

The Green Mirage: Why Alternative Protein Meat Is Not a Silver Bullet

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ABSTRACT

Global livestock production occupies nearly 30% of the Earth's ice-free land surface and contributes significantly to greenhouse gas emissions, deforestation, biodiversity loss, and socioeconomic inequality. In response to these environmental, ethical, and economic pressures, alternative proteins have emerged as proposed responses to the structural contradiction of the modern food system. This review distinguishes plant-based meat from cultivated (cell-cultured) meat and evaluates the latter as a potential substitute for conventional livestock products.

This paper evaluates cultivated meat through an integrated environmental, ethical, and political-economic framework. It contrasts the relatively low-emission, resource-efficient production systems of plant-based meat with the technologically complex, energy-intensive model of cultured meat. While plant-based alternatives demonstrate immediate and measurable reductions in land use, water consumption, and emissions, the sustainability of cultured meat remains conditional upon large-scale energy decarbonization and continued technological advancement.

Beyond environmental considerations, the paper examines ethical tensions surrounding artificialization and “de-naturalization,” as well as economic risks including labor displacement, capital concentration, and the emergence of potential “green monopolies.”

Ultimately, this study argues that cultivated meat is neither a technological panacea nor a purely symbolic innovation. Instead, it should be understood as a transitional mitigation tool within a broader multi-pathway strategy that includes rewilding, demand-side dietary shifts, and institutional reform. A sustainable transformation of the global food system requires not only technological innovation but also structural policy intervention and a redefinition of humanity's relationship with nature.

INTRODUCTION

According to the Food and Agriculture Organization of the United Nations, global livestock production occupies about 3.9 billion hectares of land, accounting for nearly 30% of the Earth's ice-free land surface and making it the largest single human land use on the planet.¹ Approximately 78% of all agricultural land—including both pastures and croplands used for animal feed—is devoted to livestock-related activities.² Specifically, around 26% of global land is used for grazing, while 33% of arable land is allocated to feed crop production.³

This extensive land demand makes livestock production a major driver of ecological pressure. In tropical regions, pasture expansion is particularly significant. In the Amazon Basin, for instance, approximately 0.3-0.4% of forest area is converted into pastureland each year, contributing to serious deforestation and habitat loss.⁴

At the climate level, livestock production is also a major contributor to greenhouse gas (GHG) emissions. The FAO estimates that the global livestock supply chain emits approximately 7.5 billion tons of carbon dioxide equivalent (CO₂e) annually, accounting for about 18% of total anthropogenic emissions.⁵ These emissions are composed of multiple sources: carbon dioxide (CO₂), primarily from land-use change and deforestation (approximately 9%); methane (CH₄), mainly from enteric fermentation and manure decomposition (35-40%); and nitrous oxide (N₂O), largely from manure management and fertilizer use (approximately 65%).⁶

In its 2013 update, the FAO revised this estimate using the Global Livestock Environmental Assessment Model (GLEAM), calculating total emissions at approximately 7.1 billion tons of CO₂e per year, or about 14.5% of global emissions.⁷ The report further attributes emissions to feed production (45%), enteric fermentation (39%), manure management (10%), and land-use change (approximately 9%).⁸

The FAO estimates above represent the widely used life-cycle accounting framework for livestock emissions. A much higher figure appears in an alternative and contested accounting approach. Goodland and Anhang estimate that livestock and its byproducts may account for up to 51% of global greenhouse gas emissions when they include additional factors such as animal respiration, land-use opportunity costs, refrigeration, and transportation. This estimate should not be interpreted as equivalent to the FAO's 14.5-18% range: it depends on broader system boundaries and accounting assumptions and has therefore

¹FAO, *Livestock's Long Shadow*, 270–72.

²FAO, *Livestock's Long Shadow*, 78–80.

³FAO, *Livestock's Long Shadow*, 86.

⁴FAO, *Livestock's Long Shadow*, 89.

⁵FAO, *Livestock's Long Shadow*, 112.

⁶FAO, *Livestock's Long Shadow*, 113–115.

⁷FAO, *Tackling Climate Change...*, 15.

⁸FAO, *Tackling Climate Change...*, 19.

been debated in the literature.⁹ They further suggest that reallocating land currently used for grazing and feed production to forest restoration could offset a substantial portion of global emissions.¹⁰

Taken together, these findings indicate a broad academic consensus: livestock production is a central driver of climate change and ecological degradation. It is not only a major source of greenhouse gas emissions, but also a key contributor to land degradation, water depletion, deforestation, and biodiversity loss. Moreover, it exacerbates global inequalities, as high levels of meat consumption in affluent regions contrast with environmental burdens disproportionately borne by developing countries. This structural

REVIEW METHODOLOGY

This paper adopts a structured narrative-review methodology designed to synthesize interdisciplinary evidence rather than conduct a formal systematic review. The literature base was assembled through targeted searches organized around four themes: livestock environmental impacts, plant-based and cultivated-meat production, ethical and consumer-acceptance debates, and political-economic consequences. Priority was given to peer-reviewed studies, major institutional reports, and life-cycle assessments that directly addressed the paper's comparative questions; non-peer-reviewed industry sources were considered only when necessary for understanding technological development or market conditions and were not used as primary evidence for environmental claims. Sources were included when they provided quantitative environmental data, technical descriptions, or explicit ethical and socioeconomic arguments relevant to alternative proteins. When estimates conflicted, the review compared their system boundaries, assumptions, and evidentiary status rather than treating them as directly equivalent. Because the literature spans different methods and stages of technological maturity, the review synthesizes findings qualitatively and treats projections for cultivated meat as conditional rather than settled outcomes.

THEORETICAL FOUNDATIONS OF VEGETARIANISM AND ALTERNATIVE PROTEINS

Vegetarianism is not merely a dietary preference but a broader ethical and philosophical framework encompassing concerns about animal welfare, environmental sustainability, and human health. Its global expansion reflects multiple overlapping motivations, including ethical beliefs, religious traditions, ecological awareness, and health considerations. Hargreaves et al. estimate that approximately 8%-19% of the global population practices some form of vegetarianism, with significantly higher proportions in countries such as India.¹¹

⁹ Goodland and Anhang, "Livestock and Climate Change," 11–12.

¹⁰ Goodland and Anhang, 13–14.

¹¹ Hargreaves et al., "Vegetarian Diet," 4067.

At its ethical core, vegetarianism is often grounded in the principle of *ahimsa* (non-violence), which emphasizes minimizing harm to sentient beings. This ethical orientation challenges the legitimacy of industrial animal agriculture by reframing meat consumption as a moral issue rather than a purely dietary choice. In this sense, vegetarianism provides an important normative foundation for the development of alternative proteins, positioning “slaughter-free protein” as both an ethical alternative and a technological extension of existing moral commitments.

From a health perspective, a substantial body of epidemiological research suggests that plant-based diets are associated with improved health outcomes. A study published in the *European Heart Journal* reports that vegetarian and vegan diets can reduce coronary heart disease mortality by approximately 30%, lower the risk of type II diabetes by up to 62%, and decrease the prevalence of obesity and hypertension.¹² These benefits are largely attributed to lower saturated fat intake, higher dietary fiber consumption, and the presence of plant-based bioactive compounds that improve metabolic function and reduce inflammation.¹³

However, vegetarian diets are not without limitations. Nutritional deficiencies—particularly in vitamin B12, iron, calcium, and zinc—may arise in poorly balanced diets, especially among strict vegans.¹⁴ Moreover, important distinctions exist between whole-food plant-based diets and highly processed plant-based products, the latter of which may contain elevated levels of sodium, refined oils, and additives.¹⁵

It is within this context that cultivated meat emerges not as a radical break from vegetarianism, but as a technological response to its limitations. While vegetarianism seeks to reduce harm through abstention, cultivated meat attempts to reconcile ethical concerns with existing consumption patterns by replicating the sensory and nutritional properties of conventional meat without requiring animal slaughter. In this sense, cultivated meat represents a hybrid paradigm—one that bridges ethical aspiration and technological intervention, while also introducing new environmental, ethical, and economic questions that require critical evaluation.

TWO CATEGORIES OF ALTERNATIVE PROTEINS

For clarity, this paper uses alternative proteins as the umbrella term for nonconventional substitutes for livestock meat. Within this review, plant-based meat and cultivated meat are treated as separate categories rather than as two forms of “lab-grown meat.” Plant-based meat restructures proteins derived from crops, whereas cultivated (or cell-cultured) meat grows animal cells in controlled culture systems. Although both aim to reduce the environmental burden of conventional livestock production, they differ fundamentally in their technological foundations, cost structures, and degrees of industrial maturity.

¹² Wang et al., “Vegetarian and Vegan Diets,” 3423–3439.

¹³ Wang et al., “Vegetarian and Vegan Diets: Benefits and Drawbacks,” 3423–3439.

¹⁴ Hargreaves et al., “Vegetarian Diet,” 4067.

¹⁵ Rowan El Sadig and Jianping Wu, “Are Novel Plant-Based Meat Alternatives the Healthier Choice?,” *Food Research International* 183 (2024): 114184.

Plant-Based Meat: Biomimetic Reconstruction As Its Core

Plant-based meat is rooted in food engineering and relies on the structural reconfiguration of plant protein to mimic the texture and sensory properties of animal muscle. Typically derived from sources such as peas, soy, or potatoes, plant proteins undergo high-moisture extrusion, a process in which heat and pressure realign protein molecules into fibrous structures resembling meat tissue.¹⁶ Additional ingredients—including plant-based fats, flavoring agents, and natural colorants—are incorporated to produce the taste, juiciness, and appearance of conventional meat products.¹⁷

From a production standpoint, plant-based meat has already achieved a relatively high degree of commercialization. Estimates from 2016 to 2018 suggest production costs ranging from approximately \$8 to \$10 per kilogram, with further reductions expected as economies of scale improve.¹⁸ Life-cycle assessments conducted by the University of Michigan indicate that, compared to conventional beef, plant-based meat products can reduce greenhouse gas emissions by approximately 90%, land use by 93%, and water consumption by 99%.¹⁹ These findings position plant-based meat as a technologically mature and immediately scalable alternative within the current food system.

Cultured Meat: Based On Tissue Engineering

In contrast, cultured meat is based on advances in stem cell biology and tissue engineering. The production process typically involves extracting a small sample of animal cells, proliferating them in nutrient-rich culture media, and guiding their differentiation into muscle fibers through biochemical and mechanical stimulation. These cells are grown on scaffolds that provide structural support, allowing the formation of three-dimensional tissue constructs.²⁰

Despite rapid technological progress, cultured meat remains in an early stage of industrial development. Since the first laboratory-grown beef patty was produced in 2013 for approximately €250,000, production costs have declined significantly, although commercial-scale cost estimates remain uncertain.²¹ However, its cost structure remains highly complex: culture media, labor, and bioreactor infrastructure represent the three largest components of production costs, each accounting for approximately 28–31% of total costs in one large-scale techno-economic model.²²

¹⁶ Center for Sustainable Systems, University of Michigan, Beyond Meat's Beyond Burger Life Cycle Assessment, 7–9.

¹⁷ Ibid., 9.

¹⁸ Ibid., 10.

¹⁹ Ibid., 11–13.

²⁰ Post, “Cultured Meat from Stem Cells,” 297–301.

²¹ Alok Jha, “First Hamburger Made from Lab-Grown Meat to Be Served at Press Conference,” *The Guardian*, August 5, 2013.

²² Greg L. Garrison, Jon T. Biermacher, and B. Wade Brorsen, “How Much Will Large-Scale Production of Cell-Cultured Meat Cost?,” *Journal of Agriculture and Food Research* 10 (2022): 100358.

More importantly, the environmental performance of cultured meat is best understood as conditionally sustainable. Unlike conventional livestock systems, which generate significant methane emissions, cultured meat produces primarily carbon dioxide emissions associated with energy consumption.²³ Modeling studies suggest that while this may reduce short-term warming impacts, long-term carbon dioxide accumulation could offset these advantages if energy systems remain dependent on fossil fuels.²⁴ Taken together, these two pathways represent distinct technological responses to the same structural problem. Plant-based meat operates through simulation—replicating meat-like properties using non-animal inputs—while cultured meat seeks reconstruction, attempting to recreate animal tissue at the cellular level. The former is characterized by low technological uncertainty and immediate environmental benefits, whereas the latter embodies high potential but significant uncertainty. This divergence highlights a broader tension in contemporary food innovation: whether sustainability is best achieved through optimizing existing systems or fundamentally redefining them.

ENVIRONMENTAL AND ETHICAL ANALYSES OF CULTURED MEAT

The conditionality of environmental benefits

Cultured meat is frequently promoted as a sustainable alternative to conventional livestock production, particularly in terms of reducing greenhouse gas emissions and resource use. However, its environmental advantages are not absolute; rather, they are highly conditional upon broader energy and production systems.

According to the FAO's Global Livestock Environmental Assessment Model (GLEAM), conventional livestock systems generate approximately 7.1 gigatons of CO₂e annually, accounting for 14.5% of global anthropogenic greenhouse gas emissions.²⁵ These emissions are primarily derived from feed production (45%), enteric fermentation (39%), and manure management (10%).²⁶

In comparison, plant-based meat alternatives demonstrate consistent and immediate environmental benefits. Life-cycle assessments indicate that such products can reduce greenhouse gas emissions by approximately 90%, land use by 93%, and water consumption by 99% relative to beef.²⁷ These reductions occur within existing energy systems, making plant-based meat a low-risk and readily deployable mitigation strategy.

The environmental profile of cultured meat, by contrast, is significantly more complex. Modeling studies by Lynch and Pierrehumbert show that while cultured meat largely eliminates methane emissions, its

²³ Lynch and Pierrehumbert, "Climate Impacts of Cultured Meat," 5–7.

²⁴ Lynch and Pierrehumbert, 8–9.

²⁵ FAO, Tackling Climate Change through Livestock, 15.

²⁶ FAO, Tackling Climate Change through Livestock, 19.

²⁷ Center for Sustainable Systems, Beyond Meat LCA, 11–13.

carbon footprint is dominated by carbon dioxide generated through energy-intensive bioreactor processes.²⁸ As a result, its long-term climate impact depends critically on whether energy systems undergo substantial decarbonization.²⁹

Moreover, the resource intensity of cultured meat production is often underestimated. Bioreactors require continuous temperature regulation, sterility, and agitation, leading to high energy consumption. The use of disposable plastics, filtration systems, and chemical culture media also introduces environmental burdens through industrial waste.³⁰ As Stephens et al. caution, without effective circular resource management, cultured meat risks shifting environmental pressures rather than reducing them—transforming agricultural emissions into industrial ones.³¹

Taken together, these findings suggest that the environmental value of cultured meat does not reside in the technology itself, but in its integration within broader energy, material, and waste-management systems. Without such systemic transformation, its sustainability remains contingent rather than guaranteed.

ETHICAL DILEMMA: THE BOUNDARY BETWEEN NATURE AND THE ARTIFICIAL

Beyond environmental considerations, cultivated meat raises fundamental ethical questions concerning the relationship between humans and nature. The central issue is not merely whether cultured meat is safe or efficient, but whether it can be considered “natural,” and whether perceptions of “naturalness” can carry moral significance in the contemporary food system.

Critics argue that cultured meat represents an extension of technological control over biological processes, further dissolving the boundary between the natural and the artificial.³² Transforming animal tissue production into an industrial, controllable system reflects a broader trajectory of “de-naturalization,” in which life itself becomes subject to human design and optimization. This raises a deeper philosophical concern: if the natural origin of food is no longer preserved, on what grounds does its cultural or ethical legitimacy rest?

At the same time, consumer responses suggest that perceptions of “unnaturalness” are not merely philosophical abstractions, but socially consequential factors shaping market acceptance.³³ Just as genetically modified organisms have encountered resistance despite scientific assurances of safety, cultured meat may face similar challenges rooted in trust, perception, and cultural meaning.

²⁸ Lynch and Pierrehumbert, “Climate Impacts,” 5–7.

²⁹ Lynch and Pierrehumbert, 8–9.

³⁰ Stephens et al., “Bringing Cultured Meat to Market,” 155–156.

³¹ Stephens et al., 155–156.

³² Post, “Cultured Meat from Stem Cells,” 297–301.

³³ Stephens et al., 158–159.

These concerns should be analytically distinguished from one another. Consumer perception of “unnaturalness” concerns trust, familiarity, and cultural acceptance; the philosophical critique of de-naturalization concerns whether sustainability should rely on deeper technological control over the living process. Neither objection, by itself, demonstrates environmental harm. Environmental risk is a separate empirical question involving energy use, material inputs, waste, and the carbon intensity of production. Keeping these three dimensions distinct prevents cultural discomfort or philosophical concern from being treated as evidence of ecological damage, while still recognizing that each can affect the social legitimacy of cultivated meat.

In contrast, the concept of rewilding offers an alternative ethical orientation. Rather than intensifying technological intervention, rewilding emphasizes reducing human control and allowing ecosystems to restore themselves.³⁴ This approach reflects a fundamentally different vision of sustainability—one grounded in restraint rather than optimization.

The tension between these approaches reveals that the ethical debate surrounding cultivated meat is not simply about naturalness itself, but about competing models of human–nature relations. On one hand, cultivated meat embodies a commitment to reducing animal suffering and improving resource efficiency. On the other hand, it reinforces a paradigm in which ecological problems are addressed through increasingly sophisticated forms of technological control.

Thus, cultivated meat emerges as both an ethical innovation and an ethical paradox. Its legitimacy does not depend solely on its capacity to reduce harm, but on how societies negotiate the boundary between intervention and restraint, and ultimately redefine what it means to act responsibly within the natural world.

THE ECONOMIC IMPACTS AND STRUCTURAL RISKS OF CULTIVATED MEAT

Discussions of cultivated meat often frame its economic viability in terms of technological feasibility and cost reduction. However, from a political economy perspective, cultivated meat is not merely a new food product, but a transformative industrial system capable of reshaping production structures, labor relations, and the distribution of capital. Evaluating its implications, therefore, requires moving beyond market potential to consider its structural consequences.

Cost structure and the challenge of scaling

The cost structures of plant-based and cultured meat differ significantly, reflecting their distinct technological foundations. Plant-based alternatives have largely achieved commercialization, with

³⁴Joseph Poore, Hannah Ritchie, and Charles Godfray, “The Rewilding Milestone Earth Has Already Passed,” BBC Future, September 9, 2025.

production costs estimated at approximately \$8–10 per kilogram and continuing to decline as scale increases.³⁵

In contrast, the cost structure of cultured meat remains highly complex and resistant to rapid reduction. Culture media, labor, and bioreactor infrastructure remain major components of production costs, with one large-scale techno-economic model estimating that they collectively account for nearly 87% of total costs.³⁶

While industry narratives often assume that costs will decrease linearly with technological progress, this assumption is questionable. Biological constraints on cell growth, the difficulty of synthesizing growth factors at scale, and the capital intensity of bioreactor systems suggest that cost reductions may encounter structural limits.³⁷ This indicates that scaling cultured meat is not simply a matter of replication, but of overcoming fundamental technological and economic barriers.

Labor displacement and uneven transition

The expansion of cultivated meat could produce labor displacement within traditional livestock sectors. Animal agriculture and its associated supply chains—including feed production, slaughtering, and logistics—support the livelihoods of hundreds of millions of people worldwide, particularly in rural and developing regions; however, this broad figure includes diverse livestock-dependent livelihoods and should not be interpreted as a direct estimate of jobs that cultivated meat would displace.³⁸

By contrast, employment opportunities created by cultivated meat are expected to be concentrated in biotechnology, engineering, and research-intensive sectors, which generally require higher levels of education and specialized skills.³⁹ This suggests even if the industry generates new employment opportunities, these positions may not directly correspond with the geographic distribution, skill profiles, or economic circumstances of workers affected by a transition away from conventional livestock production.

This transformation raises concerns about widening inequalities. Workers displaced from traditional sectors may not be readily absorbed into the new industry, potentially exacerbating rural–urban divides and reinforcing existing global disparities between developed and developing regions.

Capital concentration and the emergence of “green monopolies”

A defining feature of the cultivated meat industry is its high degree of capital concentration. Core technologies—including cell lines, culture media formulations, protein structuring processes, and

³⁵Center for Sustainable Systems, Beyond Meat LCA, 10.

³⁶Garrison, Biermacher, and Brorsen, “How Much Will Large-Scale Production of Cell-Cultured Meat Cost?”

³⁷Stephens et al., “Bringing Cultured Meat to Market,” 156–158.

³⁸FAO, *Livestock’s Long Shadow*, 269–271.

³⁹Stephens et al., 159.

bioreactor designs—are protected by patents and require substantial research and development investment.⁴⁰

These barriers to entry may limit participation by small firms and traditional agricultural actors, concentrating market power in a small number of technologically advanced corporations. This structure may give rise to “green monopolies,” in which firms leverage environmental and ethical narratives to justify market dominance while consolidating economic control.

In this context, sustainability risks are being transformed from a public good into a mechanism of capital accumulation. Rather than democratizing access to sustainable food systems, cultivated meat may reproduce patterns observed in the energy and technology sectors, characterized by technological concentration, profit concentration, and the externalization of risk.

Consumer acceptance and market stratification

Even if technological and cost barriers are overcome, consumer acceptance remains uncertain. Studies suggest that perceptions of “unnaturalness” and lack of trust may limit widespread adoption of cultured meat.⁴¹

Moreover, pricing dynamics are likely to produce stratified consumption patterns. In the short term, cultivated meat is expected to be more accessible to middle- and high-income consumers, while lower-income populations continue to rely on conventional meat.

This raises a critical question: will cultivated meat function as a form of “moral luxury good”? If ethical and environmentally sustainable consumption becomes accessible primarily to those with economic and cultural capital, then cultivated meat may reinforce, rather than reduce, existing inequalities within the global food system.

Structural implications

Taken together, these dynamics suggest that cultivated meat should not be understood as a neutral technological innovation, but as a system embedded within existing structures of power and inequality. While it offers potential environmental benefits, its development trajectory may reproduce structural asymmetries in labor, capital, and access.

Thus, the question is not simply whether cultivated meat can scale, but who benefits from its expansion, who bears its costs, and how its development reshapes the political economy of food. Without deliberate institutional intervention, cultivated meat risks becoming not a solution to systemic problems, but a reconfiguration of them.

⁴⁰ Stephens et al., 160–161.

⁴¹ Stephens et al., 158–159.

PATHWAYS AND ALTERNATIVES: BETWEEN CULTIVATED MEAT, REWILDING, AND INSTITUTIONAL REFORM

In light of the preceding analysis, cultivated meat should neither be uncritically embraced as a technological solution nor dismissed as a speculative innovation. Instead, it must be situated within a broader framework of systemic transition, in which technological, ecological, and institutional pathways interact and constrain one another.

The limits of the technological solutions

The environmental benefits of cultivated meat are fundamentally conditional. While plant-based alternatives have already demonstrated consistent emissions reductions within existing energy systems, the long-term sustainability of cultured meat depends on large-scale decarbonization, advances in production efficiency, and the development of sustainable inputs.⁴²

Consequently, framing cultivated meat as a comprehensive replacement for conventional livestock production is both unrealistic and analytically misleading. A more viable approach is to position it as a targeted mitigation strategy, particularly in high-impact sectors such as beef production, and in regions where low-carbon energy systems are already in place.

Rewilding and demand-side transformation

In contrast to the technology-centered logic of cultivated meat, rewilding offers an alternative pathway grounded in ecological restoration and restraint. By reducing grazing pressure, restoring ecosystems, and allowing natural processes to re-establish equilibrium, rewilding enhances carbon sequestration and biodiversity recovery.⁴³

At the same time, demand-side transformation plays a critical role. Reducing overall meat consumption and promoting predominantly plant-based diets can directly lower environmental pressures while creating the conditions necessary for ecological restoration.

This approach challenges the assumption that environmental crises must be addressed through increasing technological complexity. In some cases, reducing human intervention—rather than intensifying it—may offer more effective and sustainable solutions.

Institutional design and the prevention of a “green mirage”

Neither technological innovation nor ecological restoration can succeed without appropriate institutional frameworks. Left solely to market forces, cultivated meat is likely to evolve toward high levels of capital

⁴² Lynch and Pierrehumbert, “Climate Impacts,” 8–10.

⁴³ Poore, Ritchie, and Godfray, “The Rewilding Milestone Earth Has Already Passed.”

concentration, producing what may be described as a “green mirage”—a system that appears sustainable while reproducing underlying inequalities.

To prevent this outcome, at least three forms of institutional intervention are necessary. First, environmental externalities must be internalized through mechanisms such as carbon pricing and land-use regulation, ensuring that the true costs of conventional livestock production are reflected in market structures.⁴⁴

Second, governance of technological development is required to prevent excessive concentration of intellectual property and market power. Antitrust regulation and oversight of key technologies are essential to ensure that sustainability does not become a vehicle for private rent extraction.

Third, a just transition framework must be implemented to address labor displacement and regional inequality. Retraining programs, income support, and targeted development policies are necessary to ensure that the costs of transition are not disproportionately borne by vulnerable populations.⁴⁵

CONCLUSION

This review finds that cultivated meat offers real but conditional environmental advantages. It has the potential to reduce animal slaughter and some pressures on land and water resources, yet its climate performance depends on low-carbon energy, efficient bioprocessing, sustainable inputs, and effective governance. Plant-based meat, by contrast, already demonstrates lower environmental impacts within existing production systems and therefore represents the lower-risk near-term alternative.

The ethical debate also contains distinct questions that should not be collapsed into a single objection about “unnaturalness.” Consumer acceptance concerns trust and cultural meaning; de-naturalization raises a philosophical question about technological control over life; environmental risk depends on measurable production impacts, including energy use, material inputs, and emissions intensity. Cultivated meat may reduce animal suffering while simultaneously intensifying human control over biological processes, making its ethical legitimacy dependent on how these competing values are negotiated.

Its political-economic effects are similarly uncertain. Capital-intensive and patent-dependent production may concentrate market power. It may create uneven transition costs for workers and regions tied to conventional livestock production. Still, the scale of these effects will depend on how the industry develops and how public institutions respond. Sustainability must therefore be evaluated not only through emissions and cost, but also through access, labor transition, and market structure.

⁴⁴ FAO, Tackling Climate Change through Livestock, 45–47.

⁴⁵ FAO, Livestock’s Long Shadow, 269–271.

Cultivated meat should therefore be treated as a conditional and supplementary tool, not as a silver bullet. A more robust transition combines reduced meat demand, wider adoption of plant-based alternatives, cautious development of cultivated meat where low-carbon production is feasible, rewilding of land released from livestock use, and institutional measures that internalize environmental costs, limit excessive market concentration, and support a just transition.

The central question is not whether technological innovation should replace ecological restraint, or whether restraint should reject innovation entirely, but how the two can be integrated through institutions that protect both ecological and social goals. Under those conditions, cultivated meat can contribute to a broader transformation of the food system; without them, its promise risks becoming the “green mirage” described in this paper.

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