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Synergies and Trade-Offs for Sustainable Food Production in Sweden: An Integrated Approach

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Abstract: The production of food can have large impacts on sustainable development in relation to various socio-ecological dimensions, like climate change, the environment, animal welfare, livestock epidemiology, and the economy. To achieve a sustainable food production system in Sweden, an integrated approach that considers all five of these dimensions, and all parts of the food production chain, is necessary. This paper systematically reviewed the literature related to food production in Sweden, especially in association with resource distribution and recycling logistics, and identified potential sustainability interventions and assessed their effects according to the five dimensions. Participation of stakeholders across the food production chain contributed with the focus of the literature search and subsequent synthesis. In general, there were synergies between the sustainability interventions and their effect on climate change and the environment, while there often were trade-offs between effects on the economy and the other dimensions. Few interventions considered effects on animal welfare or livestock epidemiology and few studies dealt with resource distribution and recycling logistics. This indicates that there is a need for future research that considers this in particular, as well as research that considers the whole food production chain and all dimensions at once, and investigates effects across multiple scales.

Keywords: sustainable food production; resource distribution; recycling logistics; stakeholder participation; climate change; environment; animal welfare; livestock epidemiology; economy; Sweden

1. Introduction

The production of food can have large impacts on sustainable development, as agriculture, food processing, and waste management uses and transforms large amounts of resources, such as water, nutrients, energy, land, and labor. Still, processes related to food production are necessary for global food security [1,2]. As such, improving sustainability throughout both global and national food production chains is vital, especially as a number of planetary boundaries have already been crossed [3,4] and as objectives in environmental and sustainable development agreements are far from being achieved.

In Sweden, the long-term food strategy adopted in 2017 identifies increasing resource and production efficiency as one important factor that needs to be considered to achieve a sustainable

Swedish food production system [5]. It underlines that a complete view of the entire food production chain is necessary in the transition towards a more sustainable and efficient food system (see Figure 1 for a conceptual overview of the Swedish food production chain considered for this article). This implies that not only food production, but also the many inputs required in the production chain as well as waste management and waste utilization need to be considered. This consideration of resources throughout the chain must also involve the elements that allow them to be linked together, such as transport, the spatial distribution of resources and demand areas, and the required infrastructure that connects them. However, these resource distribution and recycling logistics (henceforth ReDiReL) within a sustainable food production system is an under-researched field for Swedish conditions. The fact that increased urbanization and agricultural specialization may entail increased distances between resource use and production is one example of why it is important to consider ReDiReL and emphasizes the need for improved energy efficiency and logistics optimization [6,7]. Here, ReDiReL is defined to include not only the actual transport involved in agricultural resource distribution and recycling, but also the spatial arrangement of transport infrastructure, land use, and facilities, such as bioenergy centers, farms, and slaughterhouses.

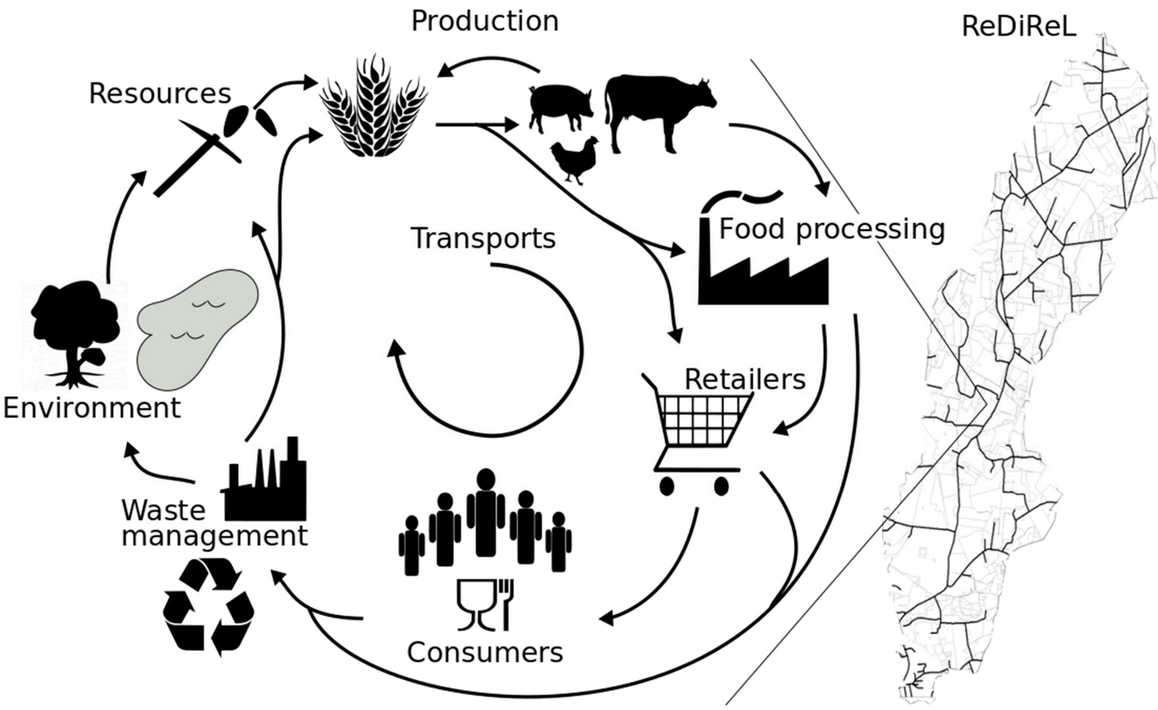

Figure 1. Conceptual overview of the different processes and steps included in the Swedish food production chain. As the food production chain is spatially explicit, resource distribution and recycling logistics (ReDiReL) are essential for food production. Here, this is conceptually represented as the spatial distribution of the road network (in black) and agricultural fields (in grey) across Sweden.

The development of a more sustainable food production system in Sweden not only requires an integrated approach in regard to the different parts of the food production chain, but also considerations of the multidimensionality of the impacts of food production [8]. For instance, agriculture strongly contributes to anthropogenic greenhouse gas (GHG) emissions and thus has an agency to reduce such emissions [9], while Swedish agriculture simultaneously needs to adapt to a changing climate in terms of, e.g., longer growing seasons and increased levels and intensities of precipitation and drought [10–12]. Water quality is another important issue, as losses of nitrogen (N) and phosphorus (P) from agricultural fields have caused serious water quality impairment over time in Sweden [13]. Agriculture is also an important driver for biodiversity loss through, e.g., land transformation [14]. Animal welfare is part of the European Union's plan for sustainable food systems [15], and maintaining a high level of animal welfare is fundamental in light of ethics, sustainability, and reduced use of antibiotics [16,17]. Disease transfer is also of particular concern. For example, shipments of animals between farms are essential for the food production system, but also have the potential of introducing animals into susceptible herds [18], and transboundary animal diseases can be extremely costly and result in the culling of millions of animals [19,20]. Finally, high crop and animal productivity in the food chain is key for both food security and economic profits. However, it is debatable if centralization, industrialization, and globalization of production and distribution is the best way of improving profitability while still ensuring a resilient and sustainable food system [21].

There are examples of studies that have examined sustainable food production in terms of environmental impacts as well as economic and social dimensions [9,22]. However, these rarely consider the entire food production chain or all relevant dimensions or focus on ReDiReL. Without an integrated approach that considers the entire Swedish food production chain as well as relevant dimensions, such as climate change, the environment, animal welfare, livestock epidemiology, and the economy, it will be more difficult for policy makers to find and assess interventions related to ReDiReL that could be useful in facilitating a shift towards more sustainable food production. Therefore, the aim of this study was to perform a systematic review of the literature related to ReDiReL within a sustainable Swedish food production system to investigate the current scientific understanding within the field. In addition, the aim was to identify potential interventions aimed at increasing the sustainability of different parts of the food production chain, as well as their potential effects on the five system dimensions mentioned above. This synthesis of information could then be used to start fruitful discussions between the actors involved in creating a more sustainable Swedish food production system, as well as identify knowledge gaps and set future research agendas.

The review identified several sustainability interventions and revealed that these interventions had synergistic effects and trade-offs among the five dimensions. In general, there were synergies between the interventions and their effects on climate change and the environment, while there often were trade-offs between effects on the economy and the other dimensions. In addition, few interventions considered effects on animal welfare or livestock epidemiology and few studies dealt with ReDiReL. This indicates that there is a need for future research that considers this in particular, as well as research that considers the whole food production chain and all dimensions at once, and investigates effects across multiple scales.

2. Methods

The methods used for this study draw from the systematic review literature [23–25], but were adopted to fit the aims of this paper and the complex nature of the agricultural system in focus. First, the objective of the review was defined together with Swedish food system stakeholders through a workshop. The subsequent stages involved systematically searching for relevant literature; applying selection criteria to include only relevant articles in the review; reviewing the articles; analyzing and synthesizing the result; validating the results by letting stakeholders comment on the relevance, knowledge gaps, and future research needs; and drawing conclusions.

The dimensions presented in this paper (Box 1) draw from the areas of expertise within the research group, but the specific types of information and scope covered in each dimension also reflect what stakeholders brought up as being relevant, as well as what is available in the literature. They are not all encompassing, but do represent a diverse constellation of topics and issues that must be addressed in the context of meeting the UN Sustainable Development goals, as well as Sweden's food strategy and environmental policies. Combining the literature and stakeholder perspectives on ReDiReL and sustainability throughout the Swedish food production chain requires iterative steps, and as such, carefully used terminology (Box 2).

Box 1. Definitions of what the five system dimensions entailed for the study.

Climate change

The climate change dimension considers both climate change mitigation and adaptation, e.g., increased use of renewable energy to reduce greenhouse gas emissions or alterations of cropping systems to adapt to a changing climate. Climate change is often addressed in life cycle assessments using the global warming potential, measured in kg CO_2 equivalents for a specific time period (usually 100 years), or energy use.

Environment

The environment dimension is focused on water quality issues related to eutrophication (surplus of nutrients lost from land) and terrestrial ecosystems related to changes in biodiversity. It also touches on issues of acidification in water and pesticide use on land. The environment can be addressed in life cycle assessments, using eutrophication and acidification potential, measured in in kg NO_3 or kg SO_2 equivalents, respectively, and land use.

Animal welfare

The animal welfare dimension is focused on means of improving the welfare of animals in the agricultural production system. Animal welfare is defined as the state of an individual animal with respect to its attempts to cope with challenges in its environment and is often measured by means of the behavior and physiology of the animal. Healthy animals, with normal, species-specific behaviors and the absence of increased stress levels, are aspects of good animal welfare, in addition to behaviors indicating positive experiences (e.g., play behaviors) [26].

Livestock epidemiology

The livestock epidemiology dimension is focused on infectious livestock diseases and considers means to prevent the spread of diseases within and between farms. Included in this dimension is also the risk of transboundary diseases affecting human health.

Economy

The economy dimension is focused on both corporate level profitability and the growth of business initiatives, and individual level profitability and the growth of individual farm(er)s. Economic effects are usually accounted for as directions (increase/decrease of income and costs) and sizes (e.g., yields).

Box 2. Definitions of important terms used in the study.

Food production chain

The food production chain consists of the different processes involved in the production, processing, retailing, and consumption of food, as well as waste management and resource use. Transport between different processes are a vital part of the production chain.

Dimensions

Dimensions represent socio-ecological elements impacted by the processes in the food production chain. The dimensions considered in this study are climate change, the environment, animal welfare, livestock epidemiology, and the economy.

Aspect

The aspects are areas that affect or are affected by the processes in the food production chain and/or dimensions and were identified during a stakeholder workshop. The aspects were mainly used to simplify the formulation of search strings that capture all relevant literature.

Intervention

Interventions are measures that can be implemented to improve the sustainability of the food production systems. The interventions include new or changed activities and can have negative, neutral, or positive effects on sustainability.

Focus area

Focus areas are similar to aspects in that they affect or are affected by the processes in the food production chain and/or the dimensions, but are generally more specific and more closely related to ReDiReL. The focus areas were formulated based on the review results.

2.1. Stakeholder Workshop

As the concept of ReDiReL is broad and complex for sustainable agriculture and food production, the literature search and subsequent synthesis required a specific focus. Stakeholder participation can be useful when assessing complex interdisciplinary problems to assure societal relevance [27,28]. Therefore, a stakeholder workshop to discuss perspectives on current and future challenges and opportunities associated with creating a more sustainable food production system in Sweden was organized. Professionals from different parts of the food production chain were invited, including representatives from the Swedish Board of Agriculture, the County Administration Board, a logistics company, a meat producer, a waste management company, an agricultural innovation company, a non-profit organization working towards a more sustainable society, and a non-profit organization working for animal welfare. Nine different aspects of sustainable agriculture and food production were determined from the workshop discussions. These aspects were used to guide the development of appropriate search terms for the literature search:

1. Transports and the supply chain.
2. Production (primary production in focus).
3. Scale of production and spatial arrangements within agriculture.
4. Waste utilization and recycling.
5. Marketing and retail of sustainable food.
6. Public procurement supporting sustainability.
7. Consumer attitudes towards sustainable food and agriculture.
8. Policy as a tool to achieve sustainable agriculture and food production.
9. Mapping of the food production chain.

2.2. Literature Search

To cover the multidimensionality of this review and to ensure the inclusion of all relevant articles, the study was structured into several separate searches. These were conducted in the database, Scopus, in May 2018. Each search string included general search terms related to agriculture and food production in Sweden. In addition, each search consisted of specific search terms related to the five system dimensions and nine aspects identified from the workshop. Thus, the search strings comprised of three parts giving 45 unique search strings in total (Table S1: Search terms used in the systematic literature search in the Supplementary Material). Only articles published in 2000 or later were included in the searches.

2.3. Inclusion Process

The inclusion process contained two steps: First, screening and selection of relevant articles based on the title and abstract, and thereafter reading the full text of the selected articles to determine what articles to include in the review. Different researchers performed the inclusion process for the specific dimension within their area of expertise.

2.3.1. Selection 1

All article search results (from 45 searches in total) were downloaded and included in the first step of the inclusion process. The first selection involved screening by reading the title and abstract of each article aspect-by-aspect. To be included, the articles needed to fulfil the criteria of (i) being related to agriculture or food production (articles concerning fishing and targeted bioenergy production from crops were excluded); (ii) focusing on Sweden; and (iii) being related to the dimension in focus. Articles that did not address the specifically considered aspect, but instead clearly belonged to one or several of the other aspects, were still included. Note that since separate searches were conducted, articles could be selected from more than one aspect and dimension at this point. For information on the number of articles found for each search string and the number of articles included after selection 1, see Table S2 (Table S2: Number of articles found in each literature search in the Supplementary Material).

2.3.2. Selection 2

The second step of the selection involved reading the full text of the articles included from the first selection, dimension-by-dimension. For final inclusion, articles had to relate to the concept of ReDiReL within a sustainable food production system, either directly or indirectly. In addition, the criteria from the first selection still had to be fulfilled. The articles selected at this stage were included in the literature review.

2.4. Review and Synthesis

The remaining articles were all reviewed and classified based on the (i) addressed dimension(s); (ii) addressed aspect(s); (iii) implied or indirect effects on ReDiReL; and the (iv) explicitly described or direct effect on ReDiReL. Subsequently, the material was assessed, and several focus areas related to ReDiReL were identified. These focus areas were related to the aspects identified in the workshop, but better reflected the reviewed literature. Next, the material was synthesized with regards to both dimensions and focus areas. Based on this synthesis, potential sustainability interventions related to ReDiReL that affected more than one dimension could be outlined and used to identify potential synergies and trade-offs between dimensions. Patterns in dimensions, focus areas, and interventions enabled identification of knowledge gaps in the literature related to ReDiReL.

2.5. Stakeholder Interviews

To further understand and validate the relevance of the literature review and synthesis in terms of reflecting "on the ground" expertise and practices in the Swedish food production system, we conducted 10 phone interviews with stakeholders. The intention was a follow-up of the stakeholder workshop that initiated and set the foundation for the literature review to get stakeholder feedback on the results. However, as there was an under-representation of stakeholders representing livestock epidemiology and farmers at the initial workshop (i.e., stakeholders that were invited, but could not attend), we selected additional interviewees to fill this gap. The 10 selected stakeholders thus spanned expertise across the entire food production chain and all five dimensions, with representatives from government, private companies, and non-governmental organisations. A semi-structured interview format [29,30] using seven open ended questions was used (Table S3: Interview guide in the Supplementary Material). Respondents were contacted and briefly introduced to the topic of the interview and sent preliminary versions of Table 1 and Table S4 (Table S4: Overview of the literature review in the Supplementary Material). The interviews lasted between 20 and 45 min, were conducted in Swedish, and followed the interview guide's structure. Interviewers took notes during interviews in Swedish and then the responses were formulated and summarized based on the guide's questions in English. The interview summaries were then sent back to respondents, who could agree or amend the statements. The aim was not to conduct a full content analysis of responses, but rather collect feedback and highlight potential shared and divergent viewpoints on the literature review. As such, individual interview summaries were compiled to validate and suggest (i) the types of literature and synergies and trade-offs that may have been missing from the review, (ii) views on the most effective interventions identified in the review to increase sustainability, and (iii) the types of future research which would be most valuable from their perspective.

Table 1. Sustainability interventions for agriculture and food production and their effect on five different system dimensions. Green indicates a positive effect, red a negative effect, and yellow both a positive and negative effect or conflicting effects. More than one green effect for an intervention indicates a synergy while interventions with at least one green and one red or yellow effect indicates a trade-off. Numbers in superscript represents which focus area(s) each sustainability intervention is related to.

Sustainability Intervention	Effects on System Dimension				
	Climate Change	**Environment**	**Animal Welfare**	**Livestock Epidemiology**	**Economy**
Limited fodder import [1,2]	Reduced GHG emissions	Reduced eutrophication			Maintained profitability; decreased yield
More time outdoors for livestock, improvements in pig rearing, free range chickens, mobile abattoirs, use of loading docks [1,2]		Increased eutrophication, in systems only considering animal welfare	Improved or decreased animal welfare, depending on intervention		Decreased profitability
Improved farm biosecurity [1,2]			[Implied] Improved animal welfare with reduced disease spread	Reduced risk of spread of livestock diseases	[Implied] Improved profitability with reduced disease spread
Improved production efficiency [2]	Reduced GHG emissions	Reduced eutrophication			Improved profitability
Reduced intensity of animal production[2]	Reduced GHG emissions	Reduced eutrophication	Improved animal welfare		Decreased profitability
Organic production [2]	Reduced GHG emissions per ha farmland; increased GHG emissions per produced unit	Reduced eutrophication and pesticide use per ha farm-land; increased eutrophication per produced unit	Improved animal welfare		Decreased yields
Integrated animal/crop production [2]		Reduced eutrophication	Improved animal welfare		
Use of inter-cropping, crop rotations with leys, mechanical weed control [2]	Reduced GHG emissions, when using ley biomass for biogas production	Reduced or increased eutrophication, depending on crop system; reduced pesticide use			Maintained yield
Decreased protein content in fodder [2]		[Implied] Reduced eutrophication			Decreased yield
Continued/increased cattle grazing [2]	Increased GHG emissions	Maintained biodiversity			
Small-scale farming[1,2,3]		Increased bio-diversity, due to higher on-farm habitat heterogeneity; [Implied] reduced eutrophication, due to low production intensity	[Implied] Improved animal welfare, due to low production intensity		Decreased profitability; reduced loss of jobs

Table 1. *Cont.*

Sustainability Intervention	Effects on System Dimension				
	Climate Change	**Environment**	**Animal Welfare**	**Livestock Epidemiology**	**Economy**
Increased farmer co-operation [3]			[Implied] Decreased animal welfare with increased disease spread	Increased risk of spread of livestock diseases, e.g., with shared use of tractors	Improved profitability
Farm-scale production of biogas from residues [3,4]	Reduced GHG emissions				Not profitable without current subsidies
Large-scale biogas production from manure and food waste [3,4]	Reduced GHG emissions (substantial)				Low profit-ability under current market conditions
Recycling of nutrients from waste (e.g., food waste, wastewater) [4]	Reduced GHG emissions	Reduced eutrophication			Decreased yield, by using food waste compared to mineral fertilizers; [Implied] improved profitability, with less use of mineral fertilizer
Integrating farmers into heat supply chains, using crop residuals [4]	Reduced GHG emissions, with shift to fossil free energy; loss of carbon from soil	Decrease in soil organic carbon			Reduced district heating price
Shift to plant-based diet [2,5]	Reduced GHG emissions, but depends on product types	Reduced or increased eutrophication; maintained biodiversity, with maintained grazing; increased acidification	[Implied] Improved animal welfare		
Labelling of sustainable food [5]	Reduced GHG emissions, with more sales of climate-certified products	Reduced eutrophication, with more sales of environment-friendly products			[Implied] Improved profitability, with high willingness to pay for sustainable food
Labelling of meat produced with high animal welfare [5]			Improved animal welfare		[Implied] Improved profit-ability, with high willingness to pay for quality products
Increased consumption of locally produced food [2,5]	Reduced GHG emissions, but not exclusively the case.				[Implied] Improved profit-ability for Swedish farmers and beneficial for the sector
Increased energy efficiency and decreased food wastage in the food chain [5]	Reduced GHG emissions	Reduced eutrophication			Improved profitability

[1] Resource utilization within production; [2] Scale of production; [3] Marketing, labelling, and consumption of sustainable food; [4] Waste utilization; [5] Transport and localization.

3. Results

The results are presented in three sections: Section 3.1 consists of the review and synthesis of the literature related to ReDiReL, detailing the conclusions from the reviewed papers, and is structured based on the five identified focus areas; Section 3.2 presents the synergies and trade-offs identified from the review; and Section 3.3 presents the reflections from the stakeholder interviews.

3.1. Synthesis of Literature Related to ReDiReL

A total of 118 articles were included in the review and synthesis, with 51 of these addressing more than one dimension. Five focus areas related to ReDiReL within a sustainable food production system could be identified from the literature:

1. Transports and localization.
2. Resource utilization within primary production.
3. Scale of production.
4. Waste utilization.
5. Marketing, labelling, and consumption of sustainable food.

Some of these focus areas correspond to the aspects used in the search, but there are also differences. The aspects of "Policy" and "Mapping" only indirectly addressed sustainability and ReDiReL in the reviewed literature, or were used as an approach to address these, and were therefore not considered to be focus areas. The aspects of "Marketing and retail", "Public procurement", and "Consumer attitudes" turned out to be difficult to distinguish in the literature. As the reviewed literature on this generally involved the effects of consumers' behaviors, how consumers perceive different products, and how producers try to increase the attractiveness of products, these aspects were merged into a single focus area: "Marketing, labelling, and consumption of sustainable food".

The focus areas relate to ReDiReL within a sustainable food production system in various ways. Transport infrastructure, in addition to the spatial arrangements and localization of different land uses, farms, bioenergy centers, slaughterhouses, and retailers, are central to the concept of ReDiReL. Resource utilization within production and the scale of production relates to ReDiReL as it is important for the use and distribution of resources. Waste utilization is also important within ReDiReL as it requires effective recycling logistics. Marketing, labelling, and consumption of sustainable food are included as a focus area, as it includes changes in the demand of certain foodstuffs, and as such, affects earlier steps in the production and processing of these items and the ReDiReL elements the process depends on.

Below is the review and synthesis of the literature, presented by focus area. In addition, Table S4 (Table S4: Overview of the literature review in the Supplementary Material) presents an overview of the review, dimensions-by-dimension and focus area-by-focus area.

3.1.1. Transport and Localization

Transport generally affects the magnitude of environmental and climate impacts when using life cycle assessments to evaluate agricultural production and recycling of waste as fertilizers in Sweden, e.g., [31,32]. Furthermore, transport related to agricultural production (e.g., milk tankers, livestock transportations) can cover large areas and many farms in a single week, potentially spreading contagious diseases [33]. This makes biosecurity measures, like cleaning and disinfection of transport vehicles, important actions towards more sustainable food production [34]. In addition, animal transport is related to animal welfare issues, and increased use of mobile abattoirs and improved animal loading protocols (e.g., using loading docks) can reduce animal stress and improve welfare [35–37].

In relation to spatial arrangements of land use, a higher heterogeneity of different habitat types, or heterogeneity of crops at a landscape scale, does not result in a higher density of migratory or farmland birds [38,39]. However, small-scale farms usually have a higher diversity of birds, insects, and plants compared to larger farms due to higher on-farm heterogeneity. Earning a living on small farms is nevertheless generally more difficult [40,41].

Import of both food and fodder is an important consideration related to both transport and localization, especially since imports to Sweden increased between 1962–1994 [42], and it is likely that these have continued to increase. Import of fodder (instead of producing it at farm level) generally results in higher eutrophication and acidification, as well as higher global warming potential [43]. In addition, at current market prices, dairy cows fed Swedish fodder with supplemented protein contribute with a similar net profit as cows fed imported feedstuff, when not considering the higher cost of production due to lower milk yields [44]. In Sweden, consumers' interest in locally produced food has grown, mainly due to the associated reduced GHG emissions through shorter transports and the support of local procurers [45]. In some cases, locally produced food can be more sustainable. For example, there is evidence that Swedish produced tomatoes have a lower carbon footprint than Dutch tomatoes. An important aspect in this case is, however, that Swedish greenhouses are heated with biofuels while Dutch ones are generally not [46]. In addition, Swedish local authorities may be interested in locally produced food, but there are sometimes difficulties in actually procuring it [45]. It is important to note that the transport's, or country of origin's, role in GHG emissions from agriculture are relatively small compared to the differences between a non-vegetarian or vegetarian diet. Hence, a vegetarian diet would be a more effective measure to reduce GHG emissions than eating locally produced foods [47]. It is also important to consider that increasing local production can involve other social or economic benefits to society even if GHG emissions are not reduced.

3.1.2. Resource Utilization within Production

Between 1990–2005, GHG emissions from livestock production in Sweden decreased by 14%, mostly due to increased production efficiency [48]. Although climate change mitigation continues to be important, it is a challenge to substantially reduce GHG emissions in the Swedish agricultural production system. This is mainly because GHG emissions are due to hard-to-control biological processes, like nitrous oxide emissions from soil and methane from ruminants (c.f. [49]), and depend on climate and other factors, like cultivation practices and availability, and nutritional and cost related characteristics of feedstuffs [50,51]. However, increased production efficiency and more efficient nutrient management in agricultural production can mitigate climate change as well as reduce environmental impacts and lead to decreased costs. This can be achieved through improvements in livestock production [52]; shifts in land allocation to better quality land [53]; reduced animal density and improved manure handling [54]; integrated animal and crop production within farms [55,56]; decreasing protein content in fodder [44]; and use of inter-cropping [57].

It is generally acknowledged that climate change adaptation is a necessity, both to avoid negative consequence as well as to gain from opportunities of climate change, but research on climate adaptation in Swedish agriculture is scarce [12,58]. Nevertheless, resource utilization could be affected both in terms of limiting vulnerability (e.g., increased use of pesticides, implementing water reservoirs, improving drainage) and taking advantage of opportunities (new crops with increased need of fertilizers and pesticides) [4]. Despite this link between climate adaptation and resource utilization (c.f. [12]), farmers generally perceive agricultural policy and market conditions as more influential drivers than climate change [58].

Less intense production systems, lower animal density, and more time spent outdoors generally lead to higher animal welfare [59,60]. However, further research and improvements are needed to improve welfare in production systems considered more animal-friendly, as these sometimes have lower animal welfare than more conventional systems [60,61]. To limit disease spread between animals in the production system, improvements of external and internal biosecurity are needed, e.g., through improved cleaning and disinfection of livestock transport, increasing livestock vaccinations, and increasing knowledge among farmers and professionals visiting farms on how diseases spread and how this can be prevented [62–65].

Life cycle assessments are commonly used when investigating how resource utilization within agricultural production can be improved. Results from these types of studies include positive effects of using Swedish rather than imported feed [43], consuming locally produced food rather than imported [46,66], and growing vegetables in plant factories instead of greenhouses [67] for global warming potential and eutrophication. In contrast, organic milk production [55] and using crop rotations with grain and grass/clover ley [68] have both positive and negative effects on these metrics.

3.1.3. Scale of Production

In general, large scale production in the form of higher animal densities and field size leads to higher farm profitability [69,70]. This is particularly striking when comparing larger producers to small-scale farms with products that require transport separated from conventional food supply chains [71]. In addition, small-scale farmers sometimes lack experience or infrastructure to solve complex problems [72]. Studies have revealed a higher animal welfare associated with small-scale slaughter [73] and that small-scale farms often have a higher diversity of plants and insects [40,41]. In addition, Swedish farmers and village action groups argue that consolidation and increased scale of farming operation can lead to a loss of business and jobs as well as a loss of several functions related to farmers' quality of life [74] and that several barriers for consolidation exists, e.g., attitudes, history and traditions, and regulations [75].

One solution to increase resource efficiency on a farm while maintaining a relatively small scale of operations is for farmers to collaborate regarding the use of equipment and utilization of buildings [76]. However, this could lead to decreased biosecurity and potential spread of diseases between farms [62]. From a climate change mitigation perspective, farm cooperation and investment in larger, shared biogas plants may be beneficial, as generating biogas from agricultural residues is currently not economically feasible at the farm level [77]. In addition, cooperative solutions to marketing and infrastructure problems can make the food supply chain more cost effective, with benefits to both climate and the environment [72].

3.1.4. Waste Utilization

The linkage between waste utilization and climate change mitigation is clear, as the use of agricultural waste, like biomass residuals, manure, and other organic waste, can be utilized for biogas production, as a way to decrease GHG emissions and make farms energy self-sufficient [78,79]. In addition, this type of biogas production may positively impact rural development and other sustainability aspects [77,80]. Nevertheless, it requires a large economic investment for farmers, with low profitability in small-scale operations and with the profitability affected by "regional availability of feedstock, the possibility to integrate with external heat sinks, appropriate process design and the scale of the plant" [81] (p. 299). Some studies [82] find that current biorefineries used for biogas production can be profitable, while others conclude that this is not the case without subsidies or sanctions [77,80]. Another option is cooperation between farmers to enable slightly larger local refineries [77], to integrate farmers into heat supply chains, and introduce more local fuel producers using crops and residues for heating, thereby reducing both GHG emissions and district heating prices [83]. However, the removal of straw residuals from fields for energy production can decrease the soil organic carbon content when not ploughed back into the soil [83].

The decision of whether to produce biogas when treating industrial food waste depends on the system at hand. A study on a large farm-based co-digestion plant in Sweden, using manure and various food industry wastes, found that GHG emissions from such a system in contrast to one with natural gas reduces emissions by 90% [79]. Different alternatives are, however, "best" from different perspectives. For example, a combined heat and power system is generally not a feasible economical choice [77], but is almost always the best choice from an energy perspective [84].

Another type of waste utilization involves the treatment and use of organic food waste and waste water (blackwater and greywater) for nutrient recycling and agricultural fertilizers. Such recycling generally reduces both eutrophication and GHG emissions [85,86]. Various methods for achieving nutrient recycling have been analyzed, sometimes compared with the use of mineral fertilizers. The use of urine separation systems, where the urine is used as a fertilizer, as well as systems where sewage sludge from wastewater is recycled as a fertilizer, are effective in terms of lowered energy use, GHG emissions, and eutrophication potential [85,87–89], but may result in the addition of some cadmium to the soil [88]. Directly recycling N and P from sewage sludge, or from ash from sewage sludge incineration, also results in lower environmental impacts, but often higher energy consumption [88,90]. Using digestate from food waste has a higher global warming and eutrophication potential compared to using mineral fertilizers and burning food waste [32]. Hence, the effects of different methods are complex, and it is not intuitively clear which treatment methods are most desirable, especially as using compost or biogas residues as a fertilizer can result in lower yields compared to using mineral fertilizers [91], and improvements of current treatment methods to recover and reuse nutrients from waste may change climate and/or environmental impacts [32].

3.1.5. Marketing, Labelling, and Consumption of Sustainable Food

From a food consumption perspective, a shift towards a diet containing less meat and more vegetables is the most important measure to mitigate climate change and most other environmental impacts, including eutrophication and biodiversity loss [31,47,66,92]. Nevertheless, many Swedish consumers seem unaware of this, as transportation, packaging, and waste are their greatest concern in terms of climate impact [93] and a shift away from the production of animal products may be met with resistance from both consumers and producers [94]. However, it can be important to consider the meat type and product origins before recommending vegetables over meat. In one study, chicken sausages produced in Sweden had equal energy inputs as imported frozen broccoli [66].

To guide consumers in their choices and to increase consumption of sustainable food, more/better communication about food production impacts is necessary [95]. However, retailers are only willing to provide better alternatives if there is a demand for them and if it coincides with commercial and financial goals [96]. Labelling of sustainable food is a way of communicating sustainability through packaging and marketing. Several studies have demonstrated that Swedish consumers generally are positive towards climate labelling [93,97], and show a willingness to pay more for locally sourced food or food produced with more regard taken to climate, environment, and animal welfare [35,36,98], thereby potentially increasing demand for these products [97]. However, results also indicate an inconsistency in willingness to pay between consumers [36].

Swedish local authorities can take responsibility for a transition towards more sustainable food production through the procurement of food for, e.g., schools, hospitals, and retirement homes. However, in terms of locally produced food (that may be more sustainable than imported) and Swedish meat with high animal welfare, there is a need for changes in procurement practices as European Union public procurement regulations currently prohibit geographical discrimination [45,95].

Both consumers, retailers, and the food production industry need to decrease food waste, in order to avoid negative impacts on climate change, eutrophication potential, and energy use from producing food unnecessarily [99–101]. At the retailer level, fresh fruits and vegetables is the food category most often wasted [102] and at the household level, about 10-20% of bought food is wasted [103]. Therefore, there is a need for people to feel personal responsibility in terms of waste, where the perception of wasting food as “morally wrong” could possibly shift consumer attitudes [103].

3.2. Synergies and Trade-Offs Related to ReDiReL

The synthesis of studies related to ReDiReL and sustainable Swedish agriculture and food production demonstrate several synergies and trade-offs between the five dimensions. Examples of synergies include:

- That increased production efficiency and more efficient nutrient handling, especially for livestock production [52], when shifting land allocation to better quality land [53] and improving manure handling [54] can mitigate climate change and reduce environmental impacts;
- that the recycling of nutrients from waste can decrease both GHG emissions and eutrophication [e.g., 85,88]; and
- that improved labelling of sustainable food [36,98] and increased energy efficiency and decreased food wastage both in the food industry and at home [102,103] have positive impacts on climate change, the environment, and the economy.

Trade-offs identified in the literature include:

- That agricultural actors, governmental agencies, and policy has often prioritized animal grazing as a way of preserving biodiversity over the climate impact of grazing animals [94];
- that less intensive production of animal products would result in reduced GHG emissions and eutrophication as well as higher animal welfare, but could also be costlier [99,104,105];
- that organic production generally requires larger land area, but has a lower nutrient surplus and impacts on global warming less than conventional production [55];
- that organic production of apples results in lower use of mineral fertilizers and pesticides, but also lower yields and lead to more damaged or rotten fruit [106];
- that biogas production has positive effects on GHG emissions, but is seldom profitable without subsidies [77]; and
- that a production system with higher animal welfare may be less profitable and have more negative environmental impacts [99].

Table 1 provides an overview of synergies and trade-offs evident in the reviewed literature, by presenting suggested sustainability interventions that address more than one dimension, as well as associated potential effects of their implementation. Note that if an intervention only presents, e.g., synergies in Table 1, this does not indicate that there are no trade-offs for that intervention, but rather that the reviewed literature does not address or point to any trade-offs for that specific intervention.

Based on Table 1, there are a number of knowledge gaps related to the interventions and their effects on the different dimensions. For example, few of the interventions addressed climate change adaption or focused on effects on biodiversity, acidification, and pesticide use. In addition, effects of the interventions were seldom considered for animal welfare and livestock epidemiology, as only nine and three of the 21 identified interventions considered effects on these dimensions, respectively.

3.3. Reflections from Stakeholder Interviews

The post literature review interviews highlighted a number of research areas that were under-represented or poorly defined in the eyes of some stakeholders. Although not all respondents disagreed with the synergies or trade-offs identified in Table 1, many pointed out that they knew of examples that contradict what some of the reviewed literature had found. Two areas stand out: There were disagreements about how animal welfare and livestock epidemiology interact with the other dimensions; and disagreements on how the economy seemed to be incompatible with other dimensions. For example, one interviewee suggested that less meat consumption, decreased animal density, or small-scale farming does not necessarily result in improved animal welfare. High animal welfare would instead depend on the specific farm system and on how a study defines low vs. high density. Interviewees pointed to the fact that there are some studies and reports that were not considered with respect to some interventions and/or dimensions. Usually, these could not be retrieved through the 45 search strings used. Interviewees also suggested that more research is needed at the interface of animal health, welfare and epidemiology, and the other dimensions. In terms of the economy dimension, interviewees pointed out that profitability is not the only metric of a good economy and that the literature reviewed focused on short-term effects and not long-term viability.

Interviewees did not agree among themselves on which sustainability interventions were most important for Sweden. Not unexpectedly, their first choice often reflected their field of expertise. For example, an organization working with farmers through extension services selected improved production efficiency in agriculture as the most important intervention, while one stakeholder working on epidemiology selected animal health as the most important. All interviewees gave examples on how their intervention would have impacts across the food production chain and across dimensions, indicating that they were thinking of the whole food production system even if they favored interventions more familiar to them. When identifying the most important interventions (questions 2 and 3, Table S3: Interview guide in the Supplementary Material), stakeholders considered improved animal welfare and health, decreased food wastage in the food chain, and small-scale farming most important. Following these three, large-scale or farm-scale biogas production, increased production efficiency including energy, and increased consumption of locally produced food were also identified as important from several perspectives. Interestingly, although moving towards more plant-based diets was mentioned as a key intervention, the importance of animals in a productive agricultural system was also highlighted. In other words, this signifies less meat production rather than no meat production.

The future research directions identified by the interviewees were in line with the knowledge gaps they previously identified during discussion about the most important interventions. Consequently, a better understanding of animal rearing with regards to all dimensions was highlighted. Another research topic that came up was the need to better characterize the role biogas can play in the hygenization of animal and other organic waste to promote safe resource recycling in a more circular economy. Many interviewees also mentioned the need for continued research that can tackle the complexity of the food system by looking at multiple dimensions and considering multiple scales. In addition, interviewees explicitly pointed out the important role of consumers in driving change and that, as such, doing research that considers these actors and also investigates how to communicate findings to the public was important.

4. Discussion

The review and synthesis of the literature related to ReDiReL, sustainability, and the Swedish food production system included studies for most dimensions and parts of the food production chain. The review identified 21 interventions potentially useful for meeting the challenges related to multiple dimensions. A majority of these interventions involved agricultural production, while only a few focused on transports and localization, despite the focus of the review effort on ReDiReL, or the scale of production. In addition, few studies and interventions considered animal welfare and livestock epidemiology.

In general, the literature pointed to synergies between interventions related to the climate change and environment dimensions, as the proposed interventions often had a positive effect on both. In terms of trade-offs, the literature most often described or indicated trade-offs between the economy and the other dimensions. Studies examining the ways of managing multiple ecosystem services (in some cases, in combination with factors, like, e.g., biodiversity) have similarly found that there can be both synergies and trade-offs among services, e.g., trade-offs between provisioning ecosystem services, like food and timber, and regulating and cultural ecosystem services [107–109]. The interviewed stakeholders emphasized increased animal welfare and health, decreased food wastage, and small-scale farming, as well as biogas production, increased production efficiency, and increased local consumption as the most important interventions for a sustainable food production system in Sweden. It is important to note the conclusions from the review and synthesis as well as the identified interventions, synergies, and trade-offs are only based on the studies found in the literature search. There is likely additional literature (from both within and outside of Sweden) that identifies additional interventions or effects, which were not included in this study, due to the Swedish focus or limitations in the search terms used. This fact was specifically pointed out by some of the stakeholders.

Therefore, the main focus of the discussion is the identification of potential knowledge gaps and future research needs.

In general, the reviewed literature seldom addressed climate change adaptation, even though this may involve effects related to all the included dimensions [110]. In addition, the included studies related to the environment more often concerned eutrophication than effects on biodiversity, despite the fact that biodiversity is important [111] and that agriculture can have a large impact on it [14]. Given how large the livestock sector is in Sweden [112] and the high costs related with disease outbreaks [19,20], it is also surprising that so few studies focused on animal welfare and livestock epidemiology. In addition, the reviewed literature almost exclusively considered the economy in the form of profitability and did not consider any further social dimensions, even though stakeholder interviews and the knowledge of the researchers involved in this project perceived economic and other social dimensions as complex and important. Profitability was often only mentioned as being positively or negatively affected in relation to other dimensions, although in reality it is a complex and dynamic set of interactions. While previous studies have highlighted the need to consider both environmental and social dimensions to ensure, e.g., policy relevance [113], studies that have looked at multi-dimensional aspects of food system sustainability from a Swedish perspective have also focused on farmer profitability when it comes to the economy (e.g., Röös et al. [114] on Swedish organic agriculture).

Some of the knowledge gaps related to the interventions and their effects are associated with the Swedish focus of the review, as studies do exist from Europe or the rest of the world. In these cases, further research is needed to investigate if effects are similar for Swedish conditions. For example, the impacts of organic farming on eutrophication, but not biodiversity, have been studied in Sweden, although a large-scale meta-analysis has found positive effects of organic farming on biodiversity [115]. Studies have revealed a link between higher animal welfare and more disease resistant animals [116,117], indicating that interventions aimed at increasing animal welfare could also affect livestock epidemiology. A review focusing on the USA found positive effects of integrated animal and crop production on yield and profitability [118], which could potentially be true under Swedish market conditions as well.

There are also some knowledge gaps where no or few relevant studies from outside Sweden exist, and thus additional research is also needed. Many of these areas involve tackling assumptions about the relationships among dimensions. That is, it can be easy to assume certain relationships based on anecdotal data, but without systematic evidence collection, it remains difficult to know if an intervention that resulted in a positive impact on two dimensions was not in fact related to another cause. One example includes determining if small-scale farming systematically leads to positive effects on environment and animal welfare, and if this is true, what would be the implications for other dimensions, such as climate change, livestock epidemiology, and profitability. In addition, both farm-scale and large-scale production of biogas reduces GHG emissions, but can probably also be expected to reduce eutrophication if the biogas residues are used as a fertilizer [119–121]. Research is also needed to investigate direct economic effects of labelling of sustainable food. The interviewed stakeholders also pointed to the fact that more measures than profitability could be used to measure economic effects.

The majority of the knowledge gaps relate to animal welfare and livestock epidemiology. Thus, it is not surprising that this was one of the main knowledge gaps identified by the interviewed stakeholders, and that these were the dimensions where most research was considered necessary. For example, studies have concluded that high livestock production intensity may decrease animal welfare [60] and thus it seems reasonable to assume that improved agricultural production efficiency should affect animal welfare, in addition to climate, the environment, and the economy. Integrated livestock and crop production have positive effects on animal welfare due to decreased animal density within farms, but could potentially also positively affect livestock epidemiology as it could lead to fewer susceptible animals per farm and potentially limit the overall animal density in the landscape, thereby decreasing the risk of large disease outbreaks. As noted by one interviewee, decreased meat consumption does not necessarily have a positive effect on animal welfare, unless there is also a shift towards less intense animal production systems. Sharing of equipment due to increased farmer co-operation leads to negative effects on animal welfare and livestock epidemiology, but further improvements to biosecurity measures should prevent this. In addition, some interventions aimed at improving animal welfare had the opposite effect [60,61], but adapting these or implementing other welfare measures should lead to only positive effects on animal welfare. Thus, much work remains to be done to better understand how animal welfare and livestock epidemiology relate to the sustainability interventions and the other dimensions.

The involvement of the stakeholders in this study proved useful, and there was agreement between the authors and stakeholders on the knowledge gaps and future research needs, as well as some of the most important sustainability interventions. There were also some similarities between key interventions identified by stakeholders in this, and another recent study, aimed at developing a future food vision for the Nordic countries [22]. For example, the focus on small-scale farming, biogas production, and subsequent nutrient recycling, decreasing food wastage, and only using animals that can be fed using biproducts and waste streams (i.e., limited livestock production) was identified by stakeholders in both studies, while only one of the stakeholders interviewed for our study brought up the importance of organic farming, which was considered important in the Nordic study. However, the Nordic study did not consider effects on animal welfare or livestock epidemiology.

5. Conclusions

To develop a sustainable food production system in Sweden, there is a need for an integrated approach that considers not only the entire food production chain, but also multiple dimensions related to the impacts of the production of food. However, few of the studies reviewed in this study focused on more than three sustainability dimensions at once (many only on one), with most focusing on climate change, the environment, or the economy and few focusing on animal welfare or livestock epidemiology. This clearly points towards a need for research related to animal welfare and livestock epidemiology that can be integrated with the other dimensions and with an ReDiReL perspective (i.e., there is of course a large international literature on these issues, difficult to mesh with the information on Swedish interventions for other dimensions). Furthermore, it can be important to consider further social dimensions beyond just the economy, e.g., equity in access to resources, quality of life and health [113]. All five dimensions need to be considered further in relation to each other in the context of potential sustainability interventions, as the results indicate important interlinkages between dimensions, but also that there is a lack of knowledge regarding the effects of certain interventions. This was also emphasized by the interviewed stakeholders, who addressed the need for further knowledge regarding, e.g., animal rearing, the role of biogas, and the circular economy. A majority of the sustainability dimensions identified in the literature involved agricultural production. Despite the importance of resource distribution and recycling logistics for a sustainable food production system, few studies dealt directly with this, e.g., few studies focused directly on transport and localization. Few studies focused on the association between different parts of the food production chain, considered it as a whole, or investigated effects across multiple scales. Thus, there is a general need for future studies that consider the above-mentioned aspects, individually, but, even more importantly, from a systems perspective that considers interactions between the aspects. It is also important that future research can be effectively communicated to policy makers as well as the public, who both have important roles in driving future changes towards a more sustainable food production system in Sweden.

Supplementary Materials: The following are available online at http://www.mdpi.com/2071-1050/11/3/601/s1, Table S1: Search terms used in the systematic literature search, Table S2: Number of articles found in each literature search, Table S3: Interview guide, Table S4: Overview of the literature review.

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