Transformation and Alternatives on the Dining Table

Nature Positive and the Food Value Chain

pwc

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Executive summary

Transformation and Alternatives on the Dining Table

1 From soil to factories

Vertical farming

Technological developments related to vertical farming enable agricultural production in closed environments with artificial light for some commodities, such as leafy vegetables, lettuce, herbs, strawberries and flowers, that can be grown under relatively low light levels. Therefore, the expectations are that some of that production will shift from soil cultivation to vertical farming with reduced energy consumption through proper management.

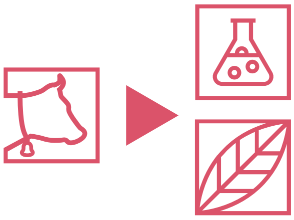
This allows for efficient use of pesticide and fertiliser components and prevents their runoff into soil and water bodies, contributing to a reduction in environmental impact.

2 From livestock to alternative proteins

Alternative foods

With the development of technologies for alternative foods, livestock products which have high GHG emissions from production may be replaced by alternative foods, such as cultured meat and plant-based meat, if they are comparable to livestock products in both taste and price.

This could reduce GHG emissions from livestock production. However, this transformation can occur with political will and consumer acceptance, not only by technological evolution.



3 From retail shops to e-commerce

E-commerce and the smart food chain

Advancements in e-commerce and smart food chain-related technologies are predicted to streamline commercial distribution and logistics, and increase the rate of food products being converted to e-commerce.

By connecting information from production to consumption, supply and demand can be adjusted in a timely manner, and inventory management and delivery can be optimised. This would lead to a reduction in food loss and its environmental impact.

Addressing climate change and biodiversity challenges in the agriculture and food sectors is becoming necessary, as these sectors are major sources of global greenhouse gas (GHG) emissions, and improper management in these sectors negatively impacts biodiversity. In response to this situation, this report analyses trends in food value chain-related technologies that contribute to Nature Positive, using PwC's proprietary Intelligent Business Analytics (IBA) tool, and provides recommendations on future prospects. This report focuses on 'vertical farming' and 'e-commerce' as trending technologies, the 'smart food chain' as a technology to propel developments going forward and 'alternative foods' as a promising seed technology, as identified by IBA. It then compares their respective technology trends and technological competitiveness by country and region.

Regarding contributions to Nature Positive, transitioning to 'vertical farming' allows for the efficient use of fertiliser components, such as nitrogen and phosphorus, while preventing their runoff into soil and water bodies, thereby reducing environmental impact. In addition, 'alternative food' technologies may help mitigate environmental impacts by replacing livestock products, which are a major source of GHG emissions, and fish and shellfish, which have a significant impact on marine ecosystems due to overfishing, fishing gear and other factors. Furthermore, post-production stages in the food value chain and the increased use of advanced technologies will make commercial distribution and logistics more efficient, and reduce food loss, thereby helping to reduce the environmental impact related to food waste. It is expected that further technological development and expanded application will reduce and reverse the impact on nature from the food value chain overall.

Background and purpose

Background

According to the Food and Agriculture Organization (FAO), 31% of global greenhouse gas (GHG) emissions generated from the food system, of which 13% is generated from farms, 7% from land modification (deforestation and peatland degradation) associated with agriculture, forestry and fisheries industries, and 10% from transport and food waste[*1]. There are also aspects of agriculture and food production that have a negative impact on biodiversity, such as chemical runoff into the environment due to inappropriate fertiliser and pesticide management. Therefore, addressing climate change and biodiversity challenges in the agriculture and food sectors is becoming necessary.

The Paris Agreement was adopted at the 2015 Conference of the Parties (COP21) to the United Nations Framework Convention on Climate Change (UNFCCC). It stipulates that the global average temperature increase should be kept well below 2˚C above pre-industrial levels, with efforts to limit the increase to 1.5˚C, and aims to strengthen the global response to the threat of climate change[*2]. Amid such circumstances, the US announced the 'Agriculture Innovation Agenda' in February 2020, setting a goal to simultaneously increase agricultural production by 40% and reduce the ecological footprint by 50% by 2050[*3]. In addition, the EU adopted the Farm to Fork Strategy in May 2020, aiming to reduce the use and risk of chemical pesticides by 50% and expand the share of organic farming to 25% by 2030[*4]. In May 2021, Japan formulated the 'MIDORI Strategy' for sustainable food systems and set forth a vision to achieve zero CO_2 emissions in agriculture, forestry and fisheries, a 50% reduction in chemical pesticide use (risk equivalent) and a 30% reduction in chemical fertiliser use by 2050[*5].

In recent years, in addition to climate change, the concept of 'Nature Positive'—which refers to stopping and reversing biodiversity loss to put nature on a path to recovery—has gained attention, with governments and various companies making efforts to support biodiversity. This concept has been incorporated into the international goals of the 'Kunming-Montreal Global Biodiversity Framework', adopted at the 2022 UN Biodiversity Conference (COP15), highlighting the growing importance of addressing biodiversity and the natural environment. One of its targets includes the sustainable management by the agriculture, forestry and fisheries industries[*6]. In particular, products such as bananas, cocoa, coffee, rice, palm oil, livestock animals, fish and shellfish are identified as High-Impact Commodities that have a significant impact on nature through production and procurement processes[*7]. As such, companies are encouraged to prioritise these commodities when beginning their raw-material procurement assessments.

On the other hand, the establishment of a food system that contributes to Nature Positive, including climate change and biodiversity, is a major business opportunity. This is because it is estimated that the size of the food, agriculture, forestry and fisheries market in 2050—when the 'MIDORI Strategy' is realised—will be up to ￥272tn (about double compared to 2019)[*8], taking into account the improved economy in the Asian region and the creation of new markets.

Purpose

In response to this situation, this report analyses trends in food value chain-related technologies that contribute to a Nature-Positive future, using PwC's proprietary Intelligent Business Analytics (IBA) tool, to provide recommendations on future prospects for this field.

Furthermore, this report will also discuss how these technologies can solve environmental issues in the food value chain and contribute to Nature-Positive practices going forward, particularly in the production and procurement of raw materials that have a significant impact on nature, as mentioned above.

Definition of terms and analytical methods

About Nature Positive

'Nature Positive' is a new concept that aims to 'restore natural capital, including biodiversity' beyond the traditional concept of 'maintaining biodiversity' by reducing negative impacts on the natural environment caused by economic activities, and has been gaining importance in corporate management in recent years.

Many economic activities depend on natural capital, and this is especially true for agriculture, forestry, fisheries and the food industry, where indirect dependence is also increasing. Because these sectors depend on the direct extraction of resources from forests and oceans and the provision of ecosystem services, such as healthy soil, clean water, pollination and a stable climate, they would suffer significant losses if nature lost its ability to provide such services[*9]. Additionally, the Living Planet Index (LPI), a key indicator of biodiversity, has worsened by 69% over the past 50 years[*10], indicating that efforts to restore biodiversity are urgently needed.

Furthermore, the establishment of the Taskforce on Nature-related Financial Disclosures (TNFD) in June 2021, aimed at supporting companies in disclosing their dependence and impact on nature, is another sign that the international trend is moving towards Nature Positive. In the field of climate change, since the establishment of the TCFD (Task Force on Climate-related Financial Disclosures), the disclosure of climate-related risks by financial institutions and companies has rapidly expanded. The TNFD also has the goal of 'redirecting the flow of funds that have a negative impact on nature and moving biodiversity towards recovery', and companies with global operations are already taking various steps to achieve this goal.

About the food value chain

The 'food value chain' refers to creating a chain of added value on food by connecting the value of each stage from the production of agricultural, forestry and fishery products to manufacturing, processing, distribution and consumption. Various initiatives shape the food value chain, ranging from pre-production materials and equipment supply varieties to branding at the point of sale (Figure 1).

Figure 1: Image of the food value chain

Source: Prepared by PwC Consulting LLC based on materials from the Ministry of Agriculture, Forestry and Fisheries

This report defines the food value chain that contributes to Nature Positive as a 'Nature-Positive food value chain'. In particular, it focuses on the reduction of land use for food production involving high-impact commodities (*see footnote), greenhouse gas reduction in food systems through regenerative and smart agriculture, greenhouse gas reduction in livestock through alternative proteins and the reduction of food waste.

* Raw materials that have a significant impact on nature:
Avocado, banana, cassava, cocoa, coffee, corn, sugarcane, rice, soybeans, nuts, tobacco, palm oil, rapeseed oil, cotton, natural rubber, wood, cattle, goats, pork, poultry, farmed seafoods, natural seafoods, dairy products, hides, phosphorus fertiliser, nitrogen fertiliser, pulp, paper

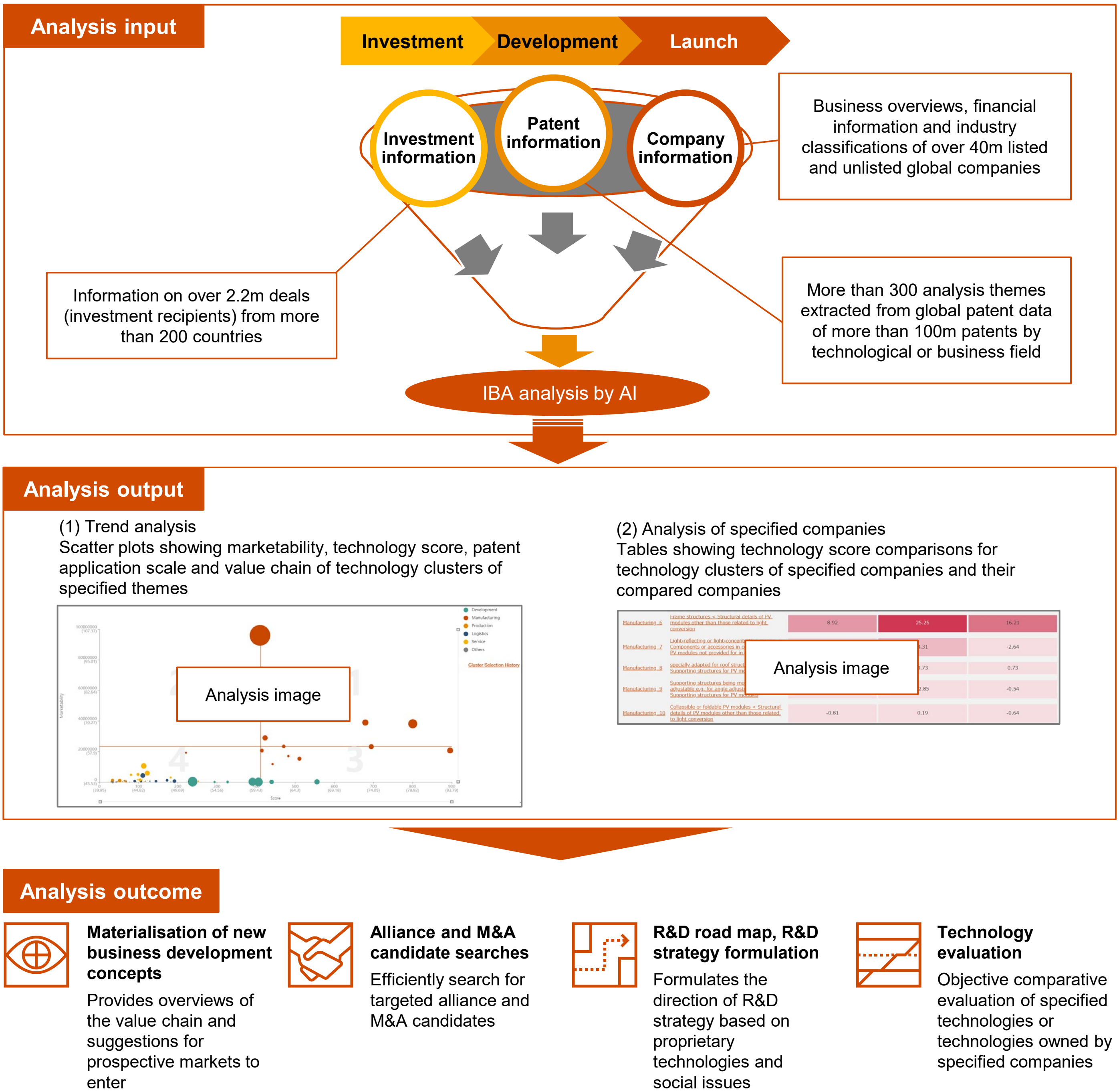
PwC’s proprietary ‘Intelligent Business Analytics (IBA)’ tool

Intelligent Business Analytics (IBA) is a new strategic analysis tool that uses AI to analyse global patent data and corporate financial and investment information in specific technology domains. It is capable of qualitative analysis of patented technologies and quantitative analysis of corporate investments, as well as a bird’s-eye view of technology trends and corporate technology portfolios from a market perspective, together with additional various functions. By grasping macro trends and various companies’ technology strategies, IBA Consulting Services offer fresh insights for corporate strategic planning in areas such as new business development, research and development, startup investments and M&A. A web app that enables clients to analyse strategies on their own is also available.

IBA utilises data pertaining to patents, finances and investments. By combining business and technological data, it is suitable for various use cases, such as new business development, R&D strategy planning, alliance partner or M&A candidate searches, and technology due diligence. Another differentiating element is the ability to visualise an individual company’s technology portfolio and drill down into their financial and patent data. This enables both idea generation and hypothesis testing based on trend identification and makes it possible to carry out more specific and robust new business development and R&D strategy planning (Figure 2).

In this report, patent information related to GHG reduction, sustainable agriculture and food loss reduction, as well as company and investment information by IBA, is analysed under the theme of ‘Nature-Positive food value chains’.

Figure 2: Overview of IBA



Source: Prepared by PwC Consulting LLC

Global trends in technological developments

Overview of the Nature-Positive food value chain

Figure 3 shows how the technology clusters generated by IBA on the theme of the Nature-Positive food value chain contribute to Nature Positive, categorised by outcome and plotted at each stage of the value chain. Given that these technology clusters are based on patent information, in this analysis, they are not referred to as 'regenerative agriculture' or 'smart agriculture'. Instead, technology clusters that can be applied to such agricultural practices are categorised as contributing to 'GHG reduction in food systems or sustainable land use'.

GHG emissions from livestock and their supply chains are estimated to account for 11.1% to 19.6% of total emissions[*11][*12]. In particular, ruminant animals, such as cattle and sheep, produce methane gas during the digestion process, which is contained in their burps and manure. This methane gas has a higher global warming effect than the same amount of carbon dioxide, resulting in a greater impact on global warming. To address this situation, in addition to developing materials like livestock feed that suppress methane gas emissions, technologies and products such as cellular agriculture (i.e. cultured meat) and plant-based alternative proteins can contribute to reducing GHG emissions from livestock production through technologies and products that substitute livestock products (Figure 3, top left).

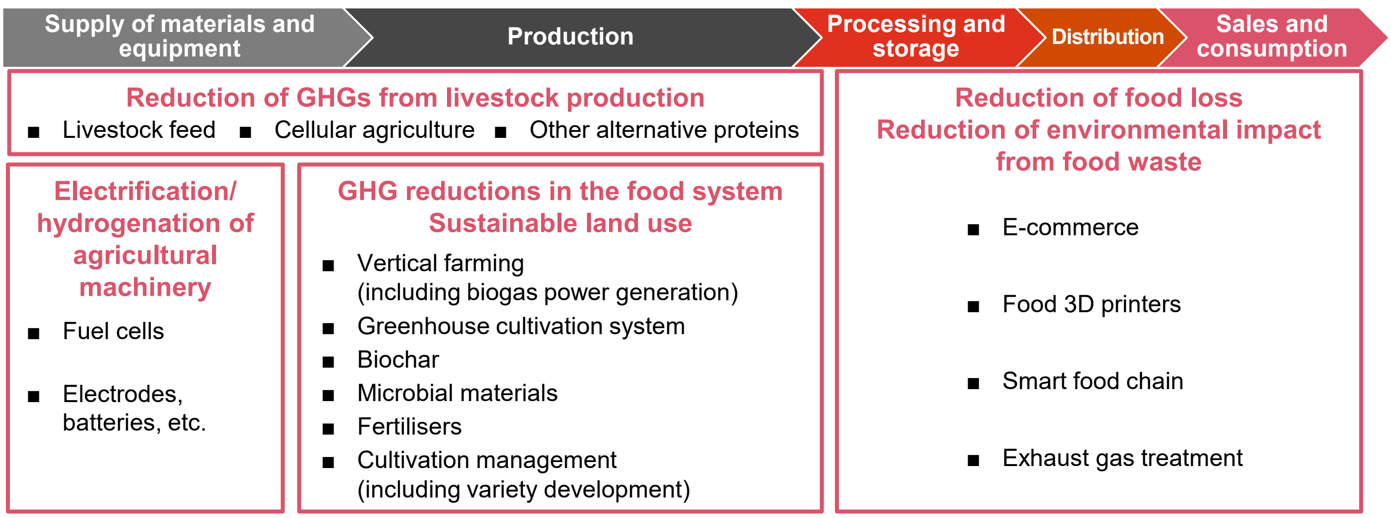
At the stage of supplying materials and equipment, technological advances in fuel cells and energy storage technology will promote the electrification of agricultural machinery and the use of hydrogen, which can also be suggested as contributing to Nature Positive (Figure 3, bottom left).

In addition, the development and utilisation of various materials with GHG reduction effects are progressing in the food production field. For example, if rice husks and livestock manure are applied directly to the soil, the carbon within them is released into the atmosphere as carbon dioxide. However, if they are carbonised and applied as 'biochar', the carbon is stored in the soil and less of it is released into the atmosphere. In addition to GHG reductions through these technologies, GHG emissions can also be reduced through vertical farming and greenhouse growing systems with appropriate technology and management (as discussed later). Moreover, these technologies enable more efficient land use (preventing the development of new agricultural land and producing more crops on smaller areas), and can be suggested as contributing to sustainable land use as well (Figure 3, bottom centre).

Furthermore, in the downstream stages of the food value chain, advancements and improvements in processing, storage, distribution and sales can contribute to reducing food loss and the environmental impact associated with food waste. These include 'food 3D printers' that enable the reuse of food materials that would be wasted (e.g. scraps) and losses generated during food processing, and 'smart food chains' that use advanced technologies to optimise supply-demand adjustment, storage and distribution, thereby reducing food losses (Figure 3, right).

In this report, the IBA analysis extracts patent information related to the food value chain, focusing on technologies that may contribute to Nature Positive, such as those related to land use or GHG reduction. Therefore, there are some technology clusters that are not generated despite having high marketability.

Figure 3: Overview of technologies related to the Nature-Positive food value chain



Source: Prepared by PwC Consulting LLC based on IBA analysis results

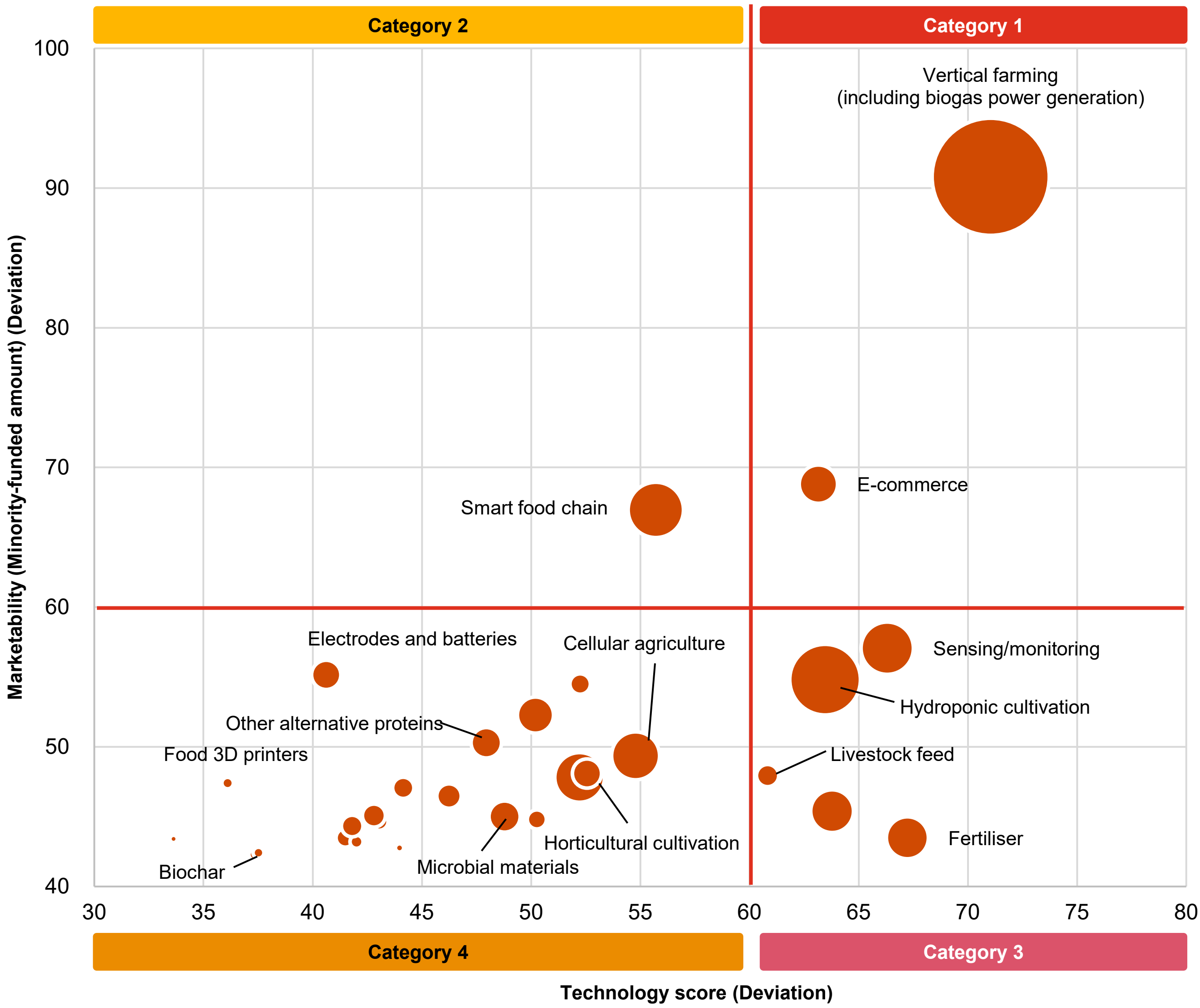
Current technology trends

Figure 4 shows an analysis of current technology trends by IBA, with the vertical axis representing the marketability of the technology cluster (minority investment), the horizontal axis representing the technology score (degree of technology maturity) and the circle size representing the scale of patent applications. This chart can be divided into four categories according to technology score and marketability: Category 1 is a technology trend; Category 2, where technological development is likely to progress in the future; Category 3, where technology is maturing; and Category 4, where new technologies are being explored.

From this chart, it can be observed that 'vertical farming' and 'e-commerce' have high technology scores and marketability, positioning them as Category 1, driving the formation of new markets. The 'smart food chain' technology cluster is positioned in Category 2. While there is still room for technological development, it has already attracted significant investment, indicating further advancements going forward. Category 3 includes technologies such as fertilisers, which have seen long-term development and are considered technologically mature. However, certain individual technologies within this area may still have high growth potential in terms of marketability and technology score. Category 4 contains technology clusters that may be the next generation of trends, although the technology score and marketability are not yet fully developed.

In this report, the main technology clusters in Categories 1, 2 and 4, along with their outlooks, are discussed in detail in the next chapter.

Figure 4: Marketability, technology score and number of patent applications for each technology



Category 2: High potential in the future
Technologies such as those pursued by startups, where technological development is immature but has attracted significant investment

Category 1: Highly valued in the market and becoming a technology trend
Technologies that are central to the formation of new markets, with technological development and investments

Category 4: Relatively new technology
Limited current technological development and investment but has the potential to become a trend in the future

Category 3: Technologically mature
Technological development has been ongoing for a long time, and the technologies are considered to be mature

Source: Prepared by PwC Consulting LLC based on IBA analysis results

Comparison of countries and regions in key technology fields

The top row of boxes in Figure 5 compare the technology scores by outcome for each country and region, and the bottom row shows the technology scores for each representative technology cluster. Each value is an average of the technology scores of the companies in each country and region, with higher values indicating higher technological competitiveness in that field. Additionally, a negative technology score does not necessarily indicate low technological competitiveness, but rather that technology developments are progressing in a different direction from trends.

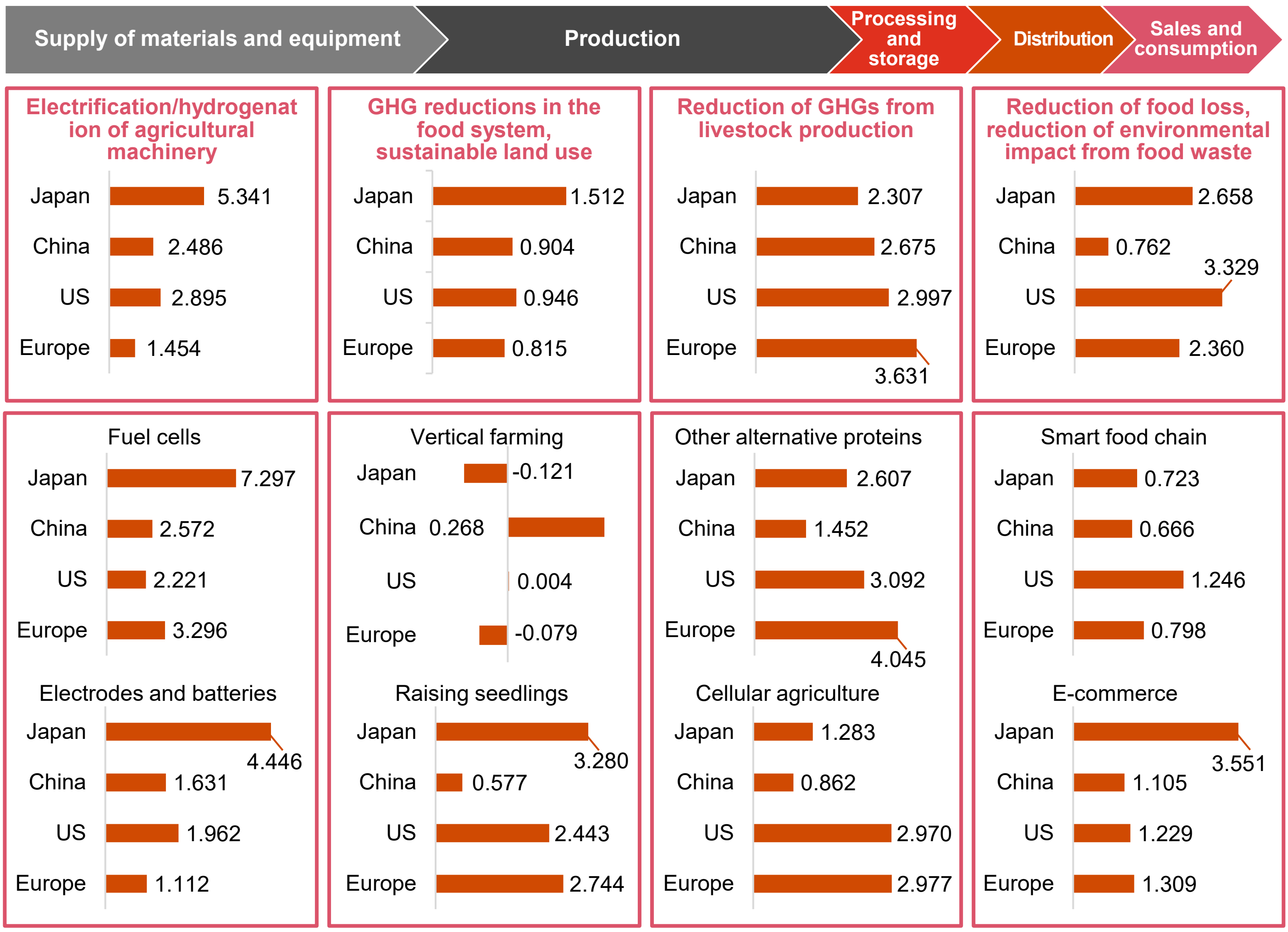
Japan's technology score is high in areas such as 'fuel cells' and 'electrodes and batteries' related to the electrification and hydrogenation of agricultural machinery, with major Japanese automakers and electronics companies leading this score.

Japan shows high scores in technologies related to GHG reduction in food systems and sustainable land use, but in the trending 'vertical farming' technology cluster, China demonstrates a strong presence. The percentage of patents filed by Chinese companies and research institutions is also high, with China exerting a significant influence over this entire technology cluster. As a result, the trend in China is regarded as the overall trend, leading to negative scores for Japan and Europe. For example, in China, some of the technologies related to vertical farming (especially wastewater treatment) are being used for pig farming in high-rise buildings, which can be viewed as indicating a different direction from other countries. Additionally, China is making progress with multi-level and large-scale vertical farming, while Japan and Europe have relatively more patents related to advanced environmental control technologies, such as lighting and wastewater management, in addition to developing unit-based and modular farms, which focus on producing only the agricultural products needed at the consumption site, highlighting the differences in technological direction.

Europe and the US scored high for technologies related to GHG reduction from livestock production. 'Cellular agriculture' is a technology that uses cell cultures to produce agricultural products, particularly livestock products. Since it is a field where technologies related to regenerative medicine can be applied, medical equipment manufacturers and biotech companies possess high technological competitiveness in this area. 'Other alternative proteins' refers to technologies and products, such as plant-based alternative foods like plant-based meat, with European food manufacturers leading the way in the development of these technologies.

The US has the highest technology score for reducing the environmental impact of food loss and food waste, which is attributed to the presence of high-quality (average technology score) US companies.

Figure 5: Technology scores by country and region



Source: Prepared by PwC Consulting LLC based on IBA analysis results

Development trends and outlooks of key technologies (1/3)

Technology trend: 'Vertical farming' and 'e-commerce'

About

In vertical farming facilities, agricultural products are grown in a controlled environment. By precisely managing factors such as light, temperature, humidity, CO_2 concentration, nutrients and moisture, crops can be produced without being affected by seasonal differences or weather conditions. Vertical farming is categorised into three types: 'solar type', which uses transparent materials like glass for the canopy or building materials to harness sunlight; 'artificial light type', which uses artificial light sources in a closed environment; and 'hybrid type', which utilises sunlight with supplemental artificial lighting, with this technology cluster falling under the 'artificial light type'. The artificial light type consumes energy and uses artificial light, making it suitable for growing leafy vegetables, lettuce, herbs, strawberries and some flowers that can be grown under relatively low light levels.

Compared to conventional open-field cultivation or cultivation in conventional greenhouses, it is possible to produce the same or a greater amount of food in a smaller area, thus making efficient use of land. In addition, advanced environmental controls in a closed environment allow the use of fertilisers, such as nitrogen and phosphorus, and pesticides to be managed and used efficiently. Drainage management can also prevent those components from leaching into soil and water sources. In addition, the transition from conventional cultivation methods to vertical farming production has the potential to contribute to Nature Positive, as mulch and coated fertilisers are not used and do not contribute to contamination of soil and watersheds from plastics. Additionally, since agricultural production is not affected by soil or climate conditions, it can be conducted near consumption areas, offering the benefit of reducing GHG emissions associated with transport.

Trends in each country and region

Figure 6 summarises policies and market trends in each country and region in relation to vertical farming. In this technology cluster, China, which had the highest score, promotes the development of agricultural technologies, including vertical farming, as a national policy due to increasing urban populations and the reduction of arable land. This allows for agricultural production without being constrained by regional limitations. Additionally, both the US and Japan have included vertical farming as eligible for subsidies and grants within their policy frameworks. On the other hand, in Europe, vertical farming is not covered under the EU's common agricultural or climate policies. As a result, since 2022, rising energy prices and other factors have forced several vertical farming companies to halt operations, declare bankruptcy or change their strategies.

Figure 6: Policies and market trends related to vertical farming in each country and region

China

Policies

- National agricultural science and technology parks have been built in various locations. Technological development in the agricultural sector has been supported through investments from subsidies and research funds.
- The 2024 'Central Document No. 1' also advocates for the use of intensive and industrialised agriculture, expressing a commitment to strengthening agricultural support through scientific technology

Market trends

- 2023: Constructed the world's first 20-level automated vertical farming

US

Policies

- 'Vertical farming' was included as a form of agriculture eligible for policy support in the 2018 Agricultural Improvement Act
- A budget of US$10m was allocated from 2019 to 2023 for the 'Urban, Indoor, and Emerging Agricultural Production Research, Education and Extension Initiative'

Market trends

- 2022: Construction of the world's largest closed vertical farming for strawberry production

Japan

Policies

- The comprehensive support grant for building strong agriculture and fostering new leaders includes highly controlled environmental cultivation facilities (including fully artificial light types) as eligible for funding
- 2023: Research study conducted towards the realisation of closed vertical farming

Market trends

- Developed the world's first closed-type vertical farming, where each cultivation shelf is sealed and environmental controls are implemented

Europe

Policies

- Artificial light type (vertical farming) is not covered by EU agricultural or climate policies

Market trends

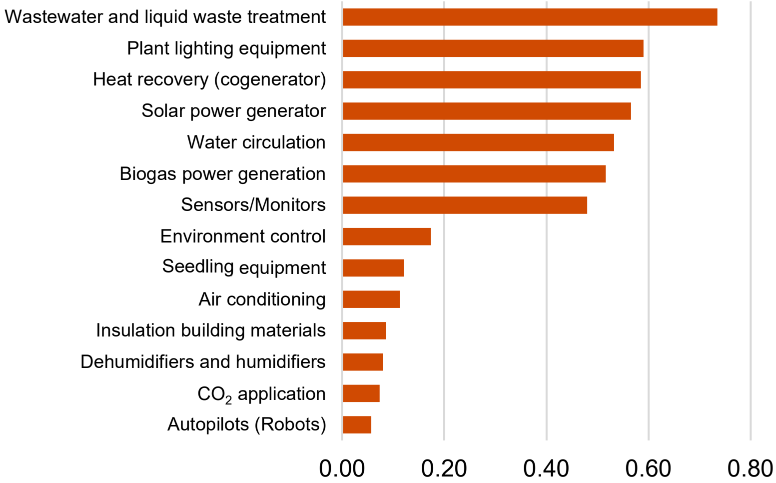
- Since 2022, several vertical farming companies have halted operations, declared bankruptcy or changed strategies due to rising energy prices and other factors

Source: Prepared by PwC Consulting LLC based on publicised materials

Technological elements related to vertical farming

Figure 7 shows the influence (factor loadings) of the main technological elements (patent classifications) that make up the vertical farming technology cluster, indicating that the higher the value, the more representative that element is within the technology cluster. It indicates that technologies such as those related to the circulation and treatment of water for the cultivation of agricultural products, power generation to produce the energy consumed in the facility and lighting to use it efficiently are important technologies.

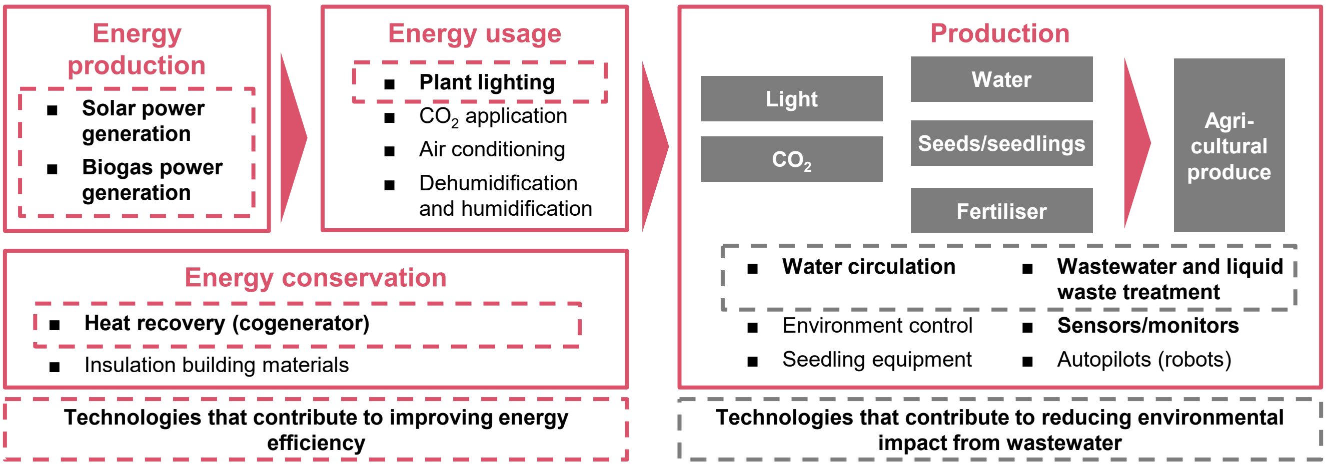
Figure 7: Typical technological elements comprising the 'vertical farming' technology cluster



Source: Prepared by PwC Consulting LLC based on IBA analysis results

Figure 8 plots these technological elements in the production process of vertical farming and shows that the important technologies mentioned below (in bold) are used to 'improve energy production and use efficiency', such as power generation, lighting and heat recovery, and 'reduce environmental impact from wastewater', such as water circulation and wastewater and liquid waste treatment. This suggests that these two in particular are central to technology trends.

Figure 8: Technological elements and production processes related to vertical farming



Source: Prepared by PwC Consulting LLC based on IBA analysis results

Outlook

Assuming that 'energy efficiency improvement'—one of the current technology trends—continues, it is possible that 'zero-energy' vertical farming, in which the farm or its attached renewable energy power generation facilities produce energy equal to or greater than the amount of energy used, could eventually become a reality. This would also address the business challenge of energy price vulnerability faced in Europe, making it a potentially ideal vision for the future of vertical farming in that context. Furthermore, regarding the other trend of 'reducing the environmental impact of wastewater', achieving zero pollution risk to the environment may become a requirement when considering the increasing demand for environmental responsibility within the food system.

At present, vertical farming produces agricultural products with a high weight value per unit that can be grown under relatively low light, which does not contribute to reducing the environmental impact of raw materials that are highly dependent on nature. However, although the range of agricultural products may be limited, as mentioned earlier, transitioning from conventional cultivation methods to production in vertical farming can reduce the environmental impact associated with fertilisers, pesticides, plastic materials and transportation.

Contribution of e-commerce to Nature Positive and country/regional scores and trends

E-commerce is less dependent on building materials and supplies because it does not require the establishment of physical stores, and logistics can be made more efficient, which has a lower impact on the environment than the operation of physical stores. In addition, the technology can contribute to Nature Positive by reducing food loss and the associated GHG reduction from food waste, such as acting as a platform for selling food products that are close to their expiration dates.

Japan scores highest in the e-commerce technology cluster, with Japanese IT companies and electronics and electrical manufacturers leading technology development (Figure 9). On the other hand, the US records the highest minority investment, followed by China (Figure 10). In both cases, most of the investments are concentrated in few, or single, major e-commerce-related companies. As in the US, the top two companies account for about 50% of total investments, while in China, a single company accounts for nearly 80%. Minority investment is considered a leading indicator for technology scores, and the US and China are expected to make significant technological progress in this area in the future. Additionally, these three companies share the common characteristic of being e-commerce platform providers.

Furthermore, in 2022, the share of e-commerce for food in various countries was 9.1% in the US, 6.5% in China, 4.2% in Japan and varied significantly across Europe. In the UK, where e-commerce is more advanced, the rate was 14.2%, while in Germany it was 2.7%[*13 *14], indicating that there is still room for further e-commerce growth in food retail.

Figure 9: Technology scores of each country in the 'e-commerce' technology cluster

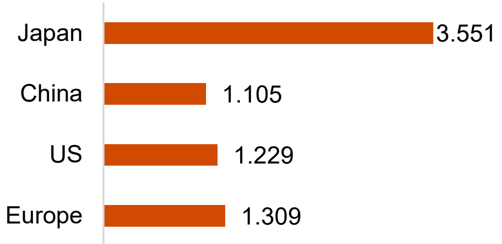
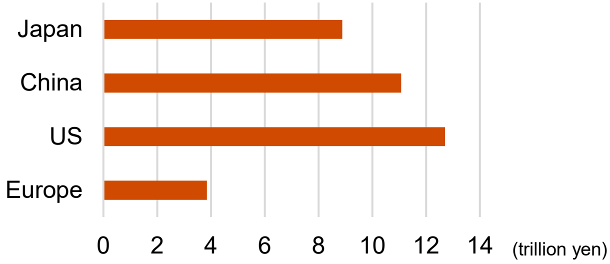


Figure 10: Minority investment amounts by companies in each country

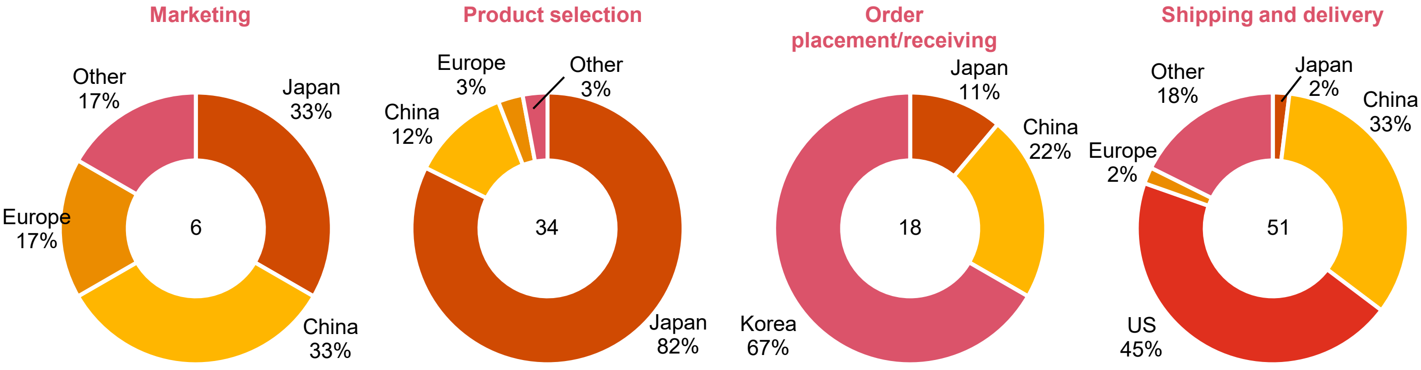


Source: Prepared by PwC Consulting LLC based on IBA analysis results

Percentage of important patents related to e-commerce held in each country and region

Figure 11 shows the percentage of related important patents (patents that account for the top 5% of the number of times they are cited in the same IPC classification)[*15] possessed by country and region. It can be seen that Japan holds many important patents related to product selection systems, such as product recommendation systems. Meanwhile, Korea owns a large number of patents related to ordering and procurement systems, and the US is strong in patents related to shipping and delivery systems, such as distribution logistics. The major platform companies that have attracted significant investment, as previously mentioned, do not have a strong presence in terms of holding important patents, with the two US companies holding only three important patents in total and the Chinese company owning just one.

Figure 11: Percentage of important patents possessed by country and region



Source: Prepared by PwC Consulting LLC based on IBA analysis results

Outlook

At the moment, major e-commerce platformers hold few important patents and are not positioned to shape technology trends. On the other hand, these companies have received significant investment and are expected to develop technology, so they are also likely to become leaders in this field from a technological standpoint going forward. It is anticipated that these companies will increasingly focus on developing technologies that reduce environmental impact and contribute towards Nature Positive in the future.

Development trends and outlooks of key technologies (2/3)

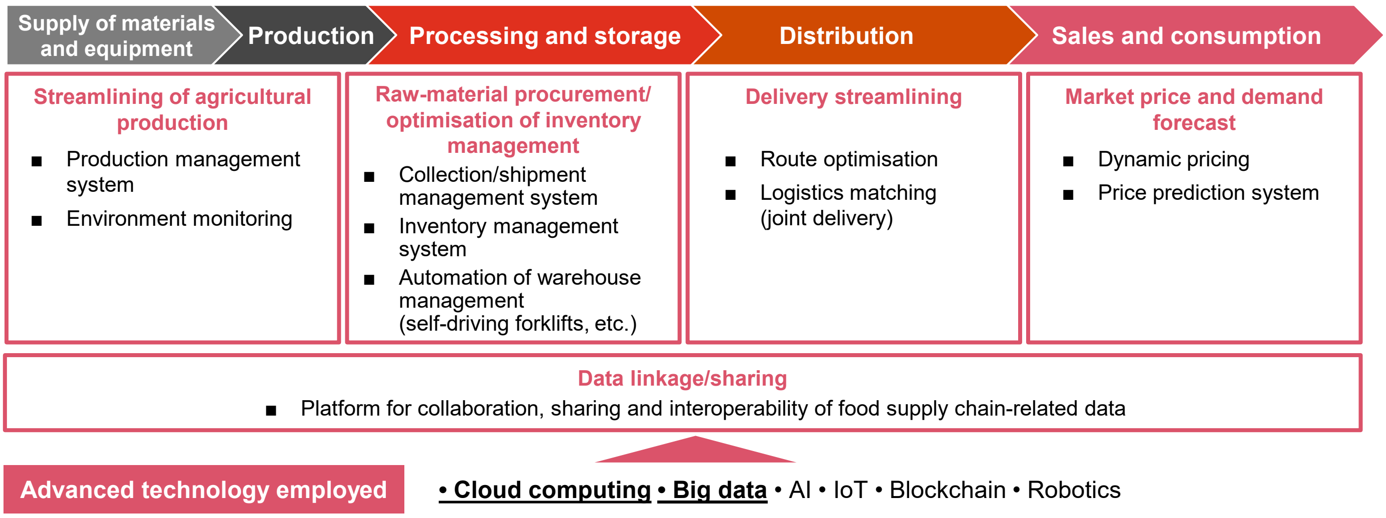
Developing technology: 'Smart food chain'

Technological elements that comprise the smart food chain

The smart food chain refers to the process of enhancing and optimising the food supply chain, from production to consumption, by utilising advanced technologies, such as robotics, AI and IoT, as well as data. It also refers to the food supply chain that has been enhanced through such technologies. By connecting information from production to consumption, supply and demand can be adjusted in a timely manner, and inventory management can be optimised, leading to reductions in food loss and food waste as a result. Food waste transportation, incineration and landfilling are sources of GHG emissions, so smart food chains can be considered a Nature-Positive technology that helps to reduce these environmental impacts.

Various systems using technologies have been established at each stage of the supply and value chain, with examples shown in Figure 12. Each of the systems employs advanced technology, and the technological elements that constitute this technology cluster were particularly prevalent using 'cloud computing (128 patents)' and 'big data (57 patents)'.

Figure 12: Representative technologies in the smart food chain

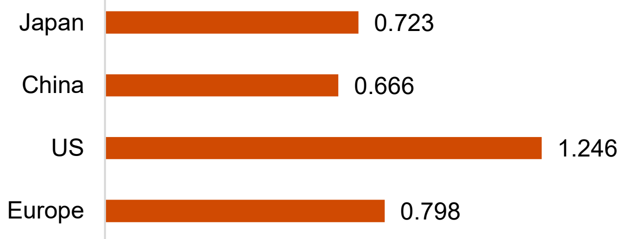


Source: Prepared by PwC Consulting LLC based on IBA analysis results

Technology scores by country and region

When comparing the technology scores of each country and region within this technology cluster, the US scored highest (Figure 13). This is due to the high average technology score of US companies. Conversely, in Japan and China, while a small number of companies show outstandingly high technology scores, many companies have negative technology scores, resulting in a lower technology score as a country than in the US and Europe.

Figure 13: Technology scores of each country in the 'smart food chain' technology cluster



Source: Prepared by PwC Consulting LLC based on IBA analysis results

Trends by country and region

A comparison of trends in each country and region regarding the linkage and sharing platforms for agriculture and food-related data, which are important for building smart food chains (Figure 14), shows that in the US, the private sector took the lead in promoting data linkage and sharing from early on, and the number of member companies is increasing. In the platform launched by a US agri-tech company, collaboration with major grain companies has rapidly expanded its user base. Additionally, the platform promotes regenerative agriculture through its environmental scoring function, contributing to GHG reduction, and showcasing fast-paced and large-scale use cases[*16]. Government-led, project-based agricultural data platforms have been launched in Japan and Europe.

Figure 14: Country and regional trends in agriculture and food-related data platforms

US

- 2005: A non-profit organisation began providing services and tools with data linkage, sharing and provision functions between food and agriculture-related companies
- 2017: An agri-tech company launched a service providing a farmer-to-farmer network and e-commerce platform

Japan

- 2017: As part of the Cabinet Office's Cross-ministerial Strategic Innovation Promotion Program (SIP), the agricultural data integration platform 'WAGRI' was launched and has been in operation since 2019. Launched an agricultural data linkage platform, where smart agriculture-related machinery and apps can interconnect and share data.

Europe

- The program 'Internet of Food and Farm 2020 (IoF2020)', which included building a data linkage platform for agricultural production, was launched, and ended in 2021. Some results were passed on to Smart Agri Hubs, a DX promotion hub for the agri-food sector in Europe.

Source: Prepared by PwC Consulting LLC based on publicised materials

Outlook

As mentioned above, there are many advantages to having the private sector take the lead in building and utilising data platforms, and in fact, there is the creation of dynamic use cases by private companies in the US. The high technology score for this technology cluster also indicates that the US private sector will continue to lead the smart food chain field.

These technological advancements will further strengthen the linkages in the food value chain, optimising supply and demand, production and consumption, and streamlining logistics and commercial distribution. This helps reduce overproduction and food loss, which in turn reduces the GHG emissions associated with their disposal. Therefore, technologies related to smart food chains will become increasingly important in attaining a Nature-Positive society.

Development trends and outlooks of key technologies (3/3)

New technology: 'Cellular agriculture' and 'other alternative proteins'

About alternative foods

Alternative foods are made from different ingredients than the original ingredients. For example, margarine and almond milk are included in the category of alternative foods. This report will mainly discuss two technology clusters: cellular agriculture (cultured meat) and other alternative proteins, which are technologies and products that replace livestock products. Technologies related to 'cellular agriculture' that cultivate cells to create alternative foods and 'other alternative protein' products made from raw materials derived from plants, insects and microorganisms both contribute to reducing environmental impact by replacing livestock products.

About cellular agriculture

Cellular agriculture refers to the technology of producing primarily meat by culturing edible animal cells. The process involves four steps: cell extraction, large-scale cultivation, tissue formation and processing to produce alternative proteins. It has the potential to help reduce environmental impact by cutting methane gas emissions and natural environmental pollution from manure, etc., compared to raising livestock, while also producing substitutes in less space. In addition to livestock meat, cellular agriculture technology is also used to develop alternative foods, such as eels and some whitefish, which are becoming increasingly scarce, as well as foie gras, for which production methods have become an issue from an animal welfare perspective.

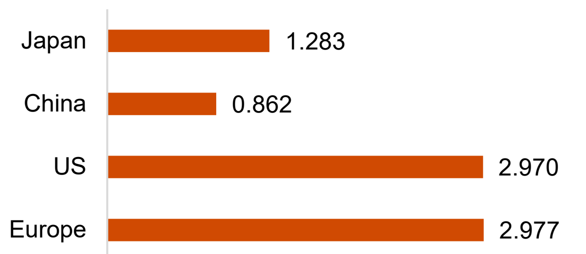
Currently, cultured meat products from cellular agriculture are available in only the three countries of Singapore, the US and Israel, and the Netherlands and Switzerland are on the way to commercialising them. While the market is still small, this is a rapidly advancing field of technological development, with various countries promoting the export of their technologies. The results of the IBA analysis show that this is the cluster with the highest growth rate in technology score among technologies related to 'GHG reduction from livestock production' in Category 4.

In some cases, 'precision fermentation' (a technology to produce food components, such as protein and fat, through the fermentation of microorganisms with specific gene insertions) is classified as cellular agriculture. In this report, however, according to the classification of technology clusters generated by the IBA, 'cellular agriculture' is defined as technology using only animal cells, while 'precision fermentation' is classified within the 'other alternative protein' cluster, described later.

Country and regional technology scores for cellular agriculture

The technology cluster for cellular agriculture scores higher in the US and Europe (Figure 15), with medical device manufacturers and biotech companies leading technology development. Medical device manufacturers convert regenerative medicine technology to cellular agriculture and develop techniques such as reproducing texture by organising meat. In addition to the reproduction of taste and texture, there are also many technological developments that lead to better animal welfare and lower costs, such as the development of animal-free ingredients for mass culture, which often use animal serum, and the development of food-grade culture media for medical-grade media.

Figure 15: Technology scores of each country and region in the 'cellular agriculture' technology cluster



Source: Prepared by PwC Consulting LLC based on IBA analysis results

Trends in cellular agriculture in each country and region

Looking at the policy trends in various countries and regions (Figure 16), the US has made significant progress in technological development as well as in policy-backed support, with the sale of cultured meat being legalised in 2023. However, Florida and some states are attempting to ban the sale of cultured meat through state laws, driven by opposition from the livestock industry and other factors, thus, there are different opinions among states. Similarly, Europe has a high technology score, with Switzerland and the Netherlands progressing towards legal frameworks for the commercial sale of cultured meat. On the other hand, Italy has become the first country in the world to pass a domestic law banning the production and sale of cultured meat, and countries such as France and Austria also oppose its production and sale, indicating a lack of alignment among European nations.

Figure 16: Trends in policies and regulations in each country and region

US

- 2021: The US Department of Agriculture announced a US$10m investment for cultured meat research facilities
- 2022: An executive order was signed prioritising food technologies, including cultured meat
- 2023: Authorisation of the sale of cultured meat (approval for two private companies to sell cultured poultry meat)

Europe

- 2022: European Parliament holds first debate session on cultured meat
- 2023: UK invests £12m in cellular agriculture, including cultured meat
- 2023: Italy adopts a law that bans the production and sale of cultured meat
- 2023: Netherlands allows a cultured-meat tasting event in the country
- 2023: Switzerland accepts application for permit to sell cultured meat products
- 2024: Italy, France and Austria submit an opinion to the European Council opposing the production and sale of cultured meat

China

- 2021: The five-year agricultural plan mentions cultured meat
- 2022: Calls for technological development of cultured meat and offers incentives

Japan

- 2022: Establishment of 'Diet members caucus for promoting a sustainable society through cellular agriculture'
- 2023: Ministry of Agriculture, Forestry and Fisheries SME Innovation Creation Promotion Project grants for cellular agriculture-related enterprises

Israel

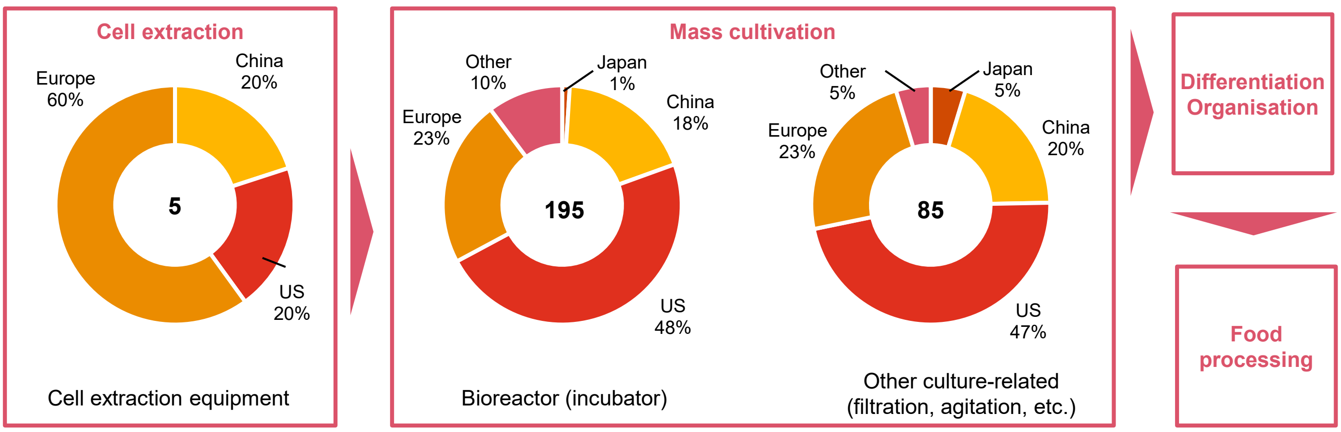
- 2024: Authorisation of the sale of cultured meat (approval to sell cultured beef)

Source: Prepared by PwC Consulting LLC based on publicised materials

Technological elements related to cellular agriculture

Looking at the relevant technological elements, the majority (96%) of the components in the technology cluster are related to cell culture, especially those related to bioreactors (72%). In addition, the ratio of important patents (Figure 17) indicates the strong influence of the US in the development of technologies related to mass culturing. This indicates that the current trend in the technology cluster of cellular agriculture is 'improving productivity of culturing' led by the US, and that the next step in the production flow—technology related to reproducing texture, such as differentiation and organisation—will advance going forward.

Figure 17: Production flow of cultured meat and percentage of important patents held by country



Source: Prepared by PwC Consulting LLC based on IBA analysis results

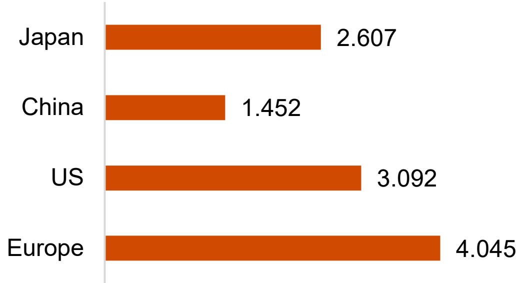
Other alternative proteins

Other alternative proteins include plant-derived foods (plant-based meat) that reproduce the texture of meat by using plant foods, such as beans and grains, as raw materials. It also includes the utilisation of insects and microorganisms. The environmental impact of producing plant materials or insects would be lower than that of livestock production, and this technology can contribute to Nature Positive by replacing livestock products and reducing GHG emissions and environmental impact.

Technology scores by country and region and percentage of important patents possessed by country and region

In this technology cluster, Europe has a high technology score, and major food manufacturers have high technological competitiveness, resulting in a high overall score (Figure 18).

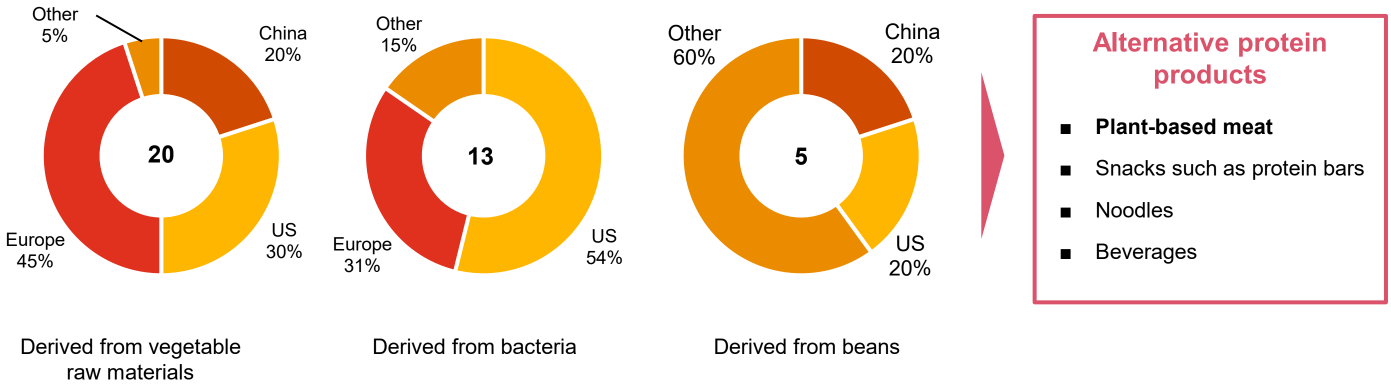
Figure 18: Technology scores of each country and region in the 'other alternative proteins' technology cluster



Source: Prepared by PwC Consulting LLC based on IBA analysis results

Many patents in this technology cluster relate to products using alternative proteins, which can be classified into three categories—derived from vegetable raw materials, bacteria or beans—depending on the raw material. Looking at the percentage and number of important patents, Europe and the US are strong, as is the technology score (Figure 19).

Figure 19: Percentage of important patents held by each country and region, and the types of alternative protein products



Source: Prepared by PwC Consulting LLC based on IBA analysis results

A wide variety of alternative foods are produced, but in terms of important patents utilised, most (16 of 24 important patents that are identifiable forms of products) are related to plant-based meats, which serve as alternatives to animal meat. This includes the production of food additives containing meat flavour components using precision fermentation, which is used to replicate the taste and flavour of meat in vegetable-based alternative protein products. Additionally, one of the most important patents pertains to 'hybrid foods combining cultured meat and plant-based protein products'. This suggests that there is a growing trend in the pursuit of 'meat-like' qualities in alternative protein foods.

Challenges: Cellular agriculture

- Cost: Cellular agriculture is an area of technology that has recently attracted investment, with the economic cost of the product currently higher than that of conventional meat. On the other hand, as a result of IBA analysis shows progress in bioreactor-related technological development, productivity improvements and cost reductions, a scenario has been found in which cultured meat can be brought to market at a price comparable to conventional meat, albeit on a research basis[*17].
- Legislation and market formation: Funding for cellular agriculture (cultured meat) in 2023 is US$226m, a significant decrease from US$922.3m in 2022. This is not only in the cellular agriculture sector but also due to inflation and rising interest rates, with global venture funding in 2023 down 42% from 2022 and investment in food tech ventures down 61%[*17]. The decrease in funding for cellular agriculture (about 75%) is greater than these. In addition to the recent weak private investment environment, the lack of market formation due to the aforementioned moves to ban cultured meat sales in various countries and regions may be a contributing factor to the decrease in funding. Rulemaking on labelling is also an ongoing issue, and even in the US where cultured meat products have been approved for sale, the labelling requirements remain unclear. In Japan, there is no law regulating so-called 'new foods' that use unconventional ingredients and production methods, so establishing labelling rules is considered a priority issue[*17].
- Consumer acceptance: Cultured meats and other food products produced by cellular agriculture technology are still only available in a limited number of countries, but general consumer interest is not particularly high. In a survey asking how appealing people found cultured meat after receiving an explanation, only 31% of respondents answered 'appealing' or 'somewhat appealing'. This breakdown also revealed that in no gender, age group or ethnic group did the percentage exceed 50%[*17]. Another research study found that 'social awareness', 'risk' and 'naturalness' were the most important factors influencing consumer acceptance or rejection of cultured meat[*18].
- Coexistence with the livestock industry: In addition to moves to ban cultured meat sales, several US states have proposed and adopted state laws that prohibit or restrict the use of meat-inspired labelling on products from cellular agriculture. While some existing livestock organisations have expressed support for these measures, groups promoting cellular agriculture have filed a lawsuit[*17] against the state law, claiming it is unconstitutional. There is concern that this will deepen the rift with the livestock industry.
- Branding and intellectual property protection: While it is not yet fully clear how the characteristics of the original cells will relate to the final product after cell cultivation, there is a strong possibility that value could be attributed to the 'cells' of branded livestock, such as premium beef. In 2020, Japan partially amended the 'Law Concerning the Prevention of Unfair Competition Regarding Livestock Genetic Resources and the Livestock Improvement and Propagation Law' to protect the genetic resources of Wagyu beef, which are highly recognised worldwide. However, this law only protects or regulates animal semen and fertilised eggs; it does not apply to the removal of cells outside Japan, nor does it apply to the export of cells from the country[*19]. Therefore, it may be necessary to consider intellectual property protection for animal cells in the future.

Challenges: Other alternative proteins

Cost and taste remain challenges for other alternative protein products as well, and these factors are affecting sales and market growth. In the US, for example, both the value and volume of sales of plant-based alternative protein products have declined for two years. This is partly due to changes in consumer behaviour caused by inflation and higher product prices, but it is also due to the failure to meet the needs of consumers. A survey of US consumers showed that plant-based meat alternatives have largely failed to meet consumer expectations, particularly regarding taste, texture and price[*20], suggesting there is still room for improvement.

Outlook

Technology trends are 'improving productivity and reducing costs' and 'pursuing quality', and are issues common to both technology clusters. Therefore, it is expected that technological developments will continue to improve cost and taste, and eventually, a 'commodity' may be created in which all the factors that consumers look for in alternative protein foods, including taste, texture, aroma and cost, are equal to or better than those of conventional meat and fish. On the other hand, non-technological issues have emerged, particularly with regard to cellular agriculture, and there is concern that these issues may be a bottleneck in this field. This is because some countries and regions are facing regulations against cellular agriculture and opposition from the livestock industry. Since consumers do not have sufficient awareness and understanding of cellular agriculture, efforts by governments, companies and society at large will be necessary to promote cellular agriculture and its products, including the establishment of laws and the improvement of consumer awareness.

Although alternative food development, particularly cellular agriculture, is a relatively new technology and there will be market expansion in the future, it has the potential to make contributions towards Nature Positive by replacing livestock, which are considered to have a high environmental impact in the agricultural industry, and seafood.

Sources

*1 FAO, 2021. The share of agri-food systems in total greenhouse gas emissions.
https://openknowledge.fao.org/server/api/core/bitstreams/ffb21ed0-05dd-46b1-b16c-50c9d47a6676/content

*2 United Nations, 2015. PARIS AGREEMENT.
https://unfccc.int/files/essential_background/convention/application/pdf/english_paris_agreement.pdf

*3 USDA, 2020. Agriculture Innovation Agenda.
https://www.usda.gov/aia

*4 EU, 2020. Farm to Fork Strategy.
https://food.ec.europa.eu/horizontal-topics/farm-fork-strategy_en#Publications

*5 Ministry of Agriculture, Forestry and Fisheries, 2021. MIDORI Strategy for Sustainable Food Systems.
https://www.maff.go.jp/j/kanbo/kankyo/seisaku/midori/

*6 UNEP, CBD, 2022. Kunming-Montreal Global Biodiversity Framework.
https://www.cbd.int/doc/decisions/cop-15/cop-15-dec-04-en.pdf

*7 SBTN, 2023. High Impact Commodity List.
https://sciencebasedtargetsnetwork.org/how-it-works/assess/

*8 Ministry of Agriculture, Forestry and Fisheries, 2022. Market Size Estimation Created by the Realization of the 'MIDORI Strategy for Sustainable Food Systems'.
https://www.maff.go.jp/j/kanbo/kankyo/seisaku/midori/attach/pdf/index-52.pdf

*9 WEF, 2020. Nature Risk Rising: Why the Crisis Engulfing Nature Matters for Business and the Economy.
https://www3.weforum.org/docs/WEF_New_Nature_Economy_Report_2020.pdf

*10 WWF, 2022. LIVING PLANET REPORT 2022.
https://livingplanet.panda.org/en-US/?utm_campaign=living-planet&utm_medium=media&utm_source=report

*11 The Breakthrough Institute, 2023. Livestock Don't Contribute 14.5% of Global Greenhouse Gas Emissions.
https://thebreakthrough.org/issues/food-agriculture-environment/livestock-dont-contribute-14-5-of-global-greenhouse-gas-emissions

*12 FAO, 2017. Livestock solutions for climate change.
https://www.fao.org/family-farming/detail/en/c/1634679/

*13 Ministry of Economy, Trade and Industry, 2023. FY2022 E-Commerce Market Survey Report.
https://www.meti.go.jp/press/2023/08/20230831002/20230831002-1.pdf

*14 Prepared by PwC based on Euromonitor data.

*15 Sugimitsu, Tatemoto, et al., 2023. A Study on the Influence of Important Patents on Financial Data of Firms.
http://fdn-ip.or.jp/files/ipjournal/vol24/IPJ24_26_38.pdf

*16 ADM, 2022. ADM, Farmers Business Network to Expand Sustainable AgTech Platform.
https://www.adm.com/en-us/news/news-releases/2022/7/adm-farmers-business-network-to-expand-sustainable-agtech-platform/

*17 Good Food Institute, 2024. 2023 State of Industry Report, Cultivated meat and seafood. 2
https://gfi.org/wp-content/uploads/2024/04/State-of-the-Industry-report_Cultivated_2023.pdf

*18 Ashkan, et al, 2021. Review of factors affecting consumer acceptance of cultured meat.
https://www.sciencedirect.com/science/article/pii/S0195666321007364?via%3Dihub

*19 Tsujimoto, N., 2021. Rulemaking and Intellectual Property on Foodtech.
https://iplaw-net.com/doc/2021/chizaiprism_202107_1.pdf

*20 Good Food Institute, 2024. 2023 State of Industry Report, Plant-based: Meat, seafood, eggs, and dairy.
https://gfi.org/wp-content/uploads/2024/04/2023_State-of-the-Industry-Report-Plant-based-meat-seafood-eggs-and-dairy.pdf

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Publication date: January 2025 (English Translation)   Control No: I202411-03

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