Article

A systematic scoping review of the sustainability of vertical farming, plant-based alternatives, food delivery services and blockchain in food systems

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Food system technologies (FSTs) are being developed to accelerate the transformation towards sustainable food systems. Here we conducted a systematic scoping review that accounts for multiple dimensions of sustainability to describe the extent, range and nature of peer-reviewed literature that assesses the sustainability performance of four FSTs: plant-based alternatives, vertical farming, food deliveries and blockchain technology. Included literature had a dominant focus on environmental sustainability and less on public health and socio-economic sustainability. Gaps in the literature include empirical assessments on the sustainability of blockchain technology, plant-based seafood alternatives, public health consequences of food deliveries and socio-economic consequences of vertical farming. The development of a holistic sustainability assessment framework that demonstrates the impact of deploying FSTs is needed to guide investments in and the development of sustainable food innovation.

Technologies in the food sector, such as cellular agriculture, are being developed at a considerable pace to facilitate the transformation towards achieving food system sustainability[1]. We here define them as food system technologies (FSTs) that have been recently introduced at various parts of the food supply chains to address current systemic challenges that prevent sustainable food systems. Data on investment trends show that their development has been accelerated by the COVID-19 pandemic and has generated strong interest from venture capital firms[2]. These FSTs are often surrounded by a sustainability halo, a socio-psychological phenomenon of perceiving a product as sustainable based on positive attributes, leading to a higher willingness to pay (WTP). This has created an innovation space that often strives to reduce climate impact from the food sector but disregards other dimensions of sustainability. As outlined in the Sustainable Development Goals (SDGs), the comprehensive concept of sustainability addresses multiple environmental, economic and social impact factors[3], with synergies and trade-offs within and across them[4]. Innovations in the food industry can impact all these sustainability pillars, potentially leading to unintended consequences[5]. Yet, while many well-defined tools exist to study the food system as a whole[6–8], there is no such defined toolset and inventory of sustainability indicators to empirically assess the sustainability performance of FSTs.

Considering the three pillars of sustainability, this multidisciplinary scoping review examines the extent, range and nature of the peer-reviewed literature that assessed the sustainability performance of FSTs and summarizes the research findings. To accomplish this, we first

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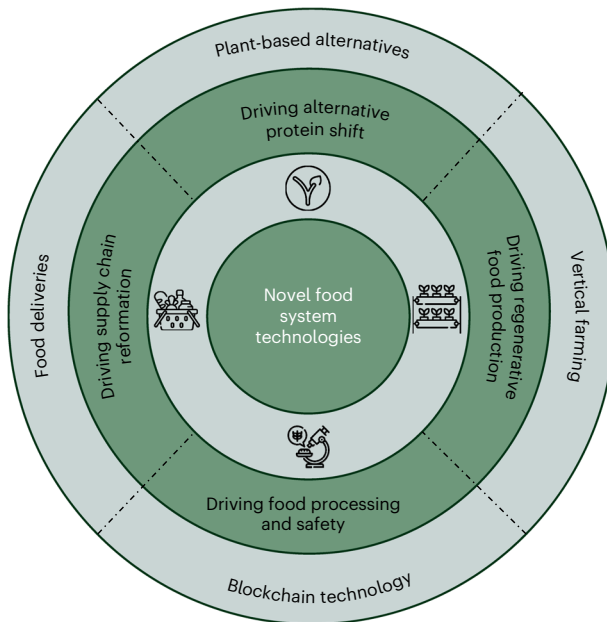
Plant-based alternatives: Vegan substitutes of meat, dairy, seafood and eggs that mimic the structure, taste and sensory profile of conventional animal-based products.

Vertical farming: Multi-layer vertical indoor crop production systems with controlled growth conditions and without solar light.

Blockchain technology: A decentralized distributed ledger technology that traces the supply chain to create transparency.

Food deliveries: The delivery of meals and groceries that have been purchased online by various means of transport. Part of the wider digital food environment.

Fig. 1 | Conceptual framework of included FSTs. Overview of the FSTs included in this review that are driving food system transformation at different entry points of the food supply chain. Credit: This figure has been designed using icons provided by Flaticon.com.

identify sustainability indicators that have been used in the literature to assess FSTs and then synthesize empirical evidence indicating FSTs sustainability performance compared with the technologies they intend to replace. Finally, we identify implications for research and practice in relation to the development of comprehensive sustainability assessments.

We focus on four divergent but representative FSTs that aim to address sustainability-related issues at different parts of the food supply chain: plant-based alternatives (PBAs), vertical farming (VF), food deliveries (FD) and blockchain technology (BT) (Fig. 1). We selected these FSTs by mapping investment flows into food start-ups in the Nordic region and selected the four FSTs that received the most investments in the first half of 2021 (Supplementary Material Section 2).

Results

We retrieved 1,493 studies from the initial search, of which 79 articles met our inclusion criteria and have been included in the analysis (Fig. 2).

Extent and range of evidence

The majority of the included papers assessed PBAs ($n = 37$), dominated by meat alternatives (PBMA) and dairy alternatives, while only two studies assessed seafood or egg alternatives. This was followed by literature that assessed VF ($n = 16$), BT ($n = 14$) and FD ($n = 11$).

The retrieved literature represents a wide geographical scope, with case studies spanning 40 countries across six continents. Regional representation varied across the different FSTs, visualized in Supplementary Material Section 5. Case studies on VF had a dominant focus on Europe (63%), FD on Asia (60%) and PBAs on Europe (55%) and northern America (19%). Literature on BT mainly elaborated a global perspective, with some case studies focusing on different countries, primarily from Asia (56%).

Nature of evidence

The sustainability of these FSTs has been addressed using a range of study designs assessing different indicators. The majority of the literature employed life cycle assessment (LCA) to study the environmental impact ($n = 26$), cross-sectional and intervention studies for consumer behaviour ($n = 11$), nutritional analysis to determine the nutritional content of foods ($n = 10$) and modelling studies for economic indicators
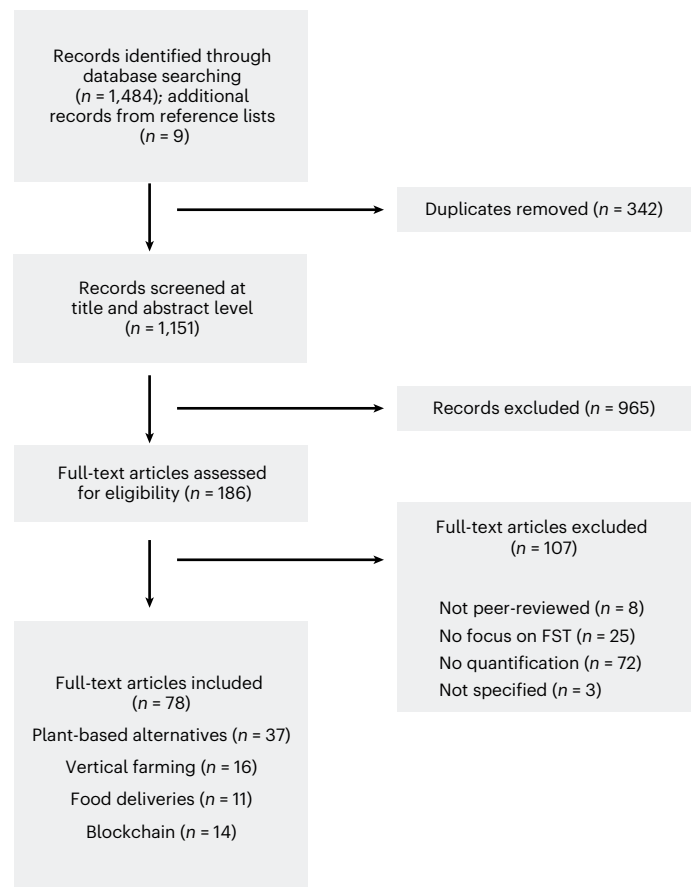

Fig. 2 | PRISMA flow chart (Preferred reporting items for systemic reviews and meta-analyses). Indicating the selection process of eligible studies.

($n = 7$). We captured systematic and non-systematic reviews ($n = 13$), mostly focusing on BT ($n = 8$). Other methods that have been applied to case studies ($n = 12$) are detailed in the Supplementary Data.
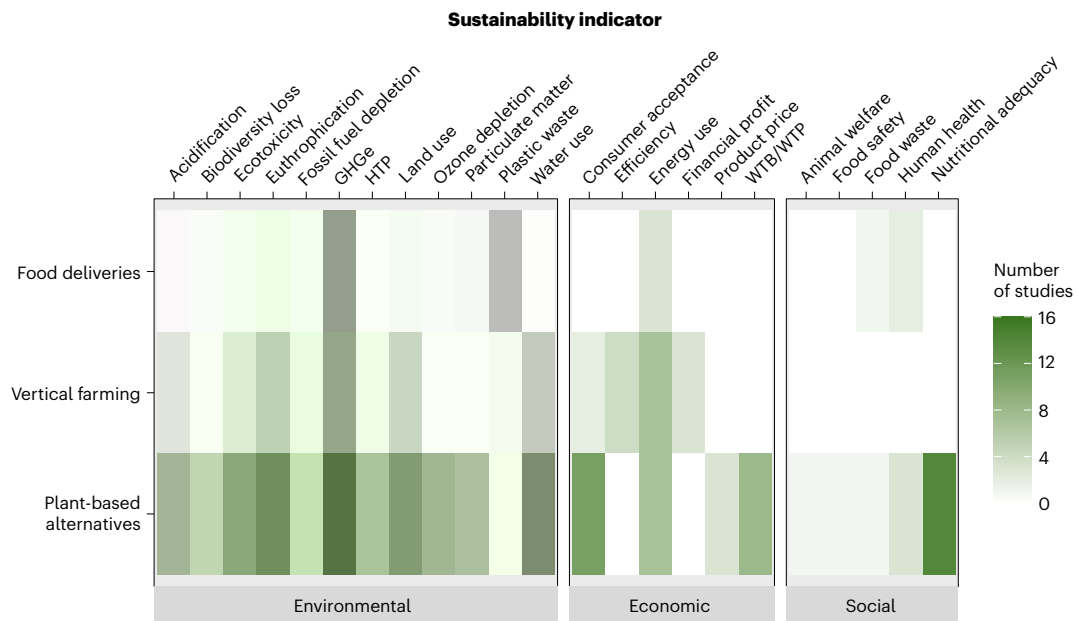
Fig. 3 | Sustainability indicators assessed in the included literature. The heat map cross-references all the included studies on PBAs, VF and FD to show the frequency of studies that investigated sustainability indicators. Impact domains are split by social, environmental and economic sustainability, from the left. Source data are provided in the Supplementary Data. HTP, human toxicity potential; WTB, willingness to buy; WTP, willingness to pay.

Indicators to assess the sustainability of FSTs

For PBAs, VF and FD we observed a wide range of indicators empirically assessing all three dimensions of sustainability, with clear differences across FSTs (Fig. 3). The results for BT are presented separately (Fig. 4) and are not analysed further as the contribution of BT to sustainability was described using different indicators and was not empirically investigated.

Studies investigating PBAs comprehensively assessed a wide range of environmental impact factors, dominated by greenhouse gas emissions (GHGe) ($n = 16$), land use (LU) ($n = 11$) and water use (WU) ($n = 12$). Evidence on the release of excess nutrients were also frequently provided, assessing the eutrophication ($n = 12$), acidification ($n = 8$) and ecotoxicity potential ($n = 10$). Three studies assessed the carbon opportunity cost of agricultural land, taking into account the amount of CO_2 that could be sequestered by replacing conventional meat with PBMA[9–11]. As metrics for social sustainability, studies assessed primarily nutritional adequacy ($n = 14$). Consumer acceptance ($n = 11$), willingness to buy and pay ($n = 8$), energy use ($n = 7$) and product price ($n = 2$) were assessed as economic indicators.

Studies that focused on the environmental impact of VF most frequently assessed GHGe ($n = 9$) and WU ($n = 6$). To indicate their economic sustainability energy use ($n = 7$), yield production efficiency ($n = 4$), financial profit ($n = 3$) and consumer acceptance have been assessed ($n = 2$).

The literature on FD focused primarily on assessing GHGe ($n = 10$) and plastic waste ($n = 7$) as environmental impact factors and energy use as an economic indicator ($n = 3$). As social indicators, human health consequences have been assessed. These encompass non-communicable diseases deriving from food plastic packaging[12] and increasing consumption of unhealthy products[13].

Applying BT to the food sector was described, but not analytical assessed, as enabling primarily social but also environmental and economic sustainability. As indicators and methods to describe the sustainability of BT deviated from the other FSTs, they are presented in a separate format (Fig. 4). Through its main function, food traceability, it can contribute to food safety by reducing the consumption of contaminated food worldwide, thereby reducing food waste and improving economic efficiency[14–20]. The potential of BT to decrease food waste has been emphasized in case studies from the dairy industry[16] and the supply chains of pork products and mangoes[19]. Findings from case studies on the halal food industry[15] and the tilapia fish industry in Ghana[21] indicate that BT can increase food quality, safety and integrity. It can further foster collaboration among food supply chain actors, thereby increasing process and cost efficiencies, trust and profitability[17]. Regarding environmental sustainability, BT can be applied to monitor environmental impacts and support farmers to reduce the use of chemical inputs, water and soil. Traceability-enabled food labelling can then indirectly improve environmental sustainability through consumers demanding veracity of sustainable food production and processing[17]. Three studies emphasized the potential of BT to reduce overfishing[18,22,23] in line with SDG 14.6 to combat illegal, unreported and unregulated fishing[17]. In general, applying BT to the fish industry has been described as beneficial to a range of SDGs[22]. Included literature also elaborated on limitations that deploying blockchain could entail (Fig. 4).

Sustainability performance

Below we outline how the various FSTs performed in relation to the three sustainability pillars and indicators compared with the baseline technology they are intended to replace, focusing exclusively on the studies that conducted this comparison (PBA = 27, VF = 10, FD = 3). BT is not included in this section as its sustainability performance was not empirically investigated (detailed in Methods).

PBA. We observed high-level agreement across the literature that PBAs tend to have a lower environmental impact than conventional animal-based products (Fig. 5). In general, they are associated with less CO_2 equivalent, less WU[9,24–26] and less LU[9,24–27] and have a lower ecotoxicity[9,10,25,28–30], acidification[9,10,25,28,30,31] and eutrophication potential[10,25–31], with some exceptions. For instance, one LCA study found that almond milk is more water-intense than dairy milk and has a higher environmental footprint in general when assessed on a cradle to consumer system boundary assumption[28]. Two studies found that the production of plant-based dairy alternatives has a higher energy demand than conventional dairy[28,31].
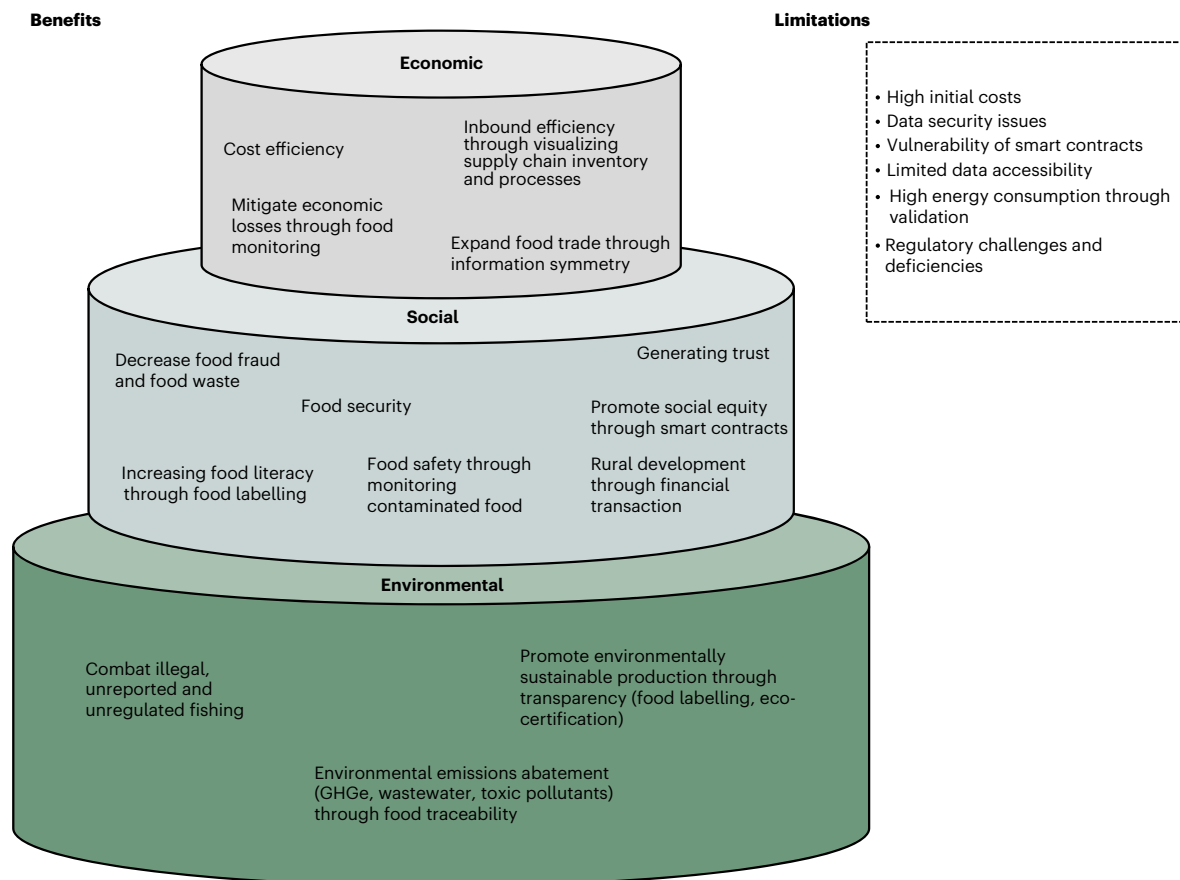
Fig. 4 | Benefits and limitations of deploying BT to the food sector. Extracted from retrieved literature and positioned in relation to the biosphere-based foundation of sustainability science adapted from ref. [69].

In contrast, no such clear agreement was observable for nutritional performance. We found PBAs generally contained lower levels of proteins, with discernible differences depending on the commodity they are based on. For instance, one study[30] found that burger patties made out of mycoprotein contained higher protein, those made from peas similar and those on a soy basis lower levels of protein content than beef patties[30]. Sodium content was found higher in cheese alternatives based on coconut oil than on cashew nuts or soy[32]. PBAs had generally lower contents of saturated fat, except coconut-oil-based cheese products[32] and two legume-based burger patties[26]. The total nutritional performance of PBAs, assessed with nutrient profiling models, was mostly higher[10,30,33], or no difference was discernible[30,34]. PBAs received lower consumer acceptance[30,35,36] and were higher in cost than conventional animal-based products[37,38].

VF. We found consensus that growing vegetables by VF outperforms cultivation on-field and in greenhouses in terms of LU[39−42] and WU[40,41,43,44]. One study modelled that lettuce production in VF in the Netherlands could require 95% less water compared with current production in greenhouses due to its water-recycling potential[44]. We identified agreement that VF is responsible for higher GHGe than open-field cultivation[39,40] but lower than greenhouses[39,40,44,45]. By contrast, VF has been assessed less efficient in terms of energy inputs than on-field cultivation[40] and greenhouses[40,43,44]. The degree of environmental impact has been found to depend to a large extent on the growing substrate, packaging material and the source of energy[46]. Regarding economic indicators, we found agreement that VF has a higher yield production than greenhouses[43], leading to slightly higher economic revenues[43,47].

FD. Grocery delivery performed better in terms of GHGe and energy use compared with individual retail trips when assuming they are made by car but not on foot, by bike or public transport[48]. Meal delivery had a lower performance than preparing the meal at home or consuming it at the restaurant[49,50], mainly attributed to plastic food packaging waste generated by delivered meals[51]. Research demonstrates that walking to the restaurant and consuming the meal there instead of having it delivered could reduce the total amount of GHGe by 68% per meal[50].

Discussion

Summary of evidence

We synthesized empirical evidence indicating the sustainability performance of four FSTs. We did not identify empirical evidence for BT and revealed considerably more evidence on the sustainability performance of PBAs than for VF and FD. Environmental indicators were assessed more frequently than social and economic indicators, adding on the concern to ensure that socio-economic sustainability receives more attention[5,52,53].

Our analysis on the sustainability performance of PBAs revealed that their environmental impacts are generally lower than those of their animal-based counterparts, while no such clear trend was observable for social and economic consequences. Public health consequences of PBAs have been exclusively addressed by comparing their nutritional profiles against conventional products, with no focus on other indicators such as food safety or epidemiological implications. Included studies found that PBAs are often higher in sodium than their animal-based counterparts, one of the leading dietary risk factors for global mortality and morbidity[54]. There is a distinct lack of studies assessing the social and economic implications of shifting towards PBAs. Included studies
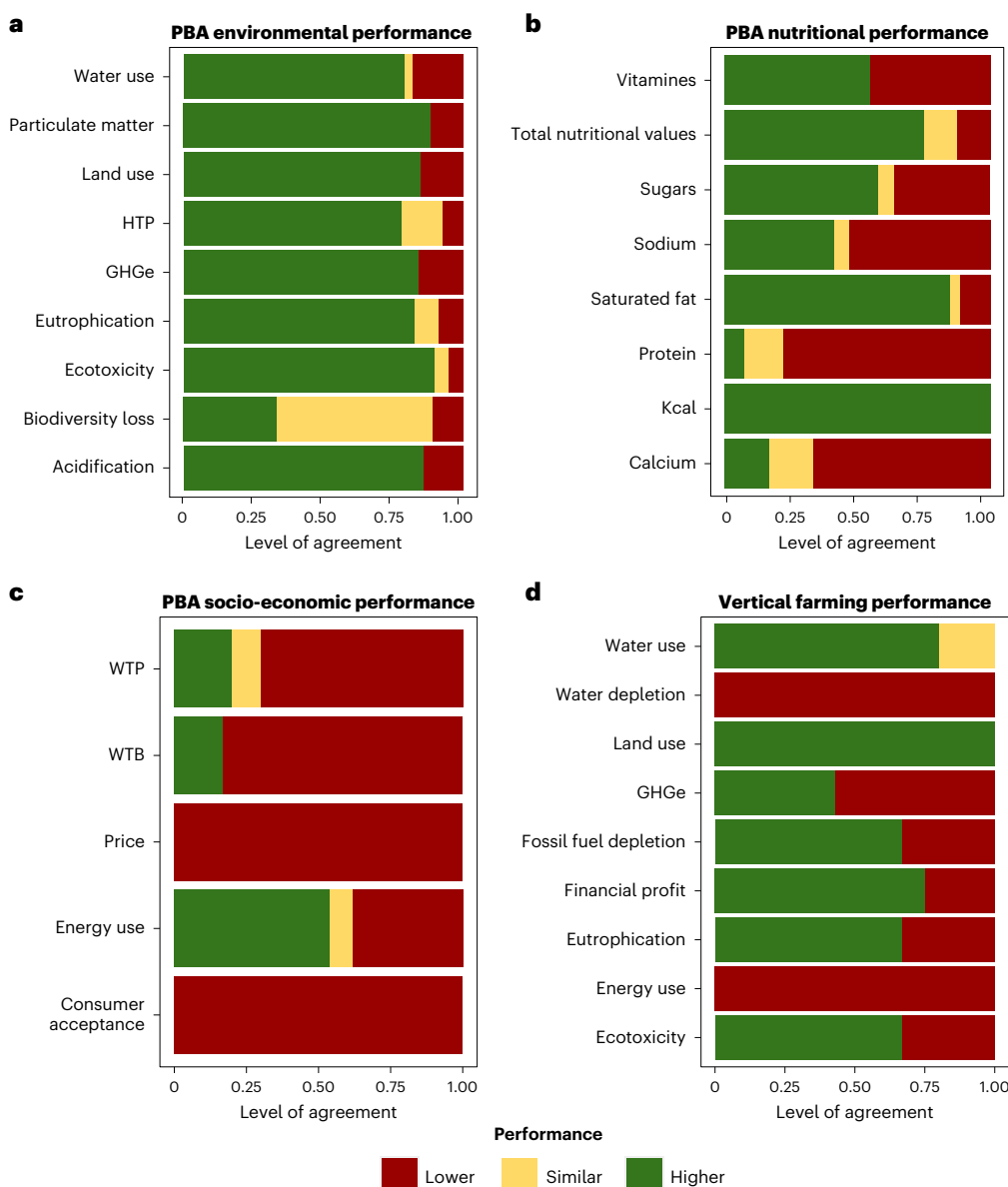
Fig. 5 | Agreement on the sustainability performance of PBAs and VF across the literature. The performance of PBAs is split by different pillars of sustainability due to the range and extent on identified literature. The performance of VF is presented as a whole. Stratified results according to different system boundary and functional unit settings are presented in Supplementary Material Section 6. This assessment could not be carried out for BT and FD as we identified insufficient literature comparing them with the baseline scenario they intend to replace.

revealed that PBAs are currently higher in costs than conventional animal products, which could generate the impression that a plant-based diet is more expensive and seen as a luxury, leading to social inequalities. We synthesized research showing that consumer acceptance and WTP for PBAs is currently lower than for conventional meat but could increase to the same level after information concerning health or environmental consequences is provided[55].

The vast majority of included PBA studies assessed meat and dairy analogues. Despite the fact that the market of seafood analogues is predicted to grow rapidly[56], only two studies investigated the sustainability of seafood analogues[27,33]. This is most likely because seafood analogues have only recently been introduced, especially outside Asia. We can assume that LCA studies on seafood analogues would present similar results to PBMA, as both are derived mainly from terrestrial plant sources such as soy and sunflower oil. However, blue foods have been associated with lower GHGe than terrestrial meat[57]. Future

studies should therefore compare seafood analogues with conventional fish, including impact factors specific to aquatic systems such as wild stock depletion. Further, while the consumption of conventional meat products is linked to human health hazards, consuming seafood is associated with nutritional benefits[58]. While seafood analogues could help to meet the growing seafood demand and reduce overfishing, it is necessary to investigate the socio-economic and public health implications of these products.

VF has been described as a resource-saving production system, improving food safety and quality while providing economic benefits[59]. However, we found a distinct lack of evidence modelling the socio-economic implications of scaling it which have been largely theoretically outlined in a recent review[60]. Further, the local food production enabled by VF is often considered as environmentally sustainable, partly due to the general assumption of high CO2 equivalent emissions resulting from transport. Conversely, we gathered evidence

that VF is responsible for higher GHGe and are more energy-intense than open-field cultivation. However, a widespread transition to renewable energy and resource-saving materials, such as paper pots and coir as growing substrate, could lead to large environmental impact reductions[46]. Further, the sustainability performance and benefit of VF depends to a large extent on the regional context, being primarily recommendable for climate-extreme areas[44,61].

FD services, especially on-time groceries, are growing rapidly and are backed by billion-dollar investments. The retrieved literature focused primarily on assessing GHGe and energy use. Beyond that, we found that their implications on environmental and social sustainability have not yet been empirically assessed. The World Health Organization also expressed concern about the still insufficiently studied public health consequences of the growing delivery sector and has called for more evidence[62].

Systematic reviews and descriptive case studies revealed the potential of BT to enable a sustainable food supply chain, but there is a distinct lack of empirical case studies validating these assumptions. Further studies that estimate correlation or causal inferences between applying BT and sustainability benefits are needed. Aside from the opportunity to strengthen the ecological dimension of sustainability through blockchain adoption, the majority of the literature addressed the potential of BT to improve social and economic rather than environmental sustainability.

Our review demonstrates that the sustainability performance of FSTs is influenced by methodological specifications, such as defining the functional unit and system boundary in LCA studies. For instance, Grant et al. calculated that almond and soy milk have a lower environmental footprint than dairy milk when assessed from cradle to gate but a higher footprint when assessed from cradle to consumer as it also factors in transport emissions[28]. We conducted a cross-spatial analysis of the study results, which necessitates cautious generalizations. Each study is unique from a geographical, temporal and methodological perspective. For example, results revealed that VF generally requires more electricity than their baseline scenario[63], but the extent strongly depends on the region and type of purchased energy. A comparative analysis found that the relative efficiency of VF compared with greenhouses in mainland Europe is low, while it is much higher in low-light spatial conditions such as northern Sweden or water-scarce regions such as Abu Dhabi[44]. Similarly, cultural differences can lead to geographically different social sustainability performances of innovations. For instance, consumer acceptance of PBMA and cellular meat was assessed higher in China than in the United States[64].

We therefore echo the concern expressed in previous studies that methodological inconsistencies among environmental assessment studies complicate generalizing results[65]. To investigate how the methodological assumptions in the included studies affect the sustainability performance of FSTs, we conducted the analysis separately for different functional unit and system boundary settings (Supplementary Material Section 6).

Strengths and limitations

The breadth and interdisciplinarity of this review posed challenges on the inclusion and analysis of heterogenetic data. We focused on synthesizing peer-reviewed articles, which excluded conference proceedings, reports and book chapters. Given the growing interest in FSTs, we assume that a range of grey literature exists that future systematic reviews should include. We yielded a wide geographic scope of publications, but our searches were limited to English-language literature.

We compared the sustainability performance of FSTs against the baseline scenario they intend to replace but not among and in between them. This generalizing approach does not necessarily allow conclusions to be drawn on individual products as the performance depends on a range of factors, such as the raw material they are based on. For example, cheese analogues based on soy were found to have a better nutritional performance than those based on coconut oil[32].

The chosen traffic light classification to indicate the sustainability performance is a conceptual and subjective approach to harmonize and standardize heterogenetic data. However, it does not allow to draw conclusion on the scientific strength of evidence and should therefore be interpreted with caution. We further did not conduct a risk of bias assessment of the included studies. This is in line with the Preferred Reporting Items for Systematic Reviews and Meta-analyses (PRISMA) guidelines, which state that scoping reviews are not intended to critically appraise the risk of bias of a cumulative body of evidence but to present results and guide future systematic reviews and meta-analyses[66].

Implications for research and practice

As previously outlined by Herrero et al. [5], the rapid development of FSTs and their expected impact on different pillars of sustainability requires improved multi-indicator sustainability assessment to reduce the risks of unintended trade-offs[5]. It would be useful to develop a comprehensive inventory of sustainability indicators that can be selected from for the assessment of respective FSTs to determine the most sustainable alternative option in a given context. For this purpose, the results of this review and other studies that provide an overview of metrics to assess sustainability in the food sector can be used[8,53]. This scoping review reveals important evidence gaps on the four included FSTs that targeted empirical assessments should aim to fill. The literature on PBAs sustainability is widespread, but there is a need to study the performance and implications of the growing market of seafood analogues. More analyses should also be conducted comparing PBAs against other alternatives such as tofu or insects to determine the most sustainable protein and fat alternatives. Studies comparing existing PBAs are also of relevance to determine the most sustainable commodity and production processes. Finally, longitudinal and controlled dietary studies comparing the nutritional and epidemiological effects of substituting animal products with alternative protein sources over the long term are needed.

Given the often-emphasized potential of vertical farms to contribute to more resilient food supply chains, it is necessary to assess their socio-economic implications and evaluate the efficiency and benefit for different geospatial and cultural contexts.

For FD, their scaling and rapid development needs to be assessed from public health, socio-economic and environmental perspectives beyond GHGe (for example, air pollution from transportation) to inform governmental policies and urban planning processes and guide more sustainable practices.

To validate the promise of BT for a sustainable, effective and efficient food supply chain, it would be important to empirically assess whether food traceability actually improves agricultural sustainability and to what extent.

Conclusion

We synthesized empirical evidence indicating the sustainability of four representative FSTs and found varying levels of performances across different indicators and pillars. We identified considerably more evidence on the sustainability performance of PBAs than for VF and FD, with no empirical evidence found for BT. In general, these FSTs have the potential to support parts of the transformation towards a sustainable food system and enhance human health. However, unintended side effects are often inherent to deploying innovations. Guiding transformative investments necessitates a more rigorous, quantitative assessment of the sustainability implications of FSTs, encompassing broad environmental, economic and social indicators, to safeguard against undesirable effects. We hope that the findings of this review provide a starting point to build such a sustainability assessment framework to assess recently introduced FSTs, to inform political guidelines and to guide the development of and investments into long-term sustainable solutions. The inventory of FSTs is long, and future research is

required to provide regional context specific recommendations and inform policy guidelines. This will have to include socio-economic sustainability impact factors to ensure that they contribute to a just transformation of the food system.

Methods

Scoping reviews are well suited to study the breadth of an area that has not been reviewed comprehensively before to provide a detailed and structured overview of the reviewed literature and to identify research gaps in the existing literature[67]. We followed the PRISMA guidelines extension for scoping reviews and provide the detailed checklist in the Supplementary Material Section 1[66]. Searches in the databases Web of Science Core Collection and Scopus were carried out in September 2021 to identify peer-reviewed literature. We included literature published from 2016 as there was an exponential rise in scientific literature focusing on these four FSTs since then (Extended data Fig. 1). Further details on the literature review are given in Supplementary Material Section 3.

We used CADIMA[68] for study screening and duplicate removal. To check for selection consistency among all researchers, an initial consistency check was conducted by independently screening a certain number of articles (5% = 57) and discussing potential divergencies. Once consistency was achieved, one reviewer (A.C.B.) screened the remaining articles at the title and abstract stage against the eligibility criteria. Full-text screening was performed by three reviewers independently: A.C.B. (80%), A.W. (10%) and L.J.G. (10%). Where inconclusive or contradictory assessments emerged, they were discussed and resolved with all authors at both abstract and full-text screening stage.

Eligibility criteria

As a primary inclusion criterion for this review, the studies had to assess the sustainability of one of the four selected FSTs as defined in the conceptual framework (Fig. 1). We exclusively searched for PBAs that are designed to mimic conventional animal-based products and hence excluded cellular meat, insect-based food products and traditional fermented legumes. We also excluded literature focusing on non-vertical aqua or hydroponical systems and the application of BT to non-food sectors. Included studies had to provide quantification for at least one indicator of sustainability. An exception was made for blockchain literature, as we found there is yet limited empirical evidence available. Hence, the blockchain literature only had to provide a narrative description on at least one indicator of sustainability. We included peer-reviewed case studies and reviews that provide a quantification; subjective studies that do not use data to back up the assessment of indicators or conference proceedings were excluded. No geographical limits were imposed, but only English literature was included. Eligibility criteria are detailed in the Supplementary Material Section 3.

Search strategy and data charting

We devised the search strategy to reflect concepts of sustainability assessment and the four selected FSTs. Search strings were tested several times against a set of predefined benchmark articles.

Data charting was done for all included articles between October and December 2021 by one author with feedback on the process by all authors. We charted data on study design, study location, sustainability indicators assessed, methods, LCA assumptions and results indicating the sustainability performance (Supplementary Data). The fact that no defined inventory of indicators spanning all dimensions of sustainability exists posed an inherent challenge to the search for and selection of them. We therefore used a combined deductive and inductive approach to extract all sustainability indicators encountered in the literature and discussed inclusion among all study authors. Detailed outline on the search strategy and the data-charting process is provided in Supplementary Material Sections 3 and 4.

Assessing the sustainability performance of FSTs

Performing a meta-analysis on the results of included studies was not applicable due to cross-study, cross-FST and methodological inconsistencies across sustainability indicators. However, to translate the results of the included studies into comparable quantitative representation, we developed a coding scheme, classifying the level of agreement on the sustainability performance per study, FST and sustainability indicator. For that step, only studies that performed a comparison against the baseline scenario they intend to replace have been included (PBA = 27, VF = 10, FD = 3). Blockchain literature was not applicable for that assessment. We defined baseline scenarios in this context as animal-based products for PBA, on-field and in-greenhouse cultivation for VF, and individual grocery retail or restaurant dining for FD.

To assess the sustainability performance of FSTs compared with the baseline scenarios, we extracted study results and coded the level of performance using the traffic light approach. A higher level of performance was assigned if they scored better (green), a similar performance (yellow) if there was no difference assessed by the respective study, or a lower performance (red) if they scored worse compared with the baseline scenario. We coded every FST that has been assessed in the included literature and compared against a baseline scenario. When different functional unit and system boundary assumptions were applied in one study, we extracted results for each assumption to reduce bias due to modelling choices. Results of the performance analysis stratified by system boundaries and functional units are presented in Supplementary Material Section 6. Duplicates have been removed.

Reporting summary

Further information on research design is available in the Nature Research Reporting Summary linked to this article.

Data availability

All data generated or analysed during this study is available in the Supplementary Data of this article or publicly available at https://doi.org/10.5281/zenodo.6550444 under a CC-BY-4.0 licence. The search strategy and extracted data on included studies is available in the Supplementary Data.

Code availability

The code generated to visualize the results of this study is publicly available at https://doi.org/10.5281/zenodo.6550444 under a CC-BY-4.0 licence.

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Author contributions

The project was conceptualized by all authors. A.C.B. developed the search strategy and conducted peer-reviewed literature searches. A.C.B., A.W. and L.J.G. conducted study screening. Data charting and analysis were done by A.C.B. with feedback from A.W. and L.J.G. Data visualization was done by A.C.B. with feedback from A.H. The original draft was written by A.C.B. and reviewed and edited by L.J.G. and A.H.

Competing interests

The authors declare no competing interests.

Additional information

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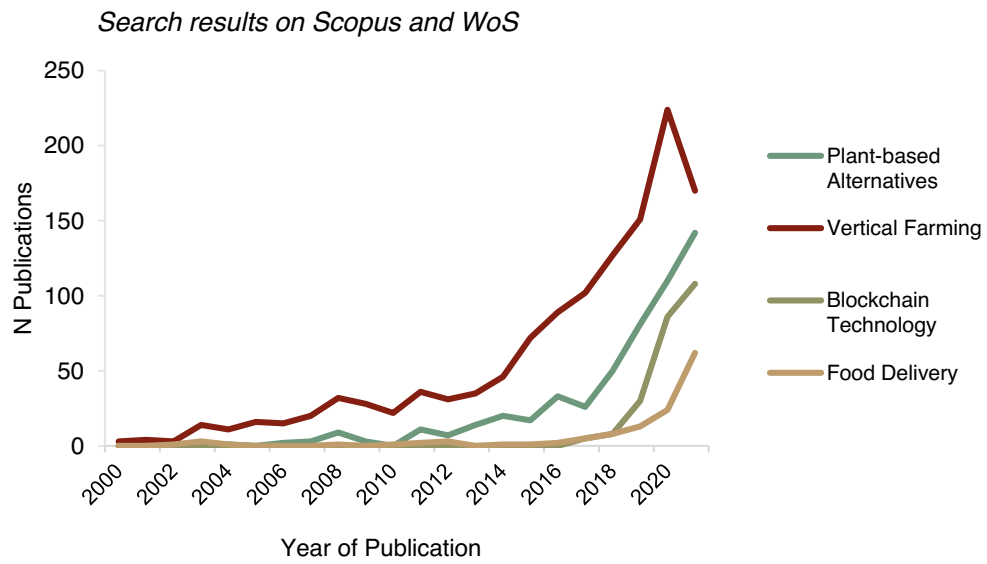**Correspondence and requests for materials** should be addressed to A. Charlotte Bunge.

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Search results on Scopus and WoS

Extended Data Fig. 1 | The increase in peer-reviewed literature assessing the sustainability of the four included FSTs. Search results on Scopus and Web of Science.

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Data collection	The review was conducted following the PRISMA guidelines. Included studies have been identified through systematic review searches in Web of Science and Scopus. The search strategy is provided in the Supplementary Material. The online software CADIMA vers. 2.2.1 was used for study selection and data charting. All inclusion and exclusion criteria are provided in the Supplementary Material.
Data analysis	Data was analyzed and visualized with R version 4.1.2, code is provided publicly available at Zenodo 10.5281/zenodo.6550444 under a CC-BY-4.0 licence.

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Study description	We conducted a systematic scoping review to identify peer-reviewed literature that assessed the sustainability of novel food system technologies. We included quantitative data, qualitative data has been excluded.
Research sample	Peer-reviewed studies that have been published between January 2016- August 2021 and have been available in the databases Web of Science and Scopus. The literature was selected based on search strings that have been tested against a set of defined benchmark articles.
Sampling strategy	We sampled the literature through systematic searches of the peer-reviewed literature. We applied search strings ,that have been previously tested against benchmark articles, to Web of Science and Scopus in order to identify peer-reviewed literature that would meet our eligibility criterion. No statistical measures where applicable to predetermine the sample size as the purpose of this study was to identify how many peer-reviewed studies have been conducted in the field of interest.
Data collection	Literature retrieved from the systematic searches have been tested against the eligibility criteria using the tool CADIMA. Blinding was not applicable to this study.
Timing	Searches have been carried out between 9th-10th September 2021 and data charting was done for all included articles between October and December 2021
Data exclusions	Subjective studies that do not use data to back up the assessment of indicators (e.g. conceptual frameworks); Conference proceedings, book chapters.Papers which do not provide quantitative assessment indicating the sustainability performance of the respective food system technology. Literature published before 2016. Plant-based alternatives exclude cellular alternatives and insects and traditional fermented legumes (tofu/tempeh), as well as meat or dairy hybrids; aqua/hydroponics or urban farms not including the term vertical in the abstract; blockchain technology focusing on a different sector than the food system (e.g. finance or health)
Non-participation	NA
Randomization	NA as we did not conduct human clinical trials, biological experiments or statistical modeling. Randomization is usually not applicable to Systematic or Scoping Reviews.

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