Agricultural Systems 225 (2025) 104270

Contents lists available at ScienceDirect

Agricultural Systems

journal homepage: www.elsevier.com/locate/agsy

Review

Which types of quantitative foresight scenarios to frame the future of food systems? A review

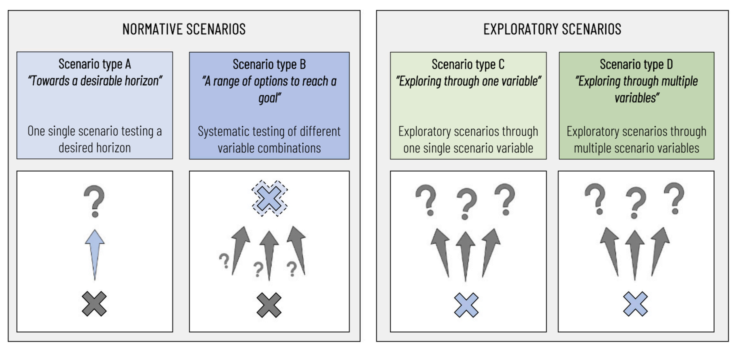
Anton Riera [*], Océane Duluins, Clémentine Antier, Philippe V. Baret

Sytra, Earth and Life Institute, UCLouvain, Croix du Sud 2/ L7.05.14, 1348 Louvain-La-Neuve, Belgium

HIGHLIGHTS

- This study reviews and categorises 36 quantitative food system scenario studies.
- A typology of four scenario types is proposed based on scenarios' purpose and design process.
- Two scenario types are more normative and two are more exploratory.
- Methodological choices are vast and have implications for interpretation.
- Different types of scenarios can be useful in different contexts and purposes.

GRAPHICAL ABSTRACT



ARTICLE INFO

Editor: Mark van Wijk

Keywords:
Foresight
Quantitative scenarios
Food systems
Farming systems
Sustainability
Typology classifications

ABSTRACT

CONTEXT: Quantitative scenarios have become common tools to explore the evolution of agricultural and food systems and their necessary transition towards greater sustainability. Yet, despite the diversity in methods and questions explored, a notable gap remains in methodically categorizing such scenarios.
OBJECTIVES: Through reviewing a broad range of studies, this paper aims to address this gap. It pursues two main objectives: (1) proposing a comprehensive typology classification of distinctive scenario types; (2) delving into the practical implications that diverse scenario designs bring to the forefront.
METHODS: Based on a snowball sampling method, 36 quantitative food system scenario studies were included in the sample and reviewed. A coding process allowed to characterize each scenario based on a set of variables focused on the scenarios' design process (e.g. purpose of the scenarios, number of scenarios tested, scale of analysis, consideration of production systems, sectors of interest, considered sustainability dimensions, etc.). Typology identification involved two iterative rounds of discussion among the authors, based on variables deemed pivotal for distinguishing scenario types.
RESULTS AND CONCLUSIONS: The paper proposes four scenario types of quantitative food system scenarios, centered on the scenarios' purpose and design process. Scenario types A and B are more normative as they seek to demonstrate the feasibility of a specific scenario or frame the conditions for its feasibility, differing in the number of scenarios tested (respectively one and many). Scenario types C and D are more exploratory as they aim to assess the consequences of different scenarios, differing in the number of scenario variables being explored (respectively one and many). Besides the proposed classification, the paper discusses important methodological

* Corresponding author.
E-mail address: anton.riera@uclouvain.be (A. Riera).

https://doi.org/10.1016/j.agsy.2025.104270
Received 20 September 2024; Received in revised form 27 January 2025; Accepted 29 January 2025
Available online 17 February 2025

considerations related to scenario design (e.g. the consideration of multiple sustainability dimensions, the adoption of participatory approaches, etc.).
SIGNIFICANCE: This paper contributes to enhancing coherence across food system foresight studies and helps to ensure that quantitative scenarios are utilized effectively for their intended purposes, such as assessing the feasibility of achieving a goal or evaluating different options.

1. Introduction

1.1. Foresight as a valuable discipline for food system transitions

Agriculture and food systems stand as significant contributors to the global and local environmental challenges faced by societies. Across the nine planetary boundaries related to Earth-system processes as defined by Rockström et al. (2009), agriculture & food systems are concerned with at least five: biodiversity loss, nitrogen and phosphorus cycles, climate change, chemical pollution and land use change (Bowles et al., 2019; Campbell et al., 2017; Foley et al., 2011). As these challenges escalate, questioning the governance and future visions of these systems becomes imperative.

The need for a fundamental transformation in global food systems is clear, calling for a re-evaluation of evolution pathways. Foresight studies constitute a valuable discipline in this perspective. Foresight is understood here as the broad discipline which gathers several sub-schools of thought and terminologies, including future studies, strategic foresight and the French *prospective* approach (Coates et al., 2010). Besides lexicographical differences, each school has its specificities (e.g. in terms of relation with decision-making, or the level of participation and actor engagement) but shares the overarching goal of facilitating the creation of new visions of the future (Coates et al., 2010; McEldowney, 2017). Contrary to forecasting which exclusively relies on the extrapolation of past trajectories to predict insights into the future, foresight adopts a broader perspective, including possible ruptures and critical uncertainties to explore mid- to long-term future situations (de Lattre-Gasquet et al., 2023; McEldowney, 2017; Woodhill et al., 2024). Foresight is embedded into systemic thinking (de Lattre-Gasquet et al., 2023). As such, foresight studies can play an essential role in addressing the uncertainty of potential futures, particularly in the dynamic landscape of agriculture and food systems. Foresight studies can contribute to empowering organisations to anticipate and prepare for forthcoming challenges or opportunities.

1.2. Quantitative scenarios as useful tools in the context of foresight studies

Scenarios, either qualitative or quantitative, emerge as central tools in foresight studies and associated frameworks such as transition management (Dendoncker et al., 2018; Duru et al., 2015; Loorbach, 2010). In particular, quantitative scenarios do so by presenting numerical data through tables and graphs. They consist of simulations that test a set of assumptions with the help of a model (see Box 1 for more detailed definitions of scenario-related terms). Quantitative scenarios offer a robust method to scrutinise the evolution of agricultural and food systems, as exemplified by numerous publications in recent years, particularly in a European context (Couturier et al., 2022; Poux and Aubert, 2018; Rieger et al., 2023; Riera et al., 2019; Röös et al., 2017a; van Selm et al., 2023). This paper positions itself at the forefront of exploring quantitative foresight scenarios within the agriculture and food systems. Our focus extends to the intricacies of quantitative scenario design, unravelling how these scenarios are constructed. We contribute a comprehensive typology categorisation to identify distinctive groups of scenario exercises. Moreover, we engage in a discussion shedding light and insights on the practical implications that diverse scenario designs bring to the fore, marking a significant contribution in the discipline of agricultural and food system foresight.

1.3. Comparative analyses of food system scenarios

The growing interest in foresight and quantitative scenario modelling for scrutinising the inherent uncertainty of food systems and their potential development pathways has spurred several analyses seeking to compare and classify scenario studies. Here we synthesise the findings of four seminal studies that analyse the design and implementation of quantitative foresight approaches within the context of food systems. We focus on existing proposals to classify scenario studies and on methodological considerations regarding scenario design, including elements of scale, sustainability dimensions and themes, production systems and participatory approaches.

Reilly and Willenbockel (2010) employ a classification derived from

Box 1
Definition of scenario-related terms.

Scenarios are defined by the European Environment Agency as *"a plausible description of how the future may develop based on a coherent and internally consistent set of assumptions about key driving forces (e.g., rate of technological change, prices) and relationships. Scenarios are neither predictions nor forecasts but provide a view of the implications of developments and actions"* (EEA, 2017).

Qualitative scenarios employ language or visual symbols, often presented as narrative storylines, to describe existing or potential drivers and strategic future directions (EEA, 2017).

Quantitative scenarios correspond to simulations derived from models following a comprehensive set of assumptions (EEA, 2017). They represent a possible trajectory in time resulting from a set of variables simulated under parameter and input combinations.

Models are mathematical or physical representations of a system that account for all or some of its known properties (EEA, 2017). They allow computing quantitative scenarios by testing the effect of changes in system components on the overall performance of the system.

Scenario variables are the variables (system components) that are affected by scenario assumptions and which, by changing their default value, affect the outcomes of the model.

Scenario exercises consist of individual studies that model one or more quantitative scenarios. Thus a scenario corresponds to one single simulation whereas as a scenario exercise corresponds to the set or family of scenarios tested by authors within one scenario study.

Börjeson et al. (2006), categorizing scenarios based on their purpose. They distinguish between three categories of scenarios, each offering unique insights into the potential evolution of food systems: *predictive* scenarios aim at finding out what will happen, *exploratory* scenarios investigate what might happen, and *normative* scenarios aim to uncover how to reach a certain predefined state. This classification is underpinned by analysing five case studies, representative of the three proposed categories. Regarding sustainability, the authors conclude from their analysis that the concept has been insufficiently explored in its multidimensionality, with overemphasis on 'narratives of growth' (and thus the economic dimension of sustainability) and too little attention to integrated assessments of the economic, biophysical, political and institutional dimensions of the food system (Reilly and Willenbockel, 2010).

Prost et al. (2023) shift their focus to exploring and defining desired futures, particularly supporting agroecological transitions at the farm level. They draw connections between the scale of analysis and the actors leading the foresight exercise, distinguishing between farmer-led scenarios focussed on the farm level, and expert-based scenarios often operating at broader levels (regional, national, European and global). In this regard, they stress the difficulty to integrate such different approaches and scales of operation, with a particular focus on the integration of the farm level. Similarly to Reilly and Willenbockel (2010), Prost et al. (2023) identify that the exploration of desired futures and targets ranges from being based on pre-identified solutions to more open and exploratory answers. Looking at farm-level assessments, the authors also note imbalances in the sustainability dimensions addressed, with a lower level of attention and detail for social sustainability.

Duru et al. (2021) contribute by reviewing six scenarios that quantify greenhouse gas emissions for achieving net-zero emissions by 2050 and shifts in dietary patterns, particularly reductions in meat consumption. Their analysis evaluates scenarios based on two key considerations: whether the climate challenge is primarily addressed through technological improvements or socio-technical behavioural changes, and whether the scenarios exclusively focus on climate objectives or adopt a more systemic approach. By doing so, they bring important considerations on the link between diverse production systems (e.g. extensive or intensive) and the choice of sustainability indicators being assessed (e.g. climate change or biodiversity). They conclude that scenarios focused on technological solutions are mostly climate-centred and tend to overlook biodiversity and health. On the other hand, scenarios considering multiple sustainability objectives (including for example biodiversity and health) are based on more systemic innovations, requiring behavioural and societal changes (e.g. regarding the consumption of animal products) which are more challenging to implement as a greater number of socio-technical barriers need to be removed (Duru et al., 2021).

Finally, de Lattre-Gasquet et al. (2023) scrutinise thirteen foresight studies, including both qualitative and quantitative approaches, with a specific focus on agroecology. Through their analysis, they provide important insights on how food system foresight approaches are currently being implemented. While not proposing an explicit classification, this research sheds light on the main characteristics of foresight approaches. Among other elements, the authors distinguish four (non-exclusive) aims of scenario exercises, including advocacy; structuring debates and navigating diverse futures; analysing and assisting political decision-making; empowerment and capability development. Further, they analyse the geographical scales of analysis and note the potential challenges related to the 'translation of scales'. They also note that the type of participation in foresight is related to scale, with global exercises mostly involving experts and researchers while more local exercises are more likely to engage with a greater diversity of actors. Looking at the sustainability dimensions and themes included and the drivers of change considered, they note high occurrences for land use issues, biodiversity and climate change (the latter being mainly considered as a driver rather than as an outcome) while water resources are not much considered. On the socio-economic side, general food security, wages, profits and trade appear well-researched whereas social sustainability is not frequent.

These comparative analyses collectively underscore the diversity of methods and questions explored in quantitative food systems scenario exercises. However, a notable gap exists in a more systematic classification and analysis of such scenarios. With the burgeoning number of quantitative scenario studies, this paper aims to fill this void. Building on the findings from the four studies presented above, this analysis aims to complement and consolidate them by pursuing two main objectives: (1) propose and/or confirm a stabilising framework to classify quantitative foresight food system studies, and (2) discuss methodological considerations and their implications with regards to elements of scenario design, such as the boundaries of scenario exercises, the inclusion of sustainability dimensions or the consideration of a variety of production systems. Importantly, we aim to base our analysis on a broader and sufficiently diverse set of studies to provide a robust framework which can support further discussions on the design and relevance of food system scenarios.

2. Methodology

2.1. Overview

A four-step methodology was rolled out in the research process: (1) a study selection step allowed to build up the set of studies that would be reviewed; (2) a coding step consisted in reviewing and characterising the selected studies with the help of a set of variables; (3) a typology identification step led to discerning main categories of scenario studies in the sample; (4) an analysis step investigated methodological considerations regarding quantitative food system scenarios.

2.2. Study selection

Initiating the literature review, the identification of studies (Fig. 1) began with two rounds of expert meetings, organised in March and April 2020, which gathered sixteen experts from across Europe. All members had a proven expertise in the subject as they had all previously co-authored or participated in food system scenario studies. Experts were tasked with compiling a list of food system scenarios, while also discussing the nuances of scenario design, encompassing research intentions and outcomes. These expert sessions yielded an initial list of eleven reference studies constituting the basis of our analysis (Table 1). This process led to the writing of a draft working paper based on the eleven reference studies. Building on this work, a more in-depth literature review was carried out in 2022–2023, consisting in an iterative process systematically exploring all studies citing these eleven reference studies, starting with the oldest one (Agrimonde scenarios; Chaumet et al., 2009). This chronological snow-ball sampling process led to the identification of additional studies (6243 citations), which were tested against inclusion/exclusion criteria. The criteria ensured focus on studies proposing new scenario exercises featuring the modelling of one or more quantitative scenario with a specific focus on the food system (Table 2). The analysis in this paper focuses on the scenario exercises as a whole (i.e. the reviewed studies), looking at how individual scenarios are constructed within those exercises. To be noted that reference studies mentioned during the expert sessions were not automatically included in the final list if they did not comply with the inclusion criteria. For instance, van Zanten et al. (2018) was excluded as it does not actually model a new scenario. In first instance, 37 studies were selected based on title and abstract reading. After reading these studies in full, one additional study was excluded as it adopted a qualitative scenario approach (Mitter et al., 2020). As a result, a total of 36 articles were eventually included (Table S1 in the Supplementary material).

2.3. Coding

Moving to the coding process, a set of coding variables was

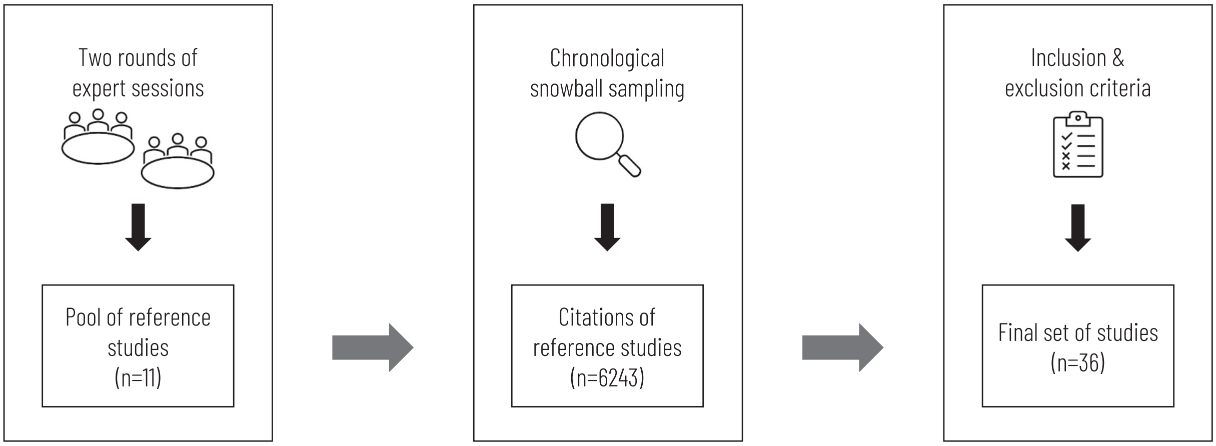


Fig. 1. Methodological approach followed for the selection of analysed studies.

Table 1
Initial compilation of reference studies identified by experts and number of associated citations that were explored as part of the snowball sampling process.

Name of the study	Reference	Cited by
1. Agrimonde: Scenarios and Challenges for Feeding the World in 2050	Chaumet et al., 2009	86
2. Afterres 2050 – Un scénario soutenable pour l'agriculture et l'utilisation des terres en France à l'horizon 2050	Couturier et al., 2016	8
3. Limiting livestock production to pasture and by-products in a search for sustainable diets	Röös et al., 2016	126
4. Agrimonde-Terra: Foresight land use and food security in 2050.	de Lattre-Gasquet et al., 2016	41
5. Protein futures for Western Europe: potential land use and climate impacts in 2050	Röös et al., 2017b	78
6. Strategies for Feeding the World More Sustainably with Organic Agriculture	Muller et al., 2017	495
7. Une Europe agroécologique en 2050: une agriculture multifonctionnelle pour une alimentation saine (TYFA)	Poux and Aubert, 2018	55
8. Less is more: Reducing meat and dairy for a healthier life and planet	Tirado et al., 2018	21
9. Defining a land boundary for sustainable livestock consumption	van Zanten et al., 2018	208
10. Pathways to Sustainable Land-Use and Food Systems	FABLE, 2019	3
11. Food in the Anthropocene: the EAT-Lancet Commission on healthy diets from sustainable food systems	Willett et al., 2019	5122

Table 2
Inclusion/exclusion criteria applied for the selection of studies following the snowball sampling process.

Inclusion	Exclusion
The study focuses on food systems (targeting activities from agricultural production to food consumption)	The study does not focus on food systems (e.g. energy sector; health sciences; etc.)
The study includes a quantitative scenario	The study includes a qualitative scenario approach (e.g. through the development of narratives and storylines)[1]
The study proposes a scenario exercise and models one or more scenarios	The study: - compares different scenarios or models but does not propose a new one[2], - defines targets allowing scenario development[3], - describes the participatory approach that leads to the modelling exercise[4], - describes the software/model used to perform the scenarios[5],
Available online text	Unavailable resources such as books
The study is a scientific report or article	The study is a master's thesis

[1] E.g. Mitter et al. (2020).
[2] E.g. van Zanten et al. (2018).
[3] E.g. van Vuuren et al. (2022).
[4] E.g. Karlsson et al. (2018).
[5] E.g. Kalt et al. (2021).

established to characterize the selected articles, and the scenario exercises they propose (Table S2 in the Supplementary material). Coding variables were initially proposed based on authors' knowledge of scenario design. Five test articles were coded in first instance to calibrate and refine the coding process. Subsequent coding of articles was conducted independently by the authors. The main focus of the coding process resided on elements including the purpose of the scenario exercises, the number of scenarios tested and the number of scenario variables, the adoption of participatory approaches, the time horizon, the scenario boundaries (in terms of geographical scale and analysed sectors), the number of production systems considered and the inclusion of sustainability dimensions.

2.4. Typology identification and classification of studies

Building a typology consists in the "*classification of objects, structures, or specimens by subdividing observed populations into a theoretical sequence or series of groups (types) and subgroups (subtypes) according to consideration of their qualitative, quantitative, morphological, formal, technological, and functional attributes*" (Oxford Reference Dictionary, 2008). The process of delineating a typology involved two iterative rounds of discussion among the authors. Initially, each author submitted two or three variables they deemed pivotal for distinguishing scenario types. As a reminder, the focus of the typology lies on the scenario exercise as a whole, i.e. the set of scenarios tested by authors within one study. The first meeting was dedicated to scrutinising and deliberating these initial proposals. Upon achieving a consensus, the authors were divided in two groups. The first group contributed to formulating descriptions of the identified scenario types and classifying the articles. Subsequently, the remaining authors rigorously tested and scrutinised the classification. Instances of disagreement were carefully discussed, fostering a refinement of both the typology descriptions and the classification of articles. This collaborative process ensured a comprehensive and robust framework for distinguishing scenario types, fostering clarity and coherence in the subsequent analysis.

The selection of variables to categorise studies and identify scenario types centred on two aspects: the purpose or intention of the research and the intricacies of scenario design. On the one hand, purpose delineates whether the desired future is distinctly identified and aligns with a singular more *normative* vision or whether a more open-ended and *exploratory* approach is adopted. On the other hand, scenario design encapsulates both the number of scenarios examined and the variables explored within each scenario (number of variables involved in scenario design and how they influence scenario design). It is pertinent to note that our classification hinges on the methodological approaches to scenario design rather than on the narratives of the scenarios (i.e. the content or storytelling that is being emphasised in the scenarios).

2.5. Analysis of scenario characteristics

Once the scenario types were identified, subsequent analyses delved further into the analysis of the coding variables, describing scenario characteristics and thus enriching contextual understanding. Specific attention was paid to the depth of actors' involvement, the scale of analysis, the consideration of production systems, the considered time horizons, the sectors of interest and the incorporation of sustainability dimensions (social, economic, environmental) within the scenarios. This multi-faceted analytical approach, performed through the lens of the identified typology when possible, facilitated a comprehensive exploration, going beyond the mere classification of scenario types.

3. Results

3.1. Identification of four methodological scenario types

Departing from a set of 36 studies, this review set out to identify different types of food system scenarios. Based on the purpose of the research and the scenario design, a typology composed of four scenario types is proposed (see Graphical Abstract, Fig. 2 and Table 3).

Purpose refers to the normative or exploratory character of the modelling exercise and what is predetermined. One coding variable allows to distinguish two groups in terms of purpose. A first group composed of 15 studies aims to demonstrate the feasibility of a specific scenario or to frame the conditions for its feasibility. A second group, composed of 21 studies, aims to assess the consequences of different scenarios or trajectories. As such, the first group can be considered as more normative whereas the other group can be considered as more exploratory.

Scenario design refers to specific modelling choices. Three coding variables were used to further subdivide the two groups obtained previously: the number of scenarios, the number and set of scenario variables. Within the 'normative group', one subgroup (scenario type A) composed of six studies tests one single scenario based on a unique set of scenario variables. A second subgroup (scenario type B), composed of nine studies, tests multiple combinations of scenario variables, often resulting in many scenarios. Within the 'exploratory group', one subgroup (scenario type C) composed of seven studies explores several scenarios by testing one scenario variable in a 'gradient' perspective. The second subgroup (scenario type D) explores several scenarios by testing multiple sets of scenario variables from one scenario to another.

3.1.1. Scenario type A – Towards a desirable option

Scenario type A delves into the feasibility and outcomes of a specific pre-identified scenario corresponding to a desirable future (Table 3). One single scenario is tested, based on a fixed set of scenario variables. Scenarios within scenario type A can be considered as normative. These studies often focus on a single production system, such as organic or agroecological farming, adopting a *hard sustainability* approach which prioritizes non-negotiable environmental objectives over socio-economic objectives.

3.1.2. Scenario type B – A range of options to reach a goal

Scenario type B studies aim to compare the effects of various scenario variables and identify their optimal combinations to attain predetermined goals, leading to many scenarios (Table 3). The focus is on defining an option space within boundaries, possibly representing the desirable future as a space rather than a specific point. As such, scenario type B can be considered as less normative compared to scenario type A. Scenario type B studies may resort to optimization models (Barbieri et al., 2021; Frehner et al., 2022).[1]

3.1.3. Scenario type C – Exploring through one variable

Scenario type C involves comparing the consequences of different scenarios without predefining a desirable trajectory nor an ideal endpoint. Only the starting point is pre-identified. Scenario type C evaluates scenarios based on a single specific variable (Table 3), such as the share of organic and local food consumed (Billen et al., 2012) or the utilisation of different leftover streams for livestock feeding (van Selm et al., 2022). The goal is to understand how changes in this variable can affect food production, land use, GHG emissions, nutrient flows, and more.

3.1.4. Scenario type D – Exploring through multiple variables

Scenario type D also explores different scenarios without predefining a desirable trajectory nor an ideal endpoint. It does so by examining the effects of multiple variables, which may be different from one scenario to another. As a result, a diversity of scenarios can emerge and new variables can be considered to develop scenarios, making this group the most exploratory (Table 3). Typically, studies in scenario type D group a business-as-usual scenario based on recent trends with one or several alternative scenario(s).

3.2. Characteristics of included studies

Upon identification of scenario types and classification of the sample studies in said categories, the review aimed at enriching the contextual understanding of quantitative food system scenarios through the analysis of several variables. In this section, our sample is presented and disaggregated in quantitative terms for transparency and clarity purposes. While we acknowledge that our sample is not fully representative of all quantitative models, we consider it important to discuss the figures observed within this set of studies. We do so with caution, refraining from generalizing these results to the broader field. These findings and their validity are further discussed and put in the perspective of the existing literature in the discussion and conclusion.

3.2.1. Purpose (classification variable)

Out of the 36 reviewed studies, 15 studies aim at demonstrating the feasibility of a specific scenario or framing the conditions for its feasibility (Table S3 in Supplementary material). As per typology construction, these studies are concentrated in scenario types A and B (except for Billen et al. (2012), classified in scenario type C). The remaining 21 studies adopt a more exploratory stance and aim at assessing the consequences of different scenarios or trajectories. These studies are thus concentrated in scenario types C and D (except for Röös et al. (2017a), classified in scenario type B).

3.2.2. Number of scenarios (classification variable)

The number of scenarios in each study varies considerably, ranging from a single scenario to as many as 56 scenarios. Six studies explore a single scenario, 18 test between two and four scenarios, and 12 test more than four scenarios, showcasing the diverse approaches employed in the reviewed foresight studies (Table S3 in Supplementary material).

[1] Regarding the use of optimisation models, as the classification was not built around this, it could be that scenario exercises resorting to optimisation models would fall under other categories. For instance, Mosnier et al., 2017 uses an optimization model to simulate typical French bovine farms but is classified in category D as the purpose and construction of the scenarios is exploratory.

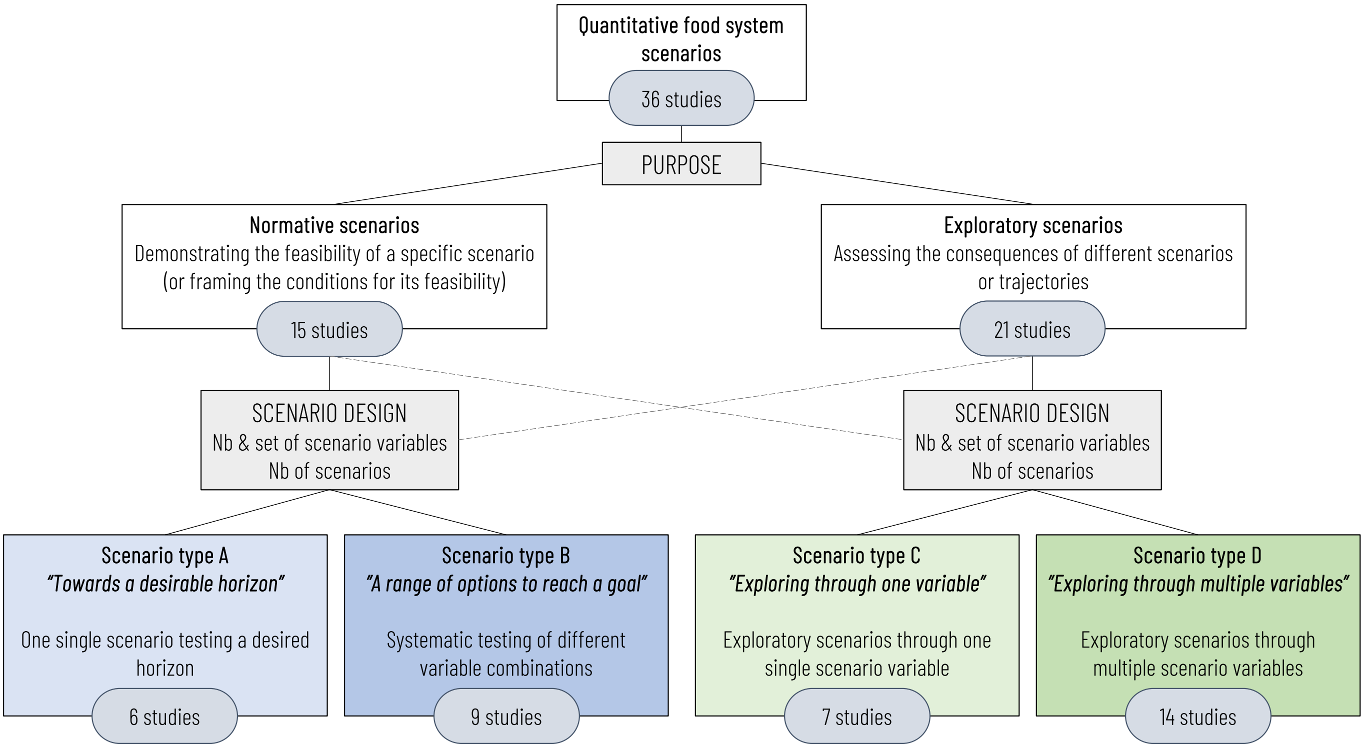


Fig. 2. Construction of a typology of four methodological groups of food system scenarios based on purpose and scenario design.

Table 3
Characteristics of four quantitative food system scenario types, based on purpose and scenario design.

Differentiating factor	Scenario type A *« Towards a desirable horizon »* *(6 studies)*	Scenario type B *« A range of options to reach a goal »* *(9 studies)*	Scenario type C *« Exploring through one variable »* *(7 studies)*	Scenario type D *« Exploring through multiple variables »* *(14 studies)*
PURPOSE				
Modelling purpose	The modelling aims to assess the consequences or demonstrate the feasibility of a specific, pre-identified scenario	The modelling compares and optimises the effects of various combinations of variables to reach specific goals	The modelling explores multiple scenarios by assessing the consequences of the change in one variable along a gradient	The modelling serves to explore contrasted scenarios, assessing and comparing their consequences
What is predetermined	The scenario being tested	The endpoint (space)	The starting point	The starting point
SCENARIO DESIGN				
Number of scenarios	1	Many	Generally, between 2 and 6	Generally, between 2 and 6
Number of scenario variables	Variable	Variable	One variable – Gradient perspective	At least two variables
Set of scenario variables	Fixed (as only one scenario is tested)	Fixed (multiple combinations are tested)	Fixed (as only one variable is considered)	Flexible (the set of scenario variables may change from one scenario to another)

Regarding scenario types, all studies with one single scenario belong to scenario type A by construction. Studies with two to four scenarios are predominantly in scenario types C and D, and studies with more than four scenarios are often in scenario type B. This group habitually leads to many scenarios, with the exception of one study that only tests two scenarios (Padró and Tello, 2022), which is explained by the fact that only two extreme situations are tested although the scenario design could allow a wide spectrum to be tested.

3.2.3. *Research process and participatory approach*

The extent of participation in scenario development, either through experts or through operational actors, greatly varies from one study to another. Out of the 36 reviewed studies, 24 did not rely on participatory approaches, while six relied on expert consultations and six engaged with operational actors (Table S3 in Supplementary material). Participatory approaches served different purposes, such as creating the narrative framework for scenarios, discussing the evolution of critical variables in the coming years, translating qualitative hypotheses into quantitative model inputs, or refining the story post-scenario analysis. With regards to the typology, all approaches engaging with operational actors except one were classified in the exploratory groups C and D, seemingly reflecting a greater participatory approach to scenario development in those categories.

3.2.4. Time horizon

In terms of time horizon, 2050 is the most common target year within our sample (21 studies). Shorter time horizons (2030, 2035 or 2040) or studies specifying no temporal horizon are less frequent (six studies and nine studies respectively; see Table S3 in Supplementary material). This highlights that, within our sample, foresight scenarios seem to be predominantly used for long-term planning.

3.2.5. Scenario boundaries: geographical scale and sectors

Scenario studies can adopt either horizontal approaches (by geographical scope) or vertical approaches (by farming sector) or a combination of both. Horizontal approaches seem to be much more frequent as they are adopted by 21 out of the 36 studies, while only four adopt a vertical approach and nine adopt a combined approach. Territorial approaches thus seem to predominate over sector-specific approaches.

The studies included in the review cover a broad range of geographical scales, from farm-level to global. Of the 36 studies, seven are global in scope, six focus on Europe, eight studies are conducted at the national scale, and six at the regional scale (understood as a sub-national level). Hence, the majority of studies (28) seem to focus on one single scale. In complement, nine studies adopt a multi-scale approach, combining different geographical scales such as regional-to-global, regional-to-national, farm-to-national or farm-to-regional. Additionally, two studies do so by examining multiple countries. Focus within the reviewed studies is on high-income countries and regions. There does not seem to be any effect of the typology on the question of geographical scale as all approaches can be found in all four scenario types (Table S3 in Supplementary material).

In terms of studied sectors, livestock productions are the more investigated within our sample, either on their own (six studies) or in combination with crop sectors (29 studies) (Table S3 in Supplementary material). Crop productions on their own are only studied in one study (Antier et al., 2018). Here too, the four scenario types do not seem to influence the choice of the studied sectors.

3.2.6. Accounting for diversity in scenarios: number of production systems considered

Beyond the inclusion of various sectors, studies showcase a range of approaches in the consideration of different production systems within those sectors. Production systems refer to different methods of producing a specific crop or animal product.

Out of the 36 reviewed studies, only 15 studies account for the diversity of production systems (i.e. more than one production system considered) while 21 studies do not account for it (i.e. either only one production system is considered or none, or no information) (Table S3 in Supplementary material). All studies in scenario type A consider one single production system (or none). As mentioned in the description of the group, these studies often focus on a single production system which they seek to assess (and/or promote), such as organic or agroecological farming. Studies in scenario type B pay less attention to the diversity of production systems (only one third). In scenario types C and D, about half of the studies account for a diversity of production systems.

3.2.7. Sustainability and productivity-related dimensions

The analysed publications approach the different dimensions of sustainability in a diversity of ways through their scenarios. Beyond the three dimensions of sustainability (environment, economy and society), three variable categories are considered for the purpose of this analysis: environmental variables, socio-economic variables and productivity-related variables.

Regarding sustainability, only seven studies cover all three dimensions of sustainability. The environmental dimension (including biophysical factors) is the most considered as it is included in all 36 studies, either on its own (13 studies), or in combination with other dimensions. Eleven studies combine the environment and the economic dimensions while five studies combine the environment and social dimensions. The economic dimension appears in 18 studies, but never on its own. The social dimension is the least studied within the sample as it only appears in 12 studies, and never on its own (Table S4 in Supplementary material). The occurrence of sustainability dimensions is not influenced by the typology.

Looking more specifically at the three variable categories, we find that within the environmental dimension, land use, climate and the nitrogen cycle are the three most common themes considered (24 studies each). Biodiversity, water and the phosphorus cycle show an intermediate occurrence (about 10 studies each). Finally, elements related to acidification, eutrophication, erosion, afforestation and deforestation, soil carbon sequestration, potassium, the use of energy, or the use of pesticides are considered less frequently within the reviewed sample (ranging from two to six studies). Regarding socio-economic variables, trade is the most common variable included in scenario studies (19 appearances). It is followed by economic results (eight appearances, including farmer income and profit), population (six appearances), labour demand and use (four appearances) and health (four appearances). Other element such as food sovereignty, policy implications, prices, animal welfare, etc. all represent two appearances or less. Economic variables are more present compared to social variables. Finally, within productivity-related variables, general production indicators are widespread in all studies (more than 40 appearances, sometimes through several themes in one study). They are followed by food demand (13 appearances), food waste (ten appearances), productivity and yield (ten appearances) and feed production and demand (nine appearances). Other elements such as food balance, technology, the size of the livestock herd and livestock density appear less than five times each. Demand-side variables and dietary shifts are well represented in the sample as only five studies do not analyse them as part of their scenarios.

These variables can either be used as input variables (constraints) or as output variables (results) in the scenario design process, or both. In the majority of reviewed studies, environmental variables are considered as outputs of scenarios. Within our sample, scenarios seem to be more commonly constrained by socio-economic variables, and even more so by productivity-related variables.

4. Discussion

4.1. Relevance of the proposed typology

The proposed typology, resulting from analysing a set of 36 articles, offers a stabilising framework for classifying quantitative food system scenarios into four major scenario types. Previous research, exemplified by that of Börjeson et al. (2006) and mobilised by Reilly and Willenbockel (2010), predominantly constructed typologies from theoretical standpoints, with classifications rooted in the key questions the authors deemed relevant for exploring future scenarios. This paper distinguishes itself by contributing to the literature with a systematic typology based on an existing body of literature. The categories within this typology are defined according to the scenarios' purpose and design (number of scenarios and scenario variables). Compared to existing classifications, the four scenario types proposed show similarities in the distinction between normative and exploratory approaches, as proposed by Börjeson et al. (2006) and Prost et al. (2023), with further fine-tuning related to the choices of scenario design in terms of numbers of scenarios and scenario variables.

In the context of this study, the proposed classification explains the diversity of scenario studies. Within the 36 reviewed studies, only two (Billen et al., 2012; Röös et al., 2017a) presented a conflict between the 'purpose group' and their 'scenario design group' (both were classified according to their 'scenario design group' rather than to their 'purpose group'). This indicates that porous relations between 'purpose groups' and 'scenario design groups' may occur (Fig. 2). Similarly, the three groups mentioned by Reilly and Willenbockel (2010) were not exclusive as some of the example studies belonged to two different groups.

This typology serves as a comprehensive framework for deliberating the choices made during scenario design and publication. On the one hand, these choices may be influenced by diverse factors, such as the goals pursued by scenario commissioners and scenario designers, their focal points of interest, and their alignment with specific development paradigms or world views (Lumbroso, 2019). The availability and ease of use of data, along with the historical and scientific context in which scenarios are designed are additional factors that influence these choices. On the other hand, these choices have a direct impact on the outcomes of the scenarios. Providing a framework that identifies and clarifies the main possible configurations in which scenario design can take place seems crucial to improve their analysis and understanding. Thus, the proposed framework not only aids in discussing the choices made during scenario design but also provides a basis for assessing the relevance of different types of scenario exercises for different scientific and political objectives. For instance, by examining the potential benefits of pursuing a predetermined scenario, studies within scenario type A may contribute to shaping specific visions for a sustainable and desirable agricultural future. In other instances, with the objective of reaching a specific goal, studies within scenario type B open up avenues for understanding the trade-offs and synergies between different variables and their combinations. Similarly, although more exploratory in the sense that they do not seek to reach a specific goal, studies within scenario type C also allow to explore the incremental effects of a specific variable. Finally, studies within scenario type D provide the flexibility to draw a vast range of exploratory scenarios, based on multiple variables.

In considering impact evaluation, various quantitative and qualitative approaches can be employed to gauge the reach and influence of specific scenarios. The framework facilitates a comparative analysis of scenarios, elucidating how they contribute to shaping representations of the future of food systems and potentially influencing or excluding specific development pathways. By showcasing diverse ways to construct scenarios using quantitative modelling and proposing a typology of scenario types, this paper encourages reflection on the strategic aspects of discourse production about the future, actively participating in the transitions of socio-technical systems. Consequently, this research lays the groundwork for assessing scenarios' contributions and impacts on the transformative processes towards more sustainable food systems.

4.2. Exploring methodological considerations of quantitative foresight scenarios

Within this review, an array of challenges and opportunities for scenarios to contribute effectively to transition dynamics emerge. They encompass the consistency and relevance of sustainability dimensions, the role of actor participation, the definition of boundaries, the consideration of diversity and the adoption of food system approaches (including interconnexions between geographical scales, sectors, food system approaches and production systems).

4.2.1. Choice of sustainability dimensions

Of the 36 studies reviewed, all included environmental considerations in their scenarios, predominantly as output variables (e.g. modelling the environmental impacts of a specific scenario) and sometimes as input variables (e.g. modelling the impacts of climate change on the food system). Within the environmental impact categories considered, there appears to be an important imbalance. On the side of the most common themes, the focus on land use, climate and nitrogen can be related respectively to the agronomic and physical feasibilities of certain scenarios, the important attention that has been given to climate change in the last decades (both in the scientific sphere for example through the work of the IPCC, and the contribution of agriculture and food systems to global GHG emissions, but also in the political sphere, for example through international agreements and COP negotiations), and to lasting concerns around nitrogen pollution and local pollution episodes (e.g. in Brittany and in the Netherlands). On the side of the less studied themes, the limited number of studies on the intensive application of pesticides in modern agricultural systems stands out in particular, although this has been the object of recent foresight exercises not included in this review (Mora et al., 2023). This discrepancy gains resonance when contextualized within the broader perspective of global pollution associated with novel entities (in a geological sense), an assessment that has only recently been undertaken (Persson et al., 2022). Overall, the occurrence of environmental themes as mentioned above is in line with that observed in previous analyses (de Lattre-Gasquet et al., 2023; Duru et al., 2021).

With regards to the multidimensional character of sustainability, the findings reveal that about two thirds of the reviewed studies (23 studies) consider socio-economic sustainability dimensions, always in conjunction with the environmental dimension. Only seven studies consider all three dimensions of sustainability. This underscores the current scientific and societal preoccupation with environmental aspects, thereby emphasizing and confirming the need for a multidimensional approach that encompasses all three sustainability dimensions (Binder et al., 2010; de Olde et al., 2016; Diazabakana et al., 2014; Lebacq et al., 2012; Prost et al., 2023; Reilly and Willenbockel, 2010; Riera et al., 2023; Schader et al., 2014).

4.2.2. Actors and their involvement

Scenarios can be developed and used in the context of participatory approaches, providing the opportunity for fostering dialogue and empowering stakeholders. Despite emphasis on such approaches (Fiala and Jacob, 2024; Prost et al., 2023), only a third of studies reviewed in our sample seem to resort to participatory processes, either with experts or with operational actors. According to Fiala and Jacob (2024), participation can be encountered in all kinds of scenario exercises and should thus not be constrained to certain scenario types. This appears to be in contradiction with our results which tend to show that exploratory scenario types C and D are more incline to participation. An explanation to this could reside in the more normative character of scenario types A and B. As studies in these groups pre-establish either the scenarios or their outcomes, participatory approaches may be less needed to explore the possible range of options. Reviewing additional studies would allow to get a better understanding of such a hypothesis given the partial representativity of the sample (see below) and the limited number of studies resorting to participation within the sample.

4.2.3. Setting the boundaries of scenario exercises

Designing scenarios entails questions on the boundaries of the exercise, including the geographical scales and the included sectors. The scenarios under review span various geographical scales, from local to global, each possibly serving different interests and audiences. Interactions among these scales are crucial, though challenging (de Lattre-Gasquet et al., 2023; Prost et al., 2023). While some scenarios can be viewed as viable at a regional or national level, their contextualisation at a larger scale (European or a global) may reveal additional constraints that could question the degree of plausibility of regional and national scenarios. A similar challenge can appear between regional and national scales (Antier et al., 2020; Riera et al., 2019). Expanding a scenario at higher scale may thus be challenging. A possible solution is to account for boundaries defined at a global scale when designing national or regional scenarios. Nonetheless, downscaling global scenarios to the national or regional levels may be challenging too (van Selm et al., 2022). Beyond geographical scales, the boundaries of scenario exercises are also defined by the production sectors included. The sample of studies reviewed illustrates that a diversity of sectors are included in scenario studies, with an apparent greater focus on livestock sectors. Analysing different sectors allows to examine their interdependencies. In particular, crop-livestock interactions and the associated feed-food debate are crucial to consider when designing sustainable food systems (Mottet et al., 2017) but cannot be satisfyingly studied if only plant-based or livestock sectors are considered.

4.2.4. Accounting for diversity in scenarios: the case of production systems

The spectrum of scenario designs unveils distinct scenario types, each possessing unique attributes that dictate their applicability based on specific objectives and contextual intricacies. A pivotal determinant of this relevance lies in the capacity of a model to embrace diverse production systems, allowing to traverse across analytical scales, bridging the micro-level such as that of the farm and the macro-level such as that of policy-making (Lynch et al., 2018; Riera et al., 2023). As observed by de Lattre-Gasquet et al. (2023), the majority of studies reviewed here depart from a shared concern that conventional, input-intensive production systems are not desirable anymore. In response, alternatives must emerge (e.g. under the wide banner of agroecology in de Lattre-Gasquet et al. (2023)). This can be through the consideration of a diversity of production systems, but not necessarily. Our review showcases different approaches in that respect. Overall, less than half of the reviewed studies consider a diversity of production systems (i.e. at least two different production systems). The remaining studies either do not consider any production system but average practices instead, with possible evolutions of certain variables in the scenarios (e.g. Agrimonde scenarios) or focus on one single production system, such as agroecology (Poux and Aubert, 2018) or organic (Smith et al., 2019). This is typically the case of studies in scenario type A.

The question of diversity poses further questions regarding the boundary-defining elements introduced in the previous section: the interconnectedness across sectors and scales. On the one hand, scenarios that incorporate a mix of agricultural or livestock farming systems facilitate discussions on both practices and the systems themselves. This approach can be likened to studies and strategies in the energy sector, where various energy sources are combined. It nevertheless adds a supplementary layer as besides changing the mix of agricultural products, it makes it possible to adapt the mix of production systems. This proves particularly valuable for debating agri-food visions based on "intensive" versus "extensive" systems and assessing their relevance in production and environmental, social, and economic impacts, as in Duru et al. (2021). On the other hand, interconnectedness across scales introduces challenges in meaningful integration. A noteworthy trade-off emerges when contemplating the diversity of production systems while crafting a scenario tailored for Europe compared to a regional-level scenario. The extent of focus, whether local or global, significantly shapes the production systems that can be considered (i.e. to what extent they can represent regional specificities) and thus scenario outcomes. This prompts a critical reflection on the overarching purpose of the model and scenarios, seeking clarity on their underlying intentions and goals. In this sense, the selection of appropriate variables is a critical step in conducting high-quality studies. With relation to scale, constraints, such as data availability, scenario design or scope, can influence this selection. When examining various production systems, regional or national studies may possess the necessary information to differentiate between systems, while international or European studies may rely on an average production system due to data limitations. This constraint significantly impacts the generalizability of findings and the ability to capture the nuances of complex systems at larger scales.

4.2.5. Moving towards food systems: the case of diets

The inclusion of demand-side solutions in scenarios (through alternative diets and a decreased consumption of animal products, mainly in Global North countries) serves as an insightful example to discuss the adoption of food system approaches (as opposed to farming system approaches) and illustrate the diverse challenges related to scenario boundaries and diversity.

By considering dietary shifts, the majority of reviewed scenarios take a first step towards food system approaches. While foresight work focusing on the farming systems is useful, farming systems do not operate separately from the food value chains and related actor networks. Rather, farming systems are embedded in food systems (HLPE, 2017), which themselves are multi-dimensional (Ericksen, 2008). The inclusion of dietary shifts in scenarios is one form of acknowledging this. Additional efforts must be made to complement current scenarios with an assessment of the related changes and necessary efforts by midstream actors, in food processing infrastructures and value chains' strategies (Grabs et al., 2024).

Although the assessment of how much meat and dairy product per capita should be consumed varies among calculations (based on four reference scenarios included the review, target levels range between 16 kg/cap/year of meat and 33 kg/cap/year of dairy products in Tirado et al. (2018); 31 kg/cap/year of meat and 91 kg/cap/year of dairy products in Willett et al. (2019); 41 kg/cap/year of meat and 45 kg/cap/year of dairy products in Couturier et al. (2016) and 41 kg/cap/year of meat and 100 kg/cap/year of dairy products in Poux and Aubert (2018)), all global scenarios show that significant dietary shifts are required, going beyond simple adaptations. First, with regards to sector interactions, studying dietary shits requires to consider both livestock and plant-based sectors as both are impacted by those shifts. Second, with regards to geographical scales, while targets defined at a global level offer a certain flexibility to account for local specificities, those globally defined boundaries are not always taken into account or may be difficult to downscale in scenarios designed at a lower level, as exemplified by van Selm et al. (2022) for the EAT-Lancet diet (Willett et al., 2019).

In the perspective of moving towards food system approaches (approximated here through dietary shifts), the consideration of different production systems also pays a role. As noted by Duru et al. (2021), existing food diets act as a constraint when transitioning from intensive, input-dependent systems to extensive ones. Conversely, a shift towards low-meat diets may facilitate the development of extensive systems. Going further, the selection of environmental themes holds significance in interpreting scenario outcomes. As noted by Duru et al. (2021), climate change indicators tend to be central in technology-oriented scenarios which favour resource-efficient systems, while biodiversity and pesticide use indicators tend to be included in 'multi-functional' scenarios which more frequently lean towards extensive, low-input systems. Such scenarios, which entail higher levels of complexity, are generally harder to implement as they need to overcome more barriers and require greater changes, e.g. in terms of meat consumption. This intricate dance of variables underscores the complexity of scenario design and its implications for sustainable agricultural and food systems.

5. Conclusions, limitations and perspectives

This paper set out to shed light on the intricacies of quantitative food system scenarios. Based on the review of 36 studies, it presents a framework composed of four scenario type groups, corresponding to distinctive ways in which quantitative food system scenarios are being approached, based on the purpose of the scenario exercise and the scenario design process. Besides the identification of a typology of scenario types, this work also delved into the methodological considerations related to scenario design. In particular, it provides insights on how sustainability is being approached in scenario studies, the extent of participation in scenario design and the methodological choices and challenges related to setting boundaries and accounting for a diversity of production systems.

Drawing conclusions on our analysis requires to reflect on its limitations and to identify possible future perspectives. In particular, the snowball sampling methodology comes with limitations in terms of exhaustivity and representativeness as it does not allow to cover the entire literature and systematically capture all relevant studies. As a result, the quantitative considerations presented in the results section should not be extrapolated to all scenario studies without putting them in the perspective of the existing literature, as done in the discussion section. The aim of this study is not to extract precise numerical conclusions from our analyses but rather to identify broader trends and assess whether these are corroborated by the existing literature. For instance, elements on the general occurrence of sustainability dimensions and indicators are confirmed by de Lattre-Gasquet et al. (2023). On the contrary, on the question of participatory approaches, our findings are not aligned with information from Fiala and Jacob (2024), possibly due to our sample being too small. As a next step, applying this framework in a more systematic review would allow to further test, validate and fine-tune the framework. Some additional references have already been identified outside of the snowball sampling method and could constitute a starting point for such an expanded and more comprehensive analysis (Aguilera and Rivera-Ferre, 2022; Barbier et al., 2019; Billen et al., 2024a; Billen et al., 2024b; Busch, 2006; Erb et al., 2016; Hasegawa et al., 2015; Le Noë et al., 2023; Marin et al., 2022; Mora et al., 2023; Popp et al., 2017; van Meijl et al., 2006; Westhoek et al., 2006). Another avenue to further expand and validate the proposed framework would consist in testing the compatibility and validity of the proposed typology in the case of qualitative food system scenarios. While this analysis was limited to quantitative scenarios, there is reason to believe it could fit more qualitative approaches too given the similarity with existing classifications such as that of Börjeson et al. (2006) and mobilised by Reilly and Willenbockel (2010), which seem to accommodate both quantitative and qualitative approaches. Finally, expanding the sector of application beyond the food system and testing the framework in the context of scenario exercises applied to other sectors (e.g. energy, biodiversity) would also constitute an interesting addition. The well-known millennium ecosystem assessment scenarios (Carpenter et al., 2005) and the more recent shared socio-economic pathways (Riahi et al., 2017) could be interesting points of comparison in this regard.

Certain elements of scenario planning and design were not researched, such as the influence of the study commissioners or of the discipline in which scenarios are developed on scenario development. de Lattre-Gasquet et al. (2023) provide elements on this in the case of agroecology. With regards to participation, it is expected that multidisciplinary research settings are more likely to lead to participatory approaches (Fiala and Jacob, 2024). Besides participation in scenario design, a better understanding of how scenarios are taken up by different scenario actors to drive change appears crucial. This retrospective analysis on the impact of quantitative scenarios does not seem to be frequently implemented based on the studies included in this review, as also suggested by Prost et al. (2023) for farm-level transitions. Integrating elements from the French *prospective* approach (although it not systematically relies on quantitative scenarios), may be interesting to this end. With regards to the purpose of scenario exercises, it is important to keep in mind that in the process of scenario design, a choice must be made either to start as close as possible from reality, limiting the level of ambition of the desired horizon, or to propose a very ambitious scenario even if it differs quite significantly from the initial reality and may be perceived as less feasible. Keeping these limitations and perspectives in mind, we believe the proposed classification and analysis provides a useful framework to better grasp the specificities that lie behind different scenarios, thus improving their understanding and the underlying assumptions.

Funding

This research was produced under the Horizon Europe project "FOOODCoST—redefining the value of food", funded by the European Union (HORIZON-CL6-2021-FARM2FORK-01-09; grant n° 101060481).

CRediT authorship contribution statement

Anton Riera: Writing – review & editing, Writing – original draft, Visualization, Methodology, Investigation, Formal analysis, Conceptualization. **Océane Duluins:** Writing – original draft, Methodology, Investigation, Formal analysis, Data curation, Conceptualization. **Clémentine Antier:** Writing – original draft, Supervision, Methodology, Investigation, Formal analysis, Conceptualization. **Philippe V. Baret:** Writing – review & editing, Methodology, Investigation, Formal analysis, Conceptualization.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.agsy.2025.104270.

Data availability

Data will be made available on request.

References

Aguilera, E., Rivera-Ferre, M., 2022. La urgencia de una transicion agroecologica en Espana—Análisis de escenarios, estrategias e impactos ambientales de la transformación del sistema agroalimentario español. Amigos de la Tierra.

Antier, C., Petel, T., Baret, P., 2018. Etat des lieux et scénarios à horizon 2050 de la filière céréales en Région wallonne. Sytra - Earth and Life Institute - UCLouvain.

Antier, C., Riera, A., Baret, P., 2020. A participatory prospective approach fails to ignite a debate on the future of the livestock sector in Belgium. In: Proceedings of the 14TH European IFSA Symposium, 576-589.

Barbier, C., Couturier, C., Pourouchottamin, P., Cayla, J.-M., Silvestre, M., Pharabod, I., 2019. L'empreinte énergétique et carbone de l'alimentation en France—De la production à la consommation. IDDRI. https://www.iddri.org/fr/publications-et-evenements/rapport/lempreinte-energetique-et-carbone-de-lalimentation-en-france-de.

Barbieri, P., Pellerin, S., Seufert, V., Smith, L., Ramankutty, N., Nesme, T., 2021. Global option space for organic agriculture is delimited by nitrogen availability. Nature Food 2 (5), 363–372. https://doi.org/10.1038/s43016-021-00276-y.

Billen, G., Garnier, J., Thieu, V., Silvestre, M., Barles, S., Chatzimpiros, P., 2012. Localising the nitrogen imprint of the Paris food supply : the potential of organic farming and changes in human diet. Biogeosciences 9, 607–616. https://doi.org/10.5194/bgd-8-10979-2011.

Billen, G., Aguilera, E., Einarsson, R., Garnier, J., Gingrich, S., Grizzetti, B., Lassaletta, L., Le Noë, J., Sanz-Cobena, A., 2024a. Beyond the farm to fork strategy : methodology for designing a European agro-ecological future. Sci. Total Environ. 908, 168160. https://doi.org/10.1016/j.scitotenv.2023.168160.

Billen, G., Garnier, J., Pomet, A., Bonnet, B., 2024b. Is food self-sufficiency possible for Reunion Island? Regional Environmental Change 24 (2), 58. https://doi.org/10.1007/s10113-024-02226-3.

Binder, C.R., Feola, G., Steinberger, J.K., 2010. Considering the normative, systemic and procedural dimensions in indicator-based sustainability assessments in agriculture. Environ. Impact Assess. Rev. 30 (2), 71–81. https://doi.org/10.1016/j.eiar.2009.06.002.

Börjeson, L., Höjer, M., Dreborg, K.-H., Ekvall, T., Finnveden, G., 2006. Scenario types and techniques : towards a user's guide. Futures 38 (7), 723–739. https://doi.org/10.1016/j.futures.2005.12.002.

Bowles, N., Alexander, S., Hadjikakou, M., 2019. The livestock sector and planetary boundaries : a 'limits to growth' perspective with dietary implications. Ecol. Econ. 160, 128–136. https://doi.org/10.1016/j.ecolecon.2019.01.033.

Busch, G., 2006. Future European agricultural landscapes—what can we learn from existing quantitative land use scenario studies? Agr Ecosyst Environ 114 (1), 121–140. https://doi.org/10.1016/j.agee.2005.11.007.

Campbell, B., Beare, D., Bennett, E., Hall-Spencer, J., Ingram, J., Jaramillo, F., Ortiz, R., Ramankutty, N., Sayer, J., Shindell, D., 2017. Agriculture production as a major driver of the earth system exceeding planetary boundaries. Ecol. Soc. 22 (4). https://doi.org/10.5751/ES-09595-220408.

Carpenter, S.R., Pingali, P.L., Bennett, E.M., Zurek, M.B., 2005. Millennium ecosystem assessment—ecosystems and human well-being : scenarios, volume 2. Millenium Ecosystem Assessment. https://www.millenniumassessment.org/en/Scenarios.html.

Chaumet, J.-M., Delpeuch, F., Dorin, B., Ghersi, G., Hubert, B., Le Cotty, T., Paillard, S., Petit, M., Rastoin, J.-L., Ronzon, T., Treyer, S., 2009. Agrimonde – Scenarios and Challenges for Feeding the World in 2050. Summary Report. Springer, Netherlands. https://doi.org/10.1007/978-94-017-8745-1.

Coates, J., Durance, P., Godet, M., 2010. Strategic foresight issue : introduction. Technol. Forecast. Soc. Chang. 77 (9), 1423–1425. https://doi.org/10.1016/j.techfore.2010.08.001.
Couturier, C., Charru, M., Doublet, S., Pointereau, P., 2016. Afterres 2050—Un scénario soutenable pour l'agriculture et l'utilisation des terres en France à l'hroizon 2050. Solagro.
Couturier, C., Gibert, C., Richard, A., 2022. Afterres2050—Biodiversité : Un scénario fondé sur la nature & pour la nature. Solagro. https://solagro.org/images/imagesCK/files/publications/f124_afterres2050_biodiversite_2022.pdf.
de Lattre-Gasquet, M., Le Mouël, C., Mora, O., Donnars, C., Dumas, P., Rechauchère, O., 2016. Agrimonde-Terra : Foresight Land Use and Food Security in 2050. Short report of the foresight. INRA & CIRAD.
de Lattre-Gasquet, M., Rostom, F.Z., Hazoumé, T., 2023. Guidance Document on Foresight Processes for Food Systems Transformation through Agroecology. FAO, CIRAD, GIZ.
de Olde, E.M., Oudshoorn, F.W., Sørensen, C.A.G., Bokkers, E.A.M., de Boer, I.J.M., 2016. Assessing sustainability at farm-level : lessons learned from a comparison of tools in practice. Ecol. Indic. 66, 391–404. https://doi.org/10.1016/j.ecolind.2016.01.047.
Dendoncker, N., Boeraeve, F., Crouzat, E., Dufrêne, M., König, A., Barnaud, C., 2018. How can integrated valuation of ecosystem services help understanding and steering agroecological transitions? Ecol. Soc. 23 (1). https://doi.org/10.5751/ES-09843-230112.
Diazabakana, A., Latruffe, L., Bockstaller, C., Desjeux, Y., Finn, J., Kelly, E., Ryan, M., Uthes, S., 2014. A review of farm level indicators of sustainability with a focus on CAP and FADN (Research Report No. D1.2; D1.2, p. 101 p.). auto-saisine. https://hal.archives-ouvertes.fr/hal-01209046.
Duru, M., Therond, O., Fares, M., 2015. Designing agroecological transitions. A review. Agronomy for Sustainable Development 35 (4), 1237–1257. https://doi.org/10.1007/s13593-015-0318-x.
Duru, M., Aubert, P.-M., Couturier, C., Doublet, S., 2021. Scénarios de systèmes alimentaires à l'horizon 2050 au niveau européen et français : Quels éclairages pour les politiques publiques ? Agronomie, environnement & sociétés 11 (1). https://doi.org/10.54800/ssa050.
Erb, K.-H., Lauk, C., Kastner, T., Mayer, A., Theurl, M.C., Haberl, H., 2016. Exploring the biophysical option space for feeding the world without deforestation. Nat. Commun. 7 (1), 11382. https://doi.org/10.1038/ncomms11382.
Ericksen, P.J., 2008. Conceptualizing food systems for global environmental change research. Glob. Environ. Chang. 18 (1), 234–245. https://doi.org/10.1016/j.gloenvcha.2007.09.002.
European Environment Agency, 2017. EEA Glossary [Glossary]. Consulted 21 January 2024. https://www.eea.europa.eu/help/glossary/eea-glossary.
FABLE, 2019. Pathways to sustainable land-use and food systems. In: 2019 Report of the FABLE Consortium. International Institute for Applied Systems Analysis (IIASA) and Sustainable Development Solutions Network (SDSN).
Fiala, V., Jacob, K., 2024. Combining the multi-level perspective framework with participatory scenario development to explore the many facets of food system transitions in Germany. Sustain. Sci. https://doi.org/10.1007/s11625-024-01505-6.
Foley, J.A., Ramankutty, N., Brauman, K.A., Cassidy, E.S., Gerber, J.S., Johnston, M., Mueller, N.D., O'Connell, C., Ray, D.K., West, P.C., Balzer, C., Bennett, E.M., Carpenter, S.R., Hill, J., Monfreda, C., Polasky, S., Rockström, J., Sheehan, J., Siebert, S., et al., 2011. Solutions for a cultivated planet. Nature 478 (7369), 337–342. https://doi.org/10.1038/nature10452.
Frehner, A., Cardinaals, R. P. M., Boer, I. J. M., Muller, A., Schader, C., van Selm, B., van Hal, O., Pestoni, G., Rohrmann, S., Herrero, M., & van Zanten, H. H. E.. (2022). The compatibility of circularity and national dietary recommendations for animal products in five European countries: a modelling analysis on nutritional feasibility, climate impact, and land use. Lancet Planetary Health, 6(6), e475-e483. doi: https://doi.org/10.1016/S2542-5196(22)00119-X.
Grabs, J., Carodenuto, S., Jespersen, K., Adams, M.A., Camacho, M.A., Celi, G., Chandra, A., Dufour, J., Zu Ermgassen, E.K.H.J., Garrett, R.D., Lyons-White, J., McLeish, M., Niehues, I., Silverman, S., Stone, E., 2024. The role of midstream actors in advancing the sustainability of Agri-food supply chains. Nature Sustainability 7 (5), 527–535. https://doi.org/10.1038/s41893-024-01296-9.
Hasegawa, T., Fujimori, S., Takahashi, K., Masui, T., 2015. Scenarios for the risk of hunger in the twenty-first century using shared socioeconomic pathways. Environ. Res. Lett. 10 (1), 014010. https://doi.org/10.1088/1748-9326/10/1/014010.
HLPE, 2017. Nutrition and food systems (no. 12). Report by the high level panel of experts on food security and nutrition of the committee on world food security.
Kalt, G., Mayer, A., Haberl, H., Kaufmann, L., Lauk, C., Matej, S., Röös, E., Theurl, M.C., Erb, K.-H., 2021. Exploring the option space for land system futures at regional to global scales : the diagnostic agro-food, land use and greenhouse gas emission model BioBaM-GHG 2.0. Ecol. Model. 459, 109729. https://doi.org/10.1016/j.ecolmodel.2021.109729.
Karlsson, J.O., Carlsson, G., Lindberg, M., Sjunnestrand, T., Röös, E., 2018. Designing a future food vision for the Nordics through a participatory modeling approach. Agron. Sustain. Dev. 38 (6), 59. https://doi.org/10.1007/s13593-018-0528-0.
Le Noë, J., Gingrich, S., Pichler, M., Roux, N., Kaufmann, L., Mayer, A., Lauk, C., 2023. Combining biophysical modeling and Polanyian theory pleads for a re-embedding of the agricultural system in 2050 in Austria. Environ. Sci. Policy 139, 228–239. https://doi.org/10.1016/j.envsci.2022.11.006.
Lebacq, T., Baret, P., Stilmant, D., 2012. Sustainability indicators for livestock farming. A review. Agronomy for Sustainable Development 33. https://doi.org/10.1007/s13593-012-0121-x.
Loorbach, D., 2010. Transition Management for Sustainable Development : a prescriptive. Complexity-Based Governance Framework. Governance 23 (1), 161–183. https://doi.org/10.1111/j.1468-0491.2009.01471.x.
Lumbroso, S., 2019. Prospective et stratégies pour l'environnement : Entre fabrique des futurs et situation de gestion, quelles prises pour l'action? AgroParisTech - Université Paris Saclay.
Lynch, J., Skirvin, D., Wilson, P., Ramsden, S., 2018. Integrating the economic and environmental performance of agricultural systems : a demonstration using farm business survey data and Farmscoper. Sci. Total Environ. 628-629, 938–946. https://doi.org/10.1016/j.scitotenv.2018.01.256.
Marin, F.R., Zanon, A.J., Monzon, J.P., Andrade, J.F., Silva, E.H.F.M., Richter, G.L., Antolin, L.A.S., Ribeiro, B.S.M.R., Ribas, G.G., Battisti, R., Heinemann, A.B., Grassini, P., 2022. Protecting the Amazon forest and reducing global warming via agricultural intensification. Nature Sustainability 5 (12), 1018–1026. https://doi.org/10.1038/s41893-022-00968-8.
McEldowney, J., 2017. Foresight – Contribution to the Debate on the Future of EU Agricultural Policy. European Parliament Research Service (EPRS).
Mitter, H., Techen, A.-K., Sinabell, F., Helming, K., Schmid, E., Bodirsky, B.L., Holman, I., Kok, K., Lehtonen, H., Leip, A., Le Mouël, C., Mathijs, E., Mehdi, B., Mittenzwei, K., Mora, O., Øistad, K., Øygarden, L., Priess, J.A., Reidsma, P., et al., 2020. Shared socio-economic pathways for European agriculture and food systems : the Eur-Agri-SSPs. Glob. Environ. Chang. 65, 102159. https://doi.org/10.1016/j.gloenvcha.2020.102159.
Mora, O., Berne, J.-A., Drouet, J.-L., Le Mouël, C., Meunier, C., 2023. Foresight : European Chemical Pesticide-Free Agriculture in 2050. INRAE.
Mosnier, C., Duclos, A., Agabriel, J., Gac, A., 2017. What prospective scenarios for 2035 will be compatible with reduced impact of French beef and dairy farm on climate change? Agr. Syst. 157, 193–201. https://doi.org/10.1016/j.agsy.2017.07.006.
Mottet, A., de Haan, C., Falcucci, A., Tempio, G., Opio, C., Gerber, P., 2017. Livestock : on our plates or eating at our table? A new analysis of the feed/food debate. Glob. Food Sec. 14, 1–8. https://doi.org/10.1016/j.gfs.2017.01.001.
Muller, A., Schader, C., El-Hage Scialabba, N., Brüggemann, J., Isensee, A., Erb, K.-H., Smith, P., Klocke, P., Leiber, F., Stolze, M., Niggli, U., 2017. Strategies for feeding the world more sustainably with organic agriculture. Nat. Commun. 8 (1), 1290. https://doi.org/10.1038/s41467-017-01410-w.
Oxford Reference Dictionary, 2008. Typology. The Concise Oxford Dictionary of Archaeology, 2 ed.
Padró, R., Tello, E., 2022. Exploring agroecology transition scenarios : a Pfaundler's Spectrum assessment on the relocation of Agri-food flows. Land 11 (6). https://www.mdpi.com/2073-445X/11/6/824.
Persson, L., Carney Almroth, B.M., Collins, C.D., Cornell, S., de Wit, C.A., Diamond, M.L., Fantke, P., Hassellöv, M., MacLeod, M., Ryberg, M.W., Søgaard Jørgensen, P., Villarrubia-Gómez, P., Wang, Z., Hauschild, M.Z., 2022. Outside the safe operating space of the planetary boundary for novel entities. Environ. Sci. Technol. 56 (3), 1510–1521. https://doi.org/10.1021/acs.est.1c04158.
Popp, A., Calvin, K., Fujimori, S., Havlik, P., Humpenöder, F., Stehfest, E., Bodirsky, B.L., Dietrich, J.P., Doelmann, J.C., Gusti, M., Hasegawa, T., Kyle, P., Obersteiner, M., Tabeau, A., Takahashi, K., Valin, H., Waldhoff, S., Weindl, I., Wise, M., et al., 2017. Land-use futures in the shared socio-economic pathways. Glob. Environ. Chang. 42, 331–345. https://doi.org/10.1016/j.gloenvcha.2016.10.002.
Poux, X., Aubert, P.-M., 2018. An agroecological Europe in 2050 : Multifunctional agriculture for healthy eating. Findings from the Ten Years For Agroecology (TYFA) modelling exercice. IDDRI.
Prost, L., Martin, G., Ballot, R., Benoit, M., Bergez, J.-E., Bockstaller, C., Cerf, M., Deytieux, V., Hossard, L., Jeuffroy, M.-H., Leclère, M., Le Bail, M., Le Gal, P.-Y., Loyce, C., Merot, A., Meynard, J.-M., Mignolet, C., Munier-Jolain, N., Novak, S., van der Werf, H., 2023. Key research challenges to supporting farm transitions to agroecology in advanced economies. A review. Agronomy for Sustainable Development 43 (1), 11. https://doi.org/10.1007/s13593-022-00855-8.
Reilly, M., Willenbockel, D., 2010. Managing uncertainty : a review of food system scenario analysis and modelling. Philos. Trans. R. Soc., B 365 (1554), 3049–3063. https://doi.org/10.1098/rstb.2010.0141.
Riahi, K., van Vuuren, D.P., Kriegler, E., Edmonds, J., O'Neill, B.C., Fujimori, S., Bauer, N., Calvin, K., Dellink, R., Fricko, O., Lutz, W., Popp, A., Cuaresma, J.C., Kc, S., Leimbach, M., Jiang, L., Kram, T., Rao, S., Emmerling, J., Tavoni, M., 2017. The shared socioeconomic pathways and their energy, land use, and greenhouse gas emissions implications : an overview. Glob. Environ. Chang. 42, 153–168. https://doi.org/10.1016/j.gloenvcha.2016.05.009.
Rieger, J., Freund, F., Offermann, F., Geibel, I., Gocht, A., 2023. From fork to farm : impacts of more sustainable diets in the EU -27 on the agricultural sector. J. Agric. Econ. 74 (3), 764–784. https://doi.org/10.1111/1477-9552.12530.
Riera, A., Antier, C., Baret, P., 2019. Study on livestock scenarios for Belgium in 2050. UCLouvain - Sytra 245. https://sytra.be/publication/scenarios-livestock-belgium/.
Riera, A., Duluins, O., Schuster, M., Baret, P.V., 2023. Accounting for diversity while assessing sustainability : insights from the Walloon bovine sectors. Agron. Sustain. Dev. 43 (2), 30. https://doi.org/10.1007/s13593-023-00882-z.
Rockström, J., Steffen, W., Noone, K., Persson, Å., Chapin, F.S.I., Lambin, E., Lenton, T., Scheffer, M., Folke, C., Schellnhuber, H.J., Nykvist, B., de Wit, C., Hughes, T., van der Leeuw, S., Rodhe, H., Sörlin, S., Snyder, P., Costanza, R., Svedin, U., et al., 2009. Planetary boundaries : exploring the safe operating space for humanity. Ecol. Soc. 14 (2). https://doi.org/10.5751/ES-03180-140232.
Röös, E., Patel, M., Spangberg, J., Carlsson, G., Rydhmer, L., 2016. Limiting livestock production to pasture and by-products in a search for sustainable diets. Food Policy 1–13.
Röös, E., Bajzelj, B., Smith, P., Patel, M., Little, D., Garnett, T., 2017a. Greedy or needy ? Land use and climate impacts of food in 2050 under different livestock futures. Blobal Environemntal Change 1–12.

Röös, E., Bajželj, B., Smith, P., Patel, M., Little, D., Garnett, T., 2017b. Protein futures for Western Europe : potential land use and climate impacts in 2050. Reg. Environ. Chang. 17 (2), 367–377. https://doi.org/10.1007/s10113-016-1013-4.

Schader, C., Grenz, J., Meier, M.S., Stolze, M., 2014. Scope and precision of sustainability assessment approaches to food systems. Ecol. Soc. 19 (3), art42. https://doi.org/10.5751/ES-06866-190342.

Smith, L.G., Kirk, G.J.D., Jones, P.J., Williams, A.G., 2019. The greenhouse gas impacts of converting food production in England and Wales to organic methods. Nat. Commun. 10 (1), 4641. https://doi.org/10.1038/s41467-019-12622-7.

Tirado, R., Thompson, K.F., Miller, K.A., Johnston, P., 2018. Less Is More : Reducing Meat and Dairy for a Healthier Life and Planet—Scientific Background on the Greenpeace Vision of the Meat and Dairy System towards 2050. Greenpeace.

van Meijl, H., van Rheenen, T., Tabeau, A., Eickhout, B., 2006. The impact of different policy environments on agricultural land use in Europe. Agr Ecosyst Environ 114 (1), 21–38. https://doi.org/10.1016/j.agee.2005.11.006.

van Selm, B., Frehner, A., de Boer, I.J.M., van Hal, O., Hijbeek, R., van Ittersum, M.K., Talsma, E.F., Lesschen, J.P., Hendriks, C.M.J., Herrero, M., van Zanten, H.H.E., 2022. Circularity in animal production requires a change in the EAT-lancet diet in Europe. Nature Food 3 (1), 66–73. https://doi.org/10.1038/s43016-021-00425-3.

van Selm, B., Hijbeek, R., van Ittersum, M.K., van Hal, O., van Middelaar, C.E., de Boer, I.J.M., 2023. Recoupling livestock and feed production in the Netherlands to reduce environmental impacts. Sci. Total Environ. 899, 165540. https://doi.org/10.1016/j.scitotenv.2023.165540.

van Vuuren, D.P., Zimm, C., Busch, S., Kriegler, E., Leininger, J., Messner, D., Nakicenovic, N., Rockstrom, J., Riahi, K., Sperling, F., Bosetti, V., Cornell, S., Gaffney, O., Lucas, P.L., Popp, A., Ruhe, C., von Schiller, A., Schmidt, J.O., Soergel, B., 2022. Defining a sustainable development target space for 2030 and 2050. One Earth 5 (2), 142–156. https://doi.org/10.1016/j.oneear.2022.01.003.

van Zanten, H., Herrero, M., van Hal, O., Röös, E., Muller, A., Garnett, T., Gerber, P., Schader, C., de Boer, I., 2018. Defining a land boundary for sustainable livestock consumption. Glob. Chang. Biol. 1–10.

Westhoek, H.J., van den Berg, M., Bakkes, J.A., 2006. Scenario development to explore the future of Europe's rural areas. Agr Ecosyst Environ 114 (1), 7–20. https://doi.org/10.1016/j.agee.2005.11.005.

Willett, W., Rockström, J., Loken, B., Springmann, M., Lang, T., Vermeulen, S., Garnett, T., Tilman, D., DeClerck, F., Wood, A., Jonell, M., Clark, M., Gordon, L.J., Fanzo, J., Hawkes, C., Zurayk, R., Rivera, J.A., De Vries, W., Majele Sibanda, L., et al., 2019. Food in the Anthropocene : the EAT–lancet commission on healthy diets from sustainable food systems. Lancet 393 (10170), 447–492. https://doi.org/10.1016/S0140-6736(18)31788-4.

Woodhill, J., Peters, B., Ingram, J., Zurek, M., Dengerink, J., 2024. Foresight for food systems change—using future thinking and scenario analysis for resilience and anticipatory policy making. Briefing paper. Foresight4Food.