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Food of the Future? A Review on the Environmental Impacts and Sustainability of Cultured Meat

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ABSTRACT

The growing global population and unsustainable consumption of natural resources are expected to exacerbate future food security challenges. Cultivated meat, a novel technology produced by culturing animal cells in controlled environments without the need for conventional livestock farming, offers a sustainable alternative that also supports animal welfare. This study presents a literature review focused on the environmental impacts of cultivated meat production, specifically analyzing studies utilizing the Life Cycle Assessment (LCA) methodology. In addition, the review considers health and safety implications, animal welfare concerns, and the economic landscape of the cultivated meat sector. Findings suggest that cultivated meat can be a sustainable solution, particularly when renewable energy sources are employed. However, energy consumption remains the primary contributor to environmental impact, with greenhouse gas emissions largely associated with energy use and culture media. The implications of large-scale production are still uncertain. While cultivated meat may benefit animal welfare, its long-term health effects are not yet fully understood. Despite a decline in investment in 2023, new market entrants and decreasing production costs reflect ongoing industry momentum. Overall, cultivated meat demonstrates strong potential as a sustainable protein source, though further research and technological development are necessary to realize its full promise.

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Introduction

It is expected that the world population will reach 9.7 billion in 2050. This growth may lead to an increase in food production to meet the nutritional needs of a growing population. In this context, sustainable food production is important to ensure food security in the future. Currently, food production accounts for over 26% of global greenhouse gas (GHG) emissions (Ritchie, 2019). The OECD-FAO Agricultural Outlook 2024-2033 report forecasts a 6% increase in GHG emissions from the meat industry by 2033, attributed to the expansion of the cattle population.

The population growth and excessive resource consumption have led to a sixfold increase in global freshwater consumption since the 1900s. Globally, 70% of freshwater is used for agriculture purposes (Ritchie & Roser, 2018). Additionally, annually 4,387 km^3 of blue and green water, equaling about 41% of total agricultural water use, is used for the production of livestock feed (Heinke et al., 2020). Agriculture requires a large amount of freshwater and has large effect on world's environment (Ritchie et al., 2022). Also, freshwater per capita is continuously decreasing from 1992 to 2020 (World Bank Open Data, 2024). Increasing freshwater consumption and limited water resources have made it necessary to use water sustainable way to prevent food insecurity issues in the future.

Global land use is illustrated in Figure 1. Land allocated to livestock—including grazing areas and croplands used for animal feed—covers approximately 38 million km^2. In contrast, croplands designated for direct human consumption and non-food uses occupy around 10 million km^2. Despite the disproportionate use of land for livestock, the majority of global calorie and protein supply is derived from plant-based sources, accounting for approximately 83% and 62%, respectively (Ritchie & Roser, 2019). This imbalance highlights an unsustainable pattern of land use that poses long-term risks to food security and environmental health. Consequently, the livestock sector must prioritize the production of high-quality protein in a manner consistent with the United Nations Sustainable Development Goals (SDGs) (OECD/FAO, 2024).

Figure 1. The world's land use (Ritchie & Roser, 2019).

Livestock sector causes substantial environmental problems due to unsustainable production. A large portion of the agricultural land is used for livestock. Additionally, livestock are responsible for 9% of carbon dioxide emissions, 35-40% of methane emissions and 65% of nitrate emissions (Güneş Bayır & Kıyak, 2022). While methane gas affects global warming 28 times more than CO_2, nitrate gas affects it 265 times more (Grossi et al., 2019). As a result, it contributes to climate change. Climate change will impact the key factors of agricultural production, such as sunlight, temperature and rainfall. This may cause a decrease in food supply and an increase in food price. Increasing food prices can contribute to world hunger and poor people are the most vulnerable to it (FAO, 2008). As a result, food insecurity will occur. To solve problems that livestock cause, alternative proteins have been developed. One of them is cultivated meat.

In their review study, Sürek and Uzun (2020) highlight that the growing global population and shifting consumer preferences have increased interest in alternative protein sources. In this context, in vitro (cultivated) meat emerges as a promising and sustainable solution. It is suggested that cultivated meat has the potential to reduce the environmental impacts associated with conventional livestock farming—particularly greenhouse gas emissions and land use-and to enable a safer form of meat production. However, factors such as high production costs, ethical concerns, and limited consumer acceptance remain key barriers to the widespread adoption of this technology. The study provides a comprehensive overview of the development process, production methods, and major challenges associated with cultivated meat.

Cultivated meat, also known as in vitro, lab-grown, or synthetic meat, refers to the production of muscle cells derived from animal tissues in a laboratory or controlled bioreactor environment, as opposed to traditional animal husbandry practices (Stephens et al., 2018; Lynch & Pierrehumbert, 2019). This emerging food technology has gained significant attention in recent years due to its potential to address environmental, ethical, and public health concerns associated with conventional meat production. As of 2023, there are approximately 170 companies globally engaged in the development of cultivated meat (Good Food Institute, 2023). However, only a limited number have received regulatory approval for commercial distribution. Notably, the U.S. Food and Drug Administration approved Upside Foods in November 2022 and Good Meat in March 2023, making the United States the second country after Singapore to authorize the sale of cultivated meat products (Douglas, 2023).

Despite its promising benefits, cultivated meat faces significant barriers to consumer acceptance. Many individuals remain skeptical due to perceptions of artificiality and the fact that the product is developed in a laboratory setting. Furthermore, the high production costs make it less accessible compared to conventional meat, which may further hinder its market penetration. Ethical concerns have also emerged, particularly regarding speculative scenarios such as the lab-based reproduction of human tissue for consumption, which raises fears of normalizing cannibalism and challenging societal norms (Doğan, 2021).

Nonetheless, cultivated meat offers substantial advantages over traditional animal agriculture. These include a marked reduction in land and water use, significantly lower greenhouse gas emissions, and the elimination of risks associated with zoonotic diseases and antimicrobial resistance (Kirsch et al., 2023). As such, cultivated meat is increasingly viewed as a sustainable and ethically responsible alternative protein source, albeit one that must overcome technological, economic, and socio-cultural hurdles before achieving mainstream adoption.

This review compiles existing studies on the environmental impacts of cultivated meat to underscore its potential as a sustainable food technology. The primary objective is to demonstrate that cultivated meat production contributes to environmental sustainability by reducing the ecological burden associated with conventional livestock systems. As such, cultivated meat may serve as a complementary alternative to traditional meat products. Furthermore, the review also addresses related dimensions including animal welfare, economic implications, and health and safety considerations.

Materials and Methods

To evaluate the environmental impact of cultivated meat, a literature review was conducted using the Web of Science database. The review process, illustrated in Figure 2, was adapted from the PRISMA (Preferred Reporting Items for Systematic Reviews and Meta-Analyses) framework. During the screening phase, the keywords "Life Cycle Assessment," "LCA," "Comparative LCA," "Environment," "Environmental Impact," and "Life Cycle Analysis" were applied to titles and abstracts. Studies employing Life Cycle Assessment were selected, as LCA is among the most widely adopted methodologies for assessing sustainability metrics. This approach facilitates the identification of key sustainability parameters relevant to industrial-scale production.

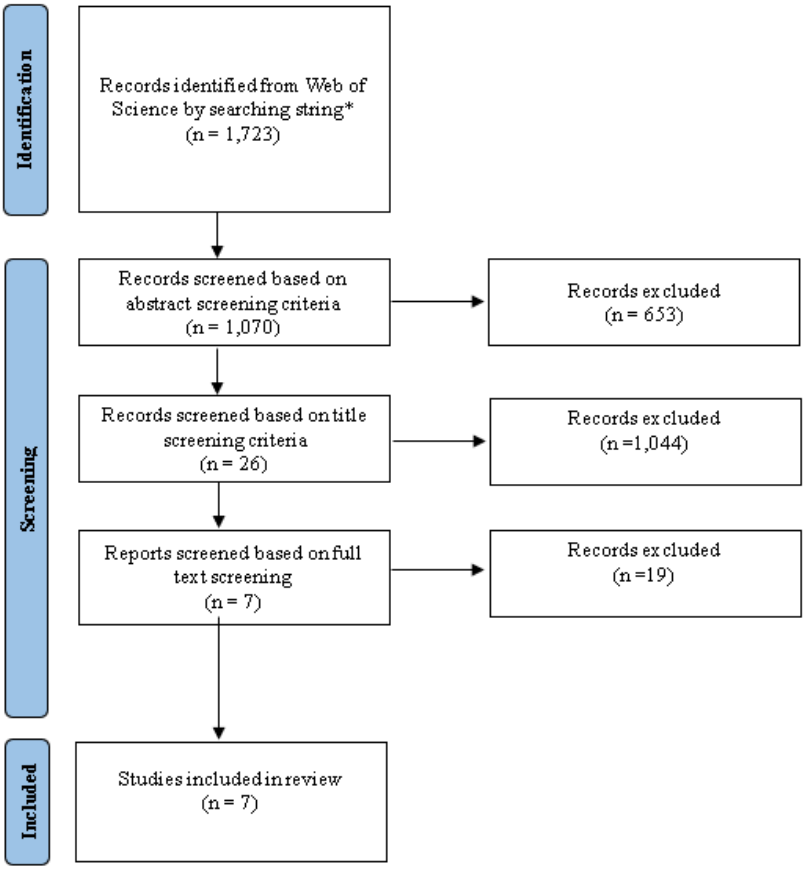

Figure 2. Flow diagram for displaying the systematic literature review (PRISMA, 2020)

Table 1. Environmental impact of conventional meat and cultivated meat from various studies.

Reference	Production or Energy source	Energy Use (MJ)	Climate change (kg CO_2-eq)	Land Use (m^2)	Water Use (m^3)	Eutrophication (g PO_4 eq)
Poore and Nemecek (2018)	Beef (beef herd)	-	99.48	326.21	1.451	301.41
	Beef (dairy herd)	-	33.3	43.24	2.714	365.29
	Pig meat	-	12.31	17.36	1.796	76.38
	Poultry meat	-	9.87	12.22	0.66	48.7
Risner et al. (2025)	-	14.89-1706.4	12.31-1508.3	-	-	0.07 -9.0 (kg N eq)
Sinke et al. (2023)	conventional energy	277.55	14.34	2.41	0.07	1
	renewable energy	163.83	2.82	2.48	0.09	1
Tuomisto et al. (2022)	-	94.1- 532.8	25.2- 4.9	6.9- 1.9	0.54- 0.12	1
Smetana et al. (2015)	-	290.7- 373	23.9- 24.64	0.39- 0.77	-	-
Mattick et al. (2015)	-	106	7.5	5.5	-	7.9
Tuomisto and Mattos (2011)	-	26-33	1.9-2.24	0.19-0.23	0.37-0.52	-

In total, seven studies were selected and subsequently compared with the benchmark findings of Poore and Nemechek (2018), as presented in Table 1.

The LCA method is based on ISO 14040 (2006) and ISO 14044 (2006) standards (ISO, 2006a; ISO, 2006b). Thereforeit is an appropriate method to compare alternative proteins, such as cultivated meat, with conventional meat. There are different LCA methods, such as cradle-to-gate and cradle-to-plate. A cradle-to-gate LCA evaluates the environmental effects associated with a product or service from raw material extraction to the completion of manufacturing. This approach consists of early stages of the life cycle, which referred to as upstream phase. A cradle-to-plate approach calculates the environmental effects of product or services from raw material extraction to consumption. It does not contain waste treatment after consumption and recycling of packaging. It has more holistic view than cradle-to-gate. In this review, there are six cradle-to-gate studies and one cradle-to-plate study were analyzed.

Economical aspect of cultivated meat was analyzed from 2023 State of the Industry: Cultivated Meat and Seafood report by Good Food Institute. The report provides quantitative and qualitative data on global investments, regional funding distribution, industry growth, and key market trends. The investment figures and trends presented in the report were reviewed and analyzed. Total global investment and regional differences were focused. For more statistical data, Our Data in the World and Statista were used.

Results and Discussions

Environmental Impact of Cultivated meat

Tuomisto and Teixeira de Mattos (2011) employed the cradle-to-gate life cycle assessment (LCA) approach to evaluate the environmental impacts of large-scale lab-grown meat production. A culture medium derived from cyanobacteria was utilized for the proliferation of muscle cells. Results are shown in Table 1. It is concluded that cultivated meat production has a lower environmental impact than conventional meat production. The energy usage of cultivated meat production is lower than beef, pork and sheep but higher than poultry. The majority of greenhouse gas (GHG) emissions from cultivated meat production are associated with the source of energy inputs. It can be reduced when renewable energy sources are used during production. As a result, replacement of conventional meat products with cultivated meat could potentially contribute to reducing environmental problems. However, the implications of large-scale cultivated meat production remain uncertain. It may adversely affect rural biodiversity due to the diminished demand for grasslands and pastures. Therefore, large-scale cultivated meat production needs more research and development.

Mattick et al. (2015), using a cradle-to-gate life cycle assessment (LCA), found that cultivated meat production requires significantly fewer agricultural inputs compared to conventional livestock farming. The results of their analysis are presented in Table 1. According to the results, the environmental impact of cultivated meat is generally lower than that of conventional meat production. However, the energy demand associated with cultivated meat is estimated to be higher than that of beef production. This outcome, however, may vary depending on specific production conditions and technological advancements. Also, it is stated that large-scale cultivated meat production could represent a new stage of industrialization in the food industry. Cultivated meat offers promising sustainability advantages in terms of agricultural inputs and land use. Nevertheless, it faces important challenges in reducing energy consumption and managing industrial processes.

Smetana et al. (2015) examined the environmental impact of meat replacements to identify the most feasible choice by using cradle-to-plate LCA. The results showed that while cultivated meat production had the highest environmental impact, insect-based and soy meal-based alternatives demonstrated the least impact among meat substitutes. It needs a large amount of energy, which causes the highest impact on the environment. Energy consumption mainly consists of medium cultivation and meat cell growth. However, its effect on land and freshwater ecotoxicity is low.

Tuomisto et al. (2022) sought to advance the understanding of the environmental implications of cultivated meat production by evaluating various bioprocess design scenarios through a cradle-to-gate life cycle assessment (LCA) approach. Their findings suggest that cultivated meat holds considerable potential to reduce the environmental burdens associated with conventional livestock farming. However, the study identified the production of culture medium as a major contributor to the overall environmental footprint of cultivated meat. In response, the authors highlighted the need for further investigation into alternative, more sustainable sources for culture media components—such as hydrolysates derived from legumes, algae, or microorganisms. Additionally, the integration of renewable energy into the production process was deemed essential for maximizing the climate-related advantages of cultivated meat. To enhance the environmental sustainability of the sector, the study ultimately recommends the adoption of renewable energy sources and the formulation of novel, resource-efficient culture media.

Kim et al. (2022) conducted a cradle-to-gate LCA on SCiFi Food's cultivated meat burger and compared it with a U.S. beef patty. The study evaluated four indicators: greenhouse gas emissions, land use, water consumption and energy consumption. The findings demonstrate that cultivated meat burgers produce 87% fewer greenhouse gas emissions, need 39% less energy, utilize 96% less water, and exert 90% less influence on land usage in comparison to U.S. beef patties. In addition to that, uncertainty and sensitivity analyses were performed to ensure the robustness of the data. Overall, this study showed that cultivated meat burger can make significant environmental improvements over traditional beef.

Sinke et al. (2023) aimed to present an assessment of the environmental implications of commercial scale cultivated meat production in 2030, compared with traditional animal production in the same year. The carbon impact of cultivated meat production is primarily derived from CO_2, which can be mitigated by utilizing renewable energy sources. It is mostly driven by energy consumption at the facility and energy use in the production of medium ingredients. By using renewable energy, its sustainability potential can be increased. It is shown in Table 1 that when renewable energy is used, the environmental impact of cultivated meat production is reduced in all categories except for land use, since renewable energy generation accounts for approximately 10–20% of total land use. However, the overall land use of cultivated meat remains significantly lower than that of conventional meat products. Replacing conventional meat with cultivated meat could free up much of the land currently used for livestock farming. These lands can be used to mitigate climate change and to support biodiversity.

Risner et al. (2025) assessed the environmental sustainability of cultured meat by using LCA across different production scenarios. A scenario analysis was performed using the metabolic requirements studied in the technoeconomic assessments (TEAs) of animal cell-based meat (ACBM) and a purification factor was used to account for the processing of the growth medium component. Also, glucose-based and amino acid-based growth media were compared with pharmaceutical-grade refined media. The results showed that cultivated meat production may lead to more environmental impacts than conventional meat production. Numerical data supporting these findings are presented in Table 1. The study pays attention that if cultivated meat is to be a truly sustainable alternative, production process and growth media have to be optimized. Also, the study indicated that the requirement of integrating comprehensive TEAs with LCA to calculate environmental effects of novel food products and agricultural technologies accurately.

The results of the LCA studies are presented in Table 1. When compared with the findings of Poore and Nemecek (2018), it is observed that cultivated meat has a lower environmental impact in terms of land use, water use, and eutrophication. However, it may contribute more to climate change than pork and poultry. An LCA study on SuperMeat cultivated chicken found that it led to a 47% reduction in carbon footprint, a 64% decrease in fine particulate formation, an 85% reduction in terrestrial acidification and a 90% decrease in land use compared to traditional poultry (Yahoo Finance, 2024). However, this depends on which energy source is used during production. Swartz (2021) indicated that the environmental effect of cultivated meat production is mainly driven by the amount of electricity used at the facility, inputs in cell culture medium and how efficiently it is used. When fossil fuels are used in the production of cultivated meat, its climate impact becomes higher than that of poultry and pork, as shown in Table 1. Lynch and Pierrehumbert (2019) stated that, with sustained elevated global consumption, cultured meat initially results in lower global warming than beef; however, this disparity diminishes with time, and in certain instances, beef production leads to significantly reduced global warming. Therefore, cellular agriculture technologies in food production require investments in sustainable energy sources in the future (Tuomisto & Ryynänen, 2024).

These life cycle assessment (LCA) studies are based on methodological assumptions, limitations, and uncertainties. First, almost all studies adopt a *cradle-to-gate* system boundary, which limits the analysis of system-wide environmental impacts. Second, most analyses are based on laboratory-scale parameters and techno-economic modelling to estimate bioreactor performance, cell proliferation, and culture medium composition. However, these assumptions are highly uncertain and might not accurately reflect operations at a commercial scale. Third, the inventory data used in these studies is notably uncertain, due to their derivation from a variety of sources such as database averages, diverse literature, and speculative techno-economic estimates. Finally, background processes frequently utilize global average data for energy consumption and agricultural inputs, which can obscure regional variability that significantly influences environmental outcomes. As a result, the impacts of large-scale cultivated meat production systems remain uncertain. There is no such system yet, so environmental effects are estimated and rely on a number of assumptions (Tuomisto & Ryynänen, 2024).

In summary, cultivated meat has the potential to mitigate environmental impact of traditional meat production when renewable energy sources are utilized in its manufacturing process. However, large-scale cultivated meat production in studies is based mostly on assumptions. Therefore, it has significant uncertainty. Future studies should focus on enhancing production efficiency, advancing sustainable input materials and integrating thorough techno-economic and life-cycle assessments to achieve reliable, scalable, and environmentally sustainable results.

The Health and Safety Aspects of Cultivated Meat

Due to increasing meat demand, intensive animal farming is on the rise. Unfortunately, this approach may lead to some problems related to the environment, health and animal welfare (Nawaz et al., 2022). In intensive farming, animals are raised in harsh conditions. Therefore, antibiotics are used to promote growth and avoid diseases. This led to the development of antibiotic-resistant bacteria and threaten human health. For example, bacterial samples from intensive animal farms in China showed an increase in resistance to colistin, which is important for human health and is considered as the antibiotic of last resort (Anomaly et al., 2023). Also, in 2021, an estimated 456,000 annual deaths from bloodstream infections might have been preventable if antibiotic resistance had not been a factor (Dattani, 2024). Cultivated meat production does not require hormones and antibiotics, which makes it healthier than conventional meat. It takes place in a fully controlled environment. In addition to that, cultivated meat production does not require costly vaccinations against diseases like influenza (Chriki & Hocquette, 2020).

Cultivated meat is produced in a completely controlled laboratory environment by scientists. In traditional meat production, the environment where animals are raised and feed used are significant in terms of preventing the animal from getting sick. Additionally, maintaining a hygienic environment during the slaughtering process is essential to avoid contamination. Since cultivated meat is unlikely to encounter pathogens such as *E. Coli*, *Salmonella* and *Campylobacter*, contamination during slaughter is eliminated (Shapiro, 2018). This may help to prevent the spread of animal-borne diseases and zoonotic epidemics due to reduced animal-human contact. In contrast, cultivated meat may only be exposed to pathogens, if production is not carried out in the needed hygienic environment. Therefore, its production environment must undergo strict hygienic controls. Nonetheless, it is important to acknowledge that producers and scientists may not be able to control every aspect of the production process, and even minor errors could potentially result in serious public health consequences. One concern arises from the extensive proliferation of cells, which may lead to dysregulation of cell lines—an issue reminiscent of the uncontrolled growth observed in cancerous cells. However, it is considered feasible that such deregulated cell lines could be identified and eliminated prior to the final stages of production or consumption (Chriki & Hocquette, 2020).

Meat that contains significant macronutrients and micronutrients like protein, fats, iron, zinc and vitamin B12, can help reduce nutritional deficiencies. However, there are several studies about the linkage between meat consumption and various diseases (Parlasca & Qaim, 2022). According to a study, the consumption of red and processed meats is linked to increased overall mortality (Zheng et al., 2019). Likewise, Sinha et al. (2019) reported that intake of red and processed meats is associated with higher risks of total mortality, cancer-related deaths, and cardiovascular disease mortality. In 2021, approximately 61% of the burden of disease results from non-communicable diseases (Roser et al., 2021).

During the production of cultivated meat, its nutritional profile can be tailored to meet specific human dietary needs. For instance, saturated fats may be replaced with healthier alternatives, such as omega-3 fatty acids, to enhance the nutritional quality of the final product (Ismail et al., 2020). Additionally, certain minerals and vitamins, such as vitamin B12, may be incorporated. Consequently, farmed meat is regarded as nutritionally advantageous regarding health and nutritional value (Doğan, 2021). However, its public health results are not clear and needs more research, such as the uptake of micronutrients. The incorporation of chemicals into growth media might make cultivated meat more like to "chemical" food, so diminishing its clean label appeal (Chriki & Hocquette, 2020).

Animal Welfare

It is expected that global meat demand will increase in the future. Intensive farming system is increasing to meet demand. To meet this demand, the use of intensive farming systems is expanding. However, in many cases, the welfare and health of animals raised in these systems are neglected in order to remain economically competitive. Such conditions may induce stress and health issues in farmed animals. Although certain countries have implemented legislation to address these concerns, enforcement has often proven ineffective. This regulatory insufficiency has contributed to a growing global interest in alternatives to conventional meat products and has accelerated research in agricultural technologies (Kirsch et al., 2023). In contrast, extensive farming may reduce animal welfare issues as animals live in more natural environment. However, these systems face several challenges, such as exposure to thermal stress, limited access to food, water, and veterinary care, in extensive farming systems (Parlasca & Qaim, 2022). These can be prevented by consumption of cultivated meat. Cultivated meat production can reduce the possibility of animals remaining in unsanitary conditions in cramped spaces and can prevent painful slaughter. It is sufficient if a small number of animals are stem cell donors (Doğan, 2021). However, the replacement of cultivated meat with conventional meat can significantly reduce, but not eliminate, animal suffering (Anomaly et al., 2023).

Economic situation

The approval of cultivated meat in the USA has significantly paved the way for its production. According to 2023 State of the Industry: Cultivated Meat and Seafood report by Good Food Institute, the number of companies has been increasing continuously and reached 174 in 2023, as illustrated in Figure 3. Seafood data is frequently included in studies and industry reports related to cultivated meat for several reasons. Firstly, many companies operating in the cultivated protein sector are not limited to producing cultivated red meat or poultry but are also developing cultivated seafood products such as fish and shellfish. As a result, when institutions or authors report on the cultivated meat industry, they often include seafood companies that use similar cell culture techniques to create alternatives to conventional seafood. This practice expands the scope from "cultivated meat" to the broader category of "cultivated proteins". They are concentrating on various aspects of the cultivated meat value chain beyond just product formulation and manufacturing, such as bioprocess design, cell line development, and the creation of cell culture media (Good Food Institute, 2023). Regionally, it is observed that the largest number of companies, totaling 45, are in the USA.

Figure 4 shows cultivated meat investments regionally. In 2023, Europe had invested the most, approximately 120 million dollars. However, between 2014 and 2023 the most of investments are made in North America. This makes North America a leader in cultivated meat industry (Statista, 2023). While the USA accounts for the majority of the investments made in North America, Israel accounts for the majority of the investments made in the Middle East. Additionally, global investment in cultivated meat industry increased by 226 million dollars in 2023 (Good Food Institute, 2023). Global investment in cultivated meat and seafood from 2013 to 2023 is reached approximately 3,1 billion dollars, as illustrated in Figure 5, and 80% of it is coming from last three years. In 2023, 225,9 million dollars investment is done with a significant decrease from 922,3 million dollars in 2022 (Good Food Institute, 2023).

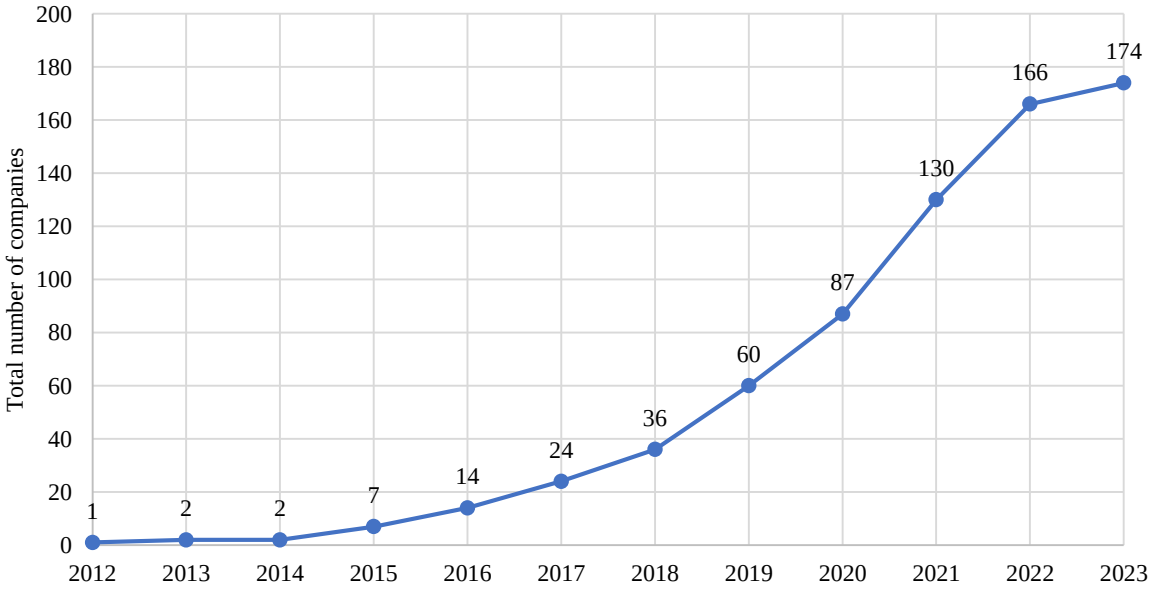

Figure 3. Number of cultivated meat and seafood companies (Good Food Institute, 2023).

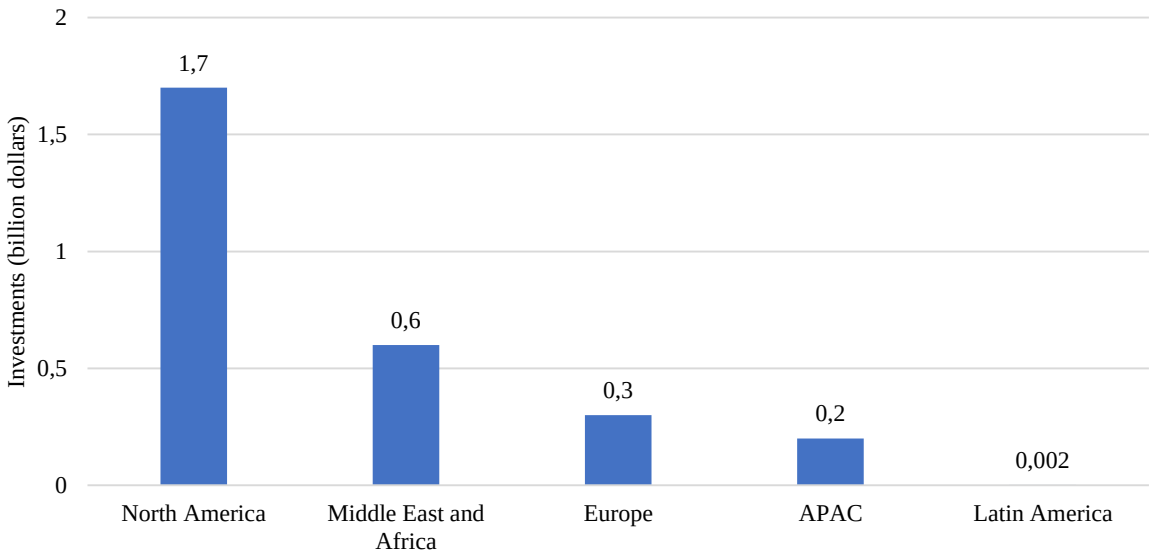

Figure 4. Investments in cultivated meat and seafood by region (2014-2023) (Good Food Institute, 2023)

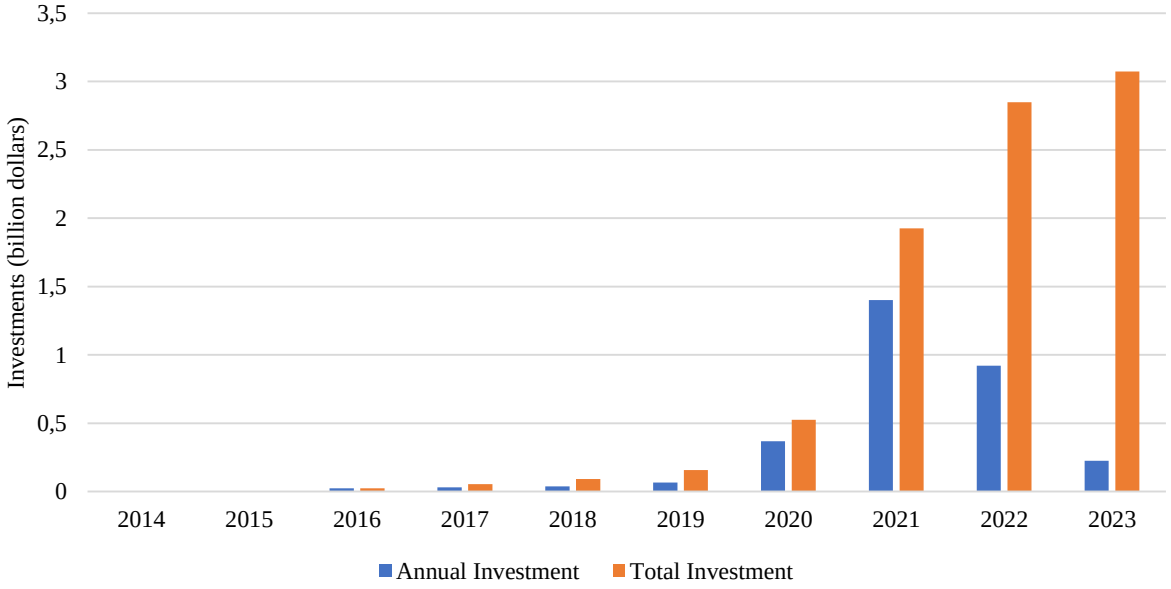

Figure 5. Total and annual investments in cultivated meat and seafood (2014-2023) (Good Food Institute, 2023)

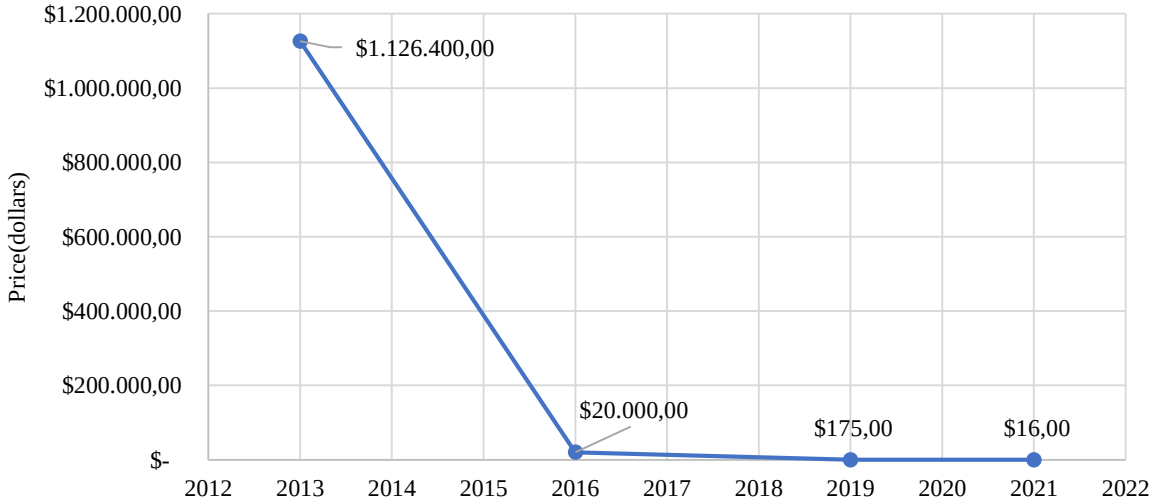

Figure 6. Production price per pound of cultured meat (Statista, 2023)

In 2013, the first cultivated meat prototype, developed by Mark Post, was produced at a cost of approximately €250,000. Since then, advancements in production technologies have contributed to a gradual reduction in manufacturing costs. As illustrated in Figure 6, the cost per pound of cultured meat has been declining significantly over time. Despite this progress, the price remains substantially higher than that of conventional meat. Nevertheless, as the cost gap narrows, consumer acceptance of cultivated meat is expected to improve accordingly.

With the development of cultivated meat, new job opportunities are expected to arise. According to Green Queen (2024), cultivated meat production may provide 25,000 to 90,000 new highly skilled employment. Therefore, there seems to be a great deal of concern that the introduction of novel meat substitutes may endanger the livelihoods of livestock producers and the animal husbandry sector, as evidenced by recent and planned laws to prohibit research on cultured meat (Reis et al., 2025). For instance, these anxieties have been the main reason why research has been blocked in Italy and other nations. The livestock sector is an indispensable part of the global food system. The fact that approximately 1.3 billion people work in the livestock sector and provide livelihoods for 1 billion of the world's poor population suggests that a restriction in the livestock sector would cause serious economic damage (Doğan, 2021). However, Reis et al. (2025) states that cultivated meat will be a complement to animal-based meat rather than a full alternative until 2040. This can mitigate concerns about employment in agriculture.

Conclusion

Cultured meat presents a transformative potential in addressing the environmental and ethical challenges associated with conventional animal agriculture. Cultivated meat offers sustainable food production when renewable energy sources are used. As this review has shown, numerous studies demonstrate that cultured meat can significantly reduce land use, water consumption, and greenhouse gas emissions, particularly when produced with renewable energy and sustainable inputs. However, LCA studies are based on numerous assumptions and are generally conducted at lab scale. Therefore, the effects of large-scale cultivated meat production are uncertain and require more holistic research.

Cultivated meat has the potential to reduce diseases that originate from conventional meat by changing its nutritional value. Additionally, it can decrease the incidence of zoonotic diseases, as it is produced in a laboratory environment under strict control by scientists. Indeed, it offers additional sustainability benefits by eliminating zoonotic disease risks and contributing to improved animal welfare. However, critical challenges remain, in particular high energy demand, uncertainties around large-scale production impacts and the environmental footprint of cultural environment components. However, more research needs to be done in mitigating consumer concerns about potential cellular dysregulation, food safety regulations, and the impact of chemicals added to the culture medium.

Overall, cultivated meat represents a rapidly emerging field with the potential to serve as an environmentally sustainable, health-conscious, and economically viable alternative to conventional meat production. However, its widespread adoption remains contingent upon addressing several critical challenges, including high energy demands, elevated production costs, and the need for regulatory approval. While it is not feasible to generalize the applicability of this innovation across all countries, national differences in development levels, environmental priorities, public income levels, and dietary reliance on meat-based protein will significantly influence the adoption trajectory. Advancements in bioprocess engineering, integration of renewable energy sources, and increased societal acceptance will play a pivotal role in shaping the future position of cultivated meat within the global food system. To unlock its full potential as a sustainable protein source, continued interdisciplinary research is essential—particularly in optimizing production efficiency, developing low-impact culture media, and reducing energy inputs. Should these technological and economic barriers be successfully addressed, cultivated meat may become a critical and sustainable component of future food systems, aligned with broader objectives of environmental conservation, public health, and ethical food production.

Declarations

Author Contribution Statement

Ömer Kurtoğlu: Writing manuscript, determination of methodology, design of formal analysis, data collection and investigation, review and editing.

Erdoğan Güneş: Supervision, project administration and management, design of methodology and formal, review and editing.

Conflict of Interest

"The authors declare no conflict of interest."

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