes about 2–10% of total emissions. The same 2019 assessment found gestation-pen infrastructure to be approximately 65% larger than stall-based infrastructure per sow, with an offsetting feed-consumption reduction of 37,758kg per year for 500 sows. We were unable to find a post-2019 peer-reviewed study comparing the embodied carbon of retrofitted stall barns with purpose-built group housing — a commercially relevant gap given that most transitions in established pork-producing countries involve retrofit rather than greenfield construction. However, this is not usually the case in Asia, which is still expanding its sow inventory especially recovering from African Swine Fever, except current limits on sow inventory in China.

Section 3 establishes the climate side of the central claim: because feed and manure dominate environmental burden and are largely independent of housing choice, and because the remaining drivers — energy and infrastructure — are individually small, the housing system itself is a secondary-order driver of climate impact. Section 4 now brings the welfare and climate evidence together.

Welfare and climate at a glance: gestating sow inputs.

Input	Welfare	Climate	Relationship
Space allowance	✓	✓	Conditionally aligned
Social stability and group management	✓	—	Conditionally aligned
Feeding system (ESF / precision feeding)	✓	✓	Aligned
Flooring type and substrate	✓	✗	Conditionally aligned

Note: ✓ = benefit, ✗ = cost, — = neutral, negligible or unresolved. Symbols show the direction of effect for each input; the Relationship column gives the classification used in the text.

Source: ARE analysis

4. Welfare and Climate: Alignment, Conflict, and Conditionality

For each input, the causal chain from the design choice is traced to both its welfare consequence and its climate consequence, and asks how the two relate; whether they are aligned (a welfare gain at no real climate cost), in conflict (a welfare gain bought at a genuine climate cost), or conditionally aligned (a relationship whose sign direction and size depend on management, technology, or context). It then aggregates these input-level relationships into a net welfare–climate profile for each system type.

4.1 Input-by-Input Analysis

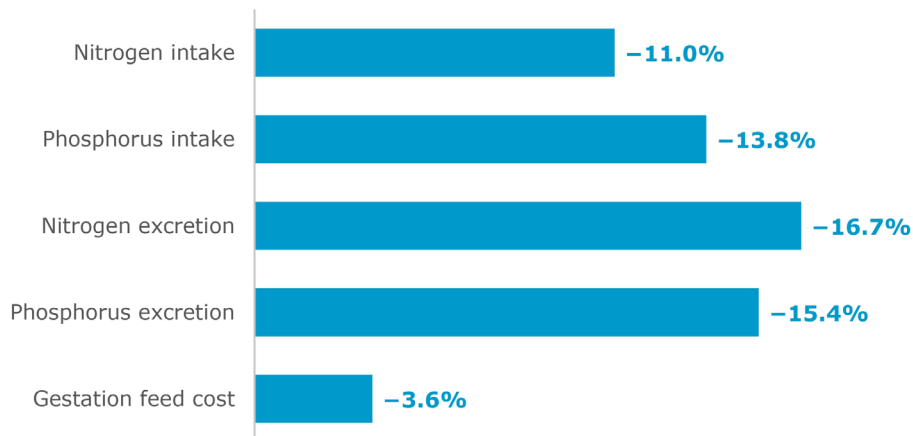
Space allowance — conditionally aligned. More usable space enlarges the behavioural repertoire, reduces aggression in the days after mixing, and lets subordinate sows avoid dominant ones (Section 2.1). The climate chain runs from greater space to greater movement and higher maintenance energy, and to a larger infrastructure footprint; the 2019 comparative LCA found gestation-pen infrastructure about 65% larger GWP per sow than stalls.

Yet the relationship is conditional rather than a fixed conflict, and is frequently net favourable. The same LCA found pens reduced overall greenhouse-gas footprint, energy, and water use, because improved reproductive performance and a feed-consumption reduction of 37,758kg per year for 500 sows offset the higher infrastructure burden. Within deep-litter systems, increasing space from 2.5 to 3m² reduced daily emissions per sow by around 28% by reducing anaerobic conditions in the litter. Management and reproductive performance are the moderating variables that determine where this input lands.

Social stability and group management — conditionally aligned, through mortality and longevity. Stable, well-socialised groups lower aggression, lameness, and lesions (Section 2.2). The climate link is indirect and runs through reproductive performance and longevity: where mixing stress, lameness, and disease are poorly controlled, culling rises and more replacement animals must be reared and fed per unit of output. Where management keeps aggression and mortality low — through static grouping, parity-matching, and early mixing — the climate penalty largely disappears, and reproductive

Precision Feeding Cuts Nutrients, Emissions and Cost

Reduction against conventional gestation feeding.



Optimised precision feeding can cut nitrogen and phosphorus excretion by up to ~40% and pig-system GHG by up to ~6%.

Source: ARE synthesis of cited LCA and feeding studies.

gains can run the other way. The moderating variables are explicit: group composition, group stability, space and stockmanship at mixing.

Feeding system — aligned, and the report’s strongest welfare–climate synergy. This is the input where welfare and climate pull in the same direction most clearly. ESF and free-access systems reduce feed competition and individualise rations; the same ESF capability enables precision feeding, which adapts rations to individual daily requirements and lowers dietary crude protein and soybean inclusion.

A 2020 study, spanning more than 5,000 gestations, found precision feeding cut²² nitrogen intake by 11.0% and phosphorus intake by 13.8%, with nitrogen excretion down 16.7% and phosphorus excretion down 15.4%, and gestation feed costs down 3.6%.

A second 2020 study confirms similar magnitudes; a 2024 multi-cycle study found nitrogen intake down 10–13% and phosphorus intake down 6–9% across three cycles, with a welfare co-benefit of reduced piglet mortality. The 2023 European review finds optimised precision feeding can cut N and P excretion by close to 40% and pig-system GHG by up to 6%.

Because feed is the dominant emissions source, this feeding-system synergy is the single most-important reason group housing can improve welfare and climate performance at once. The only qualification is that ESF consumes electricity and adds technological complexity — both minor at the system level.

Flooring type — conditionally aligned, with an N₂O trade-off. Solid resting areas, and ideally straw-based deep litter, improve claw health, comfort, affective state and reduce stereotypies (Section 2.4);

“A 2021 Chinese study found that group-housed sows had lower stress hormones and better disease resistance...”

group housing itself appears to lower the claw-lesion index relative to individual housing. But the substrate choice that most benefits welfare can carry a climate cost.²³ A 2011 study found deep litter more than doubled daily emissions per sow relative to slatted floors — an increase of about 114% — driven chiefly by nitrous oxide, which the 2023 European review links to feed nitrogen and to large manure surfaces exposed to oxygen.

The relationship is conditional rather than fixed because the cost is tractable: more space within deep litter lowers emissions and composting and biochar addition reduce N₂O formation. Sow-specific deep-litter N₂O measurement remains an evidence gap, so the magnitude carries some uncertainty. However, the sheer volume and logistics of storing and ensuring clean litter for bedded systems in parts of Asia (e.g. China, Vietnam, Thailand) can limit adoption. Additionally, they carry a risk of introducing African Swine Fever (ASF) in affected countries.

Co-benefits that reinforce the case — ammonia and antibiotic use. Two further chains (inputs) run alongside the four inputs and strengthen the alignment. On ammonia, a 2001 Dutch measurement study found free-access group systems²⁴ emitted significantly less than stalls (0.62 vs 0.72g/h per sow) because sows confine excretion to a defined area, shrinking the emitting surface; storage duration is the larger system-level driver (1.4 vs 2.6kg NH₃ per year), operationally separable from housing.

On antibiotic use, a 2022 review²⁵ argues that crowded, barren conditions drive redirected behaviours (e.g. biting and fighting), poorer immunocompetence, and higher antibiotic use, emphasising the importance of stable groups via good design and enrichment with group housing. A 2021 Chinese study²⁶ found group-housed sows had lower stress hormones ($P < 0.01$) and better disease resistance, and a 2025 review²⁷ reports higher lameness in crates. The relationship is non-linear, however. The 2019 US life-cycle assessment²⁸ showed that removing all preventive antimicrobials raised GWP by 17.32% and energy use by 18.40%, so improved housing must precede, not merely accompany, reduced antimicrobial use.

The moderating role of management. Across every input, management intensity is the variable that sets where a system lands. It cannot turn the feed cost of more movement into a free gain, but it determines the magnitude. Good stockmanship narrows the space-feed conflict, keeps lameness and culling low, captures the precision-feeding synergy, and compresses the N₂O and ammonia penalties. Poor management widens every one of these gaps at once. This is why the welfare-climate outcome tracks management quality more closely than it tracks the housing label.

Gestating Sows — Input-by-System Summary

Each cell: how the input plays out in that system · colour = net welfare–climate verdict

	Conventional crate	Group pen ESF RECOMMENDED	Group pen free-access stalls
Space allowance	Minimal space; welfare cost; lowest infrastructure	Lower density; gain; net-favourable via productivity	Lower density + retreat stalls; gain; net-favourable
Social stability / group management	No social group; restricted behaviour	Group; conditional via mortality → longevity	Group + retreat stalls; lower aggression; conditional
Feeding system	Individual feeding; no competition, no synergy	ESF precision feeding; aligned, strongest synergy	Protected individual feeding; limited precision savings
Flooring type	Slatted/stall; higher claw-lesion index	Solid/mat resting; conditionally aligned	Part-slatted/solid; conditionally aligned

■ Aligned
 ■ Conditional
 ■ In conflict
 ■ Welfare cost / climate-favourable

Source: ARE synthesis of cited LCA and welfare literature.

4.2 System-Level Summary

Aggregating the input-level relationships gives a net welfare–climate profile for each system type. The profiles differ less because any single input behaves differently across systems than because the systems bundle different combinations of inputs and degrees of confinement.

Conventional gestation crate. The crate offers no positive welfare inputs — minimal space, no stable social group, no individually controlled feeding without social contact, and extremely restricted movement — and so it sits at the bottom of the welfare scale while sitting near the top of narrow operational climate performance: lowest maintenance energy and smallest infrastructure footprint. It forgoes the precision-feeding synergy, and the reproductive and longevity gains that drive the only direct LCA in favour of pens, and the InterPig²⁹ evidence indicates crate-dominant systems are less productive per sow.

Full group pen with ESF. The ESF pen combines stable or well-managed grouping, adequate space, and precision feeding. It takes on the conditionally aligned inputs — the space–feed relationship, group-size-mediated mortality risk — while capturing the report’s strongest synergy through precision feeding, which cuts nutrient excretion and feed-related emissions. **Its net profile is the clearest case of a welfare gain at neutral or favourable climate cost, provided management is sound and ESF queuing is controlled.**

Group pen with free-access stalls. The free-access pen gives each sow a protected stall to feed in, which removes competition at feeding and lowers aggression and plasma cortisol relative to floor feeding (Section 2.3). It also carries an ammonia co-benefit: sows confine excretion to a defined area, and the 2001 Dutch measurement study

found free-access group systems emitted significantly less than stalls. Where the stalls are equipped for individual feeding, the precision-feeding gains available through ESF apply here too — the climate saving comes from matching the ration to the sow, not from the stall type itself. Elevated vulva-biting is its system-specific welfare concern. **Where precision feeding is implemented, its net profile matches the ESF pen: a substantial welfare gain at neutral or favourable climate cost.**

Floor-fed and unmanaged deep-litter pens. Neither is recommended. Floor feeding leaves feed competition difficult to control, so the aggression and body-condition variation that group housing is intended to resolve persist, and the precision-feeding route to lower nutrient excretion is closed off. Unmanaged deep litter carries the nitrous oxide penalty set out in Section 4.1 — 0.94kg CO₂e per day per sow against 0.44 for slatted floors — alongside the litter-supply logistics and African Swine Fever risk that constrain bedded systems in parts of Asia. **Both take on the conditional costs of group housing without capturing the synergy that offsets them.**

Recommendation

For new sow-housing investment, the destination is full group housing with precision feeding, delivered either through electronic sow feeders (ESF) or through free-access stalls equipped for individual feeding. It is the configuration that captures the report's strongest welfare-climate synergy: precision feeding acts directly on feed, the dominant emissions source, while stable grouping and adequate space deliver the behavioural and health gains that define the welfare case, and the only direct comparative LCA finds this pathway neutral-to-favourable on climate.

Floor-feeding and unmanaged deep-litter pens are not recommended in climate terms, because they forgo the precision-feeding savings and concentrate the conditional costs. ESF group housing is climate-compatible when configured to maintain reproductive performance and longevity through stable grouping and appropriate space, and to handle manure and litter to contain ammonia and nitrous oxide.

5. Methodological Issues

The cross-cutting methodological issues — reading the comparative figures, functional unit and system boundary, land-use-change accounting, and geographic transferability to Asian markets — are set out in the Cross-Cutting Methodological Notes in Part A. Two points are specific to the sow evidence base, both stemming from the paucity of comparative literature.

5.1 The Single Comparative LCA

The only direct comparative life-cycle assessment of gestation crates versus group pens — a 2019 US study — explicitly notes that its findings should be treated as directional rather than precise, because the Monte Carlo uncertainty ranges of the scenarios overlap. The headline figures — GWP, energy, and water each lower by around

1% in pens — should therefore be read as evidence of direction and approximate magnitude, not as fixed constants, and we were unable to find any direct comparative LCA published since.

5.2 Confounded Comparisons

The InterPig analysis, a 2022 multi-country productivity comparison, is informative but limited by confounding across country groups. Differences attributed to crate versus group housing are entangled with genetics, climate, feed supply, and management that vary by country. Manure-management and energy assumptions are similarly decisive — assigning long-storage deep-pit handling to one system and short-storage flushing to another can misattribute an emissions difference to housing when it is really a manure-practice difference.

5.3 Evidence from Tropical Systems

Almost all the comparative sow evidence reviewed here was generated in temperate conditions. The one substantial tropical dataset — a 2026 Thai study of 61,066 service records — finds reproductive performance and sow longevity lower in group gestation than in crates, with the difference concentrated in gilts and first-parity sows during the hot and rainy seasons. Three cautions apply to reading it. It covers a single commercial herd, so herd-specific management cannot be separated from housing. Its least-confined comparator combines group gestation with complete free farrowing, so part of the longevity difference is attributable to the farrowing system, which falls outside this report's gestation-only scope. And it reports no welfare outcome measures, so it speaks to reproductive performance rather than to welfare. Taken with the temperate evidence, it indicates that the magnitude of the reproductive gains reported from temperate studies requires local validation in hot and humid conditions.³⁰

6. Gestating Sow Conclusion

The crate constrains a sow to a space she cannot turn around in for the entirety of her gestation. The welfare consequences — stereotypies, muscle and bone deterioration, a higher claw-lesion index, infection rates, and suppressed natural behaviour — are well-documented. What is less well understood is how the transition to group housing sits against the climate objectives that now also bear on investment decisions. This report has examined that question, and its finding is that the two objectives are more aligned than the conventional assumption holds. Where tension remains, the levers to manage it are operational rather than structural.

The primary source of possible tension is feed: more movement raises maintenance energy, and feed accounts for up to 70–77% of pig-production emissions in import-reliant systems. But the tension runs in the opposite direction at a critical point — the feeding system. Group housing enables ESF-based precision feeding, which cuts nitrogen excretion by up to 17% and phosphorus by up to 15%, and reduces system-wide GHG by up to 6%. **The only direct comparative LCA finds group pens modestly better than stalls on global-warming potential, energy, and water use, driven by the reproductive performance that stable group management supports.**

The conflict between welfare and climate in sow housing is therefore narrower than it appears and frequently reversed by the management practices and superior reproductive performance that group housing makes possible.

The practical levers are specific to each industry and should be applied in sequence. Precision feeding through ESF acts directly on feed — the dominant emissions source — and is the strongest single intervention available. Short-storage manure handling, anaerobic digestion, and composting reduce both ammonia and greenhouse-gas emissions regardless of housing form. Stable grouping, adequate space and parity-matching at mixing protect reproductive performance and sow longevity, which is where the welfare improvement results in climate return. Flooring and litter choice carry an N₂O trade-off that composting and biochar can substantially mitigate.

For Asian producers in the tropics, the evidence carries a specific opportunity. Asia's dependence on imported feed with high deforestation risk means that precision feeding's nutrient and emissions savings are proportionally larger there than in European systems where the imported feed share is lower.

Well-managed group housing — configured to capture the precision-feeding synergy, optimise reproductive performance and sow longevity, and handle manure and litter to contain ammonia and nitrous oxide — is the right welfare and climate direction for new sow-housing investment. What remains is the work of implementation: gathering the local data, refining the right systems for regional conditions, and building the management capability to achieve these outcomes.

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Part B2: Broiler Growing Systems, Welfare, Climate Impact

Recommendation: New Broiler Investment

Cage-free floor systems, moderately slower-growing birds at reduced stocking density, with enrichment and a suitable lighting regime. Slower-growing breeds at lower density are not the highest-welfare option available but they capture most of the welfare gain at a moderate climate cost. They also reduce antibiotic use, mortality and leg problems, and help with food safety in hot climates. Feed sourcing affects the climate result more than the choice of housing.

Part B2 of the Cage-free x Climate series. Part A sets out the shared framing, methodology, and cross-cutting findings, and Parts B1 and B3 cover gestating sows and laying hens. The annex, Expanded Source Tables, holds the full evidence tables for the studies cited here.

Key takeaways

- **Conventional fast-growing, high-density broiler production sits at the bottom of the welfare scale on nearly every measure** — gait, leg health, contact dermatitis, behavioural restriction, mortalities — while sitting at the top of narrow climate performance.
- **The primary tension runs through feed:** slower genetics and lower densities raise the feed required per kilogram of output, and feed accounts for more than three-quarters of broiler emissions. But the size of that cost depends above all on feed sourcing, not on the welfare improvement itself.
- **Several welfare changes, including enrichment and lighting, cost nothing in climate terms at all.**
- **For producers in tropical and subtropical Asia, the heating-energy penalty that inflates the cage-free climate cost in temperate studies is largely absent.** The emerging trend toward multi-tier cage systems in several Asian markets runs

in the opposite direction: the welfare evidence against caging is clear, and the limited climate evidence offers no offsetting justification.

In this section

- **Terminology and Scope**
- **1. The Welfare-Climate Question in Broiler Production**
- **2. Key Welfare Determinants in Broiler Systems**
- **3. Main Drivers of Climate Performance in Broiler Systems**
- **4. Welfare and Climate: Alignment, Conflict, Conditionality**
- **5. Methodological Issues**
- **6. Conclusion**

Terminology and Scope

This report uses conventional fast-growing indoor floor systems as the baseline for comparison, and examines higher-welfare alternatives across a spectrum of system change.

- **Conventional fast-growing floor system** — the baseline: an indoor, litter-based system using fast-growing genetics at high stocking density with the shortest grow-out.
- **Lower-density conventional floor system** — the same fast-growing genetics and litter floor, but at reduced stocking density.
- **Moderately slower-growing (BCC-aligned) system** — a floor-based, litter system using moderately slower-growing breeds at lower density, with enrichment and lighting broadly aligned to the Better Chicken Commitment (BCC).
- **Very slow-growing/extensive system** — the slowest-growing breeds at the lowest densities, the most extensive of the floor systems. Slower-growing breeds are already mainstream in Asia — China's native, yellow-feathered chickens were roughly 17–18% of local broiler output in 2024 but gradually replaced by white-feathered, fast-growing broilers.¹
- **Multi-tier caged (colony) system** — stacked-cage systems prevalent in China and emerging in some Asian markets, with a limited and methodologically inconsistent evidence base.

Scope note. This section confines its analysis to on-farm broiler production — chickens raised for meat. The broader broiler system (breeder flocks, hatcheries, feed production and sourcing, veterinary medicines, agricultural inputs, water and land use, and waste management) is acknowledged but not analysed in detail except where it bears directly on the welfare–climate comparison.

Baseline. Throughout this section, the point of comparison is the conventional system: fast-growing breeds raised at high density on a litter floor. In principle, a multi-tier caged or fully slatted system could serve as an even lower welfare baseline, and such systems are increasingly used for broilers across parts of Asia. We have not adopted them as the baseline for two reasons. First, the academic literature on caged broiler production remains limited and methodologically inconsistent — and heavily skewed toward physical-health indicators while omitting behaviour almost entirely. Second,

there is correspondingly little rigorous evidence on the climate performance of these systems, leaving no sound basis for a paired welfare–climate comparison.

That said, the available evidence does not suggest caged systems are benign. A systematic review of 23 studies comparing slatted or caged housing with litter-based floors found that most reported a welfare concern with slatted floors, and **that the supposed advantages of cages — fewer footpad and hock lesions from cleaner flooring — were inconsistent and often absent.** Crucially, none of the empirical studies included a full behavioural assessment, and **not one measured dustbathing or foraging — the very behaviours a cage structurally prevents.**²

An expert survey within the review judged modern cage systems unacceptable on welfare grounds.³ The review concluded against rolling out caged systems, recommending instead that effort go into enriching litter-based barns. We take the same position; caged and slatted systems remove the highly motivated behaviours central to broiler welfare, without delivering a consistent, offsetting health benefit, while noting that more rigorous behavioural and climate assessment of these systems is still needed.

In this report, broiler welfare refers to outcomes experienced by the birds themselves — including whether they can perform highly motivated natural behaviours such as dustbathing, perching, exploratory pecking and wing-flapping, which deliver both mental and physical benefits (disease prevention, thermoregulation, social regulation and stress relief). Welfare outcomes depend on a range of system inputs and hazards including broiler genetics, and on how these are managed in practice.⁴

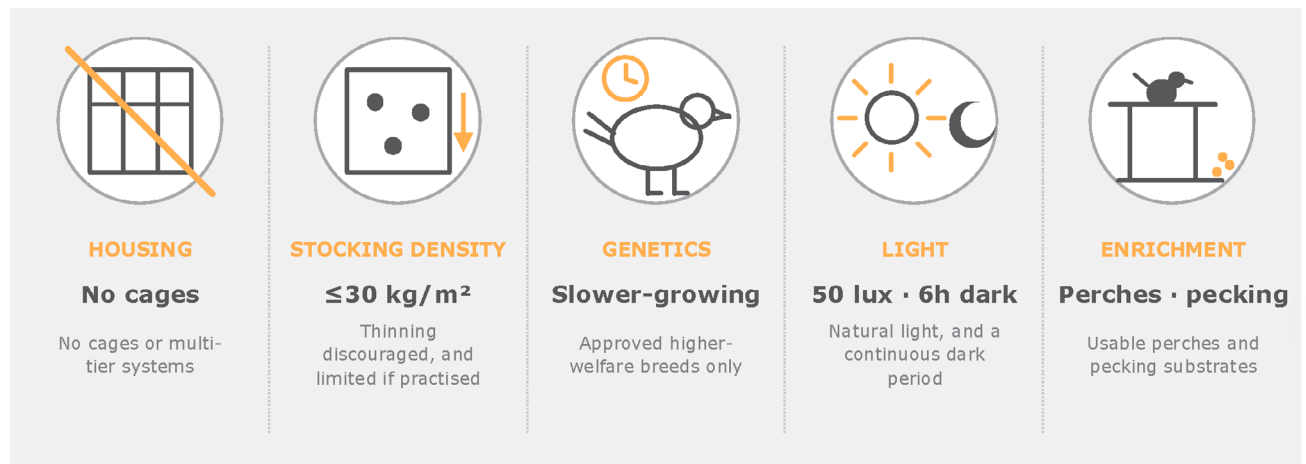
Most civil-society organisations and major independent, science-based welfare certification schemes apply minimum standards broadly aligned with the Better Chicken Commitment (BCC), also known as the European Chicken Commitment.⁵ There are already commercial examples of producers and buyers applying these standards. The Netherlands is a useful real-world reference point: domestic production for domestic consumption has transitioned to the Dutch Retail Broiler standard, which functions commercially across all facets of retail and is broadly similar to the BCC in its minimum welfare requirements.⁶

The main BCC standards are:

- no cages or multi-tier systems.
- maximum stocking density of 30kg/m² or less, with thinning discouraged and limited if practised.
- use of moderately slower-growing or higher-welfare breeds (an approved list is available).
- provision of natural light, a minimum of 50 lux, and a six-hour period of continuous darkness.
- provision of usable perches and pecking substrates, also known as enrichment.

The Better Chicken Commitment

The five minimum standards used as the welfare benchmark in this section



Source: ARE analysis, based on the Better Chicken Commitment.

1. The Welfare-Climate Question in Broiler Production

The global broiler industry raises and slaughters more than 70 billion birds annually — almost half of them in Asia — and comprises approximately 8% of the livestock sector's greenhouse gas emissions, 78% of which come from feed production alone.^{7 8 9}

Welfare pressure on this industry is mounting from multiple directions: the rapid spread of the Better Chicken Commitment among major retailers, growing investor scrutiny of fast-growing genetics and high-density housing, and the prevalence or emergence of multi-tier cage systems in several Asian markets that compound rather than reduce confinement. For a sector producing at this scale, the stakes of getting the welfare-climate relationship wrong in either direction are substantial.

Feed accounts for more than 75% of broiler emissions, and the tension in broiler production runs directly through it. Slower-growing genetics and lower densities improve welfare but raise the feed required per kilogram of output. The size of that cost depends above all on feed sourcing; a slower-growing bird on a low-deforestation diet can carry a lower net climate impact than a fast-growing bird on a high-deforestation one. A 2025 meta-analysis reviewing 46 studies found no statistically significant system-level difference in greenhouse-gas footprint after correcting for methodological variation, suggesting apparent climate penalties between systems may reflect study design rather than welfare standards as such.¹⁰

Several welfare improvements — enrichment and lighting in particular — carry no meaningful climate cost at all, despite linkage to growth, development and activity levels. The operative question for producers is therefore which combination of cage-free system changes — genetics, density, feed sourcing, housing-energy design — produces

the most balanced outcome for this animal.

This section is organised around the production-system inputs that determine both welfare and climate outcomes — caged versus floor housing, stocking density, enrichment, lighting, and genetics and growth rate — rather than around system labels.

- **Section 2** establishes the welfare evidence around these inputs.
- **Section 3** establishes the climate evidence around the main drivers of environmental performance.
- **Section 4** brings the two together, tracing each input through to its welfare and climate consequence before aggregating to a system-level summary.
- **Section 5** sets out the methodological caveats specific to the broiler evidence base, building on the cross-cutting notes in Part A.
- **Section 6** draws the argument together.

Key Welfare Determinants — Broilers

The design and management inputs analysed in this section, and the welfare measures each one drives

2.1 Caged or floor-based systems

Whether birds are housed on litter or in tiered cages

WELFARE MEASURES DRIVEN

Range of movement and behaviour · bone development · leg deformities and standing ability · thermal comfort

2.2 Stocking density

Birds per square metre, and the litter and air quality that follow from it

WELFARE MEASURES DRIVEN

Movement · litter and air quality · gait · footpad dermatitis and hock burn · heat stress

2.3 Environmental enrichment

Pecking substrates, elevated resting places, barriers and covered verandas

WELFARE MEASURES DRIVEN

Foraging and pecking · dustbathing · perching and comfort behaviour · overall activity

2.4 Lighting regimes

Light intensity, and the length of the continuous dark period

WELFARE MEASURES DRIVEN

Natural activity patterns · development · quality of rest

2.5 Genetics and growth rate

How fast the bird is bred to grow, and its breast-muscle balance

WELFARE MEASURES DRIVEN

Walking ability and chronic pain · leg disorders · contact dermatitis · metabolic problems · mortality and culls

Source: ARE analysis.

2. Key Welfare Determinants in Broiler Systems

The welfare differences between broiler systems arise from a defined set of design and management inputs — whether birds are caged or floor-raised, how densely they are stocked, the growth rate and breast muscle balance of the genetics used, and the enrichment and lighting provided. This section is organised around those inputs. The welfare outcomes that follow from them — skeletal development, gait and leg health, contact dermatitis, thermoregulation, behaviour and mortality — are presented under the input that primarily drives them.

2.1 Caged or Floor-Based Systems

A first determinant is whether birds are kept in caged or floor-based systems. Floor-based litter systems allow a greater range of movement and behaviour — walking, foraging, pecking, wing-flapping,

Higher-Welfare Standards Mean Lower Stocking Density

Maximum stocking density for broilers, kg live weight per m².



Lower density improves litter quality, gait and footpad health. The conventional figure is a typical intensive range; standards vary by market.

Source: ARE analysis. The conventional figure is a typical intensive range; standards vary by market.

dustbathing, social interaction and thermoregulation — whereas caged systems impose stronger spatial, social and behavioural restrictions. Caged systems also promote weaker bone development, compounding the skeletal problems generated by fast-growth genetics; colony cages are linked to higher frequencies of leg deformities and reduced standing ability than floor systems, along with claw injuries in slatted or wire systems.^{11 12}

While some studies report better thermal regulation in multi-tier colony cages (with closed systems and ventilation) than in floor systems, an Israeli case study found litter-based systems provided better thermal comfort, with no panting observed in floor-reared birds and more restricted behaviour in cages. As caged birds grow and their body and breast-muscle weight increases, locomotor activity declines through pain, limited space and imbalance, leading to more time spent lying, more litter contact and potentially a more stressful thermal environment they cannot escape or modify.¹³

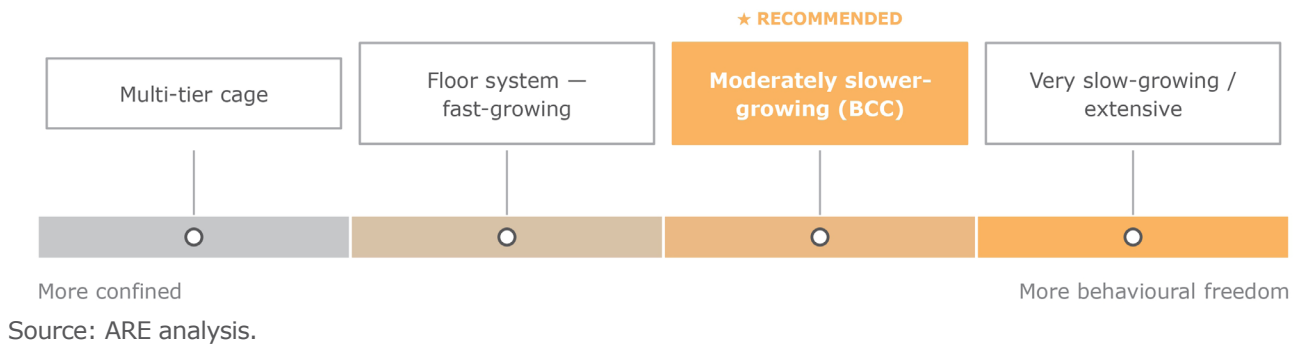
2.2 Stocking Density, Litter Quality, and Heat Stress

Higher stocking density restricts movement, worsens litter and air quality, and increases the risk of poor gait, footpad dermatitis, hock burn, and other contact lesions. Experimental and farm-based studies show that reducing stocking density improves litter quality and several welfare measures in both fast- and slower-growing broilers.¹⁴ Higher density may also worsen heat stress in hotter conditions by reducing airflow and making it harder for birds to dissipate body heat.¹⁵

2.3 Environmental Enrichment

Broilers are motivated to forage, peck, dustbathe, perch and rest comfortably, so systems providing usable litter, space and enrichment support behavioural welfare better than barren environments. A major review concluded that useful enrichments include elevated resting places, barriers, straw bales, covered verandas and outdoor access.¹⁶ Experimental work shows enrichment increases activity in both fast-

Broilers: Growing Systems by Confinement and Welfare



and slower-growing broilers, with slower-growing birds often making greater use of it given more balanced skeletal development and no chronic pain.¹⁷ Enrichment can be adapted for Asian contexts provided it is accessible and bio secure — for example, rice-hull-filled sacks.

2.4 Lighting Regimes

Lighting is a smaller but real welfare determinant. Regimes that support natural activity patterns — adequate light intensity (a minimum of 50 lux under the Better Chicken Commitment) and a meaningful continuous dark period of at least six hours — support development, rest and welfare. The standalone evidence base for broiler lighting is more limited than for density or genetics, and lighting is best understood as complementary to those dominant determinants rather than a substitute for them.

2.5 Genetics and Growth Rate

Genetics strongly influence how birds experience the production environment. Fast-growing broilers are associated with chronic pain and poorer walking ability, leg disorders, contact dermatitis, metabolic problems and reduced activity as body weight rises very quickly over a short period (more than three times the growth rate of 50 years ago). Comparative studies show slower-growing broilers to be generally more active, healthier and better able to express positive welfare behaviours.¹⁸ Farm- and pen-based studies report lower mortality, fewer culls, better gait, and lower levels of hock burn and footpad dermatitis even in moderately slower-growing birds.¹⁹

Section 2 establishes the welfare side of the comparison; Section 3 turns to climate.

3. Main Drivers of Climate Performance in Broiler Systems

Feed production dominates the climate impact of broiler systems, typically accounting for more than three-quarters of total emissions. On-farm energy and manure management are smaller, secondary contributors. Housing choice is therefore a secondary driver.

3.1 Feed — Volume, Efficiency, and Sourcing (75–78%)

Feed is the dominant contributor to broiler emissions, usually more than 75%, so climate outcomes are shaped above all by feed volume and composition rather than by housing system. Feed volume matters

because slower growth, poorer feed conversion and longer grow-out increase the feed required per kilogram of output. Composition matters because the proportion of potentially high-impact ingredients — especially soy and soybean meal — can materially change the footprint. Soy-related land-use change, particularly deforestation, can account for more than half of total climate impact in some studies.²⁰ Broiler climate results are therefore highly sensitive to the manner in which soy sourcing and land-use change are accounted for, and this driver is largely independent of housing system.

3.2 On-Farm Energy Consumption (~9%)

On-farm energy use is much less important than feed but remains relevant because it is directly affected by housing design and management. In one cradle-to-farm-gate LCA, on-farm inputs and emissions — largely heating and ventilation — contributed about 9% of total impacts.²¹ In colder regions, heating dominates direct energy input. A Finnish case study found heating demand of 1.3kWh per kg carcass weight against only 0.08kWh per kg for electricity.²² In hotter climates, ventilation and cooling dominate instead: a commercial Arkansas broiler house drew more than 88% of its electricity through ventilation fans, with consumption rising from 43kWh per metric tonne of live weight in winter to 184kWh in summer.²³ Unlike feed, this driver is directly shaped by housing system and local climate.

3.3 Manure Management (~6%)

Manure is a secondary source of total broiler emissions relative to feed but remains significant on-farm, chiefly through nitrous oxide and methane generated during litter accumulation, storage, and handling. In a Brazilian farm-gate LCA, manure management contributed roughly 6% of total GWP; within that, indirect N₂O contributed 61.8%, direct N₂O 19.3% and methane 18.9%, making nitrous oxide the dominant manure-related pathway in that system.²⁴ Manure emissions are not fixed at the point of excretion: they depend on litter moisture, residence time in the house, aeration and downstream handling. A recent farm-scale study found that covering stockpiled broiler litter significantly reduced ammonia, methane and nitrous oxide emissions, showing that post-house handling can materially alter both climate emission and air-pollution outcomes.²⁵

Section 3 establishes the climate side; Section 4 now brings the two together.

4. Welfare and Climate: Alignment, Conflict, and Conditionality

For each input, this section traces the causal chain from the design choice through to both its welfare and its climate consequence, and asks how the two relate — whether they are aligned (a welfare gain at no real climate cost), in conflict (a welfare gain bought at a genuine climate cost), or conditionally aligned (a relationship whose sign and size depend on management, technology or context). It then aggregates these input-level relationships into a net profile for each system type.

Table 2. Welfare and climate at a glance: broiler inputs.

Input	Welfare	Climate	Relationship
Stocking density (lower)	✓	✗	In conflict
Genetics and growth rate (slower)	✓	✗	In conflict
Environmental enrichment and lighting	✓	—	Aligned

Note: ✓ = benefit, ✗ = cost, — = neutral, negligible or unresolved. Symbols show the direction of effect for each input; the Relationship column gives the classification used in the text. Source: ARE analysis

4.1 Input-by-Input Analysis

Stocking density — in conflict. Lower density improves litter quality, gait, footpad dermatitis, hock burn, and thermal comfort (Section 2.2), but increases energy demand for heating, cooling, and ventilation per unit of output. The conflict is real but not fixed in magnitude. It can be mitigated through heat recovery and other housing-energy measures, and lower density may improve productivity under hot and humid conditions, compressing the cost.²⁶ Thailand illustrates the point; its Department of Livestock Development already mandates a relatively low maximum stocking density for cage-free broilers in a warm tropical climate, at 33 kg/m².²⁷ Management and climate context are the principal moderators, which makes lower density relevant not only as a welfare intervention but as a resilience measure in warmer environments.

Genetics and growth rate — in conflict, highly variable magnitude. Slower-growing birds deliver clear welfare gains — better gait, lower contact dermatitis, greater activity and lower mortality (Section 2.5). They also raise total feed demand and lengthen grow-out (around four to five additional days for moderately slower strains, depending on genetics and target weight), increasing climate burden through feed volume and poorer feed conversion.

The magnitude of the conflict depends on three things.

- **Soy sourcing:** a slower-growing bird on a low-LUC diet can carry a lower net climate impact than a fast-growing bird on a high-LUC diet. So, a fast-growing system can still look climate-intensive if its feed mix carries a large land-use-change burden.²⁸
- **Breeder stage efficiency:** the extended broiler growth period penalty can be partly offset upstream, if including breeders in scope, because slower-growing breeder systems may require fewer breeders as they experience lower mortality and longer fertile lifespans.
- **The pace of genetics:** moderately slower and very slow-growing strains differ meaningfully. Moderate strains add roughly four to five days to grow-out, while very slow-growing strains extend it considerably further up to six weeks, delivering a larger welfare gain but a more pronounced climate cost. The conflict is real, but at the moderate end of the range it stays small enough that BCC-aligned genetics remain climate-compatible.

Broilers — Input-by-System Summary

Each cell: how the input plays out in that system · colour = net welfare–climate verdict

	Conventional fast-growing	Moderately slower-growing (BCC)	Very slow-growing
		RECOMMENDED	
Stocking density	Highest density; lowest energy; welfare cost	Lower density; welfare gain; energy cost mitigable	Lowest density; largest gain; energy & feed cost mitigable
Genetics / growth	Fast; poorest leg & gait; best FCR	Slower; clear welfare gain; small, mitigable cost	Very slow; largest gain; largest feed / LUC cost
Enrichment & lighting	Often minimal; climate-neutral	BCC standard; gain; climate-neutral	Extensive; gain; climate-neutral

■ Aligned
 ■ Conditional
 ■ In conflict
 ■ Welfare cost / climate-favourable

Source: ARE analysis of cited LCA and welfare literature.

A Dutch life-cycle assessment covering the whole production chain, from breeder flocks and hatchery to harvest-ready broilers, puts numbers on the moderate end of this range. It compared conventional production with the Dutch Retail Broiler system, the commercial system closest to the Better Chicken Commitment. Dutch Retail Broilers reach slaughter weight in 49 days, about a week longer than a typical 42-day conventional cycle. On the same feed, they emitted about 9% to 16% more greenhouse gases per kilogram of live weight than conventional birds: 9% where soy comes from high land-use-change (deforestation-linked) sources, and 16% where it comes from low land-use-change sources. Soy sourcing has a much larger effect. A Dutch Retail Broiler system fed low land-use-change soy would emit about 56% less than conventional production fed deforestation-linked soy.²⁹

Environmental enrichment and lighting — aligned. Enrichment — pecking substrates, suitably designed perches or platforms, and opportunities for exploratory and comfort behaviour — improves leg and behavioural welfare without materially changing feed demand or extending grow-out.³⁰ Appropriate lighting, including adequate intensity and meaningful dark periods, supports eye and general development, rest, and welfare, while adding little to total emissions. The climate cost of both is therefore negligible. The relationship is aligned: the climate cost does not vary. What does vary is whether the welfare gain materialises, since enrichment must be accessible and biosecure to deliver its benefit, and poorly designed enrichment that birds cannot use confers no welfare gain. These measures are complementary, not substitutive: breed and stocking density remain the dominant welfare determinants, and enrichment and lighting shape activity, space use, and natural behaviour around them.³¹

The moderating role of management. Across all three inputs, management intensity is the variable that sets where a system lands.

It cannot remove the feed cost of slower growth, but it determines the magnitude: litter moisture and ventilation management compress the density penalty, feed sourcing decisions outweigh the genetic penalty, good stockmanship keeps mortality and culling low, and well-designed enrichment delivers the welfare gain it promises while poorly designed enrichment delivers none. Poor management widens every one of these gaps at once. This is why the welfare–climate outcome tracks management quality more closely than it tracks the system label.

4.2 System-Level Summary

Aggregating the input-level relationships gives a net welfare–climate profile for each system. The profiles differ less because any single input behaves differently across systems than because the systems bundle different combinations of inputs.

Conventional fast-growing, high-density floor system. The current baseline sits at the bottom of the welfare scale — poorest gait, leg health, and contact-dermatitis outcomes and the greatest behavioural restriction — while sitting at the top of climate performance through the lowest feed volume, shortest grow-out, and best feed conversion.

It is internally consistent, but consistent in the wrong direction for welfare. Fast-growth genetics also lead to higher cull rates, as birds become unable to walk, assessed in chronic pain or with defects that usually limit basic functions and lead to higher mortalities. There are also further commercial signs of the genetics reaching physical limits, leading to significant losses and direct climate impact, estimated in the US alone at more than USD200m. With the fastest-growing genetics and at the end of the grow-out period, breast muscle myopathies emerge, ranging from visible fat deposition and white striping in the best case to inedible muscular hardening (wooden breast) and carcass condemnation in the worst. These defects have been reported in fast-growth chicken from the US to Europe, Thailand to Australia.

Lower-density conventional floor system. Reducing density on otherwise conventional genetics delivers a modest welfare gain through better litter quality and thermal comfort, at a moderate climate cost from higher energy use per unit of output. This is among the most tractable of the conflicts: heat-recovery and housing-energy measures can largely close the energy gap, and under hot conditions the productivity and welfare advantages of lower density partly offset it.

Moderately slower-growing (BCC-aligned) system. Moving to moderately slower-growing genetics at lower density produces a clearer welfare gain across most indicators, at a moderate and variable climate cost shaped primarily by feed sourcing and soy land-use change. This system also carries a wider set of non-climate benefits that strengthen its case.

- **Compared with conventional fast-growing production, slower-growing broilers are associated with lower antibiotic use** — linking system choice to antimicrobial resistance, not only

welfare — improved robustness, lower mortality, and better leg health with fewer contact-dermatitis issues.

- **Lower-density housing may also offer food-safety advantages in hot climates**, where heat stress increases water intake, disrupts gut microbiota, raises harmful bacteria such as *E. coli* and reduces beneficial *Lactobacillus*; reducing thermal stress therefore supports food safety as well as welfare.
- **Improved skeletal and leg health may further reduce handling, processing and fracture-related losses.**

A large 2024 Dutch study of 113,380 commercial flocks found that systems combining reduced stocking density and moderately slower-growing breeds had fewer antibiotic treatments, lower mortality, and lower footpad-lesion scores than conventional systems.³²

Where climate performance is only equal to or slightly worse than conventional production, these wider gains can materially affect the overall assessment.

Very slow-growing or extensive system. The slowest-growing, lowest-density systems deliver the largest welfare gain — greater activity and fuller use of space and enrichment — but also the largest climate cost where feed volume and land-use change are not managed. The evidence does not support the most extensive model as the universal target for a sustainable transition.

Recommendation

For new broiler investment, the evidence points to one configuration above the others: a cage-free, floor-based system using moderately slower-growing genetics at reduced stocking density. This is not the highest-welfare option — the very-slow-growing extensive model delivers more — but it captures the large majority of the welfare gain while keeping the climate cost moderate and manageable, and it carries a wider set of co-benefits (lower antibiotic use, lower mortality, better leg health, and food-safety advantages in hot climates) that the more extreme options do not improve upon proportionally.

The two conventional systems are ruled out on welfare grounds, and the very-slow-growing model is not recommended as a universal target because its feed and land-use-change burden grows faster than its welfare return. The welfare improvement at the grower stage does not on its own deliver climate compatibility. It depends on being paired with low- or no-deforestation feed sourcing and housing-energy mitigation such as heat exchange where relevant, and may be further supported by breeder-stage gains where these are counted within scope.

5. Methodological Issues

Four methodological issues that apply across all three industries — how to read the comparative figures, the choice of functional unit and system boundary, land-use-change accounting for soy, and geographic transferability to Asian markets — are set out in the Cross-Cutting Methodological Notes in Part A. The points below are specific to the broiler evidence base.

5.1 Full Production Cycle versus Farm-Gate Boundary

Comparisons that omit breeder-flock emissions may misattribute climate differences to the housing or genetic system alone. **Slower-growing breeders may require fewer parent birds per unit of output through lower mortality and longer fertile lifespans, partly offsetting the grow-out feed penalty. Farm-gate-only LCAs should not be read as capturing the full system difference.**

5.2 Cage-System Evidence Base

The welfare and climate evidence base for broiler colony-cage systems is limited and methodologically inconsistent. The welfare–climate comparison in Section 4 is therefore better evidenced for comparisons among floor systems than for cage-versus-floor comparisons and **claims about caged systems should be read with correspondingly lower confidence.** This gap is particularly consequential because the multi-tier cage trend is growing as an Asian-market phenomenon.

6. Broiler Conclusion

Conventional fast-growing, high-density broiler production sits at the bottom of the welfare scale on nearly every measure — gait, leg health, contact dermatitis, behavioural restriction, mortalities — while sitting at the top of narrow climate performance. The challenge of moving away from it is real, but the evidence reviewed in this report does not support the view that welfare and climate objectives are in fundamental opposition.

The primary tension runs through feed: slower genetics and lower densities raise the feed required per kilogram of output, and feed accounts for more than three-quarters of broiler emissions. But the size of that cost depends above all on feed sourcing, not on the welfare improvement itself. Several welfare changes, including enrichment and lighting, cost nothing in climate terms at all.

The most important lever is feed sourcing. Avoiding high-deforestation supply chains and reducing soy dependence can deliver climate gains that dwarf any difference between housing or genetic systems. Moderate-growth genetics capture most of the welfare gain at a containable cost, and the penalty can be partly offset upstream through more efficient breeder systems with lower parent-bird mortality.

Lower stocking density improves welfare and, with heat-recovery and housing-energy measures, need not carry a large energy penalty — a point that matters especially in hot climates, where lower density also reduces heat stress and improves production resilience. Manure and litter management, through moisture control, residence-time reduction, and covered storage, addresses both greenhouse-gas and air-quality outcomes independently of housing system choice.

For producers in tropical and subtropical Asia, the heating-energy penalty that inflates the cage-free climate cost in temperate studies is largely absent. The binding constraints are ventilation and heat-stress management, where lower density is welfare-protective

and climate-compatible simultaneously. The emerging trend toward multi-tier cage systems in several Asian markets runs in the opposite direction: the welfare evidence against caging is clear, and the limited climate evidence offers no offsetting justification.

The right direction for new broiler investment is moderate-growth genetics at lower density, with low-deforestation feed sourcing and active housing-energy management. The welfare and climate costs of building to that standard are manageable — and the evidence reviewed here is substantial enough to support that conclusion in practice.

Endnotes

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Part B3: Layer Hen Housing Systems, Welfare, Climate Impact

Recommendation: New Laying Hen Investment

Cage-free, either single or multitier. Both enable hens to exhibit the behaviours on which the welfare case rests: nesting, perching, dustbathing, foraging, and free movement. The conventional cage provides none of those and the enriched cage only offers partial benefits. Single-tier systems carry less keel-fracture risk and are simpler to run. Aviaries allow the fullest range of behaviour and hold more birds per square metre of floor. Producers should choose between them on the basis of their own management capability and local conditions.

Part B3 of the Cage-free x Climate series. Part A sets out the shared framing, methodology, and cross-cutting findings, and Parts B1 and B2 cover gestating sows and broilers. The annex, Expanded Source Tables, holds the full evidence tables for the studies cited here.

Key takeaways

- **The behavioural deprivation of conventional cage housing** — the systematic denial of nesting, perching, dustbathing, and free movement — is among the best-documented welfare costs in commercial livestock production.
- **The central tension is between stocking density and feed efficiency;** cage-free hens use more energy, and feed accounts for 60–84% of the climate burden of egg production. The tension is management-dependent: it is widest in poorly run systems and narrows substantially where laying rate and feed efficiency are maintained.
- **Feed sourcing is the single most powerful lever:** deforestation-free soy procurement, or substitution with lower-impact proteins, can bring the climate footprint of a cage-free system below that of a conventionally fed caged one.
- **Several of the most welfare-significant inputs of cage-**

free housing — nest provision and perch access — carry no meaningful climate cost at all, and the dominant climate levers are largely independent of which housing system is operated.

In this section

Terminology and Scope

- **1. The Welfare-Climate Question in Laying Hen Production**
- **2. Key Welfare Determinants in Layer Housing Systems**
- **3. Main Drivers of Climate Performance in Layer Systems**
- **4. Welfare and Climate: Alignment, Conflict, and Conditionality**
- **5. Methodological Issues**
- **6. Conclusion**

Terminology and Scope

This report defines caged systems including multi-tier battery cages, netted or wire colony cages, and furnished cages. It refers to battery cages and barren colony cages as “conventional cages” and adopts the term “enriched cage” throughout for the furnished cage system, and groups single-tier barn and multi-tier aviary systems under the umbrella term “cage-free”, except where the evidence shows a meaningful difference between them, in which case the specific system (single-tier or aviary) is named and the distinction is flagged explicitly.

Scope note. This report deliberately confines its analysis to indoor housing systems — conventional cage, enriched cage, single-tier, and aviary. Free-range and organic systems, although they appear in several of the life cycle assessments (LCAs) cited here, are intentionally excluded from the comparative analysis and the pathway recommendations, as they are less comparable and either include outdoor housing access (“free-range”) or variable welfare standards (including even cages in some markets) under the wide range term “organic”.

- **Conventional cage (CC)** — also called battery cage or barren cage. Cages providing approximately 450–550 cm² per bird (pre-EU standards), offering no nest boxes or any form of enrichment. Banned in the EU since 2012.
- **Enriched cage (EC)** — also called furnished cage or enriched colony cage. A modified cage providing a minimum 750 cm² per bird under EU Council Directive 1999/74/EC, equipped with a nest box, perch, and scratching/dust-bathing substrate. Group sizes are typically 30–80+ hens per unit in modern colony designs. “Colony cage” on its own denotes only a larger cage holding more birds and does not imply enrichment; enriched cages at commercial scale remain largely a European phenomenon.
- **Floor system** — a cage-free system in which hens are housed on a single floor level with nest access and litter substrate, but no external access. Sometimes referred to as “indoor cage-free (single-tier)” or “floor housing.” Stocking densities are regulated at maximum nine hens/m² in the EU.
- **Aviary/multi-tier cage-free** — a cage-free system with

The Natural Behaviours of Laying Hens

Hens retain strong innate behaviours; some are so highly motivated that preventing them is a major welfare cost.

MOST HIGHLY MOTIVATED				— denied by conventional cages
Nesting	Foraging	Dustbathing	Perching / roosting	
seeks a secluded nest before laying	ground-pecking and scratching for food	cleans plumage, controls parasites	rests up high, especially at night	

OTHER NATURAL BEHAVIOURS			
Wing-flapping and stretching	Preening	Walking and exploring	Social interaction
comfort movement	feather care	movement and investigation	within a stable group

In natural conditions hens spend most of their active day foraging — ground-pecking and scratching.

Source: Dawkins (1989), Applied Animal Behaviour Science; behavioural-needs literature.

multiple tiers (perches, slats, feeding and drinking systems), combined with a litter floor below. Hens can move vertically and horizontally. Because the tiers add usable area, an aviary holds more hens per unit of floor space than a barn, while still meeting the EU maximum of nine laying hens per m² of usable area.¹

Use of “cage-free.” Where barn and aviary perform similarly, this report refers to them jointly as “cage-free.” Where they diverge materially, the specific system is named and the difference is highlighted.

1. The Welfare-Climate Question in Laying Hen Production

Laying hens have innate, highly motivated behaviours that along with available system inputs determine their expression and welfare outcomes. These innate behaviours are retained, despite domestication, and include nesting for protected egg laying, wing-flapping for thermoregulation (body-temperature control), dustbathing for plumage health including parasite management, perching for leg strength, hierarchy and protection, and pecking for exploration and pre-consummatory behaviour. As well as balanced breeding, adequate space, light, dark and other environmental parameters, any housing system and management needs to focus on providing for these behaviours to enable both productivity as well as basic welfare outcomes.

The welfare case for change to cage-free laying hen housing is the most clearly established of the three, and the commercial transition the furthest advanced: conventional battery cages are

banned in the EU and across several US states, over half of EU hens are already in alternative systems, and major retailers and food companies worldwide have made cage-free sourcing commitments with fixed deadlines. Against this backdrop, producers' concerns remain primarily economic, though they are often framed in environmental terms: the argument that cage-free systems use more space, more feed, and more energy per unit of output, and therefore carry a climate cost.

Feed accounts for 60–84% of the total climate burden of egg production, and the tension runs through stocking density. Giving hens more space and freedom of movement increases their energy expenditure. How large that cost is depends on how the system is run; it is widest in poorly managed low-density flocks and narrows substantially where laying rate and feed efficiency are actively maintained.

Crucially, not all welfare improvements carry a climate cost: nest provision and perch access, two of the most welfare-significant inputs of cage-free housing, are effectively climate-neutral. And the dominant climate drivers — feed sourcing and manure management — are largely independent of which housing system is operated, which means the largest abatement levers are available regardless of the cage-free configuration chosen.

This section is organised around the production-system inputs that determine both welfare and climate outcomes — space allowance, nest provision, perches and vertical complexity, floor type and substrate, and group size — rather than around housing systems or welfare outcomes directly.

- **Section 2** establishes the welfare evidence around these inputs.
- **Section 3** establishes the climate evidence around the key drivers of environmental performance.
- **Section 4** brings the two together, characterising the relationship input by input before aggregating to a system-level summary.
- **Section 5** sets out the methodological caveats specific to the layer evidence base, building on the cross-cutting notes in Part A.
- **Section 6** draws the argument together and translates it into practical implications for producers building new cage-free capacity.

2. Key Welfare Determinants in Layer Housing Systems

The welfare differences between housing systems arise from a defined set of design and management inputs — how much space each bird is allotted, whether a discrete nesting area is provided, whether perches and elevated tiers are available, whether the floor type and substrate support dustbathing and foraging, and the group size and social structure. Management intensity runs across all five and is treated here as a cross-cutting variable rather than as a further input. This section is organised around those system inputs rather than around welfare outcomes, because it is these inputs that producers, buyers, certifiers and regulators mostly specify. The welfare outcome

Key Welfare Determinants — Laying Hens

The design and management inputs analysed in this section, and the welfare measures each one drives

2.1 Space allowance and stocking density

Usable space per bird, and how densely the house is stocked

WELFARE MEASURES DRIVEN

Whether nesting, perching, dustbathing and foraging can be performed · chronic stress indicators · fearfulness

2.2 Nest provision

Whether a discrete nesting area is provided, and how well it is managed

WELFARE MEASURES DRIVEN

Pre-laying searching, pacing and vocalisation · nest use · floor-egg rates

2.3 Perches and vertical complexity

Perch availability, and movement between tiers

WELFARE MEASURES DRIVEN

Perching motivation, especially at night · long-bone strength · keel-bone damage

2.4 Floor type and substrate

Litter access versus wire, and the quality of litter management

WELFARE MEASURES DRIVEN

Dustbathing · foraging · footpad condition

2.5 Group size and social structure

Colony size, and the stability of the social group

WELFARE MEASURES DRIVEN

Severe feather pecking and cannibalism · mortality

Source: ARE analysis.

measurements that follow from them — stress physiology, nest use, keel bone health, foot health, feather pecking, and mortality — are presented under the input(s) that primarily drive them. Some outcomes, keel fractures and mortality in particular, appear under more than one input because they are multifactorial. They can also be mitigated, to a reasonable degree.

2.1 Space Allowance and Stocking Density

Behavioural-needs frameworks consistently identify that hens are highly motivated to perform a set of behaviours that are severely restricted or impossible in conventional cages: nesting prior to oviposition (egg laying), perching (especially at night), dustbathing, and foraging/scratching.^{2 3} The frustration of nesting motivation in particular is associated with pre-laying pacing, agitation, and corticosterone elevation, and is considered a significant welfare cost of conventional cage housing.⁴ Hens housed in conventional cages have shown higher feather corticosterone concentrations (a chronic stress indicator), decreased fecal immunoglobulin A (immune function indicator), and longer tonic immobility duration compared with hens in enriched floor pens.⁵

Reviews of comparative welfare in cage and cage-free systems generally conclude that conventional and enriched caged hens tend to have lower or similar levels of glucocorticoid-based stress indicators compared with cage-free hens, and lower mortality — but the behavioural repertoire in conventional cages is clearly more compromised.⁶ This is not a contradiction; it reflects the fact that certain welfare dimensions trade off against others across systems.

“In cage-free systems, nest availability and nest management are critical. Floor eggs are a persistent problem in poorly managed systems...constituting both a welfare indicator and an economic cost.”

2.2 Nest Provision

Access to a nest box is considered an essential welfare requirement. Hens show strong pre-laying motivation, manifested as searching, pacing, and vocalisation when nests are unavailable. Conventional cages completely deny nesting. In enriched cages, hens readily use nest boxes when provided, with studies finding approximately 94% of eggs laid in nest boxes in well-designed enriched cage systems.⁷ However, the adequacy of nest access in large-colony enriched cages is an ongoing management concern — nest space per bird may be insufficient at high group sizes.

In cage-free systems, nest availability and nest management are critical. Floor eggs (eggs laid outside designated nesting areas, even where nest boxes are provided) are a persistent problem in poorly managed cage-free systems, with such floor eggs commonly reported at 2–8% or more of all eggs laid, constituting both a welfare indicator and an economic cost.⁸

2.3 Perches and Vertical Complexity

Hens have a strong motivation to perch, particularly at night, with perching associated with reduced predation risk in the natural ecology and with improved bone strength through load-bearing exercise.⁹ Conventional cages completely deny perching. Enriched cages provide a perch, though space constraints limit simultaneous perching by all birds. Multi-tier aviaries provide the most extensive perching opportunities, including vertical movement between tiers.¹⁰

Skeletal health and keel bone damage.

Bone strength matters not only for robust movement and the avoidance of pain and injury during lay, but also at the end of it: injury and fractures, especially towards end of lay when birds are usually suffering osteoporosis, also occur during transport and handling prior to slaughter or depopulation. In conventional battery cages, restricted movement comes at the cost of severe osteoporosis due to inactivity.¹¹

Hens housed in aviary and floor systems generally develop stronger long bones — tibia and humerus — than cage-housed hens, owing to the greater load-bearing activity these systems permit.^{12 13} This is well-documented: aviary-reared pullets showed 41% greater humeral cortical area and 31% greater tibial stiffness than cage-reared pullets.¹⁴

The same systems that produce these skeletal gains, however, also expose hens to the physical hazards that drive keel bone fractures. Keel bone damage (KBD) — encompassing deviations and fractures

of the sternum — is widely recognised as one of the most significant welfare problems in contemporary egg production, particularly in cage-free systems.¹⁵ Keel fractures in cage-free systems often involve collisions with structures and falls from elevated tiers.¹⁶ Increased keel fracture severity predicts reduced vertical travel distance and altered movement behaviour, meaning fractures compound into further mobility loss.¹⁷

Prevalence figures can be significantly reduced in aviary systems with a series of well-designed and placed ramps between tiers. A Swiss aviary experiment in 2015 found that installing ramps between the tiers of an aviary — giving hens a continuous path to walk up and down rather than jump or fly — significantly reduced falls and collisions, and with them the incidence of keel-bone fractures across much of the laying period.

Rearing environment also strongly influences adult bone health, and the rearing stage offers a meaningful point of intervention: pullets trained for and reared in aviaries had significantly lower keel fracture prevalence at end of lay (41.6% vs 60.3%) compared with those reared conventionally, even when subsequently housed in enriched cages as adults.¹⁸ Additionally, the heritability of keel bone fracture susceptibility is estimated at 0.08–0.22, indicating genuine scope for selective breeding solutions to work alongside housing and rearing improvements.

2.4 Floor Type and Substrate Provision

Dustbathing is a highly motivated comfort and cleaning behaviour performed approximately once daily when substrate is available.¹⁹ Conventional cages deny this behaviour entirely; enriched cages provide a nominal substrate or scratch area, though the quality and extent of dustbathing expression are contested. Barn and aviary systems with litter access provide the most natural dustbathing opportunity.

Footpad health and contact surfaces.

Conventional cages are associated with a higher prevalence of footpad lesions from wire flooring.²⁰ In aviaries and floor systems, footpad dermatitis from litter contact can be common, though litter management quality strongly determines risk.²¹ Italian slaughterhouse data confirmed that footpad lesion odds were lower in enriched cages than multi-tier systems, while keel deviations were higher in enriched cages than multi-tier systems — another example of a trade-off between welfare dimensions.²²

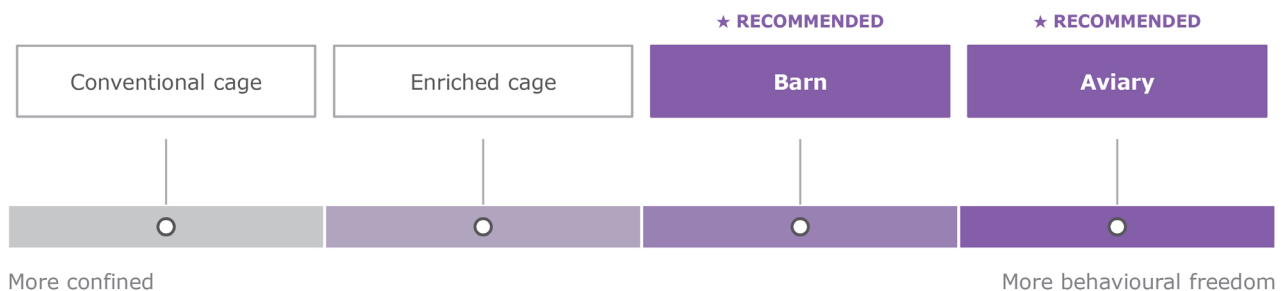
2.5 Group Size and Social Structure

Severe feather pecking (SFP) and cannibalism can be a major welfare and economic problem, especially in early or poorly managed cage-free systems, though outbreaks occur in all housing types.²³ The causes are multifactorial and individual studies often produce contradictory results. The general pattern is that cage-free systems have a higher prevalence and severity of SFP than enriched or conventional cages — though this is confounded by the fact that non-

beak-trimmed flocks in cage-free systems are particularly vulnerable.²⁴

Management interventions — adequate litter provision and space (appropriate stocking density), provision of foraging substrates, breed strain selection, and the most humane beak management (where still needed) — substantially modulate SFP risk across all systems and can minimise losses. A 2013 Bristol field study tested farm-specific management packages across 100 commercial cage-free flocks and found they significantly reduced injurious feather pecking, showing that the behaviour can be controlled through good rearing and laying-period management rather than being unavoidable in cage-free systems.²⁵

Laying Hens: Housing Systems by Confinement and Welfare



Source: ARE analysis.

Management intensity as a cross-cutting variable. Management intensity modulates the welfare consequences of every one of the five inputs.

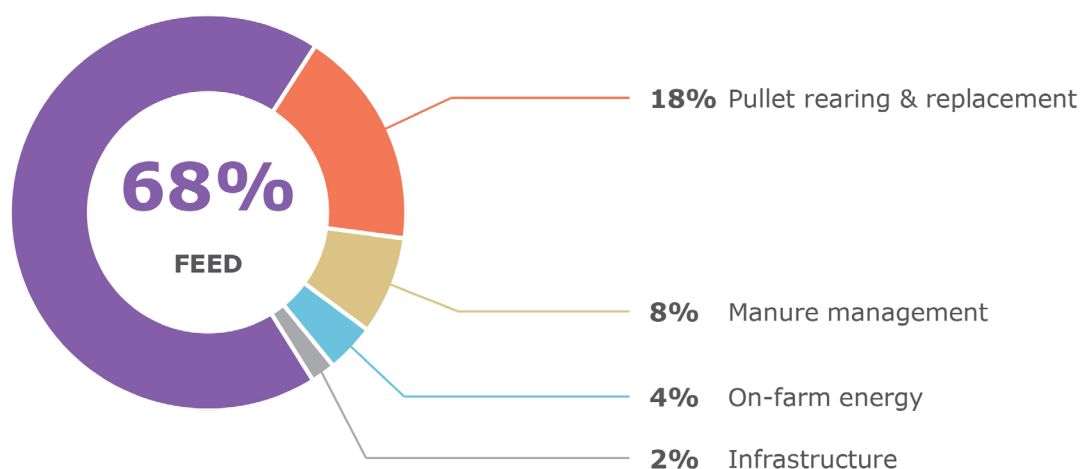
A critical insight from the literature is that welfare outcomes in cage-free systems are substantially more variable than in caged systems, and more dependent on management quality.²⁶ Well-managed cage-free systems can achieve superior welfare on most indicators, but poorly managed ones can perform far worse than enriched cages on mortality, feather cover, and injurious pecking.²⁷

Management quality also greatly influences mortality rates. Conventional cages and enriched cages historically exhibited lower mortality than cage-free systems.²⁸ The Coalition for Sustainable Egg Supply (CSES) study, a commercial-scale US comparison of conventional cage, enriched colony and aviary housing, showed that aviary hens had greater overall mortality over the production cycle compared with enriched cage and conventional cage hens. However, a more recent, large meta-analysis of 6,040 commercial flocks across 16 countries found that cage-free mortality decreases progressively with management experience, with no significant difference from caged systems observed in more mature industries.²⁹

In short, Section 2 shows that cage-free systems improve welfare but also require good management. Section 3 now turns to the climate side.

Laying Hens — Where Emissions Come From

Representative shares of total greenhouse-gas emissions; values vary by study, system boundary and geography.



Source: ARE analysis, based on cited LCA literature.

3. Main Drivers of Climate Performance in Layer Systems

Before examining individual systems, it helps to set out the drivers of climate performance in rough order of magnitude. Feed production dominates, accounting for the majority of total burdens; manure management is typically the second or third largest contributor; mortality and pullet replacement, egg yield, housing energy, and infrastructure follow. The sections below take each in turn. The central message is that the largest levers — feed and manure — are largely independent of housing system, which is why housing choice is a secondary-order driver of climate impact.

3.1 Feed — Volume, Efficiency, and Sourcing (60–84%)

Feed production is consistently the dominant environmental burden in egg LCAs, accounting for approximately 60–84% of the GHG footprint across housing systems and geographies.^{30 31 32 33 34}

Feed conversion ratio (FCR, kg feed/kg egg mass) is therefore the single most important production parameter for climate performance.³⁵ Hens in cage-free systems have higher energy requirements because of increased physical activity and, in cold climates, greater thermostatic requirements from lower stocking densities and litter-floor housing. Korean-context data from aviary systems confirmed that energy requirements increase with activity level in alternative housing, necessitating higher dietary energy levels.³⁶ Feed intake in single-tier and aviary systems tends to be 5–15% higher per hen per day compared with conventional cages.^{37 38} **Well-managed aviary systems with high laying rates can narrow this gap when results are expressed per kilogram of egg mass.**

The composition of the feed — specifically the proportion of soy and its origin — is a critically important driver of egg LCA results.³⁹ Soybean meal is the dominant protein source in most commercial laying hen rations globally. Soy produced in tropical regions, particularly Brazil and Argentina, carries a deforestation-related land-use-change (LUC) carbon penalty that can substantially alter GHG results. Deforestation-free soy versus deforestation-linked soy can differ by a factor of several times in GHG intensity per tonne of protein.

3.2 Mortality and Pullet Replacement (10–37%)

Higher mortality in a flock requires earlier replacement with new pullets, and the full environmental burden of pullet rearing must be amortised over fewer productive hen-life-days. The pullet-rearing burden — including all feed, housing, and management costs from hatch to point-of-lay — typically contributes 10–37% of total environmental burdens in cradle-to-gate LCAs.⁴⁰ This means that any housing system with substantially higher mortality will carry a disproportionate pullet rearing burden per kilogram of eggs produced.

A Canadian life cycle assessment (updated with 2019 data) confirmed that feed inputs and pullet production are the top two contributors to most environmental impact categories. Where cage-free mortality runs higher than caged — historically by around 2–4 percentage points over a production cycle — that gap contributes meaningfully to the environmental penalty. As Section 2.5 sets out, however, the gap narrows with each year of management experience and is not observed in more mature cage-free industries, so the penalty is better read as a function of management maturity than of the housing system itself.

3.3 Manure Management

Manure management is another major contributor to egg LCA results, particularly for methane and nitrous oxide emissions. The housing system influences manure management pathways directly:^{41 42}

- **Belt drying systems** (common in manure-belt cage housing) substantially reduce GHG and ammonia compared with deep-pit systems. Manure belt with forced-air drying reduces CO₂ equivalent emissions by approximately 21%, CH₄ by 16%, and N₂O by 9% compared with deep-pit housing.
- **Litter-floor systems** (single-tier and aviary) generate manure mixed with litter, which has a different emission profile. A 2023 Québec farm survey (Guay et al.), which measured greenhouse gas and ammonia emissions across 30 commercial farms operating conventional cage, enriched colony, and cage-free housing, found cage-free systems had the highest CO₂ emissions per hen per hour and the highest CH₄, against enriched cage (lowest CH₄) and conventional cage. Measurement was visit-based rather than continuous, and the cage-free results were highly variable between farms.⁴³

3.4 On-Farm Energy Consumption

Heating, ventilation, and air conditioning (HVAC) systems represent a significant but secondary contributor to egg production environmental

burdens. Cage-free systems at lower stocking densities require greater heating energy in cold climates. Modelling work for Canadian temperate and continental climates identified that alternative HVAC technologies — particularly earth-air heat exchangers and ground source heat pumps — could substantially reduce energy-related environmental burdens of egg production in these climates.⁴⁴ This could be most relevant for Northern China, Japan or other temperate Asian production locations.

The CSES study confirmed that similar indoor thermal environments were maintained across all three housing types through ventilation management, meaning that the energy comparison is system- and climate-specific. In tropical climates relevant to Southern China, India, Southeast Asia, the heating energy driver essentially disappears, and ventilation requirements for heat stress mitigation dominate instead.

Heat stress in cage-free systems can reduce egg production and alter eggshell quality more severely than in cage systems, particularly where ventilation management is inadequate.^{45 46}

Table 3. Influence of environmental drivers by housing system.

Driver	Conventional Cages (CC)	Enriched Cages (EC)	Single-tier	Aviary
Feed volume per hen	Lowest	Similar to CC	Higher (cage-free, ~+5–15%)	Higher (cage-free, ~+5–15%)
Feed efficiency (FCR)	Best	Similar to CC	Slightly worse	Variable; can approach CC if HDEP is maintained
Manure management	Belt drying feasible; low NH ₃	Belt drying feasible; low NH ₃	Litter-based; high NH ₃	Litter-based; highest NH ₃
Mortality burden	Low	Similar to CC	Higher	Higher
Pullet replacement load	Low	Low	Moderate	Moderate–higher
HVAC energy	Moderate	Moderate	Higher (cold climates)	Higher (cold climates)
Infrastructure contribution	Low	Low	Low–moderate	Moderate

Note: Body-text evidence reports cage-free feed intake as roughly 5–15% above conventional cages and does not robustly distinguish barn from aviary on feed volume; the table reflects this shared cage-free range rather than implying a precise single-tier-versus-aviary difference.

3.5 Infrastructure and Building Burdens (<10%)

Building and equipment infrastructure (cage hardware, aviary structures, flooring, ventilation systems) generally contribute less than 5–10% of total LCA burdens in most egg production LCAs and are therefore a relatively minor driver of comparative climate differences between housing systems.^{47 48 49} **They can, however, become stranded assets and a source of transition risk where regulation or market requirements move away from caged systems.**

Section 3 establishes the climate side of the central claim: because feed production dominates environmental burden and is largely independent of housing system choice, and because the remaining drivers — manure, mortality, and energy — are individually smaller and addressable through known management interventions, the housing system itself is a secondary-order driver of climate impact. Section 4 now brings the welfare and climate evidence together.

4. Welfare and Climate: Alignment, Conflict, and Conditionality

For each input, this section traces the causal chain from the design choice through to both its welfare consequence and its climate consequence, and asks how the two relate — whether they are aligned, in conflict, or conditionally aligned. It then aggregates these input-level relationships into a net welfare–climate profile for each of the four housing systems.

Table 4. Welfare and climate at a glance: laying hen inputs.

Input	Welfare	Climate	Relationship
Space allowance and stocking density	✓	✗	In conflict
Nest provision	✓	—	Aligned
Perches and vertical complexity	✓	—	Aligned
Floor type and substrate provision	✓	✗	Conditionally aligned
Group size and social structure	✓	—	Conditionally aligned

Note: ✓ = benefit, ✗ = cost, — = neutral, negligible or unresolved. Symbols show the direction of effect for each input; the Relationship column gives the classification used in the text. Source: ARE analysis

4.1 Input-by-Input Analysis

Space allowance and stocking density — in conflict. This is the clearest case where a welfare improvement carries a direct climate cost. Lowering stocking density and giving hens more usable space enlarges the behavioural repertoire and reduces the chronic stress and fearfulness associated with close confinement. In tropical climates, more space and ventilation may be essential to manage heat stress. But more space means more movement, and in cold climates lower density also means less shared body heat; both raise the bird’s energy requirement, and feed intake per hen in cage-free systems runs roughly 5–15% above conventional cages, with additional heating energy in temperate climates. **The conflict is real but not fixed in magnitude. When output is expressed per kilogram of egg mass and laying rate is maintained, the feed gap narrows, and good management can compress it further.**

Nest provision — aligned. Providing a discrete nesting area is close to a pure welfare gain. It resolves the frustration of thwarted pre-laying motivation, and hens use nest boxes readily where they are well designed. It has essentially no bearing on feed efficiency, manure

emissions, or energy use, so it carries no meaningful climate cost. The only climate-relevant qualification is indirect; where nest management is poor and floor-egg rates rise, the resulting loss of saleable eggs slightly raises environmental burden per saleable dozen. **Nest provision is thus the strongest example of welfare and climate not pulling against each other.**

Perches and vertical complexity — aligned. Perches and elevated tiers let hens express strong perching motivation and build markedly stronger long bones, and they add little to the feed, manure, or energy burden — so the welfare gain comes at near-neutral climate cost. The one real concern is keel-bone damage: the same elevated structures can cause the collisions and falls that injure the keel, and early studies reported high fracture rates in cage-free flocks. But this risk is not inherent to cage-free housing — it is largely set by how pullets are reared and aviary design. A longitudinal study of four consecutive flocks found that hens reared in complex aviary environments ended lay with substantially fewer keel-bone fractures than cage-reared hens (about 42% versus 60%). Giving hens ramps that form a continuous path between tiers further reduces falls, collisions, and fractures. The keel-fracture problem is therefore a manageable matter of rearing and design — and potentially genetic selection — rather than an unavoidable cost of giving hens vertical space.

Floor type and substrate provision — conditionally aligned. Litter substrate is the input whose welfare–climate relationship most depends on how the system is run. Litter enables dustbathing and foraging and changes the footpad-health picture relative to wire; all welfare gains. However, litter-based manure raises ammonia and methane emissions and adds a litter-management burden, while wire flooring carries the opposite profile where manure is removed very regularly. The welfare gain therefore comes with a climate cost on the emissions side. **What makes the relationship conditional rather than fixed is that this is among the most tractable of all the climate costs: low-crude-protein diets, litter moisture and removal management, and downstream abatement can cut ammonia substantially.**

Group size and social structure — conditionally aligned, through mortality. Large social groups in cage-free systems support a fuller range of social behaviour and movement, but they also raise the risk of severe feather pecking and cannibalism, if not well managed. The climate link is indirect and runs through mortality. Where pecking and disease are poorly controlled, mortality rises, and higher mortality raises environmental burden per egg because more birds must be reared and fed for each unit of output. Injurious pecking is multi-causal: a 2023 review identifies heat stress, together with high stocking density, as a major stressor capable of triggering feather-pecking outbreaks, which means the mortality associated with pecking reflects manageable risk factors that include heat, rather than cage-free housing itself. This is particularly relevant in warmer Asian production settings.⁵⁰ **Where management keeps pecking and mortality low, the climate penalty largely disappears.**

Laying Hens — Input-by-System Summary

Each cell: how the input plays out in that system · colour = net welfare–climate verdict

	Conventional cage	Enriched cage	Barn	Aviary
			RECOMMENDED	RECOMMENDED
Space allowance	Minimal space; welfare cost; climate-favourable	Modestly more but still confined; welfare cost	Lower density; gain; higher feed & energy	Lowest density; gain; largest feed & energy
Nest provision	None; welfare cost	Nest provided; aligned, climate-neutral	Litter nest area; aligned; floor-egg risk	Structured nests; aligned; floor-egg risk
Perches & vertical complexity	None; osteoporosis from inactivity	Perch provided; gain; climate-neutral	Floor-level only; limited gain; low fracture	Multi-tier; bone-strength gain; modern rearing / ramps cut keel fractures
Floor type & substrate	Wire; low NH ₃ but footpad lesions; no dustbath	Wire + scratch mat; no true dustbathing	Litter; conditional (dustbath vs NH ₃)	Litter; conditional; highest NH ₃ & dust
Group size & social structure	Small fixed groups; restricted social behaviour	Small colonies; low-moderate pecking	Large groups; conditional via pecking → mortality	Large groups; conditional; highest variance

■ Aligned
 ■ Conditional
 ■ In conflict
 ■ Welfare cost / climate-favourable

Source: ARE synthesis of cited LCA and welfare literature.

The moderating role of management. Across all five inputs, management intensity is the variable that sets where on the spectrum a given system actually lands. It cannot turn a conflict into an alignment — more space will always cost some feed — but it determines the magnitude. **Good stockmanship narrows the space–feed conflict, keeps floor eggs and mortality low, and compresses the ammonia penalty of litter. Poor management widens every one of these gaps at once.**

4.2 System-Level Summary

Aggregating the input-level relationships gives a net welfare–climate profile for each system. The profiles differ less because any single input behaves differently across systems than because the systems bundle different combinations of inputs.

Conventional cage. The conventional cage offers almost none of the five essential welfare inputs — no nest, no perch, no litter substrate, minimal space, cage confinement and small fixed groups — and so it sits at the bottom of the welfare scale while sitting at the top of climate performance: lowest feed use, low mortality, and clean belt-handled manure. **There is little for management to moderate because there is little welfare to deliver.**

Enriched cage. The enriched cage adds nest provision, a perch, a limited scratch and dustbathing substrate, and somewhat more space. Crucially, the inputs it adds are the ones whose welfare–climate relationship is aligned or near-neutral — nest provision above all — while the conflict-laden inputs are added only weakly or not at all. The result shows limited welfare improvement at roughly neutral climate cost. However, birds remain cage-contained, **and the regulatory and**

commercial direction is moving away from cage systems. Several EU member states have legislated or announced bans covering all cage systems, including enriched cages, and the corporate cage-free commitments driving the transition in Asia specify cage-free sourcing, which the enriched cage does not satisfy.

Single-tier. The barn system adds the litter floor and freedom of movement, with larger groups and lower density. It takes on the conditionally aligned inputs — litter emissions, the space-feed conflict, and group-size-mediated mortality risk — without the vertical-structure keel-fracture burden of the aviary. **Its net profile is a moderate, management-dependent climate penalty in exchange for a substantial behavioural welfare gain.**

Aviary. The aviary adds everything: vertical complexity on top of litter, the largest groups, and the lowest effective density. It delivers the widest behavioural repertoire of any indoor system but the most potential climate cost. It is also the system most sensitive to management, with the widest spread of outcomes but also close to the same hen capacity as caged systems. Several of its costs are individually tractable — through rearing and design to prevent keel fractures, improved manure and litter management for ammonia, HVAC efficiency for energy, and mortality control — which must be well managed together.

Recommendation

For new laying-hen investment, the evidence supports a cage-free system — single-tier or aviary — as the target. Both deliver the behavioural freedoms that define the welfare case (nesting, perching, dustbathing, foraging, and free movement) and that neither cage system can provide. The two are recommended as co-equal: barn carries lower keel-fracture risk and a simpler management burden, while aviary offers the fullest behavioural repertoire and higher stocking efficiency per unit of floor area, and the choice between them is best made on a producer's management capability and local conditions rather than on a welfare ranking.

The enriched cage, though an incremental improvement on the conventional cage and the lowest-climate-cost step available, remains a cage: it constrains the behavioural repertoire and falls short of the welfare standard the transition is intended to reach. In Europe, the enriched cage proved a costly interim step. Producers who invested in it still faced pressure from customers and consumers demanding cage-free eggs, and found themselves excluded from the marketing and market-segmentation opportunities that only cage-free systems unlock.

5. Methodological Issues

The four cross-cutting methodological issues — reading the comparative figures, functional unit and system boundary, land-use-change accounting, and geographic transferability to Asian markets — are set out in the Cross-Cutting Methodological Notes in Part A. Two points are specific to the layer evidence base, both of which bear on how cage-free systems in particular are assessed.

5.1 Mortality Assumptions

Mortality affects both the numerator (number of birds consuming resources) and denominator (productive eggs) of per-egg calculations. Studies that use industry-average mortality figures may understate the environmental penalty of cage-free systems in poorly managed flocks, or overstate it in well-managed ones. **Sensitivity analyses in multiple LCAs confirm that mortality assumptions drive uncertainty in cage-free system results more than in cage system results.**

5.2 Treatment of Non-Saleable Eggs

Floor eggs, crack/break rates, and dirty eggs — all higher in cage-free systems — are sometimes excluded from LCA analyses, biasing results in favour of cage-free systems when expressed per saleable egg. Floor egg rates of 2–8% in cage-free systems represent a meaningful production loss that, if not accounted for, understates their environmental burden per saleable dozen.

6. Layer Hen Conclusion

The behavioural deprivation of conventional cage housing — the systematic denial of nesting, perching, dustbathing, and free movement — is among the best-documented welfare costs in commercial livestock production. The transition to cage-free systems addresses that deprivation directly. **What this report has examined is not the welfare case, which is settled, but the climate case: whether cage-free housing can be built and operated in a way that meets sound environmental standards. The answer is that it can, provided the right combination of management decisions accompanies the housing change.**

The central tension is between stocking density and feed efficiency; cage-free hens use more energy, and feed accounts for 60–84% of the climate burden of egg production. That tension is real, and the report has not minimised it, but two things qualify it.

1. It is management-dependent — it is widest in poorly run systems and narrows substantially where laying rate and feed efficiency are maintained.

2. Several of the most welfare-significant inputs of cage-free housing — nest provision and perch access — carry no meaningful climate cost at all, and the dominant climate levers are largely independent of which housing system is operated.

Those levers are well-evidenced. Feed sourcing is the single most powerful: deforestation-free soy procurement, or substitution with lower-impact proteins, can bring the climate footprint of a cage-free system below that of a conventionally fed caged one — circular food-system approaches have demonstrated this in practice.⁵¹ Manure and litter management — through low-crude-protein diets, belt handling, and litter moisture control — can reduce ammonia by up to 85%.⁵²

Mortality control, through good stockmanship, aviary design suited to bird movement, and rearing pullets in environments that prepare them for adult housing, simultaneously addresses the dominant environmental lever in cage-free systems and the welfare problem of injurious pecking. And selective breeding for keel bone resilience — heritability estimated at h^2 0.08–0.22 — is already underway as the medium-term route to resolving the welfare-internal paradox of elevated structures. For producers in tropical and subtropical Asia, the heating-energy penalty that dominates temperate cage-free cost comparisons is largely absent; the design priority is cross-ventilation and evaporative cooling, which are both climate-compatible and welfare-protective.

Producers building new laying hen capacity are not facing a choice between welfare and environmental performance. They are facing a design and management challenge — one for which the evidence on what good looks like, across feed sourcing, manure handling, aviary configuration, rearing practice, and genetics, is now substantial.

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