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An indicator framework to guide food system sustainability transition – The case of Sweden

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ABSTRACT

Well-aligned food policies are needed at both national and international level to guide food system transformation towards sustainability. Rigorous indicator frameworks are essential in order to facilitate discussion of priorities, enable comparisons, assessment and progress monitoring, and ensure accountability. In this study, we develop a national framework for a sustainable food system, using Sweden as a case. Our framework, the *Food System Sustainability House,* advances the literature on sustainable food system frameworks in three distinct ways. Firstly, it is tailored to a specific national context (Sweden in our case); secondly, it distinguishes between impacts of domestic production arising within territorial boundaries and impacts related to Swedish consumption independent of country of origin; and thirdly, to facilitate policy priorities, it suggests how different dimensions of sustainability are interlinked at a conceptual level. From a scientific perspective, the *Food System Sustainability House* postulates the interlinkages between the societal objectives of the food system, the environmental foundations on which production takes place, and the economic system and governance which in the framework are suggested to function as enablers for an overall sustainable system. From a policy perspective, the framework provides a much-needed basis for assessing food system sustainability by suggesting indicators within a comprehensive set of sustainability themes at national level for monitoring distinct perspectives. It also provides the necessary basis for a discussion on how sustainability dimensions are interlinked.

1. Introduction

Current food production and consumption are not sustainable, neither at global (Willett et al., 2019) nor local levels in many cases, as for example in Sweden (Hallström et al., 2022; Moberg et al., 2020; Wood et al., 2019). Food systems are responsible for one third of global greenhouse gas emissions (Crippa et al., 2021) and current agricultural practices cause serious environmental degradation, which has severe impacts on biodiversity (IPBES, 2019). Low-quality, uniform diets have been shown to be a leading risk factor for premature death (GBD 2019 Risk Factors Collaborators, 2020). At the same time, many small businesses, including the farms that are vital to food systems, struggle under economically unsustainable conditions.

In the absence of effective policy, food system actors are unlikely to

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have sufficient incentives to address adverse impacts arising from their decisions and activities, leaving the negative external effects of food system activities unattended. Well-aligned food policies at both national and international level are needed to support food system transformation towards sustainability, by incentivizing food system actors to internalise their negative environmental and social impacts into their decision making. However, to successfully develop effective policy to support transformation towards sustainable food systems, policy makers need rigorous indicator frameworks that can help in setting priorities, making comparisons, monitoring progress, and holding actors accountable (Brouwer et al., 2020; Dyball et al., 2021; Fanzo et al., 2021). Previous literature has suggested several frameworks for assessing food system sustainability. These include work by Chaudhary et al. (2018), Béné et al. (2019), Fanzo et al. (2021), as well as a recent review by Hebinck et al. (2021). There are also abundant literature on assessing sustainability at the farm business level (Gómez-Limón and Riesgo, 2009; Lynch et al., 2019), but farm-level assessments, many times aimed at incentivizing farmers to take up more sustainable practices, are fundamentally different from frameworks aimed at assessing the food system as a whole. To assist policymaking in developing coherent and effective food system policies, operationalized frameworks at the food system level are needed. Existing sustainable food system frameworks need further development in three distinct areas. Firstly, many existing frameworks are developed for global assessments and comparisons across countries. However, to effectively guide policy at a local (national) level and be legitimate and salient to local policymakers, frameworks need to be tailored towards the specific context where they will be used. Secondly, to be comprehensive, inform different types of policy interventions and to avoid e.g. leakage of emissions and other negative impacts from trade (Davis and Caldeira, 2010), these tailored national frameworks need to distinguish between impacts of the food system associated with production (territorial activities) and with consumption (including imports). Thirdly, food system frameworks today provide little insight into how sustainability dimensions (social, economic and environmental) may be interlinked at a conceptual level. This means that they do not contribute to facilitating priorities in situations where there are tradeoffs between sustainability goals. In this paper, we take the position that sustainable food system frameworks already at the conceptual level should facilitate establishing priorities between sustainability dimensions, based on a conceptual understanding of food system sustainability. The overall aim of this paper is to develop a national indicator framework, which can be used to guide national food system sustainability transition by highlighting core features of a sustainable national food system. To achieve the aim, we develop a conceptual model of a sustainable food system, suggest indicators to monitor impact in relevant sustainability themes affected by such transition and conduct an inventory of data sources that can be used for food system sustainability assessment, using Sweden as a case. In particular, we suggest that a conceptualisation of a sustainable food system should focus on (i) the environmental dimensions, representing the pre-conditions for a functioning food system; (ii) the social dimensions, representing the overarching objectives regarding what the food system should achieve; and (iii) the economic dimensions and governance, functioning as "enablers" that facilitate implementation of system objectives, while environmental pre-conditions are respected. We propose the use of a *house* as a metaphor to represent a sustainable food system, to illustrate how the ceiling (societal dimensions), walls (economic dimensions and governance) and floor (environmental dimensions) are interlinked and all needed in their specific place. The ambition of the *Food System Sustainability House* is to provide a tool that can facilitate the development of integrated local food policies and evaluate progress toward food systems targets (or as Hebinck et al. (2021) put it, *"[to] visualise the (lack of) progress vis-a-vis key sustainability goals"*). Analysis based on the Food System Sustainability House developed here can help establish priorities for actions and policy designs in situations where not all sustainability concerns can be simultaneously approached.

In this article, we build on previous work in food system sustainability assessment to develop a targeted and operational national indicator framework which can be used for assessing in a comprehensive manner the sustainability of the food system. We use Sweden as a case study region. However, our novel advancements at the conceptual and methodological level are relevant to any country seeking to make its food system more sustainable. We differentiate between production and consumption, and include both in the food system indicator framework. This is particularly relevant in a country such as Sweden, where a substantial share of total food consumption (about half in monetary terms) is produced outside of the country's borders.

2. The Swedish food system – features and current monitoring

Production and consumption of food in Sweden have undergone profound transformation over time, spurred by the liberalisation of trade, on-farm structural changes leading to fewer but larger and more specialised farms, and concentration in the retail and food industry sector to relatively few actors (OECD, 2018). To sustain current consumption patterns, Sweden is presently characterised by a reliance on imported food, in particular for fruit and vegetables (e.g., for tomatoes, only around 20% of the market share was Swedish during the last four years), and beef (about 60% of the market share was Swedish in 2021), while the production of cereals most years exceeds domestic demand and is exported (Swedish Board of Agriculture, 2022a). Moreover, Swedish agriculture relies heavily on various imports of inputs such as fossil fuels, synthetic fertilisers and protein feedstuff (Eriksson, 2018).

Overall, Swedish food consumption exerts considerable environmental pressure, not only within the country's borders but also abroad (Cederberg et al., 2019). In regard to the Swedish diet, Cederberg et al. (2019) found that 83% of the use of antimicrobials in livestock production, 61% of greenhouse gas emissions, and 75–97% of the pesticide footprint took place outside Swedish borders in 2013, which illustrates the importance of monitoring the impact of the food system independent of the origin of the food. Nevertheless, territorial assessment of the food system is also important for several reasons. Each producing country is responsible for its territorial activities, in this case e.g. agriculture and food processing, and can influence these through different types of national policies. Furthermore, each country has its own specific challenges. For Sweden, the vulnerable status of the Baltic Sea, with excessive nutrient inputs leading to severe eutrophication (HELCOM, 2018), and biodiversity losses caused by intensification of agriculture in the plains and abandonment of valuable semi-natural grasslands in forest-dominated areas (Eriksson, 2022), are important areas of concern. Regional impacts and concerns thus need to be monitored and legislation and policies implemented on a territorial level.

Despite widespread access to diverse and high-quality foods, poor diets currently pose one of the greatest risks for disease and premature death in Sweden (GBD 2019 Risk Factors Collaborators, 2020). Swedish dietary guidelines recommend that current consumption of fruits and vegetables, legumes, whole grains and seafood should increase, whereas consumption of nutrient-poor foods (e.g., sweets and snacks), red and processed meat and overconsumption of food and energy should be reduced (The Swedish Food Agency, 2022). In 2015, Sweden became one of the first countries globally to include environmental sustainability perspectives in the official dietary guidelines (FAO, 2021). In 2023, the Nordic Nutrition Recommendations, upon which the Swedish dietary guidelines are largely based, were updated with the aim of integrating environmental factors into the dietary guidelines (Gonzales Fischer and Garnett, 2016). The Swedish Food Agency has further proposed goals for increasing food sustainability and how progress towards these goals can be monitored using indicators for food consumption (SFA, 2021).

Sweden is currently monitoring the status of 16 environmental quality objectives, of which few are on track to be met (Swedish

Environmental Protection Agency, 2022). Several of these are closely tied to domestic food production (Moberg et al., 2020). In addition, Statistics Sweden, in collaboration with several other government agencies, monitors the progress towards the implementation of the 2030 Agenda in Sweden using both the global indicators and indicators adapted to the Swedish context. Several of these indicators have clear links to the food system, in particular to Goal 2, entitled *End hunger, achieve food security and improved nutrition and promote sustainable agriculture* (Statistics Sweden, 2022).

As illustrated above, there are already numerous indicators in place for the monitoring of (part of) the food system in Sweden. However, although these indicators are adapted to the Swedish context, they still do not encompass the entire food system, since they have a specific entry point (healthy diets or healthy ecosystems) or have originally been designed for broader purposes, e.g., Agenda 2030, which make them less suitable for the specific conditions in a country such as Sweden. The need for a comprehensive, consolidated and tailored monitoring framework is further underlined by the many existing and sometimes contrasting perspectives among different actors regarding what constitutes a sustainable food system, and thus what measures to focus on (Röös et al., 2023).

3. Towards a Food System Sustainability House

The FAO (2021) defines a sustainable food system as one *"that delivers food security and nutrition for all in such a way that the economic, social and environmental bases to generate food security and nutrition for future generations are not compromised*". Hebinck et al. (2021) use a somewhat more refined definition, considering food systems as sustainable when they can provide diets that are *"healthy, adequate and safe … while safeguarding a clean and healthy planet"*. They also emphasise that in achieving these goals, food systems need to be economically thriving, just, ethical and equitable.

Although general definitions of food system sustainability of the kind mentioned above may be accepted by many as outlining the overarching sustainability goals of the food system, it is when these all-encompassing definitions are broken down into measurable entities—e.g., as indicators in indicator-based sustainability frameworks—that the concept of a sustainable food system is ultimately defined. This means that the definition of "sustainability" is heavily influenced by the creators of the frameworks, as it will reflect their own perspectives and priorities (Slätmo et al., 2017). Recent sustainable food system frameworks which we use as our starting point (Béné et al., 2019; Chaudhary et al., 2018; Fanzo et al., 2021; Hebinck et al., 2021) have been developed from extensive literature reviews and can be taken as representing the current state-of-the-art in the literature on sustainable food system frameworks. Still, current frameworks do not, at a conceptual level, postulate the interrelations between sustainability dimensions, and therefore do not facilitate setting priorities between different types of sustainability dimensions.

Against this background, we structure the *Food System Sustainability House* (Fig. 1) along three fundamental features of a sustainable national food system. The *Food System Sustainability House* helps to clarify the role of the economic system and of governance in a sustainable national food system, and how the sustainability dimensions are linked at an overall level:

- A **ceiling** of societal objectives that the national food system would need to achieve. From a societal perspective, these goals constitute much of the *raison d'être* of the food system, and relate to healthy and safe diets for all and to ensuring a just, equitable and ethical food system (Béné et al., 2019; Chaudhary et al., 2018; Fanzo et al., 2021; Hebinck et al., 2021). Focusing on a national food system as we do in this paper, the societal objectives are considered at a national level.
- A **foundation** of environmental pre-conditions that cannot be breached by actors in a sustainable national food system. The planetary boundary concept (Rockström et al., 2009) functions as a basis for deriving targets for such pre-conditions (though downscaling these to national level targets is fraught with difficulties). Here, we focus on a clean and healthy planet, following (Hebinck et al., 2021), to describe the environmental foundation, with the addition of aspects related to the management of natural capital indispensable to food production (e.g., land and water resources). The foundation of the *Food System Sustainability House* represents the prerequisites for the food system to achieve its societal goals. As a metaphor, it symbolises the foundations of the food system: if the environmental foundations are undermined, the system faces a risk of collapse, and thus cannot achieve its societal goals.
- **Walls,** linking the floor to the ceiling by enabling the food system to achieve its social goals while respecting the environmental boundaries. In the *Food System Sustainability House,* there are two types of enablers: (i) The economic system: a market-based food system such as Sweden's is dependent on firms that can uphold sufficient production. A well-functioning economic system where profitable and resilient firms can uphold food production and distribution over time is needed to ensure that the overall system can deliver on its societal objectives. (ii) A governance system that functions to ensure that adverse effects on ecosystems and public health and well-being are internalised into the economic decision making of food system actors, while the system delivers on its societal goals of delivering

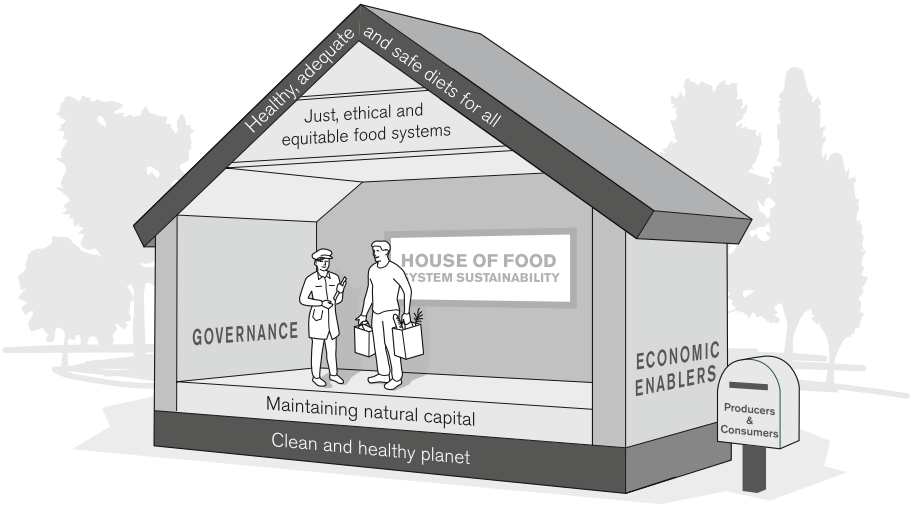

Fig. 1. The Food System Sustainability House illustrating our framework for monitoring consumption and territorial impacts.

healthy diet to all from a fair and equitable system. This means a governance system which supports actors to achieve sustainable primary production, food processing and retail, and consumption. In economic terminology, the adverse effects on ecosystems and public health and well-being by food system activities can be thought about as negative external effects of those activities. The role of the governance system is thus to ensure that those negative external effects are considered in individuals' decision making and that more sustainable practices are adopted. At the same time, the food system firms can organise their activities in such a way that they are profitable and resilient.

The *Food System Sustainability House* helps to discuss, at a conceptual level, tradeoffs between different sustainability dimensions by clarifying the different, and unique, roles played by each dimension of a sustainable food system. It also helps to clarify the functioning of the economic system and governance as enablers of a sustainable food system, and the role they have in relation to the other parts of the system. This role constitutes the foundation for a conceptual clarification of the economic system and governance. Themes and indicators which function to capture the role and function of the economic system and of the governance structure to enable a sustainable food system can be considered a blind spot in existing sustainable food system frameworks. In this paper, we therefore aim to develop such themes and indicators for the Swedish food system.

Aiming for a framework that can be used in practice, we worked with Swedish consumption and the territorial impacts of Swedish production of food as a case study. Studying this national case while developing the framework helped us to identify ways in which food system sustainability could be monitored today, and in the near future, depending on data availability. Each nation has its own specific consumption and territorial impacts, but our framework outlines how they could be handled for any nation.

4. Operationalising the Food System Sustainability House for Sweden

4.1. Approach

Based on the *Food System Sustainability House* and using the Swedish food system as an example, themes, sub-themes and indicators which can be used to trace performance in relation to the following were derived:

a. How well the food system delivers on its societal objectives, focusing on objectives at a national level, these are themes, sub-themes and indicators which can be used to assess health impacts, food security impacts and features related to a just, equitable and ethical food system;
b. How well the food system manages to stay within targets concerning environmental impacts and resource use, at territorial and non-territorial level, these are themes, sub-themes and indicators which can be used to assess effects on the environmental impacts and preconditions for food production;
c. How well the economic system performs in relation to the conditions that need to be in place to ensure continued production of the food system firms at a level that is necessary to deliver on the societal objectives;
d. How well the governance structures function in supporting food system actors to handle externalities caused by their activities and to keep within the *Food System Sustainability House*; i.e., not eroding the environmental foundation, while delivering on the societal objectives that the food system needs to achieve.

Sub-themes and indicators were selected based on the following three-step approach:

a. Firstly, we gathered sub-themes and indicators for each theme based on those used for similar themes in previous literature on food system sustainability assessment (Béné et al., 2019; Chaudhary et al., 2018; Fanzo et al., 2021; Hebinck et al., 2021).
b. Secondly, we adapted the selection of indicators to fit the context of Sweden and the conceptual framing of a sustainable national food system based on the *Food System Sustainability House*.
c. Thirdly, where necessary, we suggested how additional indicators could be developed to fully cover the context of Sweden and the conceptual framing used in this paper.

Results, highlighting themes, sub-themes, indicators and suggested data sources, are displayed in Table 1.

Data sources for assessment of indicators are suggested alongside each indicator. Where applicable, we provide two separate indicators for each sub-theme: one assessing the performance of production systems within Swedish boundaries (territorial indicator), and one assessing the impacts arising domestically and abroad due to Swedish food consumption (consumption-based indicator). The former aims to capture all sustainability impacts of the Swedish food system that occur within Swedish borders, across the supply chain—including production of agricultural inputs, primary production, food processing and retail, and transport—*regardless of whether the resulting products are consumed in Sweden or abroad*. In contrast, the latter aims to capture all sustainability impacts, across the supply chain, linked to food products consumed in Sweden, *regardless of where those impacts occur*.

Thus, these indicators build on the efforts of greenhouse gas accounting to complement territorial emissions—which have historically been the basis of emissions reporting under the United Nations Framework Convention on Climate Change (UNFCCC)—with consumption-based emissions estimates to inform policy and help avoid carbon leakage (Davis and Caldeira, 2010). The two complementary perspectives also help inform policy to address Sweden's so called *Generational Goal*—which states that the country should handle its major environmental problems before handing over to the next generation.

4.2. The food system ceiling

The ceiling of the *Food System Sustainability House* for Sweden consists of two overarching themes following Hebinck et al. (2021): *Healthy, adequate and safe diets for all* and *Just, equitable and ethical food systems*.

4.2.1. Healthy, adequate and safe diets for all

To capture the first component of the food system ceiling, *Healthy, adequate and safe diets,* we selected three themes and developed associated sub-themes and indicators: (1) Healthy and Adequate Diets, with sub-themes *Diet quality*, *Nutrient adequacy* and *Energy balance*; (2) Food Safety, with sub-themes *Foodborne disease* and *Antimicrobial resistance*; and (3) Food Availability, with sub-themes *Food available from Swedish production*, *Trade possibilities of food products* and *Stable commodity prices* (Table 1). Indicators and data sources suggested for measuring each sub-theme are presented in Table 1.

The theme Healthy and Adequate Diets includes indicators intended to measure the complex relationship between diet and health at three distinct levels based on intake of foods, nutrients and total energy. The selected indicators have been proposed to monitor nutrition- and health-related aspects in previous food sustainability frameworks (e.g., Fanzo et al., 2021; Hebinck et al., 2021; Béné et al., 2019; Chaudhary et al., 2018). The food groups and nutrients proposed to be measured in the *Food System Sustainability House* were those identified as most critical for achieving healthy diets in the Swedish population. Diet diversity is not measured per se but is assumed to be captured by including a combination of indicators focusing on both diet quality and nutrient adequacy. In the literature, several diet and nutrient quality scoring systems are described, including some specifically developed to capture a Swedish perspective (Bianchi et al., 2020; González-Padilla et al., 2022; Moraeus

Table 1
Themes, sub-themes, indicators and suggested data sources by territorial and consumption dimensions.

Themes	Sub-themes	Territorial indicators	Suggested sources of production data and comments regarding data	Consumption indicators	Suggested sources of consumption data and comments regarding data
Ceiling of the food system sustainability house					
Healthy, adequate and safe diets for all	***Healthy and adequate diets***				
	Diet quality	*n.a.*	*n.a.*	Mean population intake of critical food groups in relation to food-based dietary guidelines	National dietary surveys (Swedish Food Agency, 2012, 2018)
	Nutrient adequacy	*n.a.*	*n.a.*	Mean population intake of critical nutrients per day in relation to reference values for nutrient intake	National dietary surveys (Swedish Food Agency, 2012, 2018)
	Energy balance	*n.a.*	*n.a.*	Body mass index (BMI) (kg/mass^2)	Public Health Agency (2022)
	Food safety				
	Foodborne disease	*n.a.*	*n.a.*	Clinical reported cases of foodborne illness (per year and per number of individuals)	Public Health Agency (2022), Swedish Food Agency (2019)
	Antimicrobial resistance	Sales of antibiotics for different animal species used for food production (mg per population corrected unit)	Swedish Board of Agriculture (2022b)	Antimicrobal resistance value for imported foods to supply Swedish diets	An antimicrobal resistance value indicator can be calculated based on information about sales of antibiotics in the supplying country (when such data exist), or based on information about the existence of national laws that regulate the use of antibiotics for animals and an estimation about compliance with such regulations, and based on the total amount of imported animal-based products from the respective country.
	Food availability				
	Food available from Swedish production	Domestically produced nutrients off the fields, and domestically produced fruit & vegetables in relation to the population need.	Swedish Board of Agriculture (2023a), The Swedish Food Agency (2023)	*n.a*	*n.a*
		Domestically produced nutrients and fruit and vegetables that reach the consumer, in relation to the population need	Swedish Board of Agriculture (2023a), The Swedish Food Agency (2023)	*n.a*	*n.a*
	Trade possibilities of food products	*n.a.*	*n.a.*	Diversity of trading connections (index)	Information about trade partners for food products can be accessed via FAOSTAT (2023)
	Stable commodity prices	*n.a*	*n.a.*	KPI-J/wage increases (index), where KPI-J is the consumer price index for agricultural products	Swedish Board of Agriculture (2023a) and The Swedish National Mediation Office (2023)
Just, ethical and equitable food systems	***Market concentration***				
	Extent of market concentration	Learner index	An index can be estimated based on data from Statistics Sweden (2023a)	*n.a.*	*n.a.*
	Working conditions				
	Safe jobs	Sick leave due to occupational accident or disease (no of days during a specified time period, e. g. per year)	Statistics Sweden (2023b)	Share of sales of food products with fair trade certification, from fair trade eligible countries	Fairtrade (2023)
		Report of serious personal injuries, serious incidents and deaths. (no of days during a specified time period, e.g. per year)	The Swedish Work Environment Authority (2023)		
	Social benefit coverage	Incidence of unreported salaries in the food system, divided by the total number of workers. (no of days during a specified time period, e.g per year)	The Swedish Tax Authority (2023), outcome of random controls		
	Contribution to cultural values				
	Attractive landscapes	Area of pasture (thousands of ha)	Swedish Board of Agriculture (2023a)	*n.a.*	*n.a.*

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Table 1 (*continued*)

Themes	Sub-themes	Territorial indicators	Suggested sources of production data and comments regarding data	Consumption indicators	Suggested sources of consumption data and comments regarding data
	Preservation of food related traditions	People educated per year in artisan food preparation (no per year)	Eldrimner (2023)	*n.a.*	*n.a.*
		Livestock from threatened breeds kept (no of animal units per year)	Swedish Board of Agriculture (2023b)	*n.a.*	*n.a.*
	Recreational values	Farms that provide recreational activities (no)	To be developed based on data from Swedish Board of Agriculture (2023c) and the European Commission (2023a)	*n.a.*	*n.a.*
	Rigths of indigenous people	Reindeer owners in Sweden (no)	Sami parliament (2023)	*n.a.*	*n.a.*
		Ratio of public institutions (schools, elderly care etc.) that offer meals reflecting the rights of indigenous people	Data is currently not available. Indicator needs further development.	*n.a.*	*n.a.*
	High animal welfare				
	Total animal welfare index	Total animal welfare index for animals in production	Index based on number of animals involved in production, the animal species abilities to perceive negative effects and an animal welfare assessment of the production system.	Total animal welfare index for all animals used for total consumption of animal products	Index based on number of animals involved in production, the animal species abilities to perceive negative effects, animal welfare legislation in the country of production and law compliance in these countries.
Floor of the Food System Sustainability House					
Clean and healthy Planet	***Climate stabilisation***				
	Greenhouse gas emissions	Greenhouse gas emissions from food production, reported separately per gas (Mt) and in Mt CO_2-equivalents	Statistics Sweden (2023a,b,c,d,e,f,g) for agricultural production and land-use change; data on downstream emissions are currently not available from official statistics, but can be estimated using the PRINCE methodology (see Cederberg et al., 2019 for details).	Greenhouse gas emissions from food consumption, reported separately per gas (Mt) and in Mt CO_2-equivalents	Statistics Sweden/EXIOBASE (Stadler et al., 2018) (for fossil CO_2, CH_4 & N_2O), and (Pendrill et al., 2022) (for CO_2 from land-use change)
	Biodiversity conservation				
	Terrestrial biodiversity	Pollinator abundance and diversity	Indicator to be developed based on a new national pollinator survey program focused on agricultural landscapes Swedish University of Agricultural Sciences (2023).	Area of total agricultural land used per year (Mha)	Can be calculated based on data on yearly food consumption from Statistics Sweden and yield levels from the Swedish Board of Agriculture for Swedish produce and FAO for imported foods, see Moberg et al. (2020). Or from physical-based trade models (Kastner et al., 2012) or from multi-regional input-output (MRIO) models (Stadler et al., 2018).
		Farmland bird index	Data based on long-standing surveys of birds by Lund University (2023)	Extinctions per million species year (E/MSY)	Calculated based on the total use of agricultural land and factors in (Chaudhary and Brooks, 2018), see Moberg et al. (2020)
		Area of semi-natural grasslands (ha)	Digital maps from the Swedish Board of Agriculture (2023d), inventory of small biotopes by the Swedish Board of Agriculture (2023e) and data from Lantmäteriet (2023)	*n.a.*	*n.a.*
		Area of small biotopes (ha)	Digital maps from the Swedish Board of Agriculture (2023d), inventory of small biotopes by the Swedish Board of Agriculture (2023a) and data from Lantmäteriet (2023)	*n.a.*	*n.a.*
	Aquatic biodiversity	The Maximum Sustainable Yield (MSY) index	Swedish Agency for Marine and Water Management (2022)	Share of fish in diets that are certified or rated as green in WWF's Fishguide	Data are not available.
		Area of marine protected areas (Mha)	Statistics Sweden (2023d)		
	Diversity of domesticated plants and animals	Diversity in production index for animal and crops species respectively	Swedish Board of Agriculture (2023b) and Swedish Board of Agriculture (2022c)	No of species of animals (including breeds) and plants (including sorts) in the diet/yr	Dietary surveys by the Swedish Food Agency (2012; 2018)

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Table 1 (*continued*)

Themes	Sub-themes	Territorial indicators	Suggested sources of production data and comments regarding data	Consumption indicators	Suggested sources of consumption data and comments regarding data
	Preservation of natural resources				
	Land use	Amount of cropland used per year for production (Mha)	Swedish Board of Agriculture (2023a)	Area of cropland used for Swedish food consumption (Mha)	FAOSTAT calculated according to methodology in Moberg et al. (2020)
	Water use	Total blue water used in food production (m^3 per year)	Statistics Sweden (2021a)	Total blue water used for food consumption (m^3 $year^{-1}$ per year)	Calculated according to methodology in Moberg et al. (2020)
		Level of water stress – freshwater withdrawal as a proportion of available freshwater (%)	United Nations (2023)	Scarcity adjusted blue water use (m^3-eq per year)	WULCA (2023)
	Energy use	Primary energy use in food production in Sweden (MJ per year)	Swedish Energy Agency (2022a) and Swedish Energy Agency (2022b)	Primary energy use due to Swedish food consumption (MJ per year)	For energy use in Swedish agriculture: Swedish energy agency, for energy use to produce inputs: Import/use of agricultural inputs from e.g. Statistic Sweden and coupled energy use factors from literature. For energy use in Swedish Food industry: Swedish Energy Agency. For energy use of imported food: Research projects, I/O databases e.g. Exiobase
	Mineral fertiliser use	Use of virgin P (Mt per year)	Statistics Sweden (2023b)	Use of virgin P due to Swedish food consumption (Mt P per year)	Moberg et al. (2020)
	Clean air and water				
	Eutrophication	N and P surpluses on Swedish agricultural land expressed in total and per ha	Statistics Sweden (2021b). Statistics Sweden presents nutrient budgets for Swedish agricultural land on regular, but not yearly, basis. Yearly estimates can be compiled using other statistical data.	P fertiliser to arable land per year due to Swedish food consumption (Mt P per year)	Moberg et al. (2020)
				Total new reactive kg N to arable land per year (Mt N per year)	Moberg et al. (2020)
	Use of toxic substances	Pesticide risk index for health and environment	Swedish Chemicals Agency (2004)	Organic products' share of total market value (%)	Statistics Sweden (2023c)
	Air pollution	Ammonia emissions from food production (Mt per year)	Statistics Sweden (2023g)	Ammonia emissions due to Swedish consumption (Mt per year)	Moberg et al. (2020)
	Manage soils and water				
	Soil fertility	Change in soil organic carbon in mineral topsoils on cropland (thousand tonnes per year)	The National Inventory Report (NIR) (United Nations, 2021), based on modelling using ICBM	*n.a.*	*n.a.*
	Water management	Area of Swedish cropland that is irrigated (thousands of ha)	European Commission (2023b)	*n.a.*	*n.a.*
		Area of cropland with access to sufficient water stored in the landscape (thousands of ha)	Data is not currently available. Needs further development.	*n.a.*	*n.a.*
		Cropland with acceptable drainage (%)	Swedish Board of Agriculture (2017)	*n.a.*	*n.a.*
Walls of the Food System Sustainability House					
Governance	***Efficient policy***				
	Efficient policy	Share of greenhouse gas emissions from the Swedish food production that are included in price based policies	Emission data: the (Swedish Environmental Protection Agency, 2023a,b,c,d)	Share of greenhouse gas emissions from Swedish food consumption that is included in price based policy	Data not available. Own assessment is needed.
		Policies aiming at improving biodiversity	Data not available. Own assessment is needed.		
		Policy objective achievement	Data not available. Assessment can be based on literature review of policy objective achievement and on own assessment.	Share of sugar consumption include in price based policy	Not available since there is no taxing on sugar available in Sweden.
	Trust				
	Trust in institutions	Actors trust in public institutions	SOM-institute at Gothenburg University (Gothenburg University, 2023)	Actors trust in public institutions	SOM-institute at Gothenburg University (Gothenburg University, 2023)
Economically viable food system firms	***Economic viability***				
	Returns to capital	Returns to total economic capital (%), average for food system firms in Sweden	Statistics Sweden (2023a): Business Register for all firms, Swedish Board of Agriculture	Returns to total economic capital (%), average for food system	For agriculture: European Commission (2023a): Farm Accounting Data Network.

(*continued on next page*)

Table 1 (*continued*)

Themes	Sub-themes	Territorial indicators	Suggested sources of production data and comments regarding data	Consumption indicators	Suggested sources of consumption data and comments regarding data
			(2023c): the Farm Accountancy Data Network for agriculture.	firms which exports food products to Sweden	For other firms, data are not readily available for analysis.
	Autonomy	Value Added (VA) divided by Gross value of production (GVP), where (GVP = VA + C where C = intermediate inputs + depreciation). Governmental income supports are excluded from gross value of production.	Statistics Sweden (2023a)	*n.a.*	*n.a.*
		Value of production factors sourced from import market divided by total value of production factors	Swedish Board of Agriculture (2023c) Farm Accountancy Data Network for agriculture. Assumptions are needed about from where inputs are sourced.	*n.a.*	*n.a.*
	Diversity in production				
	Diversity	The entropy index	Statistics Sweden (2023a)	*n.a.*	*n.a.*

Note: n.a. Means not applicable.

et al., 2020). Such aggregated indicators were not proposed in this framework as they are more difficult to interpret (compared to indicators for specific food groups and nutrients) and often lack defined thresholds and goals for benchmarking. The indicators for Healthy and Adequate Diets should preferably be based on data that enable assessments in the average population as well as in specific population groups that differ in terms of e.g., gender, age, and socioeconomic characteristics. Data availability is, however, a challenge here, especially for time series.

The indicators selected to measure Healthy and Adequate Diets in the food system are primarily based on the associated health effects of consuming certain foods. However, health effects may also be linked to how the food is produced. We have included one indicator on foodborne disease (as clinical reported cases of foodborne illness per year and per number of individuals) and one on the use of antibiotics in livestock production. The use of antibiotics in livestock production increases the risk of microbes developing resistance to these drugs. The presence of microbes resistant to antibiotics hinders the successful use of antibiotics against various diseases in humans. Thus, the use of antibiotics is included as an indicator safe diets, although products from antibiotic-treated animals may not be unhealthy in themselves.

The theme Food Availability was included to capture food security and food production perspectives of the food system. The indicators related to the amount of food produced in Sweden (in terms of energy, protein, fat, and fruit and vegetables) give a measure from a food security perspective to help ensure food availability at territorial level, but also measure the extent to which Sweden contributes to global food supply. Indicators related to trade possibilities and stable commodity prices relate to accessibility of food.

4.2.2. *Just, ethical and equitable food systems*

To capture the second component of the food system ceiling—*Just, ethical and equitable food systems*—we selected four themes and developed associated sub-themes and indicators: (1) Market Concentration, with the sub-theme *Effect of market concentration*; (2) Safe Jobs, with the sub-theme *Working conditions in the food system*; (3) Contribution to Cultural Values, with sub-themes *Attractive landscapes*, *Preservation of food-related traditions*, *Recreational values* and *Rights of indigenous people*, and (4) High Animal Welfare, with the sub-theme *Total welfare index* (Table 1). The theme Market Concentration is an operationalisation of themes related to the fairness of distribution of capital, knowledge and profits described in other sustainable food system frameworks (Hebinck et al., 2021). Indicators and data sources suggested for measuring each sub-theme are presented in Table 1.

Market Concentration is a useful theme for considering the food system from the perspective just and equitable, since it is based on concentration of knowledge and capital among the food system firms. This leads to biased distribution of profits throughout the value chain. Many food value chains can be considered to take an hourglass shape, with many farmers at the one end, a few companies in the central processing and retail stages, and many consumers at the other end (Okpala, 2020). The thin waist of the system, consisting of a limited number of large multi-national agri-inputs companies, food industries and retailers, can create a basis for uneven distribution of profits, where the middle sections have monopsony power towards primary producers, and monopoly power towards consumers. With reduced market powers, each link in the value chain would share profits more equally, based on marginal costs and value added.

The theme Working conditions refers to the working conditions experienced by food system workers and consists of two sub-themes: *Safe jobs* and *Social benefit coverage*. We suggest territorial-based indicators for *Safe jobs* as number of sick leave days due to occupational accident or disease, and to incidence of serious personal injury, accident or death, and for *Social benefit coverage* we suggest an indicator measuring the share of income that is not declared, indicating the share of labor not covered by social benefits. The potential impacts of Swedish consumption on workers globally are harder to capture due to data limitations. However, to account for this in some way, we include consumption-based indicators related to Fairtrade certification.

Food systems are important for forming and upholding cultural values and traditions that citizens in general find valuable (HLPE, 2017). Here we include a set of themes, sub-themes and indicators related to aesthetic values, cultural heritage and recreational values (territorial side only). Another important aspect of a just, ethical and equitable food system concerns the rights of indigenous people to uphold and practice cultural knowledge, including rituals, arts and customs in general (United Nations, 2007). In Sweden, the most important food-related practice among the indigenous Sami population is the keeping of reindeer in the north of Sweden. Accordingly, we include two indicators to reflect this: one related to the keeping of reindeer and one related to opportunities to consume foods reflecting the cultures and traditions of the Sami population in public institutions (schools, homes for the elderly, etc.).

Animal welfare is not mentioned in the frameworks presented by Béné et al. (2019) and Fanzo et al. (2021). However, Chaudhary et al. (2018) include "animal health and welfare" in their assessment and propose the use of the World Animal Protection Index (API) as the indicator. Hebinck et al. (2021) include "high animal welfare" in their framework and suggest the share of organic- and animal welfare-certified animal products as an indicator. Our view on "high animal welfare" is in accordance with the goal outlined by Hebinck et al. (2021): "Increase share of animal products with high animal welfare

quality standards". In general, our definition of these animal welfare quality standards includes both animal health and other animal welfare aspects and the additional ethical aspect of the number of animals involved in the food production. Our indicators for consumption and territorial impacts are indices based on *number* of involved animals, the *ability* of these animals to perceive negative effects of a production system, and average level of animal welfare in production systems (Table 1).

4.3. The food system foundation – Clean and healthy planet

Themes, sub-themes and indicators related to the food system component a *Clean and healthy planet* are designed to capture the foundation of the *Food System Sustainability House*. Themes, sub-themes and indicators for measuring environmental sustainability are well consolidated across existing frameworks. The four areas of concern suggested by Hebinck et al. (2021), i.e. climate stabilisation, biodiversity conservation, preservation of natural resources, and clean air and water, were judged well suited also for the Swedish context. These areas largely correspond with Moberg et al. (2020) who suggest indicators based on the planetary boundaries framework that is used to assess the environmental sustainability of Swedish diets, as defined by the Swedish Environmental Objectives.

Thus, the floor of the *Food System Sustainability House* for Sweden consists of the following themes: (1) Climate Stabilisation, with the sub-theme *Greenhouse gas emissions*; (2) Biodiversity Conservation, with sub-themes *Terrestrial biodiversity*, *Aquatic biodiversity* and *Diversity of domesticated plants and animals*; (3) Preservation of Natural Resources, with sub-themes *Land use*, *Water use*, *Energy use* and *Mineral fertiliser use*; (4) Clean Air and Water, with sub-themes *Eutrophication*, *Use of toxic substances* and *Air pollution*; and (5) Management of Soils and Waters, with sub-themes *Soil fertility* and *Water management*. Indicators and data sources suggested for measuring each sub-theme are presented in Table 1.

Within the theme Biodiversity Conservation, we kept the sub-themes of *Terrestrial biodiversity* and *Aquatic biodiversity* as in Hebinck et al. (2021) but added a sub-theme for *Diversity of domesticated plants and animals*. These three sub-themes capture different and equally important types of biodiversity that are both affected by and vital to food production and consumption. Within these sub-themes, indicators were suggested; some are still in need of substantial further development and refinement. Under the theme Preservation of Natural Resources, we changed the indicator *Halt soil erosion* to *Land use* as the quality of soils is covered by the indicator *Soil fertility*, which we considered was better placed under a new theme called Management of Soils and Water, which was added to reflect the importance of these resources separately. While the theme Preservation of Natural Resources deals with the preservation of soils and water per se, i.e. as a sustainability issue in itself, under the theme Management Soils and Water, the management of these resources is considered in terms of their use as production resources in agriculture. That is, limiting land use to avoid agricultural expansion into pristine ecosystems is a sustainability aspect dealt with under Preservation of Natural Resources, while in Management of Soils and Water we are concerned about the fertility of agricultural soils for agricultural production. In addition, under the theme Preservation of Natural Resources, we added two new sub-themes, *Energy use* and *Mineral fertiliser use*, as energy and minerals are important resources for food systems. Energy and mineral fertiliser use are two of the indicators measured by Swedish authorities for capturing sustainability in Swedish farming (Statistics Sweden, 2022), and these are key drivers of several types of environmental damage and therefore central to food system sustainability.

4.4. The food system walls

4.4.1. Economic viability of food system firms

Themes, sub-themes and indicators for measuring firm-level economic aspects of sustainability and economic viability are well developed in the economics and business studies literature, and are used to some extent in existing sustainability frameworks. However, in current frameworks (e.g. by Chaudhary et al., 2018; Béné et al., 2019; Fanzo et al., 2021; Hebinck et al., 2021), the themes, sub-themes and indicators suggested have so far not been selected based on an argument about the role the economic system could take in a sustainable food system. We note that the literature on food system sustainability is not well consolidated regarding economic indicators. In devising these themes and indicators for the *Food System Sustainability House*, we departed from the economic themes and indicators used by Hebinck et al. (2021), and augment these with themes and indicators based on the argument that firms active in the food system need to operate in such a way that food production can be sustained over time, by focusing on their profitability and resilience. Three themes were developed: (1) Returns on capital, which considers how well the firms are able to use their production inputs in their economic activities; (2) Autonomy, which indicates firms' dependence on externally purchased production factors; and (3) Diversity in production, which functions as a risk management tool to safeguard against loss of overall production in the event of poor production conditions in single production types. The overall argument is that when those three aspects are well-functioning, the market-based food system firms should be able to sustain production over time.

Following this logic, changes were made in relation to the economic indicators suggested by Hebinck et al. (2021). In particular, we opted to remove the indicators pertaining to innovation and R&D. Our argument is that the effects of these should be incorporated in "Returns on capital", and that they are thus determinants of this indicator rather than indicators in themselves. We also moved indicators concerning profit distribution to the ceiling of the *Food System Sustainability House*, as these relate to the fairness of the food supply chain.

4.4.2. Governance

To protect common goods affected by large-scale systems that include a large number of actors, such as the food system, governance is necessary to be able to efficiently address overuse of natural resources and external effects (e.g. Jagers et al., 2020). Within the *Food System Sustainability House,* we refer to this as a governance system that ensures that the system stays firmly on its foundation of environmental boundaries while delivering on its social goal that is defined by the ceiling. In particular, we focus on the role of society in governing actors such that overuse of natural resources and other external effects are avoided. Ideally, governance in this respect should be designed in such a way that actors have incentives to choose a sustainable production and consumption path where the environmental foundations are respected. Such policy interference in the markets should thus ensure, e.g., that profit maximisation for producers is where external effects are included in economic decision making, and that these decisions are reflected towards the final consumers. At the same time, the governance system should be developed in such a way that the *ceiling* of the *Food System Sustainability House* can be ensured.

The governance component of the *Food System Sustainability House* consists of two themes: (1) Efficient policy and (2) Trust in institutions. Indicators and data suggested for measuring these themes are displayed in Table 1. We suggest indicators related to policy coverage and policy objective achievements, and to actors' trust in public institutions which impacts the efficiency of policy (e.g. OECD, 2013). It can be noted that availability of data for assessing the theme "Efficient policy" presents a particular challenge.

5. Discussion

In this paper, we have developed an indicator framework, which can be used to guide national food system sustainability transition by highlighting core features of a sustainable national food system. To do

so, we developed the *Food System Sustainability House,* where we clarify at a conceptual level how sustainability dimensions are related within a sustainable food system. We used the Swedish food system as an example to populate the *Food System Sustainability House* with themes, sub-themes and concrete indicators and to suggest data sources for sustainability assessment that are either available or in need of development for national food system sustainability assessment. In relation to existing sustainability frameworks, the *Food System Sustainability House* advances the state of the art by making explicit at a conceptual level the roles of the different sustainability dimensions, in particular by clarifying the role of economic viability and of governance in a sustainable food system. Our conceptual framework can therefore help facilitate discussions among actors on how to simultaneously achieve targets in all or multiple sustainability dimensions. Furthermore, it separates production and consumption in order to account for impacts at territorial and non-territorial level. This feature is particularly useful when discussing food system sustainability in an import-dependent country such as Sweden. The indicator framework can be used for several purposes, including discussing interrelations between sustainability dimensions, sustainability monitoring and assessment and impact analysis of determinants of a sustainable food system.

Several features of our conceptual framework should be highlighted. In our ambition to clarify how sustainability dimensions are related to each other, we argue that it is central to identify at a conceptual level what role the economic system and governance take in a sustainable food system. Zooming in on the economic system, it can be noted that themes and indicators used by previous sustainable food system frameworks serve to capture disparate aspects such as food affordability (Chaudhary et al., 2018), financial performance, employment rates, economic distribution (Béné et al., 2019), innovation, robustness, jobs and profit distribution (Hebinck et al., 2021). However, as highlighted by Béné et al. (2019), there is a lack of consensus about the content of the economic sustainability dimension. In this paper, we introduce the role of the economic system and governance as being that of enablers of a sustainable food system, ensuring that the system can deliver on its societal goals while resting firmly on a foundation of environmental boundaries. We also highlight the societal themes of the food system as being the *raison d'etre* of the system, at a societal level, and the environmental dimensions as the foundations which are pre-conditions for production and consumption.

The structure of the *Food System Sustainability House* has the ambition to acknowledge the boundaries of the food system. Themes and indicators included in the framework are selected such that the food system itself has the direct and major influence over them. For example, in comparison to previous sustainable food system frameworks (Chaudhary et al., 2018; Béné et al., 2019; Fanzo et al., 2021; Hebinck et al., 2021), our framework does not include employment as a theme or indicator. We argue that employment is a desirable outcome of a sustainable food system, but should not be considered a goal of the system as such as employment can evolve or be created just as well in other sectors. Typically, technological advancement in specific industries often implies a substitution between workers and capital in firms' operations, and that workers, after a transition period, are absorbed by other industries or by more advanced tasks (Autor, 2015). Hiring might also increase after technology investment (Liu et al., 2022), for instance by the introduction of new job openings (Acemoglu and Restrepo, 2018; Autor, 2015). That is, the creation of jobs should not be considered as a goal to be strived for in food system sustainability as it is the responsibility of the society as a whole, rather than the food system, to make sure that people have access to meaningful occupation. If rural jobs specifically are wanted, these could also be created in other sectors, like in education and other service sectors. For the reasons given above, we argue that provision of employment cannot be an objective of a sustainable food system.

In relation to previous food system sustainability frameworks (Chaudhary et al., 2018; Béné et al., 2019; Fanzo et al., 2021; Hebinck et al., 2021), we also refrain from including themes or indicators related to *fair wages* in terms of territorial impacts. The reason is that wages in a Swedish setting are typically set in a negotiation between workers' and employers' trade unions and should thus represent the market value of labour in a particular sector in the country. It should also be noted that there might be employers who do not pay proper wage taxes, which also implies workers whose wages are set outside of the negotiation between trade unions. The occurrence of this should be covered by the indicator share of unreported salaries in relation to total number of food system workers.

We also refrain from including *food affordability* as an indicator of a sustainable food system, contrary to existing frameworks (Chaudhary et al., 2018; Béné et al., 2019; Fanzo et al., 2021; Hebinck et al., 2021). Affordability is strongly related to the overall income in the country, where consumers in high-income countries can afford higher food prices in their home countries. Typically, the high-income countries also have higher food prices. However, the *Food System Sustainability House* is designed to focus on those sustainability aspects that the food system itself can affect, and only part of the affordability aspect (such as food prices) is determined by actions that occur within the food system, whereas other parts (such as income) are determined by all sectors where citizens work and by income redistribution decisions by the government. We argue that as long as prices are determined by food system actors' price levels (i.e. that they do not exercise market power over consumers), the food system cannot be "blamed" for relatively high prices, and that the affordability aspect needs to be considered in relation to total income levels. In the *Food System Sustainability House* for Sweden, we suggest focusing on stability in food prices, which are, at least to some extent, directly controllable by food system actors through their actions to hedge against fluctuations in input prices.

The *Food System Sustainability House* for Sweden is developed to conceptualise a sustainable food system and to derive indicators for measuring its different components in terms of themes and sub-themes. In particular, it aims to guide practical policy decision making in an environment such as the Swedish food system, which is based on a market-based solution where coordination between supply and demand happens on the market, supply is based on the cost structures of companies, and demand is based on the preferences and income of consumers.

The *Food System Sustainability House* has clear implications for food system actors in their efforts to achieve a sustainable food system, and thus implications highlight clear take-home messages for food system actors. Looking at the supply side, the framework highlights that in a sustainable food system, companies need to keep their profit-maximising business models within the House; this means that they respect the environmental boundaries represented by the foundations of the House while contributing to the objectives of the system as indicated in the ceiling of the House. Thus, companies with substantial emissions need to be incentivsed to reorganise their activities to reduce harm to the environment, while also organising themselves so that they are profitable and viable. Looking at the demand side, consumers' actions to maximise their utility in a sustainable food system also have to take place within the House. When making consumption decisions, they need to be encouraged to do so subject to certain limits on their environmental impact, in tandem with other considerations such as preferences and budget constraints. Policy makers play a vital role here as they can enable such conditions for companies and consumers and the *Food System Sustainability House* provides a model to conceptualise how such sustainable production and consumption can happen.

Beyond the conceptual model provided in this paper, it should also be noted that our inventory of data availability for food system sustainability assessment highlights important areas where sufficient data for food system sustainability assessment is currently not available. Thereby, the data inventory presented here provides a useful basis for discussions about additional data collection efforts to facilitate monitoring and impact analysis for food system sustainability.

6. Guiding policy decision making based on the Food System Sustainability House

From the perspective of public and private policy making where actors are interested in developing measures to address food system sustainability problems, a practical application of the *Food System Sustainability House* has similarities with a classical maximisation problem under given constraints. We consider policy makers here in a broad sense, covering both public (local and national as well as international governance structures) and private (e.g. collaborations and contracts between food supply chain actors) policy makers focused on food system sustainability. From a societal perspective, actors would be interested in ensuring that the food system can deliver on societal goals, which from the perspective of society constitute the reason to maintain and develop a food system. Activities geared towards the societal goals of the food system are however constrained by the limits put in place by the environmental floor of the *Food System Sustainability House*.

An analogy from production economics can be used to illustrate this problem: any activity operating under a budget constraint can only maximise output subject to this budget constraint; and a company interested in achieving a specific production goal can only do so given the constraints imposed by its production technology and the prices it meets on the market. Extending this way of thinking to the food system implies that policy makers interested in designing policy to maximise the delivery of the food system on its social goals can only do so subject to the constraints put in place by the environmental foundation and while considering the viability of food system businesses. From the perspective of the policy maker, the walls of the *Food System Sustainability House*, i.e. the enablers, function as the tools which can be used to ensure that activities are kept within the House, while the objectives are achieved. This also means that the role of economic viability is precisely to function as an enabler, and it is against this role that it needs to be evaluated, and not as an end in itself as when we approach it from the overarching perspective of the food system as such.

This approach to policy decision making highlights that sustainability problems need to be addressed simultaneously in an integrated manner, instead of as separate problems. Based on the *Food System Sustainability House* thinking, we propose the following sequence for the development of policy action, which can help structure discussions about how to handle tradeoffs:

1. Use the *Food System Sustainability House* to assess the performance of the food system across all dimensions.
2. Identify areas where performance is far from the target and/or exhibiting unfavourable trends.
3. Develop a pool of suggested actions to remedy problems with sustainability performance.
4. Use an *integrated approach*, taking all sustainability dimensions in the *Food System Sustainability House* into consideration, to evaluate proposed actions to remedy sustainability problems before they are implemented in the food system. This means that suggested actions to remedy problems in one dimension need to be evaluated against their impacts on all other dimensions, and that the role of and hierarchy between sustainability dimensions as defined by the *Food System Sustainability House* must simultaneously be considered. In this process, goal conflicts are inevitable. The ambition of the *Food System Sustainability House* is to provide a basis for discussing the type of role that each sustainability dimension takes. This can help solve goal conflicts by clearly defining the space within which activities of the food system need to take place.

7. Conclusions

To achieve food system transformation away from current unsustainable practices of food production and consumption, there is a need for effective food policy. Without such policy, actors are unlikely to rationally consider adverse impacts on food systems in their decision making. Rigorous sustainable food system frameworks are therefore needed to facilitate discussion of priorities, enable comparisons, assessment and progress monitoring, and ensure accountability. In this paper, we have developed the *Food System Sustainability House*, a sustainability framework which imagines at a conceptual level how different sustainability dimensions in the food system are interlinked. In particular, the *Food System Sustainability House* views the societal dimension as the objective of the system; this is the ceiling of the *House*. The environmental dimension is viewed as the foundation of natural resources upon which activities of the system are built. This is the foundation of the *House*. The economic dimension is viewed in terms of economic viability and governance which are enablers of the system; these are the walls of the *House* and link the environmental foundations to the societal objectives of the system. We populated the *Food System Sustainability House* with themes, sub-themes and indicators and suggested data sources for sustainability assessment of the Swedish food system. The ambition of the *Food System Sustainability House* is to support practical public policy actions. In particular, at a conceptual level, the *Food System Sustainability House* highlights how different sustainability dimensions are interlinked. In doing so, this study contributes insights that are needed to facilitate discussions in the likely situation of tradeoffs between sustainability dimensions. It also considers production- and consumption-based sustainability impacts separately, which is useful for national food system sustainability assessment in trade-dependent countries. Finally, the themes, sub-themes, indicators and data sources linked to the *Food System Sustainability House* for Sweden are helpful for food system sustainability analysis in the country. The *Food System Sustainability House* is developed for assessment at the level of the entire food system. Future research will have an important task in investigating strategies to move the food system towards better sustainability and thus in defining what can be considered determinants of a sustainable food system. Furthermore, future research will have a key role in adapting the *Food System Sustainability House* to facilitate decision making at the level of individual food system actors (e.g., firms and/or consumers), and thus help them pursue more sustainable activities.

CRediT authorship contribution statement

Helena Hansson: Writing – review & editing, Writing – original draft, Visualization, Supervision, Resources, Project administration, Methodology, Investigation, Funding acquisition, Conceptualization. **Sarah Säll:** Writing – review & editing, Investigation, Formal analysis, Conceptualization. **Assem Abouhatab:** Writing – review & editing, Formal analysis, Conceptualization. **Serina Ahlgren:** Writing – review & editing, Formal analysis, Conceptualization. **Åsa Berggren:** Writing – review & editing, Formal analysis, Conceptualization. **Elinor Hallström:** Writing – review & editing, Formal analysis, Conceptualization. **Peter Lundqvist:** Writing – review & editing, Conceptualization, Formal analysis. **U. Martin Persson:** Writing – review & editing, Formal analysis, Conceptualization. **Lotta Rydhmer:** Writing – review & editing, Funding acquisition, Formal analysis, Conceptualization. **Elin Röös:** Writing – review & editing, Writing – original draft, Formal analysis, Conceptualization. **Pernilla Tidåker:** Writing – review & editing, Formal analysis, Conceptualization. **Anna Winkvist:** Writing – review & editing, Formal analysis, Conceptualization. **Li-hua Zhu:** Writing – review & editing, Conceptualization, Formal analysis.

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.

Data availability

No data was used for the research described in the article.

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