

Cage-Free x Climate

The case for compatibility



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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

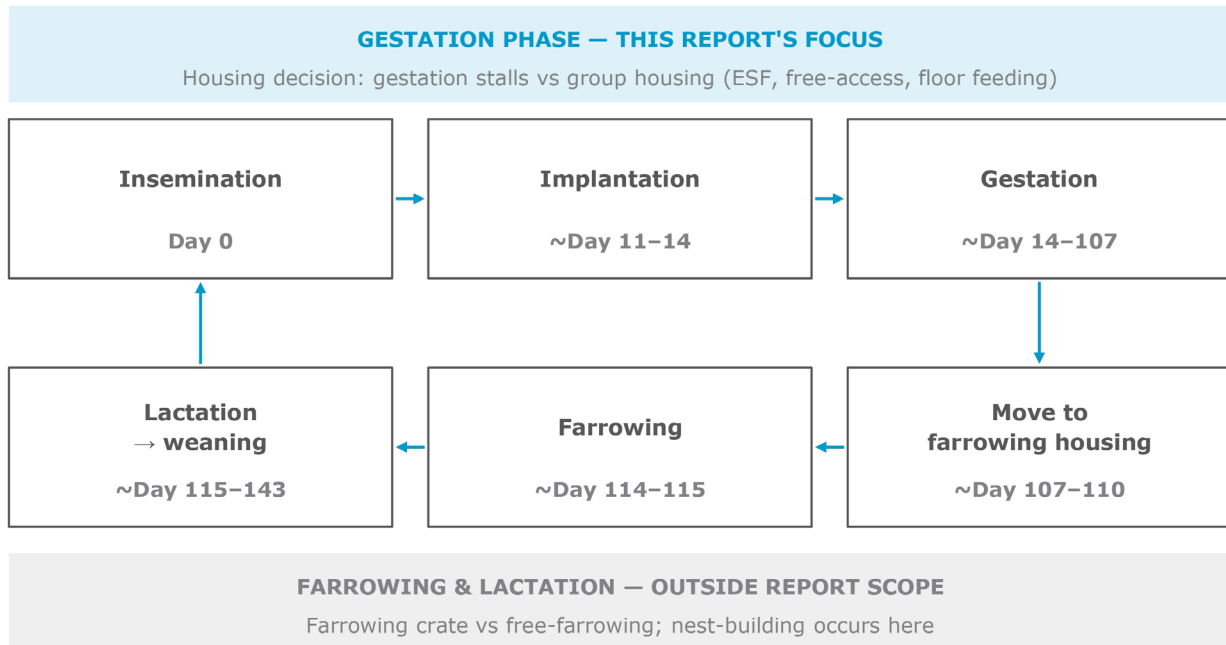
Space standards and management refinements.³ The principal regulatory benchmark for space is EU Council Directive 2008/120/EC, which requires a minimum unobstructed floor area of 2.25m² per sow and 1.64m² per gilt where animals are kept in groups, rising by 10% for groups of fewer than six and falling 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.

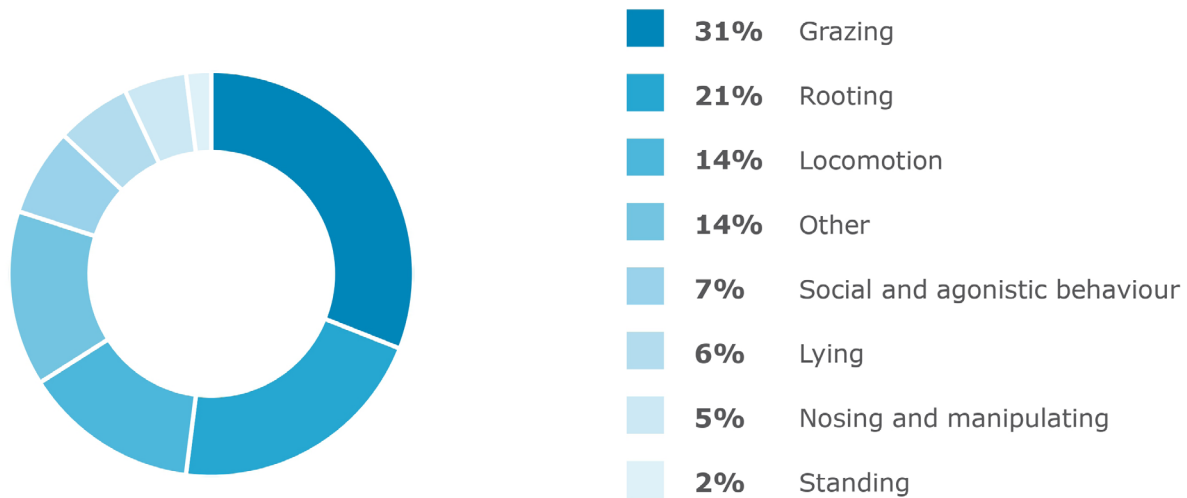
2. Welfare Determinants in Sow Housing Systems

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.

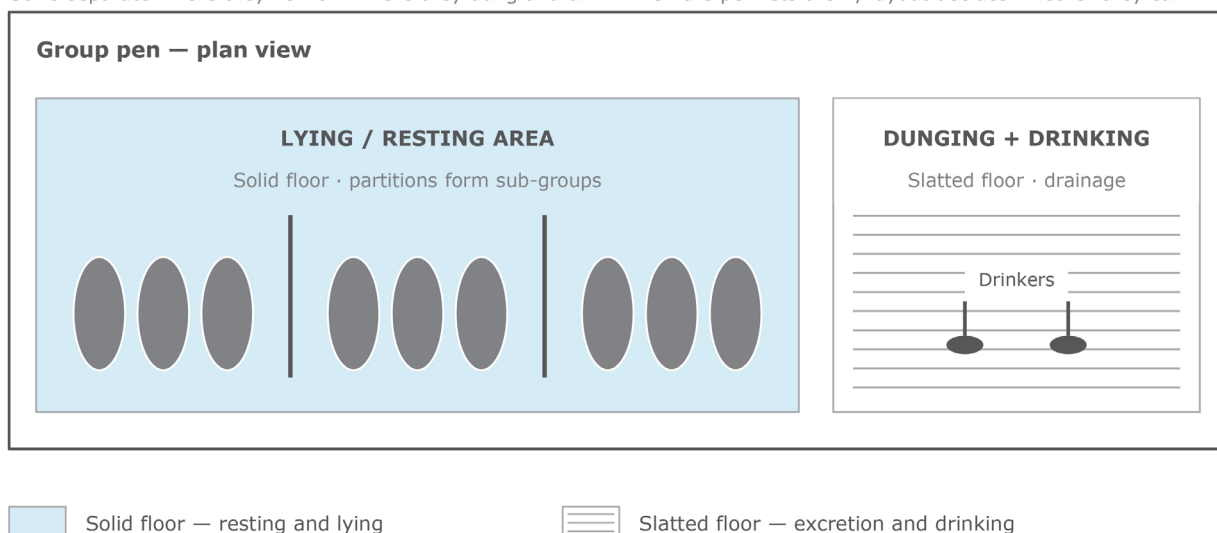
We were unable to find any systematic review or meta-analysis published post-2015 that directly compares ESF and free-access stall welfare outcomes, a noted gap for producers choosing between configurations. Because the feeding system is also the principal route to precision feeding, it is the input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

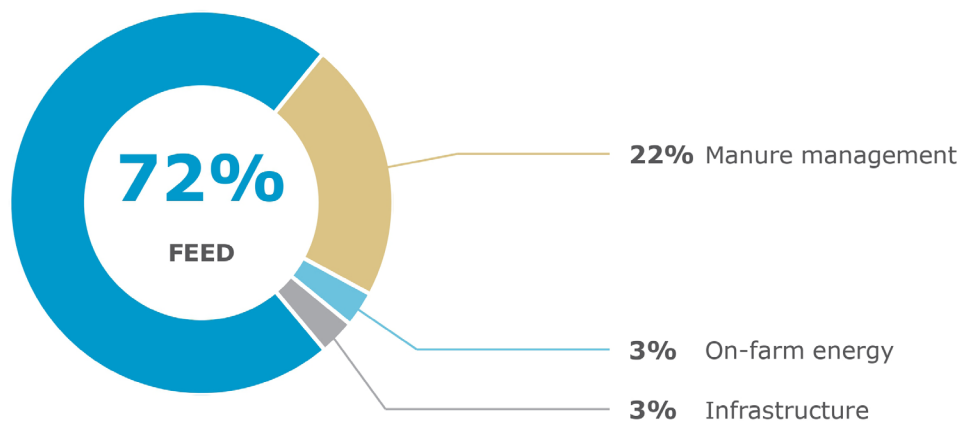
Before examining individual systems, it helps to set out the drivers of climate performance in rough order of magnitude.

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

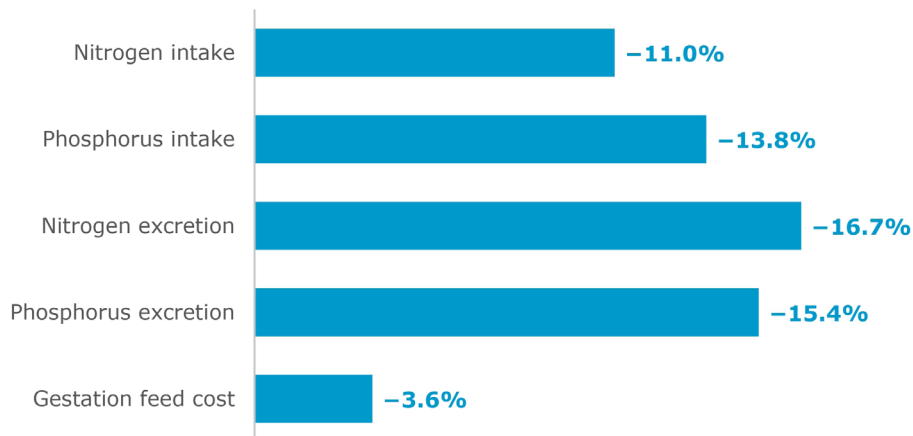
Space allowance — conditionally aligned. More usable space enlarges the behavioural repertoire, reduces aggression in the days after mixing, and lets subordinate sows avoid dominant ones (Section 2.1). The climate chain runs from greater space to greater movement and higher maintenance energy, and to 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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