From Lab to Real Operation:

Measuring the Environmental Footprint (LCA) of Industrial-Scale Cultivated Meat Production

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1. Why the World Needs Sustainable Meat

Our global appetite for meat is growing. We face a simple yet alarming equation: the world's population is increasing, and so is its standard of living, which directly leads to higher protein consumption. As a result, global meat production has been rising steadily—from approximately 291 million tonnes in 2010 to 358 million tonnes in 2022 (Ritchie et al., 2017, rev. 2023). However, this trend is unsustainable in the long term.

The current food system, especially conventional livestock farming, places an enormous burden on the planet. According to studies, this sector is responsible for 25% to 35% of all global greenhouse gas emissions (Poore & Nemecek, 2018; Crippa et al., 2021). And perhaps even more surprisingly: nearly 80% of all global agricultural land is used for livestock in some way—whether as pasture or as fields to grow feed (Ritchie et al., 2017, rev. 2023).

Simply put, our planet does not have the resources to meet the growing demand for meat in this way.

The Environmental Cost of Conventional Meat

20–30%
of Global GHG Emissions from Food Systems

Nearly
80%
of Agricultural Land Use for Livestock

Global Meat Production Increased by
23%
in 12 Years

The Potential of Cultivated Meat

It is at this critical juncture that cultivated meat (CM) enters the scene. This technology, which allows animal cells to be grown in cultivators (similar to those used for beer or yogurt), offers a revolutionary alternative—real meat without the need to raise and slaughter billions of animals.

This is not a distant future. In 2024, there were already 155 companies worldwide actively engaged in the development and production of CM (State of the Industry Report, 2024). Products from cultivated cells are already commercially approved for sale in key markets like Singapore and the United States.

This potential is enormous, but it brings with it one fundamental and logical question: Is cultivated meat truly environmentally sustainable?

While proponents logically argue for massive savings in land and water, critics rightly point to the potentially high energy consumption required to operate the bioreactors. The only way to settle this debate is to abandon assumptions and start measuring precisely.

The Problem with "Laboratory" Data

Until now, measuring environmental impacts—known as Life Cycle Assessment (LCA)—has been very problematic. The reason is simple: the vast majority of published LCA studies (e.g., Sinke et al., 2023; Tuomisto et al., 2022) have had to rely on theoretical models, estimates from scientific literature, and data collected in small laboratories.

These studies lacked the most important ingredient: real data from industrial-scale production. Data from a lab scale cannot simply be extrapolated to an industrial operation. Processes that are feasible in small volumes have completely different energy and raw material balances in large-scale production. Such estimates are inherently inaccurate and unreliable.

And it is this critical "data gap" that our study is the first in the world to fill.

Process specialists from BeneMeat collaborated with LCA experts from the Czech Technical University in Prague - Faculty of Mechanical Engineering. This comprehensive LCA analysis is not based on estimates, but on primary data from a pilot process and detailed process models of a real industrial plant with a daily capacity of 400-600 kg of cultivated meat.

Our work thus provides the first robust and real-world benchmark for this entire emerging industry. We are not asking *if* cultivated meat can be sustainable. Instead, we are showing how sustainable it already is in actual operation today and where the keys lie to make it even more sustainable in the future.

2. How We Measure Real Impact: The LCA Methodology in Practice

To seriously and objectively assess the environmental profile of any product, it is essential to use a standardized and scientifically based framework. This framework is the Life Cycle Assessment (LCA), a globally recognized methodology defined by international standards ISO 14040 and ISO 14044.

LCA allows for the systematic quantification of all environmental impacts associated with a product throughout its entire life cycle.

Phases of an LCA Study

The standardized LCA process consists of four main phases, which we carefully followed in our study:

1. **Goal and Scope Definition:** Defining the subject of the study, its boundaries (what is and is not included), and the "functional unit," which serves as the basis for comparison.
2. **Life Cycle Inventory (LCI) Analysis:** Detailed collection of data on all inputs (energy, raw materials, water) and outputs (product, emissions, waste) within the defined boundaries.
3. **Life Cycle Impact Assessment (LCIA):** Converting the collected inventory data into specific environmental impacts (e.g., how many emissions equal what impact on climate change).
4. **Interpretation:** Analyzing the findings, identifying key "hotspots" with the greatest impact, and formulating conclusions and recommendations.

How We Proceeded in Our Study

Phase 1: Goal and Scope

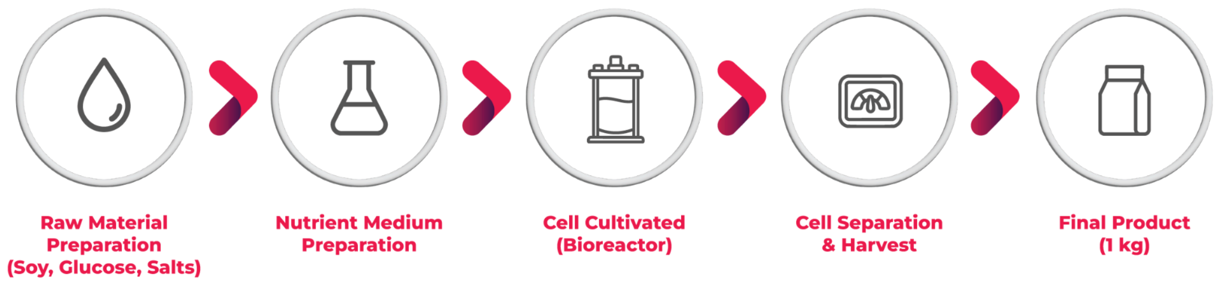
Our goal was to create the first robust benchmark of the impacts of industrial-scale cultivated meat production.

We set the system boundaries as "cradle-to-gate." This means our analysis covers everything from the cultivation and production of raw materials (e.g., soy, glucose) and their transport, through all processes within our production plant (consumption of energy, heat, water), to the final product leaving the factory gate.

As a comparative functional unit, we chose **1 kg of finished cultivated meat.**

Phase 2: Inventory (Data Collection)

This is where the key uniqueness of our study lies. Instead of theoretical estimates, we built a Life Cycle Inventory (LCI) model based on primary data, mass and energy balances from detailed technological preparation, and the pilot operation of the BeneMeat industrial plant with a capacity of **400-600 kg/day.**



Phases 3 and 4: Impact Assessment and Interpretation

To convert the collected data (LCI) into understandable impacts (LCIA) and for overall modeling, standardized software tools and databases were used. The calculations themselves were performed in the internationally recognized **SimaPro** software, which serves as the main platform for life cycle modeling and impact assessment.

To complete the model, our primary production data was supplemented with "background" processes (e.g., electricity production in the national mix, chemical production, cultivation of raw materials abroad). For this data, we drew from globally recognized LCI databases: **Ecoinvent** (for industrial and energy processes) and **Agri-footprint** (for detailed agricultural products). These databases provide the necessary inventory data that SimaPro uses for the final calculations.

For the impact assessment (LCIA), we tracked a wide spectrum of categories. For this report, we selected five key metrics that are most relevant for assessing food production and specifically cultivated meat:

1. **Climate Footprint (GWP):** Measures the impact on global warming (in kg CO_2 eq.). This is a key metric because conventional farming is a significant source of emissions (including methane), whereas for CM, the main sources of greenhouse gas emissions are energy consumption and raw material production within the supply chain.
2. **Impact on Ecosystems (Land Use):** This metric evaluates not just the occupied area (m^2) but primarily the qualitative impact of its use on biodiversity (in units of PDF.m^2.year - potential species loss). This is critical: conventional farming occupies nearly 80% of agricultural land. While CM production itself requires almost no land, its raw materials (like soy) do. This metric sensitively shows the difference between the impacts of sustainably grown soy and soy that contributes to deforestation.

3. **Water Consumption Footprint (Water Use):** Measures the volume (in m^3) of "consumed" water. This refers to water that is actually withdrawn from a watershed and not returned to it (e.g., it evaporates, becomes part of the product, or is polluted), as opposed to simple "flow-through" (e.g., for cooling). It thus tracks the direct impact on local water resources.
4. **Cumulative Energy Demand (CED):** Tracks the total amount of primary energy (in MJ) from all sources (fossil and renewable) throughout the entire life cycle. This metric is essential for CM. Industrial production in bioreactors is an energy-intensive process, and CED shows the true energy dependence of this technology compared to conventional production.
5. **Overall Score (PEF Single Score):** An aggregated impact across all categories. To ensure maximum relevance and comparability, we used the **Product Environmental Footprint (PEF)** methodology for the final evaluation. This is a unified framework recommended by the European Commission (2021/2279) to harmonize the environmental assessment of products on the EU market.

The comprehensive PEF methodology works with impacts in 16 different categories and, through a precisely defined procedure of characterization, normalization, and weighting, can aggregate them into a single overall score (Single Score). This score is invaluable for quickly and clearly comparing the overall profile of different products (e.g., our CM vs. chicken meat).

However, it is important to realize that any such aggregation carries methodological uncertainties, especially in the "weighting" process—that is, determining what weight (importance) is assigned to individual impacts (e.g., is climate change "more important" than toxicity?). Therefore, in our analysis, we track both the overall score and the detailed results in individual key categories to ensure complete transparency.

3. Key Results: How Do We Compare to Conventional Meat?

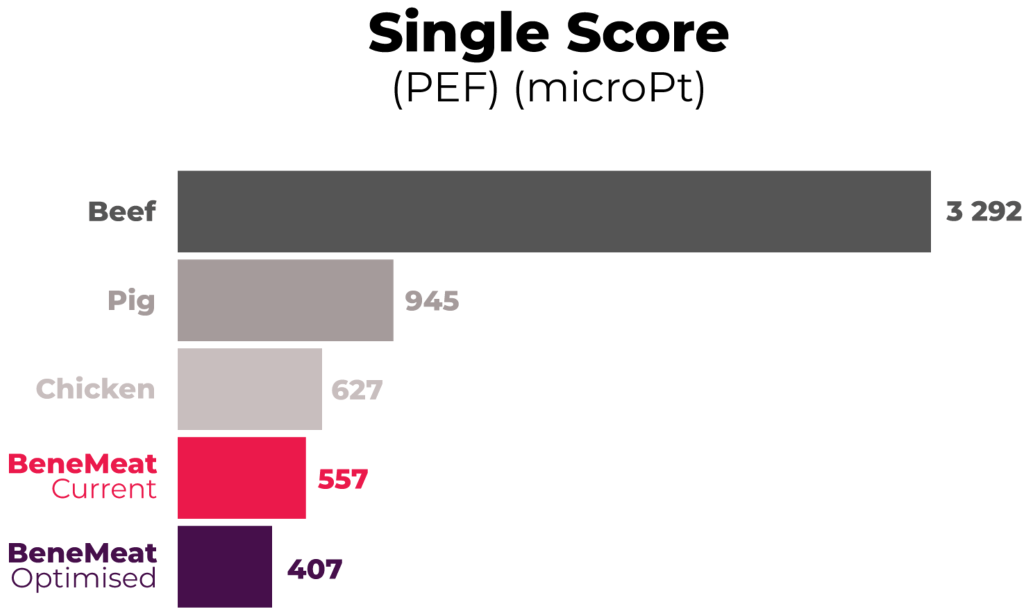
After defining the problem and our robust methodology, the key question arises: What are the actual impacts of industrial-scale cultivated meat (CM) production, and how do we stack up against conventional products? For this comparison, we benchmarked our calculated values against results from the renowned agricultural product database, **Agri-footprint.**

The **Overall Score (PEF Single Score)** is ideal for this comparison. This single number allows us to clearly compare the total environmental footprint of different products.

Overall Comparison: CM as an Ethical and Sustainable Alternative

Our analysis shows that cultivated meat produced at an industrial scale using BeneMeats' technology already has a **comparable, or even lower, total environmental impact** than its closest competitor—conventional chicken meat.

Compared to pork and beef, its environmental footprint is dramatically lower.



The Path to Improvement: We Know Where the Keys to Success Lie

The magic of a comprehensive LCA study is not just in "measuring something." It's in knowing exactly what drives our environmental impact. Our analysis identified two main "hotspots" (key factors):

1. **Raw Materials:** Especially the source of the key nutrient, soy protein isolate (SPI).
2. **Energy:** The consumption of electricity and heat to operate the bioreactors and the entire plant.

Precisely because we know these factors, we analyzed various scenarios to find the optimal path forward. Here are the two most important examples:

1. Raw Material Optimization (The Impact of Soy)

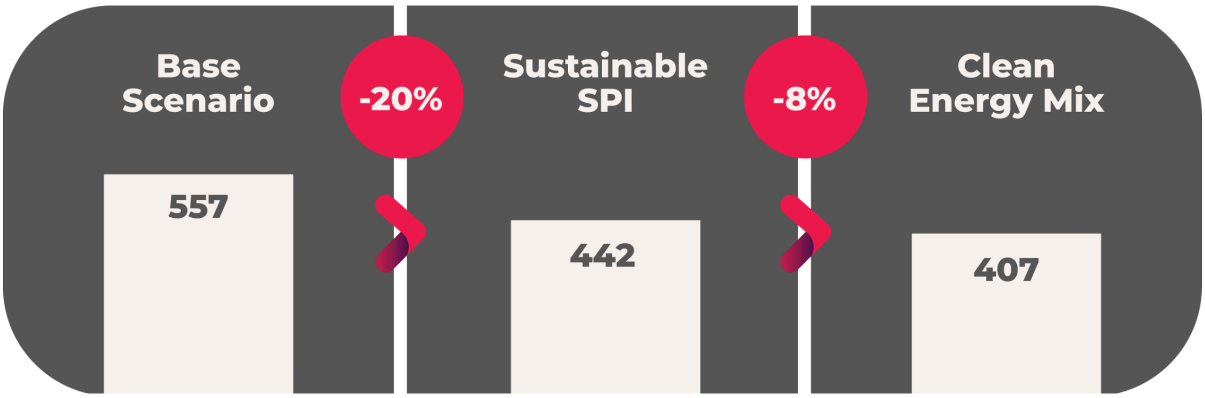
We found that not all soy is created equal. If we consider the current scenario where SPI comes from the Chinese market (which is heavily reliant on Brazilian soy with a high deforestation impact - Land Use Change), our total impact is significantly higher.

By **simply changing the supplier** to one that uses sustainably grown soy from the USA (with almost zero deforestation impact), we can reduce the product's total environmental footprint by approximately **20%.**

2. Energy Optimization (Energy Mix)

The Czech Republic's expected transition to a greener energy mix by 2030, combined with the potential installation of our own photovoltaic panels on the plant's roof, will bring a further significant reduction in impacts, especially for the climate footprint (GWP).

This optimization of raw materials and energy clearly shows that our current excellent results are just the beginning. Further potential for impact reduction lies in optimizing the production process itself, which will enable higher conversion efficiency of inputs and better use of energy.



How Do We Stack Up in Other Categories?

The results are encouraging across all key metrics:

- **Climate Footprint (GWP):** Our optimized process achieves a value of **3.3 kg CO_2 eq.** per 1 kg of meat. This is fully comparable to the best European chicken production (3.7 kg CO_2 eq.) and significantly better than average pork (5.9 kg CO_2 eq.).
- **Impact on Ecosystems (Land Use):** Here, the advantage of CM is absolutely fundamental. Because we "grow" meat vertically in a bioreactor and not horizontally on fields, our impact on land occupation and biodiversity loss is **over 50% lower than chicken** and **over 95% lower than beef.**

- **Water Consumption (Water Use):** Our water consumption is comparable to US chicken production. However, compared to European farms, our results are worse. This is due to a strategic choice by BeneMeat: instead of energy-intensive water recycling from the residual medium, the plan is to use this "spent medium" as a valuable by-product, which allows the environmental impacts to be better distributed.
- **Energy Consumption (CED):** As expected, the energy-intensive production of cultivated meat performs worse than chicken and pork. However, previous theoretical studies (e.g., Sinke et al., 2023) estimated energy consumption at **163-277 MJ** per 1 kg of meat. Our analysis shows that the optimized BMT industrial process requires only **61.5 MJ/kg**. This value is already lower than the CED for beef.

4. Conclusion and Discussion: A New Standard for Sustainable Protein

The debate on the environmental impacts of cultivated meat has, until now, been purely theoretical. This study is the first to move it into the realm of real data. By replacing laboratory estimates and hypothetical models with a detailed inventory and process data from a real, commercially-approved industrial operation, we are providing the first true benchmark for this entire industry.

Our findings are direct and of fundamental importance:

1. **We Are Competitive Today.** Our analysis confirms that the total environmental impact (measured by the PEF methodology) is already, in its current phase, comparable to or even lower than conventional chicken meat. Compared to pork and beef, our technology's footprint is dramatically lower.
2. **Real Engineering Beats Theory.** Perhaps the most significant finding is the difference between theoretical concerns and reality. While previous studies (e.g., Sinke et al., 2023) estimated energy consumption (CED) in the range of 163-277 MJ/kg, our real-world data shows a consumption of **only 61.5 MJ/kg** for the optimized process. **That is 2.5x to 4.5x less.** It turns out that efficient technological design and process optimization carry much more weight than hypothetical models.
3. **Our Technology Has Key Advantages.** Behind these excellent results are specific technological decisions. A key factor is the relative simplicity of our production process and its high efficiency (e.g., continuous cultivation instead of batches, heat recovery). A crucial advantage is also the **absence of antibiotics.** As other studies have confirmed (e.g., Riesner et al., 2023), the use of antibiotics in cultivation media can dramatically increase environmental impacts. Our technology avoids this entirely.

The Path Forward is Not an Estimate, But a Clear Plan

This study is not a final verdict, but a starting point. By precisely identifying our key "hotspots" (raw materials and energy), we are not under any illusions; rather, we have a clear and measurable optimization plan.

Our current results are the baseline. The path we have outlined—transitioning to sustainable soy sources and a greener energy mix—is a clear strategy to go from "good" to "even better."

For investors, B2B partners, and the media, the message is clear: The BeneMeats' process is not just a scientific concept. It is a commercially-prepared, industrially-verified, and—as now proven by real data—environmentally sustainable process, ready to become the new standard for 21st-century protein.

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