Shifting focus from yields to food supply

An evaluation of the ‘number of people fed per hectare’ indicator at farm and national levels.

Ida Ekqvist

Degree project/Independent project • 30 credits
Swedish University of Agricultural Sciences, SLU
Faculty of Natural Resources and Agricultural Sciences
Sustainable Food Systems – Master’s Programme
Molecular Sciences, 2020:36
Uppsala, 2024

Shifting focus from yields to food supply

An evaluation of the "number of people fed per hectare" indicator at farm and national levels

Ida Ekqvist

Supervisor:	**Elin Röös, Swedish University of Agricultural Sciences, Department of Energy and Technology**
Examiner:	Pernilla Tidåker, Swedish University of Agricultural Sciences, Department of Energy and Technology

Credits:	30 credits
Level:	Second cycle, A2E
Course title:	Master thesis in Food Science
Course code:	EX0875
Programme/education:	Sustainable Food Systems – Master’s Programme
Course coordinating dept:	Department of Molecular Sciences
Place of publication:	Uppsala
Title of series:	Molecular Sciences
Part number:	2020:36
Year of publication:	2024
Cover picture:	Fotograf: Jenny Svennås-Gillner, SLU

Keywords:	Land use efficiency, Sustainability indicators, Agricultural productivity, Food production

Swedish University of Agricultural Sciences

Faculty of natural Resources and Agricultural Sciences

Department of Energy and Technology

Abstract

The challenge of feeding a growing global population while reducing the pressure on climate and ecosystems has gained much attention in research over the last decades. A crucial yet often overlooked aspect in research addressing this complex challenge is the efficiency of food production in meeting nutritional needs within the constraints of global cropland resources.

Addressing this gap requires a perspective on productivity that extends beyond the traditional metric of yield per hectare to also consider the diverse nutrient needs of a complete diet. An indicator that effectively capture this aspect is the 'number of people that can be fed per hectare' in terms of adequate intake of calories, protein and fat. The mission of this thesis is to evaluate if and how this indicator can offer valuable insights at different levels in the food system. To comprehend the potential benefits of using the indicator and identify its most suitable area of use, the indicator was applied at two different levels in the food system. Calculations were conducted at 1) the national level, focusing on Sweden as a whole, and 2) the individual farm level, applying the indicator to a selection of real farms in order to explore the strengths and shortcomings of the indicator at different scales of application. The case farms, consisting of nine livestock farms that started a transition to a more diversified agriculture, were analysed before and after implemented production changes.

At national level, the indicator proved effective in providing information on the current utilization of edible nutrients in the food system and by highlighting the supply capacity within existing agricultural production. The application of this indicator to Sweden's agricultural output show that the country's current food production can meet the daily calorie needs of about 5 people per hectare and slightly fewer in terms of protein and fat. Shifting the crops currently used for feed, fuel and other uses towards direct human consumption would double calorie provision and increase protein supply by 50%. Less than half of the edible fat and only around 30% of the proteins and 40% of the calories from crops produced in Sweden 2020 were used as food, with 11% of plant protein and 10% of edible fat going to biofuel and ethanol production.

Applied at farm level, the indicator can serve as a tool for understanding the performance of individual farms, providing insights into how different production decisions affect farm output and land use efficiency in terms of food supply. Its primary utility at farm level lies in tracking the impact of agricultural practices on a particular farm over time. However, it is not ideally suited for benchmarking performance across farms with different natural conditions for agricultural production.

Finally, this thesis emphasizes the necessity of adopting a holistic approach in the assessment of a farm or region. To ensure a multi-dimensional evaluation that captures the complexities and interdependencies inherent in sustainable agricultural systems, the 'number of people fed per hectare' needs to be integrated with a broader range of sustainability indicators, covering ecological, economic, and social aspects.

In conclusion, the 'number of people fed per hectare' indicator demonstrates greater utility when applied at the national scale than at the farm level. Its application to broader food systems offers valuable insights into agricultural productivity and food supply capacity of a country, which can be useful to evaluate the land use efficiency of current production and further to identifying possible actions to increase the national food supply.

Keywords: Food production, Land use efficiency, Sustainability indicators, Agricultural productivity

Table of contents

List of tables **6**

List of figures **7**

1. Introduction **8**
1.1 Point of departure 8
1.2 Study aims an research questions. 9

2. Background **11**
2.1 The global food system 11
2.1.1 Agricultural land use 11
2.1.2 Global food production 12
2.1.3 Sustainability of food systems 13
2.1.4 Changing diets 14
2.2 Future food demand 14
2.3 Swedish Agriculture 15
2.4 Ways of monitoring impacts from food systems 17

3. Methods **19**
3.1 Case study description 19
3.1.1 The case farms 19
3.1.2 Sweden’s total food production 2020 21
3.2 Indicator: Number of people fed per hectare 22
3.3 Total production 24
3.3.1 System boundaries and methodological approach 24
3.3.2 Net yield 26
3.3.3 Edible content – utilization rates for crops and meat 26
3.3.4 Nutritional content 27
3.3.5 Utilization of crops produced at Swedish cropland 29
3.4 Daily nutritional requirements 31
3.5 Total land use 31
3.5.1 Land use from purchased feed at the farm level 32
3.5.2 Land use from imported feed at the national level 33
3.5.3 Estimated land use in animal production from sold an exported feed 34

4. Results **36**
4.1 Farm level 36
4.2 Swedish food production 39
4.2.1 Macronutrients 39
4.2.2 Fruit and vegetables 43
5. Discussions **44**
5.1 Applicability at the farm level 44
5.1.1 The impact of crop utilization and production strategies 44
5.1.2 Complete protein 45
5.1.3 Possibilities and constraints in farm level application 46
5.2 Applicability at the national level 48
5.2.1 In the lens of global food responsibility 48
5.2.2 Feed food competition 49
5.2.3 Possibilities and constraints in national level application 50
5.3 Fruit and vegetables 52
5.4 Comparison with previous studies and findings 52
5.5 Limitations of study 54
6. Conclusions **56**
References **57**
Popular science summary **70**
Acknowledgements **71**
Appendix 1 .... **72**
Appendix 2 .... **74**

List of tables

Table 1. Characteristics of the Swedish case study farms 21
Table 2. The factors representing the percentage of the crop yield used for seed 26
Table 3. Percentage of the crop that can be utilized for human consumption.................. 27
Table 4. Percentage of bone free meat in the carcass weight of animal products 27
Table 5. References for energy, protein and fat content in food and feed........................ 28
Table 6. Percentage of Swedish grown crops used for food and feed 30
Table 7. Percentage of Swedish grown crops used for fuel and liqour............................. 30
Table 8. Calculations of daily reference intake values for energy, protein, and fat. 31
Table 9. Macronutrients provided from the consumption of fish and seafood 31
Table 10. Mass allocations factors for ingredients in purchased feed (by-products)........ 32
Table 11. Crop yields used in the calculations of land use from purchased feed. 33
Table 12. Estimated quantity of imported feed 34
Table 13. Hectare yields used for calculations of land use from imported feed. 34
Table 14. Feed ratio of the external meat production 35
Table 15. Number of people who can be fed in total from Swedish production 40
Table 16. Number of people that can be fed per hectare from Swedish production 41
Table 17. Number of people that can be supplied with the daily recommended intake of fruit and vegetables from the Swedish production... 43
Table 18. The total production of lupine beans, brown beans and other legumes. 72
Table 19. Total exported quantity of cereals (in tonnes) and percentage of the export distributed by food and feed use... 73

List of figures

Figure 1. Number of people that the total food production and the edible macronutrients embedded in the total crop production on each farm can feed in terms of daily recommended intake of (a) energy, (b) protein, (c) complete protein and (d) fat in the first and second years respectively. 37

Figure 2. The percentage losses of (a) edible calories, (b) edible proteins and (c) edible fat in the production intended for human consumption at each farm compared to if all edible crops at the farm were used for food. 38

Figure 3. Proportions of the edible content of energy and macronutrients in the total crop production used for food, biofuel, ethanol production, feed and other use. 42

Figure 4. Proportions of the Swedish cropland used for food crops, animal production and other. 42

Figure 5. Proportion of the total amount of edible (a) energy, (b) protein, (c) complete protein and (d) fat in Swedish food production that comes from crop production and animal production respectively. 43

Figure 6. Quantity of edible fat and protein embedded in the total crop production in Sweden 2020, distributed by area of use. 74

Figure 7. Proportion of cropland used for feed production on the case farms. 74

1. Introduction

1.1 Point of departure

Current food systems are not delivering healthy diets for all and causing serious environmental pressure and social problems. Food production accounts for 30% of greenhouse gas emission globally (Crippa et al. 2021) and agricultural expansion is a major driver of biodiversity loss (Williams et al. 2021). Further, ongoing climate change and decline of ecosystem services impose negative impact on food security (Ortiz-Bobea et al. 2021; Farooq et al. 2022). The challenge of feeding a growing global population while reducing the pressure on ecosystems has gained much attention in research over the last decades (Godfray et al. 2010; Foley et al. 2011; Gerten et al. 2020). Numerous studies have mapped the environmental impact of food products throughout their entire life cycle (Poore & Nemecek 2018; Ahmad et al. 2019; van Hal et al. 2019). Additionally, there is a growing body of research focused on potential strategies for more resource-efficient agricultural production, often referred to as 'sustainable intensification' (Godfray & Garnett 2014; Cassman & Grassini 2020). However, a mere focus on improvements on the production side of the food system is not enough to address future challenges of global food supply. Substantial changes to consumptions patterns, such as shifting diets towards less animal products in high income countries and reducing food waste is also required (Röös et al. 2017; Willett et al. 2019; Webb et al. 2020; IPCC 2023b). In addition, a limited amount of global cropland is available to nourish the world's population (Cassidy et al. 2013) and further expansion of crop land stand in direct conflict with the urgent need for biodiversity preservation (Zabel et al. 2019). Thus, a responsible use of the existing crop land, in order to ensure access to nutritious and sufficient food for all while mitigating the environmental pressure from production is crucial to reach the global target of zero hunger (United Nations Department of Economic and Social Affairs 2023).

Currently, a large share of the world's crops is not utilized as food but is being fed to animals or turned into fuel. Less than half of the global cereal production and about a fifth of the soy production is consumed directly by humans, most of the remaining share is used for animal production and a considerable amount becomes fuel (Ritchie & Roser 2023). Redirecting edible crops away from human consumption entails a substantial loss of food, which is why several authors advocate a shift in focus from 'yield per hectare' to 'number of people fed per hectare

(Cassidy et al. 2013; Röös et al. 2021). Focusing solely on yield levels neglects key aspects of food system productivity: the overall quantity of food produced and its capacity to meet the population's nutritional needs. To address this gap, Cassidy et al. (2013) introduced the indicator 'number of people that can be fed per hectare' which offers an alternative measure of agricultural productivity, capturing these crucial factors. However, the practical application of this indicator across varying scales, ranging from individual farms to a broader food system, requires further exploration. At farm level, this raises central questions: How can a farm take on global food responsibility? And how might individual farmers assess their farm's capacity to contribute to the global food equation, that is, to produce sufficient food for a growing population within the constraints of existing cropland?

Numerous studies have focused on the environmental impact at the farm level, but few of these studies investigate how much food the farm contributes (Repar et al. 2017; Lampridi et al. 2019; Soulé et al. 2021; Kokemohr et al. 2022). This represents an important area for further research, to gain better understanding of how different production strategies at the farm level can contribute to global food security. Assessing farm-level production in terms of its contribution to global food supply is challenging due to various factors like biophysical conditions and the organization of local food systems and resource supplies. Previous research by Elin Röös et al. (2021) utilized the indicator 'number of people that can be fed per hectare' in terms of calories and protein, to assess the contribution of a single farm to global food security. Although this indicator does not capture the full extent of what a farm produces in terms of nutrition and other values, it serves as a straightforward tool to obtain information on a farm's food production output. Further, it can serve as a method for evaluating how changes in the production, in terms of distribution of different crops and livestock products on a particular farm, affect the land use efficiency linked to food security. However, the farm may not be the appropriate scale for applying this type of indicator, given that individual farms have different conditions for agricultural production. It might be more relevant to apply this indicator at a national or regional level to capture how a specific country or region utilizes its agricultural production capacity and to identify potential strategies for increasing the national food supply.

1.2 Study aims an research questions.

This thesis aims to explore the applicability of the 'number of people fed per hectare of cropland' indicator as a tool to evaluate agricultural production systems at two different levels: 1) the national level, focusing on Sweden as a whole, and 2) the individual farm level, applying the indicator to a selection of real farms in Sweden. The objective is to evaluate and discuss the performance of these agricultural systems in terms of food supply and to discuss the utility of this indicator when applied at these various scales.

Research questions include:

- How can the indicator be used at farm level to provide farmers with insights into the impact of their production changes or strategies on their contribution to global food supply.
- Is this indicator effective in evaluating a country's capacity to supply food when applied to national agricultural production data?
- What is the most useful level of application of this indicator: at the individual farm level or across a broader food system?
- What are the potential possibilities and limitations of using this indicator to evaluate the effects of various strategies and changes in agricultural production on food supply?

The indicator was applied to nine livestock farms that have begun a transition to a more diversified agriculture by growing a greater proportion of crops intended for human consumption. Calculations were made on the farm's total production before and after implemented changes. In addition, calculations were made on Swedish food production, based on the official agricultural statistics for the production year 2020, to evaluate and compare the applicability at different levels in the food system.

2. Background

2.1 The global food system

2.1.1 Agricultural land use

The global use of agricultural land has expanded substantially over the past three centuries (Ramankutty et al. 2018) and is today the largest biome on the planet (Foley et al. 2011). Global food production utilizes 4.8 billion hectares of land worldwide which constitutes around one third of the global terrestrial land surface (Silver et al. 2021; Conchedda et al. 2023) This agricultural land contributes the main part of the global food supply. It has been estimated that around 90% of available food calories (Cassidy et al. 2013) and 80% of the protein and fats (Steinfeld et al. 2006) are produced on agricultural land.

One third of the global agricultural land is used as cropland, while the remaining two-thirds are utilized as meadows and pastures for animal production (Conchedda et al. 2023). Out of the 1.6 billion of hectares of cropland available worldwide, 88% was estimated to be arable land in 2021 (ibid.). *Arable land* is defined by FAO as land used for temporary crops, temporary meadows, and temporary fallow. The main part of the arable land was used for annual crops such as rice, wheat, and maize. The remaining 12% of the cropland was used for permanent crops such as cacao, coffee, fruit trees and palm plantations in 2021. The area used for permanent crops increased by 40% since 2020 (Conchedda et al. 2023). Further, about a fifth of the total global crop land area is equipped for irrigation, of which 40% is in Asia (ibid.)

The global expansion of cropland has accelerated over the past two decades, primary driven by agricultural growth in Africa and South America. According to a study by Potapov et al. (2022) there was a 9% increase of global cropland area between 2003 and 2019. Half of this newly established cropland replaced grasslands and forests, contradicting the goal of preserving terrestrial ecosystems (ibid.). As cropland expansion is a major driver of biodiversity loss, the scope for increasing the area of global cropland is severely restricted (Molotoks et al. 2018; Zabel et al. 2019).

Globally available cropland per capita has decreased over time along with population growth. In year 2021, the available cropland per person worldwide was estimated to 0.2 hectare (Conchedda et al. 2023), which is less than half of the 0.45

hectares available per person in 1961 (FAO 2020). During the same period there has been a substantial increase in the annual net primary productivity (NPP) per hectare of cropland due to agricultural intensification (Potapov et al. 2022). However, there is a growing consensus that agricultural intensification alone is insufficient to sustainably meet the future demand for food on current cropland area (Beltran-Peña et al. 2020).

The largest per-capita cropland area is found in Oceania, which has 0.8 hectares of cropland per person, followed by Europe and America. In Asia, the per-capita cropland is 0.1 hectares, making Asia the region with the least available cropland per person (Conchedda et al. 2023). Conversely, Asia holds the largest share of crop land, accounting for 38% of the global total, followed by America and Europe whereas Oceania has the smallest proportion of cropland, making up only 2% of the total global cropland area (ibid.).

The per capita cropland differs considerably across countries within regions, due to variations in population density, land use patterns, and agricultural practices. In 2021, the average cropland area per person in Europe was 0.4 hectare, with the lowest per capita crop land found in the Northern and Western Europe (0.2 hectare/capita) and the largest in Eastern Europe (0.7 hectare/capita) (Conchedda et al. 2023).

2.1.2 Global food production

The agricultural production efficiency has accelerated rapidly since 1960's, with a threefold increase in crop production, due to developed technologies and purchased inputs that enabled higher yield and intensified use of the crop land (Pellegrini & Fernández 2018). The strive to feed a growing world population has led to a transformation of the global food system from being predominately rural and local into todays intensified and industrialized agricultural system. However, the pathways for increased food production have differed geographically. While increased yields has driven the productivity in regions with irrigated agriculture (such as Europe and Asia), land expansion has been the most prevalent driver for increased/enhanced food production in large parts of Africa (Giller et al. 2021). The transition towards intensified agriculture has contributed more food to the global food system. However, it has also resulted in a decline in food diversity and less diverse agricultural landscapes, which has implications for the global availability of nutrients and future food security (Campi et al. 2021). Currently, the global food system is dominated by four major staple crops (maize, soy, rice and wheat) which are widely traded between regions (Silver et al. 2021). As a result, national food supply worldwide has become more interdependent and more homogeneous in composition (Khoury et al. 2014).

The structure of agricultural production varies geographically in terms of diversity, farm sizes, and food commodities. Large farms dominate food production in North America, South America, and Oceania, whereas small farms predominate in South Asia, China, and sub-Saharan Africa. Very small farm, with less than 2 hectares of agricultural land, provide the main part of the local food supply in some parts of the world and account for roughly 30% of the world's total food production (Herrero et al. 2017). Research indicates that nutrient diversity decreases with increasing farm size (Ricciardi et al. 2018) and that regions with greater agricultural diversity tend to produce more nutrients overall (Herrero et al. 2017). Most of the global production of fruits, vegetables, pulses, cereals, roots, and tubers comes from farms smaller than 50 hectares located in regions with high agricultural diversity. Conversely, sugar and oil crops are often produced in monocultures on large farms (ibid.).

Further, biophysical conditions for food production, including soil quality and climate, exhibit great variations across different regions worldwide. Thus, global trade plays a critical role in ensuring food security, especially in regions such as Africa and Southeast Asia, where the estimated capacity for food self-sufficiency is notably low (Silver et al. 2021). Approximately one quarter of the global food production is traded internationally (D'Odorico et al. 2014). The intensified production of high yielding crops provide a surplus of nutrients accessible on the global market (Herrero et al. 2017) but the production is often associated with an excessive use of chemical fertilizers and exploitation of ground water with great implications for sustainability (Wang 2022). The importance of smallholder systems in global food security has been highlighted in several studies (Herrero et al. 2017; Giller et al. 2021). Smallholder farms produce about 50% of the global food supply (Samberg et al. 2016; Ricciardi et al. 2018) on 40% of the global agricultural land area (Silver et al. 2021). However, the productivity of these agricultural systems is often limited by yield gaps and economical constraints (ibid.).

2.1.3 Sustainability of food systems

Enhanced global trade and increased agricultural efficiency has made diets of higher quality accessible for an increasing number of people around the world. However, this development has come at a great environmental cost and the current food systems fail in delivering nutritious diets for all (Ramankutty et al. 2018; Ambikapathi et al. 2022). There is more calories per capita produced than ever globally (Cassidy et al. 2013) and enough to feed the global population (D'Odorico et al. 2014). Yet, the vast majority of the world's population living in rural and developing countries, in total around three billion people, cannot afford a nutritious diet (Ambikapathi et al. 2022) and the number of people suffering from hunger and malnutrition is rising worldwide (FAO et al. 2022; IPCC 2023a).

In addition, a vast part of the produced food is never consumed, it is estimated that one third of all food produced in the world is wasted annually which accounts for 8-10% of the global greenhouse gas emissions (United Nations Environmental Programme 2021). In addition, climate change poses serious threats to global food security (IPCC 2023a). Extreme weather events, changing rainfall patterns, rising temperatures, and increased pest pressures affect agricultural productivity and disrupt supply chains. Additionally, environmental degradation, land degradation, and water scarcity further compound the challenges of sustainable food production.

Global food production accounts for 70% of the water extracted from nature (FAO 2018b) and one third of the greenhouse gas emissions caused by human activity (Crippa et al. 2021).Further, the food imports of industrialized nations drive extinctions of species in highly biodiverse regions in the world (Chaudhary & Kastner 2016).

2.1.4 Changing diets

As incomes rise and societies urbanize, dietary preferences are shifting towards more resource-intensive food products, such as meat and dairy. It has been estimated that as much as 40% of the calories imbedded in global crop production is used for animal production (Pradhan et al. 2013). An increasing proportion of the calories, proteins and fats consumed on a global scale derive from energy dense foods and animal products, which has caused a rise in diet related diseases, such as obesity and heart disease (Khoury et al. 2014). This shift in consumption patterns poses a great challenge to food security and puts pressure on natural resources and eco systems as animal-based foods require more land, water and energy compared to plant based alternatives (Chaudhary & Kastner 2016; Willett et al. 2019; Viana et al. 2022) However, there is a stark contrast between low-income and high-income regions in the world regarding the proportion of crops used for human consumption. In high-income regions, approximately 20% of the cereal is used for food, while low-income countries allocate a much higher proportion – on average 80%- for human consumption (Ritchie 2021).

Numerous studies highlight the extensive food loss (Pradhan et al. 2013; Shepon et al. 2018; Silver et al. 2021) and environmental impacts (Clark & Tilman 2017; Chaudhary et al. 2018; Gerten et al. 2020; Hayek et al. 2021; Xu et al. 2021; Gibbs & Cappuccio 2022) associated with consuming resource intensive animal foods compared to if the crops were used directly for human consumption.

Although these findings put light on the crucial need of diet changes to meet food security goals, particularly in industrialized countries, the value of using crops for direct human consumption varies greatly between different regions and food systems in the world due to different conditions for food production. Further, with optimized feed provision strategies, animal production has the potential to contribute to a sustainable food system by converting unutilized resources into nutritious food. In addition, livestock can serve as promoters of ecosystem services by managing agricultural landscapes (Karlsson 2022).

2.2 Future food demand

The world's population is projected to increase by nearly 2 billion people by 2050, predominantly in developing countries (United Nations 2022). This population growth poses a major challenge to food production, as a substantial increase in agricultural output is required to meet the rising demand. There are various projections concerning the extent of future food demand based on different assumptions concerning sustainability, technological development, and diets. A meta-analysis by van Dijk et al. (2021) that reviewed 57 studies on future food security suggests that the global demand of food is expected to increase somewhere around 35-56% between 2010 and 2050. Another study predicted future food demand to increase threefold by the year 2100 (Beltran-Peña et al. 2020).

Global cropland has been projected to expand by 7% by 2030 (Alexandratos & Bruinsma 2012) although research suggests that further expansion would imply adverse damage of ecosystem functions due to extensive biodiversity loss and a reduction of carbon storage both in soil and vegetation (Molotoks et al. 2018). Multiple studies indicate that meeting the increasing food demand on current cropland while safeguarding the ecosystem is possible, but would require substantial changes in farming practices and consumption patterns. This includes implementation of efficient farming techniques to minimize yield gaps, such as enhanced water management strategies. Additionally, it involves the spatial reallocation of cropland, a considerable reduction of food waste, and substantial shifts towards less resource-intensive diets, specifically by reducing meat consumption (Mauser et al. 2015; Erb et al. 2016; Springmann et al. 2018; Beltran-Peña et al. 2020; Gerten et al. 2020).

Agroecological farming methods, such as increased on-farm diversity (agricultural diversity), has been highlighted as a potential pathway to enhance food security (FAO 2019; Bezner Kerr et al. 2021) by mitigating the pressure on biodiversity in food systems (Jones et al. 2021) and enhance food production by increasing ecosystem services (Palomo-Campesino et al. 2022). However, an increase in crop yields and biodiversity alone is not sufficient to address future global food security challenges, a food system transformation that also tackle poverty and inequalities of access to food is needed to reach these goals (D'Odorico et al. 2019).

2.3 Swedish Agriculture

Sweden has a total land area of approximately 41 million hectares (Statistics Sweden 2023), of which around 70% are covered by forests. Forests play a crucial role in Sweden's economy and is primarily utilized for timber production and other forestry products. Cropland and pasture make up a smaller portion of the available land. Cropland in Sweden covers approximately 2.5 million hectares while pasture occupies almost 0.5 million hectares (The Swedish Board of Agriculture 2023a). Sweden's per capita cropland is approximately 0.28 hectares, which is slightly above the global average of 0.2 hectare/person (Statistics Sweden 2023). The Swedish diet on the other hand, is highly land demanding, requiring 0.4 hectares per capita and year (Sonesson & Östergren 2019).

The use of crop land in Sweden has decreased sharply in the last 100 years, from 3.8 million hectare in 1922 to the current cropland area of roughly 2.5 million hectare (The Swedish Board of Agriculture 2021a). Swedish agriculture has since the post war period transitioned from a predominantly subsistence-based system to more large scale and specialized industry. Historically, agriculture in Sweden has played a crucial role in providing sustenance for the population, with small-scale farms practicing a mix of crop cultivation and livestock rearing. However, changes in the competitive landscape, political decisions, technological advancements, and mechanization have led to a shift towards larger and fewer agricultural enterprises, often specializing in either one types of animals or crop cultivation (Jansson & Mårald 2005).

The main crops grown on Swedish cropland are grass-clover leys and cereals. Around 44% of the total available cropland is utilized for temporary grazing and cultivation of ley and forages while cereal cultivation makes up approximately 38%. Further, oil crops are cultivated on 5% of the total cropland area, while 6% is dedicated to other edible crops, with grain legumes accounting for around 2%. The domestic consumption of cereals and oil crops is allocated between food, animal feed and biofuel purposes. A large share of the cereals is exported (The Swedish Board of Agriculture 2023a).

Agricultural land is mostly concentrated to the southern parts of Sweden, although agricultural land exists over almost the entire country, with the exception from parts of Norrland. Major crop producing regions are found in the southern parts of Sweden, particularly Skåne, Halland, Västra Götaland and Östergötland (The Swedish Board of Agriculture 2020e). These regions have favorable climatic conditions and fertile soils that support the cultivation of a wide range of crops with high yields. Swedish horticulture is concentrated in Skåne, where over 70% of all vegetables, fruit and berries are grown (LRF 2022).

Common beans for human consumption are mainly cultivated in Gotland, Öland and the Kalmar region, where the crops benefit from many hours of sunshine and calcareous soils (ibid.). Other regions, such as Västergötland, have a large presence of dairy farms (The Swedish Board of Agriculture 2020a), while Norrland, in the northern part of the country is dominated by extensive forests and forestry industry (SCB 2023).

Large parts of Sweden are primarily suitable for cultivating forage crops (Statistics Sweden 2023). Therefore, milk and meat production traditionally dominate in these regions, where forage can be converted into high-quality food. This is partly why Swedish food production has historically relied largely on 'processed grass', meaning milk and meat from animals that can convert non-edible biomass into high-value food (Leibring & Svanberg 2020).

Sweden has witnessed a decrease in pork production, resulting in a shift from being a net exporter to a net importer. This is largely due to increased price competition in connection with Sweden’s entry into EU but also due to an increased consumption of pork (Nordin 2020; The Swedish Board of Agriculture 2023c).

Moreover, Sweden's degree of self-sufficiency for beef and dairy has decreased over the past 30 years. Population growth and changing diets explains parts of this decline. However, milk production has seen a steady decline also in terms of volume over the last decades (ibid.).

Approximately 44% of the food calories in Sweden 2020 was imported, as reported by the Federation of Swedish Farmers (LRF 2021)

Out of the food products currently produced within the country, Sweden is only self-sufficient in cereals and relatively self-sufficient in eggs, sugar, carrots, potatoes. However, Swedish agriculture heavily relies on imported inputs, including pesticides, fertilizers, feed and fuel. Without these imported inputs, the agricultural production would be lower (The Swedish Board of Agriculture 2023b).

Further, LRF (2022) emphasize the potential to increase Swedish production of livestock as well as fruit and vegetables, through more efficient use of cropland and natural pasture.

2.4 Ways of monitoring impacts from food systems

The food system has profound effects on the sustainability of our planet and effective monitoring of its impact is crucial to guide decision-making towards more sustainable production systems. Various methods are employed to assess impacts from the food system, providing valuable data and insights into environmental, social, and economic aspects. However, assessing sustainability of a food system or a farm is a complex task, and the selection of a suitable method relies on the specific question and context being examined.

Life Cycle Assessment (LCA) is a widely used method that assess environmental burden of a product associated with production, processing, transportation, consumption, and waste (Muralikrishna & Manickam 2017). LCA is a useful tool to identify what stages in the life cycle of a product or process that cause the most environmental burden, considering environmental factors such as greenhouse gas emissions, water use, land use and energy consumption. This data can be utilized to find efficient measures to lower the environmental impact of a product. LCA can also be used to compare the environmental burden per unit of different food products, e.g., one kg of meat compared to one kg of grain legumes (ISO 2006).

Although LCA provides quantitative and valuable insights into a product's environmental sustainability, it alone is not a sufficient tool to evaluate the overall sustainability of a food system. This task requires additional tools that can also capture the socio-economic aspects. There are numerous multi-indicator sustainability assessment tools that take a broad food system approach by combining different aspects of economic, social and environmental sustainability (Schader et al. 2014; Arulnathan et al. 2020; Chopin et al. 2021). These tools are useful to conduct a holistic assessment of a farm or a food system. There are several such sustainability frameworks that cover a wide range of different quantitative and qualitative indicators grouped by themes. The result of these frameworks is often presented in a spider diagram showing how the production system is performing in each sustainability theme. An example of such a method is SMART, which include more than 350 indicators gathered in 21 themes, based on SAFA indicators (FAO 2013), making it one of the more comprehensive sustainability frameworks (Arulnathan et al. 2020). The existing sustainability frameworks can serve as useful tools to obtain a wide set of data to provide an overall picture of a system's sustainability performance. However, there is currently a lack of consensus on the most effective approach for evaluating sustainability in agricultural systems (de Olde et al. 2017). And an important aspect is often overlooked when assessing food system sustainability: the amount of food or edible nutrients produced.

As the global food system faces the task of feeding a growing population on limited cropland resources, it’s essential to find a relevant metric that emphasize productivity in terms of food supply. The commonly used metric to demonstrate agricultural productivity is 'yields per hectare'. While this metric effectively evaluates the pure agricultural productivity within farming systems, it falls short in highlighting the actual amount of food produced.

However, there are several examples of studies that have combined existing sustainability frameworks with additional indicators encompassing the farm or food system's output in relation to food and nutrition to reach a more comprehensive sustainability assessment (Chaudhary et al. 2018; Sonesson et al. 2019; Grassauer et al. 2021). Cassidy et al. (2013) introduced an indicator that effectively captures the efficiency of a food system by measuring the number of people whose nutritional needs can be met per hectare of cropland. Subsequent studies have built onto this research by utilizing this indicator, in conjunction with other assessment tools to estimate the overall sustainability on an individual farm e.g. Röös et al. (2021) and Resare Sahlin et al. (2022). To get a realistic picture of food supply however, this indicator should not be limited to calories alone, but also encompass the various macronutrients required for a sufficient diet, such as proteins and fat (Cassidy et al. 2013). To achieve an even more sophisticated estimate the protein quality should also be considered since animal products, unlike crops, provide complete protein (i.e. include all essential amino acids).

3. Methods

The previous sections outlined the challenges confronting the food system and emphasized the imperative of sustainably producing enough food on limited global cropland resources. A crucial yet often overlooked aspect in research addressing this complex challenge is the efficiency of food production related to nutritional need and available cropland resources. Further, there is a call for emphasizing output in terms of food supply when assessing the overall sustainability of an agricultural system. One way to capture this aspect is to employ the indicator 'number of people that can be fed per hectare of cropland' based on the daily recommended intake of calories, protein, complete protein, and fat.

To comprehend the potential benefits of using the indicator and identify its most suitable area of use, the indicator was applied at two different levels in the food system. Calculations were conducted at both farm and national levels to explore the strengths and shortcoming of the indicator at different scales of application.

The upcoming sections begin by describing the case study objects and subsequently delve into the technical aspects of the indicator. This includes a detailed account of the underlying calculations encompassing data sources, reference values and assumptions integrated into the analysis.

3.1 Case study description

3.1.1 The case farms

In order to evaluate the applicability of the indicator at the farm-level, assessments were conducted for nine case study farms. All farms included in this study are Swedish cattle farms featuring a spectrum of sizes distributed across the country in areas with various biophysical conditions for agricultural production. Both conventional and organic farms are represented. The farms exhibit diverse production systems, yet they all have in common the rearing of ruminants. Two farms are specialized in dairy production, involving the sale of surplus calves for meat production. Six of the farms are exclusively focused on meat production, while one farm engages in both dairy production and the rearing of fattening calves for meat production. Feed practices vary among farms, with silage derived from ley grown on cropland serving as the primary source across all. Most farms incorporate additional feedstuffs like cereals and concentrates, while some achieve self-sufficiency in feed, and others opt for purchased feed concentrate as a supplement.

All farms involved in this study were participants in the UNISECO project, a European research project that aims to increase knowledge about the drivers and barriers for further development of agroecological farming practices in the EU.

The farms participated in the Swedish case study which was focusing on the diversification of farming systems for enhanced sustainability (see https://uniseco-project.eu/case-study/sweden). The farms actively sought participation in the project and were purposedly chosen to represent a spectrum of milk and beef producing farms. As part of the project, the farmers undertook to diversifying their production systems by incorporating more crops for human consumption.

Table 1 presents relevant information and characteristics of the case farms. The farms' anonymity has been taken into account in the selection of the data presented.

Collection of data concerning the farm production, such as yield, number and weight of slaughtered animal, cropland area and purchased feed were collected from the farmers. The farmer also declared if the crop was sold as food or feed or used as feed on own farm. All data related to on-farm production were collected during the base year i.e. before introduction of diversification measures (hereby referred to as Year 1) and for the year after diversification measures were implemented (hereby referred to as Year 2).

Further details on the data collection process can be found in the supplementary material accompanying the article '*Delivering "less but better" meat in practice – a case study of a farm in agroecological transition*' by Resare Sahlin et al. (2022).

The referenced article is based on a comprehensive sustainability assessment of one of the case farms incorporated in this thesis. It encompasses, among a range of other aspects, results derived from the work conducted and presented within this thesis.

Table 1. Characteristics of the Swedish case study farms

		Cropland (ha)	Area of natural constraints	Ley (ha)	Cereals (ha)	Oil crops (ha)	Grain Legumes (ha)	Other crops (ha)	Animal production
Farm 1	Year 1	48	No	10	28			10	Meat
	Year 2	63		23	27			13	Meat
Farm 2	Year 1	80	Yes	55	25				Meat & dairy
	Year 2	90		47	39		4		Meat & dairy
Farm 3	Year 1	111	Yes	68	33	10			Meat
	Year 2	121		65	45	5	6		Meat
Farm 4	Year 1	53	Yes	33	20			1	Meat
	Year 2	67		41	26				Meat
Farm 5	Year 1	27	No	12	15				Meat
	Year 2	55		28	26			1	Meat
Farm 6	Year 1	519	Yes	191	279	49			Meat
	Year 2	485		163	322				Meat
Farm 7	Year 1	147	Yes	113	34				Meat & dairy
	Year 2	140		100	40				Meat
Farm 8	Year 1	27	Yes	16	9			2	Meat
	Year 2	23		16	4			3	Meat
Farm 9	Year 1	204	Yes	121	60	23			Meat & dairy
	Year 2	260		142	60	44	14		Meat & dairy

3.1.2 Sweden's total food production 2020

An assessment was made based on Sweden's food production in 2020, in order to evaluate the applicability of the indicator at national level. Data on total agricultural and horticultural production in 2020 and total cropland area (including fallow cropland) were obtained from the National Statistics Database (The Swedish Board of Agriculture 2020d). The specific year was chosen on the basis that it was estimated to be most representative of the recent five years (2017-2021) in terms of yield levels. Total production of lupine beans, brown beans and other grain legumes that is not presented in the national official statistics was calculated based on reported cultivation areas multiplied by reported median yields (references in Appendix 1).

Total yields were used from agricultural and horticultural production (fruit and vegetables) and statistics on total produced quantity of meat (slaughter weight), eggs and milk were used for animal production.

Information on the proportion of the total yield of edible crops used for food, feed, industrial purposes or export was obtained for each crop individually, drawing from various sources (Table 6). The intended use of exported crops, whether for food, feed, or industrial purposes, was considered. In case where a proportion of the exported quantity of a specific crop (e.g., rye) was designated for food use, that quantity was incorporated into the total share of the yield used for food for that specific crop. In case where exported crops were used as animal feed, these were accounted for in terms of estimated animal production from exported feed (more detailed information is found in section 3.3.4 and 3.5.

Accounting for micronutrients

The Swedish production of fruits and vegetables was included to address the micro-nutrient requirements. Data on the total horticultural production was taken from Sweden's official agricultural statistics database (The Swedish Board of Agriculture 2020d).

In addition, to gain a more comprehensive perspective on the underutilized capacity for providing micronutrients from Swedish land, calculations were extended to also include the total production of berries from Swedish forest land. This data was sourced from official statistics on forest production in Sweden, specifically blueberry and lingonberry for the year 2020 (Nilsson et al. 2021). Although it is not realistic to assume that all berries are harvested and consumed, it offers an insight into the untapped resources within Swedish forests.

3.2 Indicator: Number of people fed per hectare

Macronutrients

Yields of crops and animal products were recalculated into the edible amounts of energy (kcal) protein (g), complete protein (g) and fat (g) in each specific crop or product. Complete proteins refer to proteins that contain an optimal composition of all the essential amino acids required by the human (refer to 3.3.4 for further details).

Nutritional content in crops was calculated based on assumptions on how the crop is normally consumed as food, e.g., as whole grain or converted to cooking (see section 3.3.3 for more details).

The indicator 'number of people fed per hectare' for energy and macronutrients was calculated according to following formulas:

$$\mathrm{Pf_{Energy}} = \left(\mathrm{T_{Energy}} / \mathrm{NR_{Energy}}\right) / \mathrm{ha_{Tot}}$$

$$\mathrm{Pf_{Protein}} = (\mathrm{T_{Protein}} / \mathrm{NR_{Protein}}) / \mathrm{ha_{Tot}}$$

$$\mathrm{Pf_{C.Protein}} = (\mathrm{T_{C.Protein}} / \mathrm{NR_{C.Protein}}) / \mathrm{ha_{Tot}}$$

$$\mathrm{Pf_{Fat}} = (\mathrm{T_{Fat}} / \mathrm{NR_{Fat}}) / \mathrm{ha_{Tot}}$$

Where:

$T_{Energy/Protein/C.Protein/Fat}$ = Total production of energy/protein/complete protein/fat in tonnes/year of edible part of crops and animal products (see section 3.3)

$NR_{Energy/Protein/Fat}$ = The yearly nutritional requirement of energy (in kcal), protein (in tonnes) and fat (in tonnes) per person minus the amount of nutrients assumed to be provided by seafood (see section 3.4)

ha_{Tot} = the total area of cropland in hectares (see section 3.5)

$Pf_{Energy/Protein/C.protein/fat}$ = Number of people fed per hectare in terms of energy, protein, complete protein and fat.

Micronutrients

The Swedish horticulture production was included in the calculations based on macronutrient content according to the formula above. Since the Swedish production of fruit, berries and vegetables contribute a relatively small amounts of macronutrients, additional calculations were applied separately to this production to also capture its contribution of micronutrients. To get an idea of the micronutrient supply in Sweden, the indicator was calculated based on the recommended intake of 500g of fruits and vegetables per person and day (Nordic Council of Ministers 2014), instead of macronutrient content. Theoretically, a more precise analysis could have been achieved by considering the specific micronutrients embedded in the fruit and vegetables produced in Sweden, but this approach was dismissed since it would require excessive workload. It was reasoned that the recommended intake of 500g of fruits and vegetables per day serves as a sufficient reference point, offering insights into the capacity of Swedish food production to meet the population's micronutrient needs.

The indicator 'number of people fed per hectare' for fruit, berries and vegetables was calculated according to following formulas:

$$Pf_{Fruits\ and\ vegetables} = \left(T_{fruit\ and\ vegetables} / RI_{Fruit\ and\ vegetables}\right) / ha_{Tot}$$

Where:

$T_{Fruit\ and\ vegetables}$ = Total production of fruit, berries and vegetables in tonnes/year.

$RI_{Fruits\ and\ vegetables}$ = The yearly recommended intake of fruit and vegetables in tonnes per person, based on the reference intake value of 500 g per person and day.

ha_{Tot} = The total area of cropland in hectares.

3.3 Total production

3.3.1 System boundaries and methodological approach

This section describes the application of the 'number of people fed per hectare' indicator. At both farm and national levels the indicator was applied to 1) the total food production and 2) the potential edible part of the total crop production. At national level, the total food production (1) was elaborated further into three sub categories (a, b c) with various system boundaries and assumptions regarding crops exported for feed use, which is detailed below. In addition, the indicator was applied to two hypothetical scenarios (3,4).

External meat production refer to the meat production that is assumed to take place on other farms from the crops that are sold as feed (farm level) or in other countries from crops exported for feed use (national level). Calculations encompassing *external meat production* cover both the edible macronutrient content of the meat produced and any additional land use required to produce this meat. See sections 3.3.4 and 3.5 for more information on the calculations of external meat production.

Farm level application:

1) *Total food production* - includes the edible portion of both crop and animal production intended for human consumption plus external meat production from crops sold for feed use

2) *Total edible crop production* - includes the potential edible portion of all crop yields at the farm, regardless of their actual use as food or feed. It also include the edible part of any purchased feed.

National level application:

1) *Total food production* - includes the edible portion of crop and animal production used for human consumption. This category was further divided into three sub-categories with various system boundaries and assumptions regarding external meat production:

a) *Excluding external meat production from exported feed* - this approach does not take into account the meat produced from the crops exported for feed use. However, land use from these crops is included in the calculations.

b) *Including external meat production (beef)* - in this approach, the crops exported for feed use are assumed to be used for beef production in other countries.

c) *Including external meat production (chicken)* - in this approach, the crops exported for feed use are assumed to be used for beef production in other countries.

2*) Total edible crop production* - includes to the potential edible portion of all crops grown on Swedish cropland.

Additionally, the indicator was applied to two hypothetical national-level scenarios, each based on the 1(b) approach, which involved modifications to crop utilization:

3) *Barley used for food instead of beer* - scenario assuming that the barley currently used for beer production was instead consumed as whole grain.

4*)* *Crops for food instead of biofuel and spirits* - scenario assuming that all crops currently used for biofuel and ethanol production (including hard liquor) were redirected for food use.

As presented above, the system boundaries for the category *Total edible crop production (2)* differ between farm level and national level. At the national level, unlike the farm-level calculations, macronutrients embedded in imported feed (corresponding to purchased feed at farm-level) are not included. This distinction was made because, on a national level, it was deemed more relevant to make visible how many people the production from Swedish cropland alone can feed rather than to highlight the total food loss in the broader food system. Choosing this approach, the indicator can contribute insights into the potential of domestic agricultural production.

On both farm and national level, the total production of each macronutrient was obtained by calculating the edible content of energy, protein and fat respectively for each crop separately. The calculation of the number of people who can be fed per hectare is based on the total cropland area, including the cropland used for fallow and ley cultivation.

The edible yield of each crop was derived by multiplying the net yield (section 3.3.2) by a factor representing the edible share of the specific crop based on assumptions on how the crop is normally consumed (section 3.3.3). The edible content of macronutrients was then obtained by multiplying the edible yield with the nutrient content of the specific crop (section 3.3.4).

The *total food production (1)* was obtained by multiplying the edible yield of each crop with the proportion of the crop declared to be used as food (section 3.3.5).

The following sections describes the technical details and data sources underlying the calculations of the total edible production.

3.3.2 Net yield

Net yield was calculated by subtracting the farmers use of seed from the total yield according to the percentages presented in Table 2.

Table 2. The factors representing the percentage of the crop yield used for seed, for each crop. Data on seed use taken from Lantmännen Lantbruk (2023) unless otherwise stated

Factors for seed	
Oats[1]	4.0%
Barley[1]	3.6%
Rye[1]	2.6%
Triticale[1]	3.1%
Rape	0.4%
Turnip rape	0.4%
Peas[2]	8.8%
Field beans	8.4%
Brown beans[3]	6.7%
Lupines[4]	5.7%
Potatoes[5]	4.7%
Maize	0.4%
Mixed grains[1]	2.6%
Sugar beets[6]	0.0004%

1. Swedish Board of Agriculture (2022).
2. The Swedish Board of Agriculture (2004).
3. Fogelberg (2008).
4. Möller & Sjöberg (2019).
5. Lyckeby (2022).
6. Calculated based on 100,000 seeds per hectare and a seed weight of 3 mg. Seed weight taken from Holmberg (2016).

3.3.3 Edible content – utilization rates for crops and meat

The edible yield was obtained by multiplying the yield of each crop by a factor representing the share of the crop that can be utilized for human consumption (Table 3). All cereals were assumed to be consumed as whole grain products except barley, that was assumed to be consumed as beer (see *Alcoholic beverages* in section *3.3.4* for further details). Rape and turnip rape seed were assumed to be consumed as cooking oil, starchy potatoes as potato starch and sugar beets as granulated sugar. Green fodder maize was recalculated into estimated yield of maize kernels (calculations is presented in Appendix 1). The utilization rate for all horticultural production (fruits and vegetables) was assumed to be 100%.

Table 3. Percentage of the crop that can be utilized for human consumption

Utilization rates for crops	
Oat	67%[1]
Barley	97%[2]
Rye	97%[2]
Triticale	97%[2]
Wheat	97%[2]
Rape/Turnip	42%[3]
Peas & Beans	100%
Maize	100%
Green fodder maize	53%[4]
Starchy potato	25%[5]
Cooking potato	100%
Sugar beet	16%[6]

1. Information from Oatly, 200605.
2. Information from Saltå Kvarn, e-mail 200315.
3. Utilization rate for rapeseed oil, taken from (Landquist & Nordborg 2019).
4. Estimated content of maize kernels, refer to Appendix 1 for calculations.
5. Information from Lyckeby, e-mail 230405.
6. Sugar content in sugar beets, taken from Dansukker (2023).

The utilization rates for meat, presented in Table 4, is based on conversion factors taken from EU Commission (2019) and refers to the percentage of bone free meat in carcass weight.

Table 4. Percentage of bone free meat in the carcass weight of different animal species. Data taken from European Commission (2019).

Utilization rates for animal products	
Sheep, ewe, lamb	88%
Cattle, calves	70%
Pig	78%
Poultry	88%

3.3.4 Nutritional content

The amount of energy, protein and fat provided by the production system was obtained by multiplying the edible *net yield* by the amount (per kg) content of energy, protein and fat for each specific crop separately.

Data on nutritional content was taken from the Swedish Food Agency food database (2023) when available, and from other sources when necessary. The nutritional content in food crops and animal products is presented in Table 5.

The milk yield was converted to Energy Corrected Milk (ECM), which means that the amount of milk produced was adjusted to an energy content of 750 Kcal per kg corresponding to 3.3 % protein and 4% fat in accordance with a formula taken from Sjaunja et al. (1990).

The protein and fat content of the milk produced on the case study farms was provided by the farmer. For the national milk production, the average protein and fat content of the milk delivered to dairies in Sweden year 2020 were taken from the official agricultural statistics (The Swedish Board of Agriculture 2020b).

Table 5. References for energy, protein and fat content in food and feed. Data taken from the Swedish Food Database (SLV, 2020a) unless otherwise is stated

Crop/food/feed	**Energy content (Kcal/kg)**	**Protein content (kg protein/ kg)**	**Fat content (kg fat/kg)**
Oat	3750	0.095	0.07
Barley	3510	0.092	0.031
Barley for beer brewing	400	0.004	0
Rye	3230	0.092	0.015
Wheat	3280	0.102	0.02
Rapeseed oil	8840	0	1
Peas	3170	0.215	0.01
Peas for canning	600	0.04	0.04
Field beans	3180	0.25	0.017
Lupine beans[1]	3055	0.356	0.066
Other grain legumes [2]	3172	0.22	0.015
Potato	790	0.017	0.001
Starch potato[3]	3460	0	0.004
Maize	3540	0.127	0.067
Sugar beet[4]	4050	0	0
Meat from sheep and lambs[5]	1660	0.190	0.113
Pork meat[5]	1546	0.192	0.087
Meat from cattle and calves[5]	1638	0.214	0.066
Milk (ECM)[6]	750	0.033	0.044
Egg	1370	0.123	0.097
Meat from poultry[5,10]	1150	0.215	0.031
Milk replacer[7]	3941	0.215	0.16
Soy meal/expeller[8]	3370	0.49	0.02
Soybeans	3980	0.34	0.17
Sunflower seeds	6180	0.206	0.56
Whole grain silage, Cereals[9]	3442	0.095	0.034

1. Average value of nutrient content in the varieties Lupine mirabor and Lupine Regent, taken from Nordisk Råvara.
2. Nutritional content for Brown beans.
3. Nutritional content for potato starch.
4. Nutritional content for granulated sugar.
5. Data provided by Elin Röös, Department of Energy and Technology, SLU.
6. Sjaunja et al. (1990).
7. Nutritional content of *Bastant Kalvnäring,* Lantmännen.
8. USDA (2019).
9. Average value of the nutrient content for wheat, oats, rye and barley.
10. Includes meet from chicken and turkey.

Complete protein

Complete protein refers to high quality protein, i.e. protein that contains all the essential amino acids required by the human body in the appropriate proportions. Essential amino acids cannot be produced by the body and must be obtained through diet. Foods that are considered complete proteins include various animal-based sources such as meat, fish, poultry, eggs, and dairy products (EFSA Panel on Dietetic Products, Nutrition and Allergies (NDA) 2012). A complete amino acid profile can also be attained by combining grain legumes and cereals, as these crops together contains all the essential amino acids in sufficient amounts (ibid.).

The total production of complete protein in this study includes all protein from animal production and all protein from grain legumes plus the equivalent amount protein from cereals. For example, if a farm produces one tonne of protein from grain legumes and five tonnes of protein from cereals, the total amount of *complete protein* produced is one tonne (from legumes) + one tonne (from cereals) + the amount of protein produced from animal products.

Alcoholic beverages

Barley used for human consumption in Sweden is almost exclusively utilized as brew malt for beer production. The production of 5 kg of beer requires 1 kg of barley (Ingvarsson 2012), therefore, the total production of barley used for human consumption was multiplied by 5 and the macronutrient content was then calculated based on the nutritional content of beer.

The calculations regarding the potential edible content in the total crop production is made on the assumption that barley is consumed as whole grain and is based on the nutritional value for barley in Table 5.

Cereals used for production of hard liquor are not included as food, since alcohol has no relevant nutritional value. Cereals used for alcohol production includes exported rye used for whiskey production and wheat used for ethanol (beverage) production (see Table 7).

Meat production from sold and exported feed.

The nutritional content of the estimated meat production from the crops that the farms sold as feed was calculated based on a mean value of chicken and beef production and based on the mean value of the nutritional content in poultry and cattle (Table 5).

The nutritional content in the estimated meat production from crops that was exported from Sweden for feed use was calculated for chicken and beef production separately and based on the nutrient content for cattle and poultry (Table 5).

3.3.5 Utilization of crops produced at Swedish cropland

Information on whether the crops were used as feed, food, fuel or hard liquor was drawn from several sources and the data was recalculated from quantity to percentage of the total national yield when needed.

The percentages in Table 6 and Table 7 include both domestical use and intended use of exported crops. Seed use is not deducted from the percentage unless otherwise stated. All horticultural production was assumed to be used for human consumption. The area of use for the exported cereals was based on the estimated percentage distribution between feed and food for each crop in a typical year, for more information see table 19 in Appendix 1.

Table 6. Percentage of Swedish grown crops used for food and feed

Crop	Human consumption	Feed
Oat[1]	44%	51%
Barley[1]	40%	55%
Rye[1]	55%	9%
Wheat[1]	37%	38%
Triticale[1]	-	80%
Peas[2]	28%	72%
Field beans[3]	1%	99%
Cooking potato	100%	-
Starch Potato[4]	60%	-
Green fodder maize	0%	100%
Maize	100%	-
Mixed grains	-	100%
Rape and Turnip rape[5]	65%	15%
Sugar beet	100%	-
Other grain legumes[6]	100%	-

1. Cereals used for food or feed in Sweden taken from Swedish Board of Agriculture (2022), seed use is excluded. Cereals exported for food or feed use is based on information given by Per Gerhardsson, purchasing manager for cereals at Lantmännen, by e-mail 230503 (See Appendix 1).
2. Peas used for food or feed in Sweden was taken from Blom (2022). Peas exported for food use is based on information on quantity regarding the year 2019, given by Elisabeth Alströmer at Lantmännen, by e-mail 200416.
3.(Blom 2022)
4. Based information given by Lyckeby, e-mail 230405.
5. Based on information given by Per Gerhardsson, purchasing manager for cereals at Lantmännen, by e-mail 230507 and information given by Charlotte Elander, Energifabriken, phone call 230502.
6. Including brown beans, peas for canning, lupine and other grain legumes for human consumption.

Table 7. Percentage of Swedish grown crops used for fuel and liqour

Crop	Fuel	Liquor
Rye[1]	-	26%
Wheat[2]	22%	-
Rape and Turnip Rape[3]	20%	-

1. Exported rye used for whiskey production. Information from Per Gerhardsson, purchasing manager at Lantmännen, e-mail 230503.
2. Information from Svebio (Andersson 2022) and Swedish board of Agriculture (2022).
3. Information from Charlotte Elander, VD at Energifabriken, phone call 230502.

3.4 Daily nutritional requirements

The daily required intake of energy, protein and fat were based on the Nordic Nutrition Recommendations (Nordic Council of Ministers 2012). The daily requirement varies depending on gender, level of activity and weight. The daily reference intake values are calculated as presented in Table 8.

Table 8. Calculations of daily reference intake values for energy, protein, and fat. Data taken from Nordic Nutrition Recommendations (2014)

Macro Nutrient	Daily reference intake	Reference
Energy	2550 kcal	Mean value of the daily requirement of energy for men and woman 18-30 years[1].
Protein	84.7 g	Based on a protein intake of 15E%, which corresponds to 1.1 g protein per kg body weight multiplied by the average weight in Sweden 2018-2019 (77kg)[2].
Fat	80 g	Based on a fat intake of 33E% which corresponds to 80 g per day (average of men and women)

1. Physical Activity Level (PAL) 1,6
2. Average weight in Sweden 2018-2019 is taken from Statistics Sweden (SCB).

The proportion of the annual nutritional requirement assumed to be supplied by consumption of seafood is considered in the calculations of 'number of people fed per hectare' Nutrient content in a 'global fair share of wild-caught fish' (3.5 tonnes per person and year) introduced by Karlsson et al. (2017) were subtracted from the daily reference intake of each macronutrient. Energy, protein and fat content in the assumed seafood consumption per person per day (Table 9) was calculated using mean values for nutritional content in different type of seafood by data taken from the Swedish Food Database.

Table 9. Macronutrients assumed to be provided from the consumption of fish and seafood

Contribution of nutrients from seafood consumption per person and day		
Kcal	Protein	Fat
11.3	1.8	0.4

The daily recommended intake of fruit and vegetables used in the study is 500 g per person and day, based on the Nordic Nutrition Recommendations (Nordic Council of Ministers 2014).

3.5 Total land use

For each case farm, the land use was calculated by summing the total hectares of cropland utilized for that year's crop production (including ley) and the estimated hectares required for producing purchased feed (refer to section 3.5.1).

Additionally, the land needed for estimated meat production from crops sold as feed was included (see section 3.5.3).

The calculations for total crop production, regardless of whether the crops were sold as feed or food, include the cultivated cropland on the farm and the additional hectares for producing purchased feed (see section 3.5.1).

The calculation of land use for Sweden's total food production in 2020 includes all available cropland as reported by Sweden's official statistics (Statistics Sweden 2023) plus the additional hectares used for producing imported feed (refer to section 3.5.2), and the extra land required for estimated meat production from crops exported as feed. The calculations for total crop production include solely the available cropland in Sweden.

The official statistics on cropland in Sweden include also land used for fallow.

3.5.1 Land use from purchased feed at the farm level

Purchased feed concentrate used at the farms is associated with external land use. Calculations were made to account for the external cropland embedded in purchased feed based on the contents and proportions of ingredients in each feed mix and based on the hectare yields presented in Table 11. All ingredients in the purchased feed, except for soy, was assumed to be grown in Sweden. Information on feed mix composition were obtained from the feed supplier.

Only the ingredients which made up 70% of the feed were considered in the calculations to make the calculations manageable and since the remaining 30% of the feed usually consist of a range of smaller amounts of ingredients such as salts, minerals, fibres and molasses, which are not directly relevant for calculation of land use. The ingredients constituting 70% of the total quantity in the feed mix were then scaled up to 100 %.

Since feed often consists of by-products from the food industry, the ingredients were allocated based on mass (Table 10). Land use was calculated for each of the included ingredients, mainly based on average crop yields taken from national crop statistics provided by the Swedish Board of Agriculture (Table 11).

Table 10. Mass allocations factors for ingredients in purchased feed (by-products).

Feed	Mass allocation factor
Soybean meal	71%[1]
Rapeseed cake	0%
Agrodrank	49%[2]
Wheat Bran	15%[3]
Wheat feed flour	6%[3]
Malt sprout pellets	0%
Rapeseed oil	100%

1. Mogensen et al. (2018).
2. Flysjö et al. (2008).
3. Cederberg et al. (2008).

Table 11. Crop yields used in the calculations of land use from purchased feed on farm level. Unless otherwise is stated, the hectare yields are Swedish standard yields for year 2020, taken from Swedish agricultural statistic database (The Swedish Board of Agriculture 2020d)

Crop yields in purchased feed	kg/ha
Oat	4220
Wheat (incl. wheat feed flour and wheat bran)	5529[1]
Barley	5473[2]
Soy	3275[3]
Rape seed	2656[4]
Cereals	5083[5]
Field beans	3266

1. Average of spring wheat and winter wheat.
2. Average of spring barley and winter barley.
3. Average soybean yield in Brazil year 2020 (FAOSTAT 2023).
4. Average of spring rape and winter rape.
5. Average of wheat, barley, oats and rye.

Milk replacers were used as feed at the dairy farms. Milk replacer for calves is normally made up of milk powder, whey, vegetable fats, minerals, and vitamins, with some variation in content but often with milk powder being around or just under 50% of the ingredients (Kalvportalen 2017). The exact type or brand of milk replacement used at the case study farms was not known at the time of data collection. For simplification, calculations of the land use associated with milk replacement are thus based on milk powder. The average land use for Swedish milk was in this study estimated to be 1.7 m^2 per kg of ECM milk, based on Henriksson et al. (2014). According to information from Arla (2022) it takes 8-10 kg milk to produce 1 kg of powder milk which, based on the abovementioned milk yield, gives approximately 590 kg milk powder per hectare.

The land use for milk replacer was calculated based on the estimated yield of 590 kg of milk replacer per hectare of cropland.

3.5.2 Land use from imported feed at the national level

Land use associated with imported feed was calculated based on estimated feed import for different feed stuffs in Sweden (Table 12) and average hectare yields for the feed crop (Table 13).

The estimations of the amount of imported feed in Sweden (Table 12) were calculated based on net import shares of different feed stuffs and the total feed use in Sweden (in weight) taken from a study by Einarsson et al. (2022) This feed data (ibid.) represents average values for the years 2015-2017, which was considered sufficiently representative to be used in the current study as livestock production in Sweden in the years 2015-2017 did not differed substantially in composition and quantity compared to year 2020.

Hectare yields (Table 13) were taken from FAOSTAT (2023) and represents the average hectare yield in the country from which the feed crop is most commonly imported in Sweden, according to Per Gerhardsson at Lantmännen[1]. The source of imported fat for feed use is unknown and was assumed to consist of rape seed oil.

No land use was allocated for by-products if the main product is food, such as rapeseed cake, beet pulses, molasses and wheat bran. Land use for Soybean meal and rapeseed oil was allocated in accordance with Table 10.

Table 12. Estimated quantity of imported feed (excluding by-products from food production) used for calculations of land use from imported feed. Estimations based on data from Einarsson et al (2022).

Imported feed	Tonnes
Rapeseed	12724
Soybean meal/expeller	182111
Soybean	19349
Sunflower seed	124
Fat	8512

Table 13. Hectare yields used for calculations of land use from imported feed. Average yields year 2020 taken from FAOSTAT (2023).

Crop yields for imported feed	kg/ha
Rape	3683[1]
Soy	3275[2]
Sunflower seed	2023[3]
Fat (rape seed oil)	3683[1]

1. Average rapeseed yield in Germany.
2. Average soybean yield in Brazil.
3. Average yield of sunflower seeds in Ukraine.

3.5.3 Estimated land use in animal production from sold an exported feed

The crops that the farmers sold as feed and the Swedish-grown crops that were exported for feed use were assumed to be used for meat production elsewhere. To account for the external land use associated with sold and exported crops used for feed, calculations were made to obtain the additional cropland (ha) required to produce silage or cereals for a complete feed ratio.

At farm level, the assumed production of meat from crops that were sold as feed was based on a mean value for chicken and two types of beef production systems as presented in Table 14. The external land use from sold feed were calculated for each of the meat production systems separately and then presented as a mean value of the additional hectares obtained from each system.

At national level, the crops that was exported from Sweden for feed use was calculated separately for chicken production and beef production to make visible how different assumptions about external neat production affect the results.

Usually, chicken feed rations contain a certain proportion of soybeans or other protein crops. To simplify the calculations, it was assumed that the entire amount

[1] Per Gerhardsson, Purchasing manager of cereals at Lantmännen. E-mail 230414.

of feed (in kg) included in the feed ratio consists of cereals. Consequently, chicken production involves no external land use in the calculations. The yield levels for soybean and cereals differ slightly, which may affect the accuracy of the calculation to some extent, but is likely to have a marginal impact on the results.

Table 14. Feed ratio of the production systems used in the calculations of land use associated with the meat production from crops that were sold (at farm level) or exported (at national level) for feed use

Food ratio of the production systems	**kg silage/ kg meat**	**kg cereals/ kg meet**	**Kg cereals/ kg carcass weight**
Beef production (steers)[1]	10.3	1.86	
Beef production (bulls)[1]	7.66	8.21	
Chicken production[2]			2.52

1. Data representing a Swedish production system, taken from Mogensen et al. (2018).
2. Data provided by Elin Röös, Department of Energy and Technology, SLU.

4. Results

4.1 Farm level

The number of people that can be fed per hectare varies greatly across the case farms, as shown in Figure 1. The solid bars in Figure 1 show the total food production including external meat from crops sold as feed. The transparent bars show the edible content of the total production of crops plus purchased feed. Blue colour shows production for the base year and red colour shows production the second year, i.e. after diversification measures have been implemented.

After implementing diversification strategies in the second year, most farms saw an increase in the number of people that can be fed per hectare in terms of calories. However, this increase was less pronounced for protein and fat, with only a smaller proportion of farms showing improved figures.

As seen in Figure 1, if all edible crops on the farms (including those in purchased feed) were utilized for human consumption a vast majority of the farms would substantially increase the number of people fed per hectare with calories in both years 1 and 2, compared to the current food production. However, this trend is less evident concerning fat and proteins. These nutrients show more variability among the farms, with some even showing a decrease in the number of people fed per hectare when all edible crops are used for food.

No complete protein is provided by edible crops year 1, while three of the farms grow leguminous crops that provide complete protein year 2.

Figure 2 illustrates the 'Total loss of edible calories' as the difference between the total amount of edible crop calories produced by the farm and the actual amount delivered to the food system. Furthermore, the majority of farms reduced the proportion of land allocated for feed production in year 2 compared to the previous year (refer to Appendix 2).

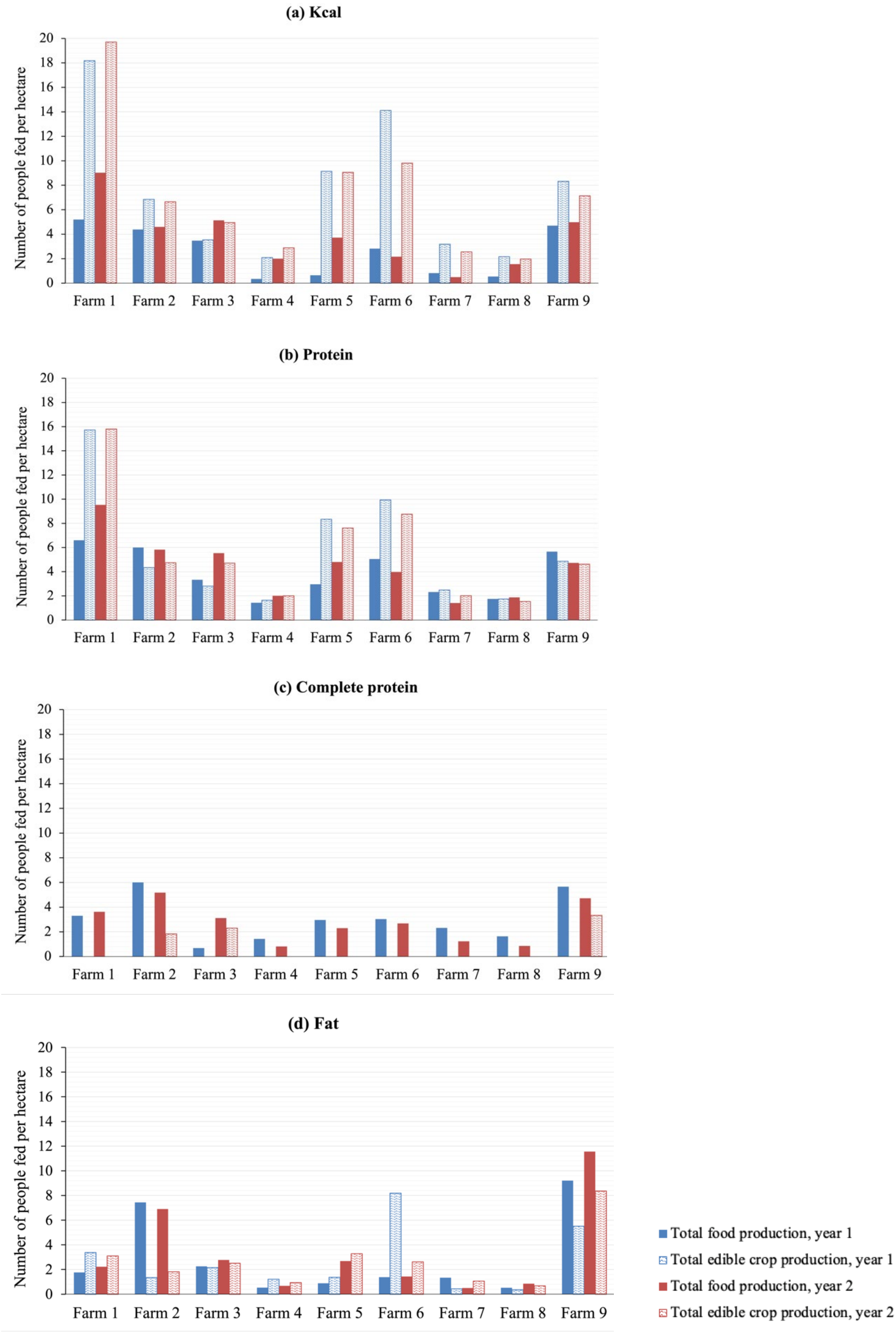

Figure 1. Number of people that the total food production (filled bars) and the edible macronutrients embedded in the total crop production (transparent bars) on each farm can feed in terms of daily recommended intake of (a) energy, (b) protein, (c) complete protein and (d) fat in the first and second years respectively.

Figure 2. The percentage losses of (a) edible calories, (b) edible proteins and (c) edible fat in the production intended for human consumption at each farm compared to if all edible crops at the farm (including purchased feed) were used for food.

4.2 Swedish food production

4.2.1 Macronutrients

The following tables present data on the number of people that can be fed from Sweden's total production in 2020, both in total (Table 15) and per hectare (Table 16). These tables include the macronutrient content of the total food production (1) under various assumptions about meat production from exported feed (scenarios a, b, c), and the edible portion of the total crop production (2). Additionally, the results are analysed under two hypothetical scenarios (3,4) each based on assumptions about alternative crop use. Scenario 3 refers to the total production for human consumption assuming that all cereals used for beer production instead would be used for food. Scenario 4 refers to the total production for human consumption, assuming that all crops used for biofuel, ethanol and beer production would instead be used for food. The results show that by redirecting all crops produced in Sweden in 2020 to direct human consumption, instead of their current use in feed, biofuel, and alcoholic beverages, the food supply could theoretically be substantially enhanced. According to Table 16, this change would almost double the food calorie capacity per hectare. Additionally, it could provide about 50% more people per hectare with their daily recommended protein intake. However, this scenario would fall short in producing enough complete proteins.

According to Table 15, redirecting the barley presently used for beer production to direct consumption as whole grain could potentially fulfil the daily caloric needs of an extra million people. Additionally, this shift could satisfy the daily protein and fat requirements of approximately half a million individuals.

Table 15. Number of people whose recommended daily intake for each macronutrient can be met from (1) the total production of crops and animal products for human consumption in Sweden 2020 and (2) the total production of edible crops on Swedish cropland. Presented by different assumptions of exported feed (a, b, c) and hypothetical scenarios regarding crop use (3, 4)

	Millions of people that the total production can feed			
	Energy (Kcal)	Protein	Fat	Complete protein
1a) Total food production, excluding external meat production from exported feed.	12.9	11.7	10.0	6.9
1b) Total food production, including external meat production (beef)	13.1	12.1	10.2	7.3
1c) Total food production, including external meat production (chicken)	13.0	12.2	10.0	7.4
2) Total edible crops produced on Swedish cropland.	24.1	17.2	10.4	1.9
3) Total food production, barley used for food instead of beer.[1]	14.0	13.5	10.8	7.3
4) Total food production, crops for food instead of biofuel and spirits.	16.8	15.5	12.3	7.3

Table 16. Number of people that can be fed per hectare and year by (1) the total production of crops and animal products for human consumption in Sweden 2020 and (2) the total production of edible crops on Swedish cropland (2). Presented by different assumptions of exported feed (a, b, c) and hypothetical scenarios regarding crop use (3, 4)

	Number of people that the total production can feed per hectare and year.			
	Energy (Kcal)	Protein	Fat	Complete protein
1a) Total food production, excluding external meat production from exported feed.	5.0	4.5	3.8	2.7
1b) Total food production, including external meat production (beef).	4.8	4.4	3.7	2.7
1c) Total food production, including external meat production (chicken)	5.0	4.7	3.8	2.8
2) Total edible crops produced on Swedish cropland.	9.5	6.8	4.1	0.8
3) Total food production, barley used for food instead of beer.[1]	5.1	4.9	3.9	2.7
4) Total food production, crops for food instead of biofuel and spirits.	6.1	5.6	4.5	2.7

Figure 3 shows the distribution of edible macronutrients in Sweden's total crop production for 2020, categorized by their use for food, feed, fuel, and liquor. The 'other use' category encompasses both industrial and unspecified uses.
This data indicates that in 2020, 41% of Sweden's potentially edible crop calories were used for animal feed, along with 48% of the protein and 34% of the fat from these crops (Figure 3). Additionally, it was found that 11% of the total edible plant protein embedded in Swedish crop production was utilized for biofuel and ethanol production and 10% of the edible fat was allocated to biofuel production.

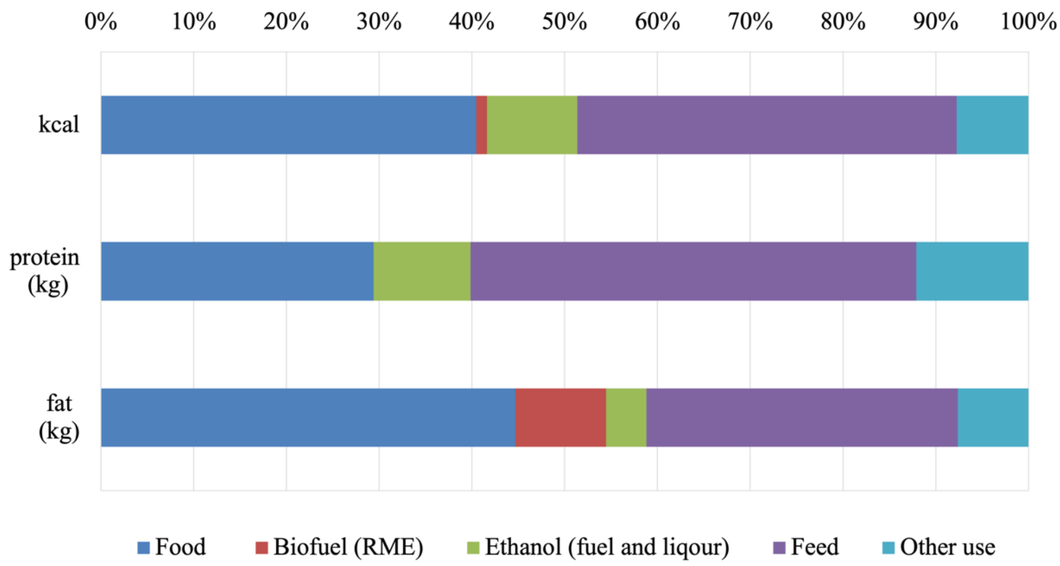

Figure 3. Proportions of the edible content of energy and macronutrients in the total crop production used for food, biofuel, ethanol production, feed and other use.

As seen in 4, animal production occupied 65% of the total cropland area in 2020 (for feed production and temporary grazing) while contributing a quarter of the edible calories and about half of the protein and fat produced in the country (Figure 5). These proportions are similar if meat from exported feed and cropland area from imported feed are included in the calculations.

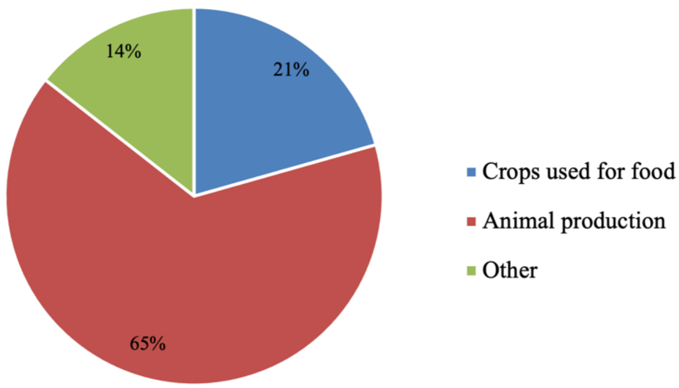

Figure 4. Proportions of the Swedish cropland used for food crops, animal production and other. Animal production includes feed and temporary grazing. The category 'other' includes e.g. biofuel and fallow cropland.

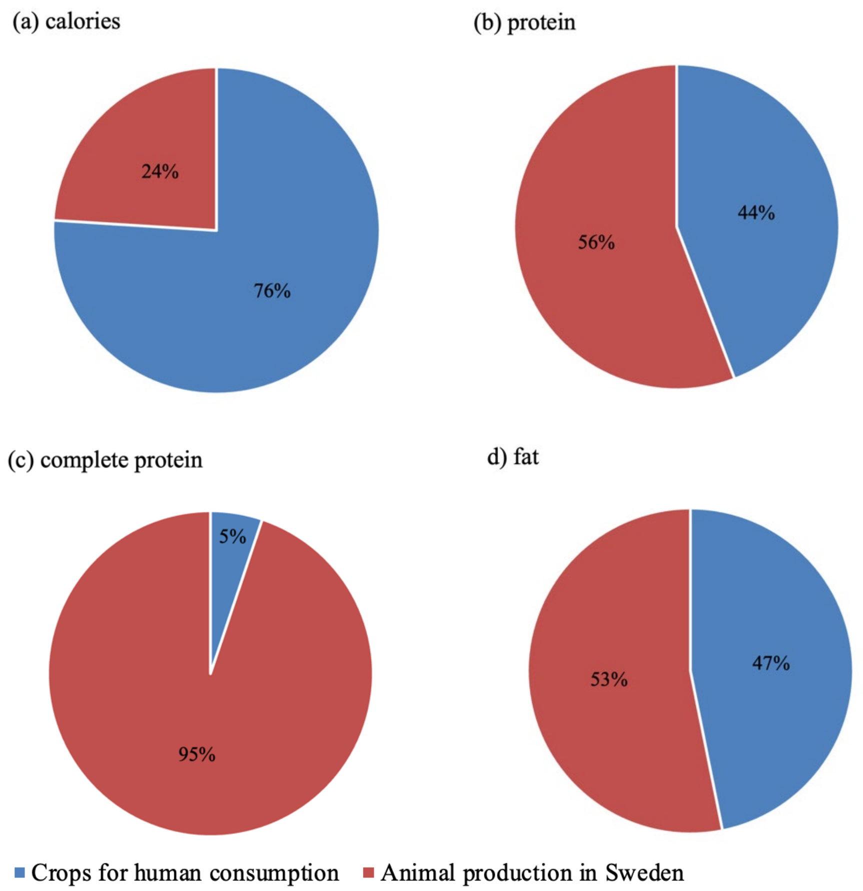

Figure 5. Proportion of the total amount of edible (a) energy, (b) protein, (c) complete protein and (d) fat in Swedish food production that comes from crop production and animal production respectively. Refers only to crops and animals produced in Sweden.

4.2.2 Fruit and vegetables

Table 17 shows how many people that can be provided with their daily recommended intake of 500 g fruit and vegetables in total and per hectare in Sweden 2020. The results are divided into two categories: 1) the total production of fruits and vegetables from Swedish cropland, and 2) the combined total production from Swedish cropland plus the blueberries and lingonberries available in Swedish forests in 2020.

Table 17. Number of people that can be supplied with the daily recommended intake of fruit and vegetables from the total production of fruits and vegetables and from the berries available in Swedish forests

	Total millions of people	**Number of people per hectare**
1) Total cropland production of fruit and vegetables	2.3	0.9
2) Total cropland production of fruit and vegetables and available berries in Swedish forests	8.2	3.2

5. Discussions

5.1 Applicability at the farm level

The results from using the indicator at farm level show that, compared to the base year, most case farms experienced an increase in the number of people that can be fed per hectare in terms of calories year 2, while the corresponding increase regarding fat and protein is smaller and varies more between the farms. This is explained by the fact that most farmers included in this study chose to grow a greater proportion of crops for human consumption in year 2, and a majority of the farms had to some extent decreased the production of meat and/or milk, which is clearly reflected in the results.

Cereals is the main crop grown for food by the case study farms, which highly impacts the results concerning calories, with some variations depending on the type of cereal grown and the current year's harvest. Meat and milk production on the other hand contains more fat and protein than the cereals that are grown, which explains why fat and protein do not increase to the same extent. This is clearly demonstrated in the results by *Farm 1* that show the highest production of calories per hectare of all farms, due to the cultivation of high yielding crops rich in carbohydrates, while *Farms 2* and *9* have a significant higher production or proteins and fat due to milk production.

5.1.1 The impact of crop utilization and production strategies

The practice of feeding edible crops to animals is, associated with great food loss. To quantify this loss of edible nutrients, the indicator was applied to the total crop production on each farm plus the edible content in purchased feed. The difference between the quantity of edible macronutrients embedded in all crops on the farm compared to the total amount of macronutrients in the farm's food production is presented as percentage food loss in Figure 2. Most farms reduced the loss of calories, proteins, and fat the second year compared to the base year. The loss of fat, however, exhibit larger variation across farms, primarily due to the large impact of changes in milk production on the results. *Farm 7* increased the loss of fat by almost 160% year 2, which is mainly explained by the farm ceasing milk production. Since there was about the same amount of edible fat embedded in feed on the farm both years, the large amount of fat provided by milk production year 1 made a huge effect on the results.

The decreased loss of macronutrients that is seen year 2 can be attributed to a larger share of crops being sold for human consumption and to a shift in the feed composition that involved fewer cereal-based feedstuffs. For some farms, the loss of macronutrients is very small or even negative, indicating a very low content of edible crops in the feed composition. *Farm 3* for instance, produce more calories, protein and fat during the current food production comparing to if all edible crops were used for human consumption, implying that livestock add nutrients to the farm system by acting as converters of non-edible biomass. However, several other case farms reared their animals exclusively on roughage year 2, but with higher rate of edible nutrient loss since these farms sold a certain amount of cereals intended for feed use elsewhere.

The dairy farms included in this study (i.e., *Farm 2, Farm 7* and *Farm 9*) can serve as an illustrating example of how the indicator can be utilized to highlight the impact that different production decisions and strategies have in terms of food supply capacity. All dairy farms reduced their milk production to some extent year 2 compared to the base year, which strongly affects the results both in terms of calories, fat, and protein for human consumption in different ways depending on the chosen strategy. *Farm 2* grew exclusively crops for its own feed use in year 1 and added 10 ha of oats for human consumption year 2, which resulted in a raise in calories but a decrease concerning fat and protein since the type of crops that was grown didn't make up for the loss of fat and protein caused by the reduced milk production. *Farm 9*, on the other hand, increased the numbers for both calories and fat year 2, due to an expanded production of rape seed for human consumption. At the same time, the production of edible protein per hectare decreased, despite a marginal decrease in the total production of protein, which is mainly explained by the added hectares of rape seed cultivation (that contribute no edible protein).

Farm 7 exhibits a notable decrease in the number of people that can be fed per hectare for all macronutrients. This can be attributed to the cessation of milk production and a reduction in meat production in year 2, while using approximately the same amount of cropland and having a similar composition of crop production both years.

When employing the indicator to assess alternative production pathways it is shown that the calorie loss resulting from the absence of milk production at *Farm 7* could be offset by cultivating 6 hectares of grain legumes. This action would also lead to a twofold increase in the quantity of complete protein produced compared to year 1.

5.1.2 Complete protein

The production of complete protein decreased for nearly all farms in the second year, because of decreased animal production. However, several of the case farms clearly demonstrate the potential of raising the amount of complete protein produced per hectare by cultivating leguminous crop. As an example, Farm 3 elevated the number of individuals nourished per hectare in terms of complete protein by approximately 400%, year 2 compared to the base year. An upswing in meat production accounts for only a minor part of this increase, while the dominant part resulting from the 6 hectares of grain legumes for human consumption grown at the farm in year 2. Of the total production of complete protein at this particular farm, the meat production accounted for 26% using 54% t of the total crop land, whereas the added hectare of grain legumes together with the amount of cereals needed to achieve complete protein provided about 74% of the complete protein on 16.5% of the cropland. In this case, the animal production was limited to forage and pasture, thus the cropland used for animal production consisted solely of cultivated ley.

The results presented Figure 1 and Figure 2 show that this particular farm produce more macronutrients during the current food production compared to if all edible crops were used for human consumption, which imply that the livestock add nutrients to the farm system by converting inedible biomass into nutrients available for human consumption. Livestock, in particular ruminants, can form an integral part of a sustainable farm by providing high-value nutrients and promoting biodiversity (De Boer et al. 2014; Dumont et al. 2018). However, the results clearly demonstrate how the production of complete protein can be sustained with less cropland resources by replacing reduced livestock production with additional hectares of grain legume cultivation.

5.1.3 Possibilities and constraints in farm level application

Several parameters affect the results when using the indicator at the farm level, such as the nutrient composition of the crops grown, the amount and type of feed produced and the use of purchased feed. Additionally, the natural conditions of the specific location must be considered if comparing farms situated in regions with different biophysical circumstances.

Further, the potential impact of ley cultivation on the results needs to be considered, as this practice adds essential values to sustainable farming, both in terms of productivity and environmental aspects. Integrating ley into crop rotations can benefit biodiversity, soil health and carbon sequestration and has shown potential to reduce the need of pesticide use (Urruty et al. 2016; Prendergast-Miller et al. 2021; Henryson et al. 2022). Since these values are not captured by the ‘number of people fed per hectare’ indicator, it is necessary to exercise caution when interpreting the results to avoid drawing misleading conclusions. A shift in feed composition towards a higher proportion of ley as a substitute for cereal-based feed stuffs may reflect negatively in the results due to increased cropland use but still constitute a beneficial production change.

A high proportion of ley production becomes visible in terms of decreased food loss (Figure 2). Hence, this parameter should be factored when applying the indicator at the farm level. However, for a comprehensive and holistic assessment of a farm's performance, the 'number of people fed per hectare' indicator must also be integrated with other sustainability frameworks.

Since the case farms included in this study have various conditions and production compositions and have implemented different production measures to increase food diversity on farm, it is difficult to make a meaningful comparison of the results between the farms. Hence, a general conclusion of this study is that the indicator is not particularly useful as a tool for benchmarking between individual farms. For such a comparison to contribute useful information, the compared farms must have similar conditions for agricultural production.

However, the difference in performance within each case study farm between year 1 and year 2 gives an idea of how different production strategies affected the farm output, in terms of food supply per hectare. A second finding of this study is therefore that the indicator can provide valuable information when used on an individual farm to monitor its performance over time. In that way, it can serve as a tool to gain understanding on how various production measures affect farm output in terms of food supply and further, to identify agricultural activities that have a particularly large impact in relation to this aspect.

In addition, the indicator could hold potential value for a farmer who wants to get a better understanding of how the farm is performing in relation to the shared responsibility for global food supply. It gives an idea of the farm's performance, but it is important to keep in mind that one individual farm does not necessarily need to produce all nutrients needed for a complete diet. As part of a larger food system, there may be advantages to specializing in the foods most suited to produce in the given location.

Intensified and specialized production of high yielding crops can play an important part in the global food system by enabling a surplus of macronutrients on the global market (Herrero et al. 2017). However, a high level of agricultural concentration and specialization at national level has been shown to have negative implications on a countries ability to cope with climatic disturbance and adversely affects food security (Campi et al. 2021). Although both diverse smallholder farms and larger specialized production systems can play an important roles in terms of contributing to global food security, there is a growing evidence that mixed and diverse farming system, such as agroecological farming practices, can contribute to improved food security and nutrition (Bezner Kerr et al. 2021). Several authors has emphasized the potential benefits of on-farm diversity, such as increased resilience, enhanced nutrient diversity, improve ecosystem services and increased profitability (D'Annolfo et al. 2017; Dumont et al. 2018; Rosa-Schleich et al. 2019; Tamburini et al. 2020; Jones et al. 2021; Palomo-Campesino et al. 2022). However, the unilaterally focus on productivity in terms of kg yield per hectare occasionally raise dubiety regarding the capacity of agroecological and organic farming system to contribute enough food to feed the world's population. This narrow emphasis on yield levels can potentially overlook or even compromise the environmental benefits these systems offer (Röös et al. 2018).

The relatively lower average yields associated with organic farming compared to conventional methods have fuelled debates against its large-scale adoption. Critics, like Kirchmann (2019), argue that a widespread transition to organic farming would require substantially more land to meet the global food demand. A frequently overlooked aspect in these discussions however is the impact of production choices, on the capacity to meet the population's nutritional needs.

Farming systems with relatively moderate crop yields could potentially sustain enough people per hectare by redirecting production toward nutrient dense crops designated for human consumption. Although such a shift in production may require substantial changes in food consumption patterns, this perspective offers important and often disregarded opportunities for increased food supply.

Consequently, evaluating agricultural productivity by the 'number of people fed per hectare' can help illuminate alternative pathways to food security, beyond the current narrative of high-input, intensified agriculture as the only viable way to manage to feed the world's population.

However, it is important to acknowledge that farm-level production decisions are largely driven by profitability and market mechanisms. While addressing these economic drivers is vital in the broader discussion of agricultural production, it falls outside the scope of this thesis.

5.2 Applicability at the national level

The results from using the indicator at the national level reveal that Sweden's food production in 2020 was more than sufficient to supply its population of approximately 10.5 million people with adequate calories and protein intake and nearly sufficient for the recommended daily intake of fat. (see Table 15).

However, when considering the protein quality, the picture changes: the production was only capable of meeting about 65% of the population's needs. The majority of complete proteins were sourced from animal production, with only 5% coming from crop-based sources. Of the total amount of edible macronutrients provided by animal production, dairy accounted for 46% of the protein and 72% of the fat and calories. Further, poultry was the second largest source of animal protein, providing 19% of the total, followed by pig (16%), cattle (10%) and eggs (8%).

5.2.1 In the lens of global food responsibility

If cropland area is taken into account, the food produced in Sweden 2020 was capable of feeding approximately 5 people per hectare in terms of calorie content and around 4.5 people per hectare in terms of protein content slightly less in terms of proteins, whereas total content of fat in the produced food is only sufficient to support around 3.8 people per hectare. Thus, according to the current study, the per capita food supply in Sweden is relatively in line with the global average requirement of 5 people per hectare in terms of calories and proteins but is slightly below this figure in terms of fat.

It's important to note, however, that this value should be considered as an average rather than a definitive benchmark as the available cropland per capita and the conditions for food production vary greatly, both within nations and globally (Zabel et al. 2014; Silver et al. 2021; The World Bank 2021). Furthermore, regions with favourable conditions for agricultural production that have the capacity to produce a surplus will likely need to contribute food to the global market to fill food shortages in areas with limited cropland resources (FAO 2018a).

Determining what constitutes sufficient food production per hectare for a specific region is thus not straight forward. Nevertheless, the 'number of people fed per hectare' indicator can be a valuable tool in assessing the potential supply capacity of various food systems. When applied on a global scale, Cassidy et al. (2013) discovered that the total global food production could feed an average of 6 people per hectare. Moreover, their study revealed a large variation in per-hectare food production across different countries and made visible key factors affecting the food supply capacity of different regions. In such way, using the indicator can help to point to possible routes for a more efficient use of the cropland which is particularly urgent in light of the growing food demand. The projected global population increase of 2 billion by 2050 poses the challenge of sustainably providing a sufficient diet for an average of 6.25 people per hectare of cropland worldwide, assuming no expansion of cropland. Several strategies have been identified as key solutions to meet this challenge, including improved cropping efficiency, altered dietary patterns and reduced food waste (FAO 2018a; Gerten et al. 2020). Less often addressed in this context, however, is how the use of cropland – in terms of what crops are grown and for what purpose - impacts the ability to provide sufficient food. As previously discussed, highlighting this aspect requires a measure of productivity that goes beyond kilograms per hectare by also including the needs of different nutrients in a complete diet.

5.2.2 Feed food competition

As illustrated in Figure 3, 41% of the potential edible crop calories produced in Sweden year 2020 was utilized for feed, with the proportions being 48% for protein and 34% for fat. The food loss associated with consuming animal foods instead of using the edible crops for direct human consumption is emphasized by numerous studies (Pradhan et al. 2013; Shepon et al. 2018; Drofenik Jan et al. 2021; Silver et al. 2021). Cassidy et al (2013) found in their study that 36% of global crop calories were allocated to animal feed. They further estimated that if all crops were grown exclusively for direct human consumption globally, given the current mix of crop uses, the available food calories could potentially increase by up to 70%, which could, in theory, provide nourishment for an additional 4 billion people. Another study suggest that replacing all animal foods consumed in US with plant based foods of similar nutritional value would enable up to 20-fold more food produced per hectare of cropland which would by far exceed the current rate of food loss in the country (Shepon et al. 2018). However, livestock often play an important role in food system as providers of complete protein. As shown in Table 15, the total production of complete protein in Sweden would decrease with almost 75% if all crops were used for direct human consumption assuming no animal production. By limiting livestock feed to non-edible biomass, such as by-products from food industries, permanent pastures and ley, livestock can provide nutrients that would otherwise be unavailable for human consumption and form an integral part of sustainable food system (Karlsson & Röös 2019; Wyngaarden et al. 2019; Naderi et al. 2022).

Figure 4 illustrates that in 2020, animal production utilized 65% of Sweden's total cropland area for feed production and temporary grazing. Despite this substantial land use, it contributed only a quarter of the country's edible calories and roughly half of the protein and fat, as shown in Figure 5. Although these figures highlight the disparity in land-use requirements between animal production and plant-based food, it's essential to recognize that a considerable portion of cropland land in Sweden is dedicated to ley cultivation (43% in 2020). As previously discussed, ley cultivation serves an important role in sustainable agricultural systems.

Regarding the production of complete protein, animal production accounts for as musch as 95% of the total production. However, the production of complete protein could be achieved with a reduced use of cropland resources, as exemplified by one of the case farms (Farm 3). This farm illustrates how grain legume production can substitute animal-based complete protein while decreasing land use requirements. These findings are consistent with prior research conducted by Röös et al. (2020) which indicates the feasibility of generating adequate complete protein in Sweden while lessening the demand for cropland (ibid.). Their study show that by replacing 50% of Sweden's meat consumption with domestically grown grain legumes, the country could sustain the capacity to meet the population's complete protein needs while reducing cropland use by 23%. This conversion would require that the area for grain legume cultivation increased to 3.2% of the total cropland area in Sweden, which would imply that an addition of 1% of Sweden's cropland is cultivated with grain legumes. The realization of such a scenario, however, presupposes a major shift in consumption patterns given that the current consumption of legumes in Sweden is very low (Röös et al. 2020). Nevertheless, these findings illuminate the potential to provide sufficient complete protein while economizing cropland resources, by limiting animal production to non-edible biomass.

5.2.3 Possibilities and constraints in national level application

Using the indicator 'number of people fed per hectare' on the Swedish food production illustrate how utilization of agricultural production can impact the ability to enhance food availability from a limited area of cropland. By directing all crops produced in Sweden 2020 to human consumption instead of the current use for feed, biofuel and alcoholic beverage, the food supply capacity per hectare would nearly double in terms of calories (Table 16). In addition, around 50% more people per hectare would be provided with the daily recommended intake of protein. However, as previously mentioned, the production of complete protein would be notably constrained in such a scenario. The reason for that is attributed to the limited quantity of grain legumes cultivated in Sweden, amounting to a mere 2% of the total crop land (The Swedish Board of Agriculture 2023a).

Less than half of the potential edible fat embedded in crops produced in Sweden 2020 was used as food and as little as 30% of the proteins and 40% of the calories (Figure 3). If measured in tonnes however, 83% of the edible crops was used for food, which is due to nutrient-dense crops being utilized for feed and biofuel.

Biofuel and ethanol production (including liquor) accounted for 11% of the total edible plant protein and 10% of the edible fats inherent in the crops produced in Sweden 2020.

Barley for human consumption was in this study assumed to be used for beer brewing, since this is the main area of barley use for human consumption in Sweden. If the Swedish barley currently used for beer production were instead eaten directly as whole grain, it would suffice to provide an additional million people with the daily requirement of calories and about half a million people with the recommended intake of proteins and fat (Table 15).

In total, the domestically produced crops that were used for biofuel, ethanol production and beer brewing in year 2020 contains enough edible nutrients to feed about 3.7 million people with their caloric needs (corresponding to 1.3 people per hectare) and 3.4 million people concerning protein (Table 15). These results put light on the importance of considering nutrient content of crops and its area of use when assessing the efficiency of a food system.

As illustrated in the above discussion, the indicator 'number of people fed per hectare' shed light on the current utilization of edible nutrients in the food system when applied on a national level. This offers valuable insights into the food supply capacity within the constraints of limited cropland resources. In conclusion, the indicator holds potential value by providing information on the current utilization of edible nutrients in the food system and by highlighting the supply capacity within existing agricultural production in a region or a nation. Information that can be useful in evaluating the land use efficiency of current production and further to identifying possibly actions to increase the national food supply.

However, envisioning a long-term sustainable food system requires a holistic approach that extends beyond mere productivity. Agriculture must also generate additional values, such as carbon sequestration, the promotion of fertile soils through increased soil carbon, ensuring clean water and air (or minimizing negative environmental impact), and fostering a diverse and nutritionally balanced diet. Moreover, the agricultural system needs to be adapted to local needs and must be robust enough to cope with unexpected events and future conditions, including a changed climate and reduced access to energy (FAO 2022). Therefore, to provide a meaningful overall picture of how a farm or region contributes to the global food supply, the indicator 'how many can be nourished per hectare' should be complemented with other indicators to measure how well the farm or region performs in terms of ecological, economic and social sustainability. The results should also be weighted according to the agricultural production capacity of the ecoregion.

5.3 Fruit and vegetables

To gain insight into the micronutrient supply in Sweden, the application of the indicator was expanded to also encompass the number of individuals sustained by domestically produced fruits and vegetables, based on the recommended daily intake of these foods (500 g per person per day).

The horticultural production in Sweden during the studied year is only enough to provide approximately 22% of the Swedish population with the daily recommended intake of fruits and vegetables, which corresponds to 0.9 people per hectare (Table 17). Since Sweden has a very limited production of fruit and vegetables, the application of the indicator was extended to also include berries from Swedish forests to highlight the potential for domestic micronutrient supply.

If the blueberries and lingonberries found in Swedish forests in 2020 were fully utilized for human consumption, and added to the existing cropland, the total production of fruit, vegetables and berries (including horticulture production) could support almost 80% of the Swedish population. Although it may not be realistic to assume that all forest berries are used for human consumption, these findings shed light on the extent of underutilized food resources in Sweden.

5.4 Comparison with previous studies and findings

The findings of the current study show general consistency with Linderholm's study (Linderholm 2018) that mapped the edible macronutrient content in Sweden's agricultural production in 2017-2018. However, there are some notable differences. A key disparity is observed in the amount of edible proteins produced. In Linderholm's research, the edible protein content in Sweden's total crop production for 2017-2018 was estimated to be 26% higher compared to the results of the current study. This discrepancy can be partly attributed to the larger production of field beans in 2017-2018, contributing to around one-tenth of the difference in protein supply.

Furthermore, the reference values used to calculate the edible content of various crops differ between the two studies, which explains part of the discrepancy concerning protein content in the production of edible crops. A large part being attributed to different assumptions regarding utilization of oil crops for human consumption. In the current study, oil crops were assumed to be used primarily for cooking oil, thereby contributing no edible protein. In contrast, Linderholm (2018) included the edible protein in oil crops (rape seed), accounting for a considerable portion of the total proteins reported. Similar outcomes apply to the calculations of edible protein content in potatoes, which in the current study were presumed to be used for starch (see Table 3 and Table 5). Linderholm's aggregation of certain agricultural production categories also plays a role in the variations observed in protein content results.

Sweden's degree of self-sufficiency is often stated to be around 50%, a figure commonly highlighted in communications from the Federation of Swedish Farmers

(LRF 2022). Further, the Swedish Board of Agriculture regularly compiles statistics on Sweden's market shares for various food products (The Swedish Board of Agriculture 2023b). Interestingly, it seems to be a large discrepancy between the food supply capacity of Swedish food production according to the findings of the current study compared to the reported market shares and claimed self-sufficiency rate. However, since Sweden's market share does not take nutrients into account, these figures offer only a rough comparative picture. In 2020, The Federation of Swedish Farmers investigated Sweden's net import share of macronutrients and found that around 44% of the food calories consumed in Sweden were imported, with similar figures for protein and slightly lower for fat (LRF 2021).

According to the current study, almost a fifth of the food produced in Sweden 2020, measured in tonnes, was exported. When considering the content of edible macronutrients in the crops exported as food, it appears that this export accounted for 30% of the calories, 46% of the protein, and 17% of the fat in Sweden's total production of crops for human consumption. Sweden's export of animal products is marginal. A rough calculation of the macronutrient content of the animal products that, according to Swedish trade statistics (The Swedish Board of Agriculture 2021b), were exported in 2020 shows that only about 0,05% of the calories, protein and fat in the total animal production in Sweden is exported.

If deducting the exported food macronutrients from the total food production in Sweden 2020, the domestically produced food that remains in the country is sufficient to meet 97% of the population's calorie needs, 91% of their protein requirements, and slightly less for fat (calculated on the population in Sweden in 2020). These findings present a remarkable contrast to the high import shares of food macronutrients, as reported by the LRF (The Federation of Swedish Farmers). Food loss and waste likely contribute to this gap. Swedish Environmental Protection Agency (Lindow et al. 2021) reported that approximately one million tonnes of food were discarded in 2020, 70% of which occurred in households (Hultén et al. 2022). Food losses in the production stage constitute a smaller part, but the quantity is not without significance: around 9% of beef (Lindow et al. 2021), 20% of potatoes (Strid et al. 2023), and 33% of carrots (Olsson 2023) never enter the food system.

The estimated food loss in Sweden 2020 (Lindow et al. 2021) corresponds to about 10% of the total amount of food (in tonnes) that, according to the current study, was produced on Swedish cropland during the same year. Since Swedish food waste statistics are presented by weight, the extent of nutrient loss is unknown. However, it is unlikely that food loss alone account for the observed discrepancy between the supply capacity of macronutrients and the reported import share of these nutrients. High consumption of meat and energy-dense foods is likely a contributing factor to this gap. Official statistics (The Swedish Board of Agriculture 2020c) estimate the average protein intake per person and day in 2019 to 104 grams, which is substantially higher than the recommended daily intake of 84.7 grams used in this study. The average calorie and fat intake in the same year also far exceeded recommended intake levels by far.

5.5 Limitations of study

The underlying assumptions and data sources in calculating the 'number of people that can be fed per hectare', such as recommended daily intake (Table 8) and edible shares of different crops (Table 3), likely influence the outcomes to some degree. Specifically, the decisions regarding the utilization of various crops affect the calculated contribution of macronutrients. For instance, in this study it is assumed that cereals are consumed as whole grains, which does not reflect the actual consumption patterns in Sweden, but rather shows the maximum potential nutrition these cereals could offer. As discussed in previous section, these methodological choices can impact the outcome of edible macronutrient production.

The system boundaries, in terms of inclusion of land use for imported feed and meat production from exported feed had a marginally impact on the results.

When incorporating external meat production from exported feed into the calculations, a slightly higher amount of calories and protein is observed, with a minimal difference between chicken and beef production, as shown in Table 15.

The additional land required for external beef production (accounting for additional feed production to make up a complete feed ratio) leads to only a slight reduction in the number of people that can be fed per hectare (Table 16).

This weak impact on the results is attributed to the small proportion (2.3%) of Sweden's total crop production that was exported for feed use according to the data used in this study. Based on the calculations, 17% of the crops produced 2020 was exported, the main part for human consumption. Information on the area of use for the exported crops was provided by Lantmännen and was based on an estimated percentage distribution between food and feed for each exported crop (wheat, rye, barley etc) in a typical year.

However, exploring hypothetical scenarios sheds light on the distinct outcomes between beef and chicken production in this context. For instance, assuming that the amount of crops produced for feed export is tenfold, accounting for about 18.5% of Sweden's total crop production, the results vary greatly depending on the assumption about the type of livestock feed. When all exported feed is hypothetically used for beef production in this scenario, the number of people that can be fed per hectare in terms of protein shows a slight decrease. In contrast, assuming the same exported feed is used for chicken production would allow nearly two more people to be fed per hectare of cropland. This disparity is less pronounced in terms of calories and fat.

Variations in yield levels between different production years have an impact on the share of imports and exports of different crops in Sweden. For instance, the production of rye in Sweden in a given year commonly influences its export use, according to Per Gerhardsson at Lantmännen[2].Years with high rye production often see a substantial portion of the rye exported for whiskey production. Conversely, in years with lower rye yields, the export predominantly targets feed use. This pattern

[2] Per Gerhardsson, purchasing manager at Lantmännen, phone-call 230510.

is largely due to the logistics of whiskey production, which requires large grain volumes to fill the substantial cargo ships used for transportation.

In addition, the data on feed imports and crop exports were obtained from various sources, as Sweden's official statistics do not offer the required categorization and details required for this study. Some of the crop export data used in this study were based on expert estimates that might not have been fully accurate for the current year, which may have influenced the outcome of the indicator.

Further, imported and purchased feed which consist of by-products from the food industry, such as rapeseed cake, beet pulses and malt sprout pellets, was allocated completely to the main product and thus did not add any cropland area to the calculations. From a global perspective, however, it can be debated whether this type of food production that results in large amount of potentially edible by-products, is the most efficient use of land, which is an aspect not made visible in this study.

The Swedish statistics on available cropland exclude agricultural enterprises with less than 2 hectares of land. Consequently, a small portion of Sweden's available cropland is not accounted for in our calculations. This exclusion could slightly impact the accuracy of the study's findings regarding the total cropland area and its productivity, but this influence is likely to be marginal.

6. Conclusions

This study evaluated the ‘number of people fed per hectare’ indicator as a metric for assessing agricultural productivity, using data from a number of real farms in Sweden as well as from Sweden as a whole.

The analysis at national level revealed that Sweden’s current food production is sufficient to feed approximately 5 people per hectare with their daily calorie needs, and slightly less regarding proteins and fat. Currently, a considerable part of edible macronutrients produced in Sweden are not consumed as food. The findings indicate that less than half of the total edible fat, approximately 30% of the proteins and 40% of the calories derived from crops in Sweden (in 2020) were allocated for human consumption. while 11% of the protein and 10% of the fat being directed for production of biofuel and ethanol. Shifting crops from feed, biofuel, and ethanol production towards direct human consumption could substantially increase food supply capacity per hectare in Sweden, potentially doubling calorie provision and increasing protein supply by 50%.

At national level, the application of the indicator effectively highlighted the efficiency of current edible macronutrient utilization in the food system and demonstrated the supply capacity of existing agricultural production. However, at farm level, results varied widely and the indicator was found to be less suited for benchmarking performance across farms, given diverse conditions for agricultural production. Its primary utility at this level lies in tracking the impact of agricultural practices on individual farms over time, providing insight into how different strategies affect food supply which helps to identify agricultural activities that have a particularly large impact in this regard. Most farms included in the study increased the the number of people that can be fed per hectare after implemented diversification measures, and some farms showed potential to increase the production of fat and complete protein per hectare, despite reduced meat production.

In summary, the 'number of people fed per hectare' indicator demonstrates greatest utility when applied at the national scale, offering valuable insights into the efficiency of current agricultural production and highlights potential pathways for enhancing national food supply. However, to accurately assess a farm or region's performance in terms of contribution to global food security the ‘number of people fed per hectare´ indicator must be integrated with a broader range of sustainability indicators covering ecological, economic, and social aspects.

References

Ahmad, S., Wong, K.Y. & Ahmad, R. (2019). Life cycle assessment for food production and manufacturing: recent trends, global applications and future prospects. *Procedia Manufacturing*, 34, 49–57. https://doi.org/10.1016/j.promfg.2019.06.113

Alexandratos, N. & Bruinsma, J. (eds) (2012). *World agriculture towards 2030/2050: the 2012 revision*. (ESA Working Papers 12-03). https://doi.org/10.22004/ag.econ.288998

Ambikapathi, R., Schneider, K.R., Davis, B., Herrero, M., Winters, P. & Fanzo, J.C. (2022). Global food systems transitions have enabled affordable diets but had less favourable outcomes for nutrition, environmental health, inclusion and equity. *Nature Food*, 3 (9), 764–779. https://doi.org/10.1038/s43016-022-00588-7

Andersson, K. (2022). Kan man tillverka etanol av vete när Ukrainas veteexport styps? *Svebio*. https://www.svebio.se/press/blogginlagg/kan-man-tillverka-etanol-av-vete-nar-ukrainas-veteexport-styps/ [2024-01-06]

Arla (2022). *Vimmerby pulveranläggning*. *Arla*. https://www.arla.se/om-arla/mejerier/vimmerby-pulveranlaggning/ [2022-01-06]

Arulnathan, V., Heidari, M.D., Doyon, M., Li, E. & Pelletier, N. (2020). Farm-level decision support tools: A review of methodological choices and their consistency with principles of sustainability assessment. *Journal of Cleaner Production*, 256, 120410. https://doi.org/10.1016/j.jclepro.2020.120410

Beltran-Peña, A., Rosa, L. & D'Odorico, P. (2020). Global food self-sufficiency in the 21st century under sustainable intensification of agriculture. *Environmental Research Letters*, 15 (9), 095004. https://doi.org/10.1088/1748-9326/ab9388

Bezner Kerr, R., Madsen, S., Stüber, M., Liebert, J., Enloe, S., Borghino, N., Parros, P., Mutyambai, D.M., Prudhon, M. & Wezel, A. (2021). Can agroecology improve food security and nutrition? A review. *Global Food Security*, 29, 100540. https://doi.org/10.1016/j.gfs.2021.100540

Blom, S. (2022). *Ökad odling av baljväxter till livsmedel och foder - Möjligheter och umaningar*. (2022:07). The Swedish Board of Agriculture. https://www2.jordbruksverket.se/download/18.3071dc1b181b2b565e014e05/1656583209886/RA22_7.pdf [2024-01-06]

Campi, M., Dueñas, M. & Fagiolo, G. (2021). Specialization in food production affects global food security and food systems sustainability. *World Development*, 141, 105411. https://doi.org/10.1016/j.worlddev.2021.105411

Carlsson, G. (2018). Baljväxter till livsmedel och foder. https://adm.greppa.nu/download/18.28b36abe16527b8975b957c7/1538632535277/Baljväxter%20till%20livsmedel%20och%20foder.pdf [2023-05-01]

Cassidy, E., West, P., Gerber, J. & Foley, J. (2013). Redefining Agricultural Yields: from Tonnes to People Nourished per Hectare. *Environmental Research Letters*, 8, 034015. https://doi.org/10.1088/1748-9326/8/3/034015

Cassman, K.G. & Grassini, P. (2020). A global perspective on sustainable intensification research. *Nature Sustainability*, 3 (4), 262–268. https://doi.org/10.1038/s41893-020-0507-8

Cederberg, C., Berlin, J., Henriksson, M. & Davis, J. (2008). *Utsläpp av växthusgaser i ett livscykelperspektiv för verksamheten vid livsmedelsföretaget Berte Qvarn*. (772 2008). Institutet för livsmedel och bioteknik. http://www.diva-portal.org/smash/get/diva2:943295/FULLTEXT01.pdf

Chaudhary, A., Gustafson, D. & Mathys, A. (2018). Multi-indicator sustainability assessment of global food systems. *Nature Communications*, 9 (1), 848. https://doi.org/10.1038/s41467-018-03308-7

Chaudhary, A. & Kastner, T. (2016). Land use biodiversity impacts embodied in international food trade. *Global Environmental Change*, 38, 195–204. https://doi.org/10.1016/j.gloenvcha.2016.03.013

Chopin, P., Mubaya, C.P., Descheemaeker, K., Öborn, I. & Bergkvist, G. (2021). Avenues for improving farming sustainability assessment with upgraded tools, sustainability framing and indicators. A review. *Agronomy for Sustainable Development*, 41 (2), 19. https://doi.org/10.1007/s13593-021-00674-3

Clark, M. & Tilman, D. (2017). Comparative analysis of environmental impacts of agricultural production systems, agricultural input efficiency, and food choice. *Environmental Research Letters*, 12 (6), 064016. https://doi.org/10.1088/1748-9326/aa6cd5

Conchedda, G., Santis, G. & Tubiello, F. (2023). Land statistics and indicators 2000-2021 Global, regional and country trends Analytical Brief 71. https://doi.org/10.4060/cc6907en

Crippa, M., Solazzo, E., Guizzardi, D., Monforti-Ferrario, F., Tubiello, F.N. & Leip, A. (2021). Food systems are responsible for a third of global anthropogenic GHG emissions. *Nature Food*, 2 (3), 198–209. https://doi.org/10.1038/s43016-021-00225-9

D'Annolfo, R., Gemmill-Herren, B., Graeub, B. & Garibaldi, L.A. (2017). A review of social and economic performance of agroecology. *International Journal of Agricultural Sustainability*, 15 (6), 632–644. https://doi.org/10.1080/14735903.2017.1398123

DanSukker (2023). *Hållbar odling och produktion*. https://www.dansukker.se/se/om-socker/haallbar-odling-och-produktion [2023-05-15]

De Boer, J., Schösler, H. & Aiking, H. (2014). "Meatless days" or "less but better"? Exploring strategies to adapt Western meat consumption to health and sustainability challenges. *Appetite*, 76, 120–128. https://doi.org/10.1016/j.appet.2014.02.002

van Dijk, M., Morley, T., Rau, M.-L. & Saghai, Y. (2021). A meta-analysis of projected global food demand and population at risk of hunger for the period 2010–2050. *Nature Food*, 2, 494–501. https://doi.org/10.1038/s43016-021-00322-9

D'Odorico, P., Carr, J.A., Davis, K.F., Dell'Angelo, J. & Seekell, D.A. (2019). Food Inequality, Injustice, and Rights. *BioScience*, 69 (3), 180–190. https://doi.org/10.1093/biosci/biz002

D'Odorico, P., Carr, J.A., Laio, F., Ridolfi, L. & Vandoni, S. (2014). Feeding humanity through global food trade. *Earth's Future*, 2 (9), 458–469. https://doi.org/10.1002/2014EF000250

Drofenik Jan, Pahor Bojan, Kravanja Zdravko, & Pintaric Zorka Novak (2021). Scenario Analysis of Changes in the Food Supply Chain. *Chemical Engineering Transactions*, 88, 721–726. https://doi.org/10.3303/CET2188120

Dumont, B., Groot, J.C.J. & Tichit, M. (2018). Review: Make ruminants green again – how can sustainable intensification and agroecology converge for a better future? *Animal*, 12, s210–s219. https://doi.org/10.1017/S1751731118001350

EFSA Panel on Dietetic Products, Nutrition and Allergies (NDA) (2012). Scientific Opinion on Dietary Reference Values for protein. *EFSA Journal*, 10 (2), 2557. https://doi.org/10.2903/j.efsa.2012.2557

Einarsson, R., Henriksson, M., Hoffmann, M. & Cederberg, C. (2022). The nitrogen footprint of Swedish food consumption. *Environmental Research Letters*, 17 (10), 104030. https://doi.org/10.1088/1748-9326/ac9246

Erb, K.-H., Lauk, C., Kastner, T., Mayer, A., Theurl, M.C. & Haberl, H. (2016). Exploring the biophysical option space for feeding the world without deforestation. *Nature Communications*, 7 (1), 11382. https://doi.org/10.1038/ncomms11382

European Commission (2019). *EU agricultural outlook for markets and income 2019-2030*. Publications Office. https://data.europa.eu/doi/10.2762/904294

FAO (2013). *SAFA Indicators - Sustainability assessment of food and agricultue systems.* https://www.fao.org/fileadmin/templates/nr/sustainability_pathways/docs/SAFA_Indicators_final_19122013.pdf [2023-09-01]

FAO (2018a). *The future of food and agriculture - alternative pathways to 2050. Summary version.* https://www.fao.org/3/CA1553EN/ca1553en.pdf [2023-10-01]

FAO (2018b). *Water for sustainable food and agriculture: A report produced for the G20 Presidency of Germany*. Food & Agriculture Org.

FAO (2019). *Scaling up agroecology to achieve the sustainable development goals - Proceedings of the second FAO international symposium: 3 - 5 April 2018, Rome, Italy*. FAO. https://www.fao.org/documents/card/en/c/CA3666EN/ [2024-01-04]

FAO (2020). *Land use in agriculture by the numbers*. *Food and Agriculture Organization of the United Nations*. http://www.fao.org/sustainability/news/detail/en/c/1274219/ [2024-01-04]

FAO (2022). *The future of food and agriculture – Drivers and triggers for transformation*. FAO. https://doi.org/10.4060/cc0959en

FAO, IFAD, UNICEF, WFP, & WHO (2022). *The State of Food Security and Nutrition in the World 2022: Repurposing food and agricultural policies to make healthy diets more affordable*. FAO, IFAD, UNICEF, WFP, WHO. https://doi.org/10.4060/cc0639en

FAOSTAT (2023). *FAOSTAT - Crop Production, Yield, Harvested Area - 'FAO catalog'*. https://data.apps.fao.org/catalog/dataset/crop-production-yield-harvested-area-

global-national-annual-faostat/resource/45e995e9-1021-4288-abed-ab933d3a3c01 [2024-01-06]
Farooq, M.S., Uzair, M., Raza, A., Habib, M., Xu, Y., Yousuf, M., Yang, S.H. & Ramzan Khan, M. (2022). Uncovering the Research Gaps to Alleviate the Negative Impacts of Climate Change on Food Security: A Review. *Frontiers in Plant Science*, 13. https://www.frontiersin.org/articles/10.3389/fpls.2022.927535 [2024-01-03]
Flysjö, A., Cederberg, C. & Strid, I. (2008). *LCA-databas för konventionella fodermedel : miljöpåverkan i samband med produktion*. (772 2008). SIK Institutet för livsmedel och bioteknik. https://urn.kb.se/resolve?urn=urn:nbn:se:ri:diva-503 [2024-01-06]
Fogelberg, F. (2008). Svenska bönor inte bara bruna. *JTI -Institutet för jorbruks- och miljöteknik*. JTI Informerar (121). http://www.baljvaxtakademin.se/home/odling/JTIinfo121_Svenska_bonor_inte_bara_bruna.pdf [2023-06-10]
Foley, J.A., Ramankutty, N., Brauman, K.A., Cassidy, E.S., Gerber, J.S., Johnston, M., Mueller, N.D., O'Connell, C., Ray, D.K., West, P.C., Balzer, C., Bennett, E.M., Carpenter, S.R., Hill, J., Monfreda, C., Polasky, S., Rockström, J., Sheehan, J., Siebert, S., Tilman, D. & Zaks, D.P.M. (2011). Solutions for a cultivated planet. *Nature*, 478 (7369), 337–342. https://doi.org/10.1038/nature10452
Gerten, D., Heck, V., Jägermeyr, J., Bodirsky, B.L., Fetzer, I., Jalava, M., Kummu, M., Lucht, W., Rockström, J., Schaphoff, S. & Schellnhuber, H.J. (2020). Feeding ten billion people is possible within four terrestrial planetary boundaries. *Nature Sustainability*, 3 (3), 200–208. https://doi.org/10.1038/s41893-019-0465-1
Gibbs, J. & Cappuccio, F.P. (2022). Plant-Based Dietary Patterns for Human and Planetary Health. *Nutrients*, 14 (8), 1614. https://doi.org/10.3390/nu14081614
Giller, K.E., Delaune, T., Silva, J.V., Descheemaeker, K., Van De Ven, G., Schut, A.G.T., Van Wijk, M., Hammond, J., Hochman, Z., Taulya, G., Chikowo, R., Narayanan, S., Kishore, A., Bresciani, F., Teixeira, H.M., Andersson, J.A. & Van Ittersum, M.K. (2021). The future of farming: Who will produce our food? *Food Security*, 13 (5), 1073–1099. https://doi.org/10.1007/s12571-021-01184-6
Godfray, H.C.J., Beddington, J.R., Crute, I.R., Haddad, L., Lawrence, D., Muir, J.F., Pretty, J., Robinson, S., Thomas, S.M. & Toulmin, C. (2010). Food Security: The Challenge of Feeding 9 Billion People. *Science*, 327 (5967), 812–818. https://doi.org/10.1126/science.1185383
Godfray, H.C.J. & Garnett, T. (2014). Food security and sustainable intensification. *Philosophical Transactions of the Royal Society B: Biological Sciences*, 369 (1639), 20120273. https://doi.org/10.1098/rstb.2012.0273
Grassauer, F., Herndl, M., Nemecek, T., Guggenberger, T., Fritz, C., Steinwidder, A. & Zollitsch, W. (2021). Eco-efficiency of farms considering multiple functions of agriculture: Concept and results from Austrian farms. *Journal of Cleaner Production*, 297, 126662. https://doi.org/10.1016/j.jclepro.2021.126662
van Hal, O., Weijenberg, A.A.A., de Boer, I.J.M. & van Zanten, H.H.E. (2019). Accounting for feed-food competition in environmental impact assessment: Towards a resource efficient food-system. *Journal of Cleaner Production*, 240, 118241. https://doi.org/10.1016/j.jclepro.2019.118241

Hayek, M.N., Harwatt, H., Ripple, W.J. & Mueller, N.D. (2021). The carbon opportunity cost of animal-sourced food production on land. *Nature Sustainability*, 4 (1), 21–24. https://doi.org/10.1038/s41893-020-00603-4

Henriksson, M., Cederberg, C. & Swensson, C. (2014). Carbon footprint and land requirement for dairy herd rations: impacts of feed production practices and regional climate variations. *Animal*, 8 (8), 1329–1338. https://doi.org/10.1017/S1751731114000627

Henryson, K., Meurer, K.H.E., Bolinder, M.A., Kätterer, T. & Tidåker, P. (2022). Higher carbon sequestration on Swedish dairy farms compared with other farm types as revealed by national soil inventories. *Carbon Management*, 13 (1), 266–278. https://doi.org/10.1080/17583004.2022.2074315

Herrero, M., Thornton, P.K., Power, B., Bogard, J.R., Remans, R., Fritz, S., Gerber, J.S., Nelson, G., See, L., Waha, K., Watson, R.A., West, P.C., Samberg, L.H., van de Steeg, J., Stephenson, E., van Wijk, M. & Havlík, P. (2017). Farming and the geography of nutrient production for human use: a transdisciplinary analysis. *The Lancet Planetary Health*, 1 (1), e33–e42. https://doi.org/10.1016/S2542-5196(17)30007-4

Holmberg, M. (2016). *Inverkan av vattenhalten i såbotten för uppkomsten hos sockerbetor*. (Grundnivå, G2E). SLU, Institutionen för mark och miljö. https://stud.epsilon.slu.se/8886/ [2024-01-06]

Hultén, J., Sörme, L. & Eriksson, M. (2022). *Livsmedelsavfall i Sverige 2020*. (INFO-serien, 8891). Naturvårdsverket. https://www.naturvardsverket.se/4ac543/globalassets/media/publikationer-pdf/8800/978-91-620-8891-0.pdf [2024-01-08]

Ingvarsson, A. (2012). Dyrare öl vid högre maltkornspris? | LLB. *Land Lantbruk.*,. https://www.landlantbruk.se/dyrare-ol-vid-hogre-maltkornspris [2023-06-02]

IPCC (2023a). *Climate Change 2022 – Impacts, Adaptation and Vulnerability: Working Group II Contribution to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change*. 1. ed Cambridge University Press. https://doi.org/10.1017/9781009325844

IPCC (2023b). *IPCC, 2023: Climate Change 2023: Synthesis Report. Contribution of Working Groups I, II and III to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change [Core Writing Team, H. Lee and J. Romero (eds.)].* Intergovernmental Panel on Climate Change (IPCC). https://doi.org/10.59327/IPCC/AR6-9789291691647

ISO (2006). ISO 14040 International Standard. Environmental management - Life cycle assessment - Principles and framework, International Organization for Standardization. https://www.iso.org/standard/37456.html [2024-01-27]

Jansson, U. & Mårald, E. (eds) (2005). *Bruka, odla, hävda: odlingssystem och uthålligt jordbruk under 400 år*. Kungl. Skogs- och lantbruksakademien. (Skogs- och lantbrukshistoriska meddelanden; 33)

Jones, S.K., Sánchez, A.C., Juventia, S.D. & Estrada-Carmona, N. (2021). A global database of diversified farming effects on biodiversity and yield. *Scientific Data*, 8 (1), 212. https://doi.org/10.1038/s41597-021-01000-y

Kalvportalen (2017). Översikt Kalvnäringar. *Compilation from the magazine Husdjur.* http://www.kalvportalen.se/media/1042/husdj1701s24-25-mjolknaring.pdf [2022-10-10]

Karlsson, A.-M. (2021). Arealen av åkerbönor, sötlupiner och andra baljväxter. *Jordbruket i siffror*. https://jordbruketisiffror.wordpress.com/2021/02/03/arealen-av-akerbonor-sotlupiner-och-andra-baljvaxter/ [2024-01-06]

Karlsson, J. (2022). *Livestock as resource users and landscape managers - A food systems perspective*. (Diss.). Swedish University of Agricultural Sciences. https://doi.org/10.13140/RG.2.2.25926.14403

Karlsson, J., Röös, E., Sjunnestrand, T., Pira, K., Larsson, M., Andersen, B.H., Sørensen, J., Veistola, T., Rantakokko, J., Manninen, S. & Brub, S. (2017). *Future Nordic Diets - Exploring ways for sustainably feeding the Nordics.* (207:566). Nordic Council of Ministers. https://norden.diva-portal.org/smash/get/diva2:1163192/FULLTEXT01.pdf

Karlsson, J.O. & Röös, E. (2019). Resource-efficient use of land and animals—Environmental impacts of food systems based on organic cropping and avoided food-feed competition. *Land Use Policy*, 85, 63–72. https://doi.org/10.1016/j.landusepol.2019.03.035

Khoury, C.K., Bjorkman, A.D., Dempewolf, H., Ramirez-Villegas, J., Guarino, L., Jarvis, A., Rieseberg, L.H. & Struik, P.C. (2014). Increasing homogeneity in global food supplies and the implications for food security. *Proceedings of the National Academy of Sciences*, 111 (11), 4001–4006. https://doi.org/10.1073/pnas.1313490111

Kirchmann, H. (2019). Why organic farming is not the way forward. *Outlook on Agriculture*, 48 (1), 22–27. https://doi.org/10.1177/0030727019831702

Kokemohr, L., Escobar, N., Mertens, A., Mosnier, C., Pirlo, G., Veysset, P. & Kuhn, T. (2022). Life Cycle Sustainability Assessment of European beef production systems based on a farm-level optimization model. *Journal of Cleaner Production*, 379, 134552. https://doi.org/10.1016/j.jclepro.2022.134552

Lampridi, M.G., Sørensen, C.G. & Bochtis, D. (2019). Agricultural Sustainability: A Review of Concepts and Methods. *Sustainability*, 11 (18), 5120. https://doi.org/10.3390/su11185120

Landquist, B. & Nordborg, M. (2019). *Produktion och konsumtion av livsmedel i Västra Götaland 2003 och 2016 - Detaljerad resultat- och metodikrapport*. (RISE Rapport 2019:06). RISE Research Institutes of Sweden AB. https://ri.diva-portal.org/smash/get/diva2:1324389/FULLTEXT01.pdf [2023-05-01]

Lantmännen Lantbruk (2023). *Utsädesmängd. LM Odla - Odlingsstrategier för lantbrukare*. https://www.odla.lantmannenlantbruk.se/utsadebetning/utsadesmangd/ [2024-01-06]

Leibring, K. & Svanberg, I. (2020). *Nötkreatur i Sverige: kulturhistoriska och samtida perspektiv*. Institutet för språk och folkminnen. https://www.isof.se/download/18.4d384471179f5c20b29a223/1623660699869/Notkreatur_i_%20Sverige.pdf

Linderholm, K. (2018). *Sveriges självförsörjningsgrad - energi till människor och motorer från svenskt jordbruk 2017–2018*. https://silvberg.se/onewebmedia/Sveriges%20självförsörjningsgrad-%20energi%20till%20människor%20och%20motorer%20från%20svenskt%20jordbruk.pdf

Lindow, K., Strid, I., Olsson, M., Wallgren, T., Lundh, Å., Östman, Ö., Persson Hovmalm, H., Larsson Jönsson, H., Stenberg, J.A. & Östergren, K. (2021). *Food loss in Sweden : National follow-up methods for increased knowledge about losses and resources in food production*. (2021:2). The Swedish Board of Agriculture. https://res.slu.se/id/publ/113844 [2024-01-08]

LRF (2021). *Importandelen eller 'Varannan tugga är svensk'*. https://www.lrf.se/media/1q0pwsjv/importandelen_2021-2.pdf [2024-01-20]

LRF (2022). *Försörjningsgrad*. https://www.lrf.se/las-mer/forsorjningsgrad/ [2024-01-05]

Lyckeby (2022). *Odla åt oss*. *Lyckeby*. https://www.lyckeby.com/lantbruk/odla-at-oss/ [2024-01-06]

Mauser, W., Klepper, G., Zabel, F., Delzeit, R., Hank, T., Putzenlechner, B. & Calzadilla, A. (2015). Global biomass production potentials exceed expected future demand without the need for cropland expansion. *Nature Communications*, 6 (1), 8946. https://doi.org/10.1038/ncomms9946

Mogensen, L., Trydeman knudsen, M., Dorca-Preda, T., Ingemann Nielsen, N., Sillebak Kristensen, I. & kristensen, T. (2018). *Baeredygtighedsparametre for konventionelle fodermidler till kvaeg*. (DCA RAPPORT NR. 116). Aarhus Universitet. https://dcapub.au.dk/djfpublikation/djfpdf/DCArapport116.pdf [2024-01-20]

Möller, E. & Sjöberg, C. (2019). *Odling av svensk lupin - stragegier med fokus på ogräshantering.* (Bachelor thesis). Swedish University of Agricultural Sciences. https://stud.epsilon.slu.se/14955/11/moller_e_sjoberg_c_190826.pdf [2023-04-05]

Molotoks, A., Stehfest, E., Doelman, J., Albanito, F., Fitton, N., Dawson, T.P. & Smith, P. (2018). Global projections of future cropland expansion to 2050 and direct impacts on biodiversity and carbon storage. *Global Change Biology*, 24 (12), 5895–5908. https://doi.org/10.1111/gcb.14459

Muralikrishna, I.V. & Manickam, V. (2017). Chapter Five - Life Cycle Assessment. In: Muralikrishna, I.V. & Manickam, V. (eds) *Environmental Management*. Butterworth-Heinemann. 57–75. https://doi.org/10.1016/B978-0-12-811989-1.00005-1

Naderi, N., Ghorbani, G.R., Erfani, H. & Ferraretto, L.F. (2022). Feeding Byproduct-Based Concentrates Instead of Human-Edible Feed Ingredients Increases Net Food Production and Improves Performance of High-Producing Holstein Cows. *Animals : an Open Access Journal from MDPI*, 12 (21), 2977. https://doi.org/10.3390/ani12212977

Nilsson, P., Roberge, C. & Fridman, J. (2021). *Forest statistics 2021*. Swedish University of Agricultural Sciences. https://www.slu.se/globalassets/ew/org/centrb/rt/dokument/skogsdata/skogsdata_2021_webb.pdf [2023-05-05]

Nordic Council of Ministers (2014). *Nordic Nutrition Recommendations 2012 : Integrating nutrition and physical activity*. Nordisk Ministerråd. https://urn.kb.se/resolve?urn=urn:nbn:se:norden:org:diva-2561 [2024-01-05]

Nordin, C. (2020). *Investigation of the livestock prices in Sweden and the effect of the membership of the European Union*. (Bachelor thesis). Mid Sweden University.

https://www.diva-portal.org/smash/get/diva2:1528819/FULLTEXT01.pdf [2023-09-01]
de Olde, E.M., Moller, H., Marchand, F., McDowell, R.W., MacLeod, C.J., Sautier, M., Halloy, S., Barber, A., Benge, J., Bockstaller, C., Bokkers, E.A.M., de Boer, I.J.M., Legun, K.A., Le Quellec, I., Merfield, C., Oudshoorn, F.W., Reid, J., Schader, C., Szymanski, E., Sørensen, C.A.G., Whitehead, J. & Manhire, J. (2017). When experts disagree: the need to rethink indicator selection for assessing sustainability of agriculture. *Environment, Development and Sustainability*, 19 (4), 1327–1342. https://doi.org/10.1007/s10668-016-9803-x
Olsson, M. (2023). *Livsmedelsförluster vid produktion av morötter*. (2023:4). The Swedish Board of Agriculture. https://www2.jordbruksverket.se/download/18.701c6806185e7b2d8d8340d0/1674660755614/ra23_4.pdf [2023-05-15]
Ortiz-Bobea, A., Ault, T.R., Carrillo, C.M., Chambers, R.G. & Lobell, D.B. (2021). Anthropogenic climate change has slowed global agricultural productivity growth. *Nature Climate Change*, 11 (4), 306–312. https://doi.org/10.1038/s41558-021-01000-1
Palomo-Campesino, S., García-Llorente, M., Hevia, V., Boeraeve, F., Dendoncker, N. & González, J.A. (2022). Do agroecological practices enhance the supply of ecosystem services? A comparison between agroecological and conventional horticultural farms. *Ecosystem Services*, 57, 101474. https://doi.org/10.1016/j.ecoser.2022.101474
Pellegrini, P. & Fernández, R.J. (2018). Crop intensification, land use, and on-farm energy-use efficiency during the worldwide spread of the green revolution. *Proceedings of the National Academy of Sciences of the United States of America*, 115 (10), 2335–2340
Poore, J. & Nemecek, T. (2018). Reducing food's environmental impacts through producers and consumers. *Science*, 360 (6392), 987–992. https://doi.org/10.1126/science.aaq0216
Potapov, P., Turubanova, S., Hansen, M.C., Tyukavina, A., Zalles, V., Khan, A., Song, X.-P., Pickens, A., Shen, Q. & Cortez, J. (2022). Global maps of cropland extent and change show accelerated cropland expansion in the twenty-first century. *Nature Food*, 3 (1), 19–28. https://doi.org/10.1038/s43016-021-00429-z
Pradhan, P., Lüdeke, M.K.B., Reusser, D.E. & Kropp, J.P. (2013). Embodied crop calories in animal products. *Environmental Research Letters*, 8 (4), 044044. https://doi.org/10.1088/1748-9326/8/4/044044
Prendergast-Miller, M.T., Jones, D.T., Berdeni, D., Bird, S., Chapman, P.J., Firbank, L., Grayson, R., Helgason, T., Holden, J., Lappage, M., Leake, J. & Hodson, M.E. (2021). Arable fields as potential reservoirs of biodiversity: Earthworm populations increase in new leys. *Science of The Total Environment*, 789, 147880. https://doi.org/10.1016/j.scitotenv.2021.147880
Ramankutty, N., Mehrabi, Z., Waha, K., Jarvis, L., Kremen, C., Herrero, M. & Rieseberg, L.H. (2018). Trends in Global Agricultural Land Use: Implications for Environmental Health and Food Security. *Annual Review of Plant Biology*, 69 (1), 789–815. https://doi.org/10.1146/annurev-arplant-042817-040256
Repar, N., Jan, P., Dux, D., Nemecek, T. & Doluschitz, R. (2017). Implementing farm-level environmental sustainability in environmental performance indicators: A

combined global-local approach. *Journal of Cleaner Production*, 140, 692–704. https://doi.org/10.1016/j.jclepro.2016.07.022

Resare Sahlin, K., Carolus, J., von Greyerz, K., Ekqvist, I. & Röös, E. (2022). Delivering "less but better" meat in practice—a case study of a farm in agroecological transition. *Agronomy for Sustainable Development*, 42 (2), 24. https://doi.org/10.1007/s13593-021-00737-5

Ricciardi, V., Ramankutty, N., Mehrabi, Z., Jarvis, L. & Chookolingo, B. (2018). How much of the world's food do smallholders produce? *Global Food Security*, 17, 64–72. https://doi.org/10.1016/j.gfs.2018.05.002

Ritchie, H. (2021). *If the world adopted a plant-based diet we would reduce global agricultural land use from 4 to 1 billion hectares*. *Our World in Data*. https://ourworldindata.org/land-use-diets [2024-01-04]

Ritchie, H. & Roser, M. (2023). Is our appetite for soy driving deforestation in the Amazon? *Our World in Data*,. https://ourworldindata.org/soy [2024-01-04]

Röös, E., Bajželj, B., Smith, P., Patel, M., Little, D. & Garnett, T. (2017). Greedy or needy? Land use and climate impacts of food in 2050 under different livestock futures. *Global Environmental Change*, 47, 1–12. https://doi.org/10.1016/j.gloenvcha.2017.09.001

Röös, E., Bajzelj, B., Weil, C., Andersson, E., Bossio, D. & Gordon, L.J. (2021). Moving beyond organic – A food system approach to assessing sustainable and resilient farming. *Global Food Security*, 28, 100487. https://doi.org/10.1016/j.gfs.2020.100487

Röös, E., Carlsson, G., Ferawati, F., Hefni, M., Stephan, A., Tidåker, P. & Witthöft, C. (2020). Less meat, more legumes: prospects and challenges in the transition toward sustainable diets in Sweden. *Renewable Agriculture and Food Systems*, 35 (2), 192–205. https://doi.org/10.1017/S1742170518000443

Röös, E., Mie, A., Wivstad, M., Salomon, E., Johansson, B., Gunnarsson, S., Wallenbeck, A., Hoffmann, R., Nilsson, U., Sundberg, C. & Watson, C.A. (2018). Risks and opportunities of increasing yields in organic farming. A review. *Agronomy for Sustainable Development*, 38 (2), 14. https://doi.org/10.1007/s13593-018-0489-3

Rosa-Schleich, J., Loos, J., Mußhoff, O. & Tscharntke, T. (2019). Ecological-economic trade-offs of Diversified Farming Systems – A review. *Ecological Economics*, 160, 251–263. https://doi.org/10.1016/j.ecolecon.2019.03.002

Samberg, L.H., Gerber, J.S., Ramankutty, N., Herrero, M. & West, P.C. (2016). Subnational distribution of average farm size and smallholder contributions to global food production. *Environmental Research Letters*, 11 (12), 124010. https://doi.org/10.1088/1748-9326/11/12/124010

SCB (2023). *Markanvändningen i Sverige 2020*. *Statistiska Centralbyrån*. https://www.statistikdatabasen.scb.se/sq/144097 [2024-01-04]

Schader, C., Grenz, J., Meier, M.S. & Stolze, M. (2014). Scope and precision of sustainability assessment approaches to food systems. *Ecology and Society*, 19 (3). https://www.jstor.org/stable/26269618 [2024-01-05]

Shepon, A., Eshel, G., Noor, E. & Milo, R. (2018). The opportunity cost of animal based diets exceeds all food losses. *Proceedings of the National Academy of Sciences of the United States of America*, 115 (15), 3804–3809

Silver, W.L., Perez, T., Mayer, A. & Jones, A.R. (2021). The role of soil in the contribution of food and feed. *Philosophical Transactions of the Royal Society B:*

Biological Sciences, 376 (1834), 20200181. https://doi.org/10.1098/rstb.2020.0181

Sjaunja, L.O., Baevre, L., Junkkarinen, L. & Pedersen, J. (1990). A Nordic proposal for an energy corrected milk (ECM) formula. *27th Session of ICRPMA*, 156–157

Sonesson, U., Davis, J., Hallström, E. & Woodhouse, A. (2019). Dietary-dependent nutrient quality indexes as a complementary functional unit in LCA: A feasible option? *Journal of Cleaner Production*, 211, 620–627. https://doi.org/10.1016/j.jclepro.2018.11.171

Sonesson, U. & Östergren, K. (2019). *Underlag till Färdplan för en väsentligt mer hållbar livsmedelskedja*. RISE Research Institutes of Sweden. https://urn.kb.se/resolve?urn=urn:nbn:se:ri:diva-38872 [2024-01-04]

Soulé, E., Michonneau, P., Michel, N. & Bockstaller, C. (2021). Environmental sustainability assessment in agricultural systems: A conceptual and methodological review. *Journal of Cleaner Production*, 325, 129291. https://doi.org/10.1016/j.jclepro.2021.129291

Springmann, M., Clark, M., Mason-D'Croz, D., Wiebe, K., Bodirsky, B.L., Lassaletta, L., de Vries, W., Vermeulen, S.J., Herrero, M., Carlson, K.M., Jonell, M., Troell, M., DeClerck, F., Gordon, L.J., Zurayk, R., Scarborough, P., Rayner, M., Loken, B., Fanzo, J., Godfray, H.C.J., Tilman, D., Rockström, J. & Willett, W. (2018). Options for keeping the food system within environmental limits. *Nature*, 562 (7728), 519–525. https://doi.org/10.1038/s41586-018-0594-0

Statistics Sweden (2023). *Land use in Sweden 2020.* (Land Use in Sweden 2020 2023:1.). https://www.scb.se/contentassets/3c2419244f5043429cf2a0b1f6a57efd/mi0803_2020a01_sm_mi03br2301.pdf [2024-01-04]

Steinfeld, H., Gerber, P., Wassenaar, T.D., Castel, V., Rosales M., M. & Haan, C. de (2006). *Livestock's long shadow: environmental issues and options*. Food and Agriculture Organization of the United Nations. https://www.fao.org/3/a0701e/a0701e.pdf

Strid, I., Fernqvist, F., Thörning, R. & Andrae, L. (2023). *Livsmedelsförluster av potatis vid odling, skörd, lagring och packeri*. (2023:2). The Swedish Agricultural Agency. https://www2.jordbruksverket.se/download/18.701c6806185e7b2d8d833a31/1674660274176/ra23_2.pdf [2023-05-10]

Swedish Food Agency (2023). *The Swedish Food Agency food database, version 2023-06-13*. https://soknaringsinnehall.livsmedelsverket.se/ [2024-01-06]

Tamburini, G., Bommarco, R., Wanger, T.C., Kremen, C., van der Heijden, M.G.A., Liebman, M. & Hallin, S. (2020). Agricultural diversification promotes multiple ecosystem services without compromising yield. *Science Advances*, 6 (45), eaba1715. https://doi.org/10.1126/sciadv.aba1715

The Swedish Board of Agriculture (2004). Odlingsbeskrivningar Trindsäd. The Swedish Board of Agriculture. http://www2.jordbruksverket.se/webdav/files/SJV/trycksaker/Pdf_ovrigt/p8_15-2.pdf [2023-05-10]

The Swedish Board of Agriculture (2020a). *Agricultural companies' operating direction by county*. The Swedish Agricultural Agency's statistical database. https://statistik.sjv.se/PXWeb/pxweb/sv/Jordbruksverkets%20statistikdatabas/?rxid=5adf4929-f548-4f27-9bc9-78e127837625 [2024-01-05]

The Swedish Board of Agriculture (2020b). *Dairy production year 2020: Average content of fat and protein in milk delivered to dairies*. https://statistik.sjv.se/PXWeb/sq/46c1e72b-e997-4c20-8163-df5c46550fbc [2024-01-06]

The Swedish Board of Agriculture (2020c). *Livsmedelskonsumtion och näringsinnehåll. Uppgifter till och med 2019*. (JO1301). The Swedish Board of Agriculture. https://jordbruksverket.se/om-jordbruksverket/jordbruksverkets-officiella-statistik/jordbruksverkets-statistikrapporter/statistik/2020-12-09-livsmedelskonsumtion-och-naringsinnehall.--uppgifter-till-och-med-2019 [2023-05-13]

The Swedish Board of Agriculture (2020d). *Total yield (tones) and hectar yields (kg/ha) in Sweden, by crop, in 2020*. https://jordbruksverket.se/om-jordbruksverket/jordbruksverkets-officiella-statistik/statistikdatabasen

The Swedish Board of Agriculture (2020e). *Use of agricultural land in 2020, preliminary statistics.* (JO 10 SM 2001). SCB. https://www.scb.se/contentassets/2e011f0876324b1a918c1e70b5ef088a/jo0104_2020a01_sm_jo10sm2001.pdf [2024-01-04]

The Swedish Board of Agriculture (2021a). *Långa tidsserier – Basstatistik om jordbruket åren 1866–2020*. https://jordbruksverket.se/om-jordbruksverket/jordbruksverkets-officiella-statistik/jordbruksverkets-statistikrapporter/statistik/2021-08-16-langa-tidsserier---basstatistik-om-jordbruket-aren-1866-2020 [2024-01-05]

The Swedish Board of Agriculture (2021b). *Utrikeshandel årssammanställning 2020*. https://jordbruksverket.se/download/18.1155bdf117880dfd1477c84b/1703165733476/Utrikeshandel-arssammanstallning-2020-tga.pdf [2024-01-29]

The Swedish Board of Agriculture (2022). Cereal balance sheet for 2020/2021. [Internal material]

The Swedish Board of Agriculture (2023a). *Jordbruksstatistisk sammanställning 2023*. (JO1901). https://jordbruksverket.se/om-jordbruksverket/jordbruksverkets-officiella-statistik/jordbruksverkets-statistikrapporter/statistik/2023-08-10-jordbruksstatistisk---sammanstallning-2023 [2024-01-04]

The Swedish Board of Agriculture (2023b). *På tal om jordbruk och fiske - fördjupning om aktuella frågor. Hur stor andel av svensk matkonsumtion skulle kunna täckas av livsmedel producerade i Sverige?* https://jordbruksverket.se/download/18.7c9e97891882252c14c3cdd2/1684340659369/Pa-tal-om-jordbruk-och-fiske-maj-2023-tga.pdf [2023-07-04]

The Swedish Board of Agriculture (2023c). *Total consumption of goods. Years 1960-2022.* The Swedish Agricultural Agency's statistical database. https://statistik.jordbruksverket.se/PXWeb/pxweb/sv/Jordbruksverkets%20statistikdatabas/Jordbruksverkets%20statistikdatabas__Konsumtion%20av%20livsmedel/JO1301K2.px/table/tableViewLayout1/ [2024-01-05]

The World Bank (2021). *World Bank Open Data - Arable land (hectares per person)*. *World Bank Open Data*. https://data.worldbank.org [2024-01-07]

United Nations, D. of E. and S.A., Population Divison (2022). *World Population Prospects 2022: Summary of results.* https://population.un.org/wpp/Publications/ [2024-01-04]

United Nations Department of Economic and Social Affairs (2023). *The Sustainable Development Goals Report 2023: Special Edition*. United Nations. https://doi.org/10.18356/9789210024914

United Nations Environment Programme (2012). *The Critical Role of Global Food Consumption Patterns in Achieving Sustainable Food Systems and Food for All. A UNEP Discussion Paper*. https://wedocs.unep.org/xmlui/handle/20.500.11822/25186 [2024-01-04]

United Nations Environmental Programme (2021). *UNEP Food Waste Index Report 2021. UNEP - UN Environment Programme*. http://www.unep.org/resources/report/unep-food-waste-index-report-2021 [2024-01-04]

Urruty, N., Deveaud, T., Guyomard, H. & Boiffin, J. (2016). Impacts of agricultural land use changes on pesticide use in French agriculture. *European Journal of Agronomy*, 80, 113–123. https://doi.org/10.1016/j.eja.2016.07.004

USDA (2019). *FoodData Central - Soy meal, defatted, raw.* https://fdc.nal.usda.gov/fdc-app.html#/food-details/172445/nutrients [2024-01-06]

Viana, C.M., Freire, D., Abrantes, P., Rocha, J. & Pereira, P. (2022). Agricultural land systems importance for supporting food security and sustainable development goals: A systematic review. *Science of The Total Environment*, 806, 150718. https://doi.org/10.1016/j.scitotenv.2021.150718

Wang, X. (2022). Managing Land Carrying Capacity: Key to Achieving Sustainable Production Systems for Food Security. *Land*, 11 (4), 484. https://doi.org/10.3390/land11040484

Webb, P., Benton, T.G., Beddington, J., Flynn, D., Kelly, N.M. & Thomas, S.M. (2020). The urgency of food system transformation is now irrefutable. *Nature Food*, 1 (10), 584–585. https://doi.org/10.1038/s43016-020-00161-0

Willett, W., Rockström, J., Loken, B., Springmann, M., Lang, T., Vermeulen, S., Garnett, T., Tilman, D., DeClerck, F., Wood, A., Jonell, M., Clark, M., Gordon, L.J., Fanzo, J., Hawkes, C., Zurayk, R., Rivera, J.A., Vries, W.D., Sibanda, L.M., Afshin, A., Chaudhary, A., Herrero, M., Agustina, R., Branca, F., Lartey, A., Fan, S., Crona, B., Fox, E., Bignet, V., Troell, M., Lindahl, T., Singh, S., Cornell, S.E., Reddy, K.S., Narain, S., Nishtar, S. & Murray, C.J.L. (2019). Food in the Anthropocene: the EAT–Lancet Commission on healthy diets from sustainable food systems. *The Lancet*, 393 (10170), 447–492. https://doi.org/10.1016/S0140-6736(18)31788-4

Williams, D.R., Clark, M., Buchanan, G.M., Ficetola, G.F., Rondinini, C. & Tilman, D. (2021). Proactive conservation to prevent habitat losses to agricultural expansion. *Nature Sustainability*, 4 (4), 314–322. https://doi.org/10.1038/s41893-020-00656-5

Wyngaarden, S., Lightburn, K. & Martin, R. (2019). Optimizing livestock feed provision to improve the efficiency of the agri-food system. *Agroecology and Sustainable Food Systems*, 44, 1–27. https://doi.org/10.1080/21683565.2019.1633455

Xu, X., Sharma, P., Shu, S., Lin, T.-S., Ciais, P., Tubiello, F.N., Smith, P., Campbell, N. & Jain, A.K. (2021). Global greenhouse gas emissions from animal-based foods are twice those of plant-based foods. *Nature Food*, 2 (9), 724–732. https://doi.org/10.1038/s43016-021-00358-x

Zabel, F., Delzeit, R., Schneider, J.M., Seppelt, R., Mauser, W. & Václavík, T. (2019). Global impacts of future cropland expansion and intensification on agricultural markets and biodiversity. *Nature Communications*, 10 (1), 2844. https://doi.org/10.1038/s41467-019-10775-z

Zabel, F., Putzenlechner, B. & Mauser, W. (2014). Global Agricultural Land Resources – A High Resolution Suitability Evaluation and Its Perspectives until 2100 under Climate Change Conditions. *PLOS ONE*, 9 (9), e107522. https://doi.org/10.1371/journal.pone.0107522

Popular science summary

Traditionally, farm productivity have been measured by how much the farm can produce per hectare of land. But this measure doesn't tell the full story. A large part of the crops grown aren't eaten by people but are used as animal feed or converted into fuel. This traditional metric also overlooks the nutrient content of the crops produced. So, is there a better way to measure agricultural productivity? This thesis explores an alternative approach: calculating how many people can be nourished with the daily required calories, protein, and fat from each hectare of cropland. To investigate the applicability of this indicator at different scale in the food system, this method was applied to both the agricultural production of nine diverse farms in Sweden and to Sweden as a whole.

The study found that Swedish food production contributes enough calories and protein to feed the country's population, with the capacity to feed 5 people per hectare. This number align with the global average requirement of food production per hectare. Interestingly, if all edible crops were directly consumed by humans, instead of being used as animal feed or for fuel, twice as many people could be fed. However, currently, less than half of the edible calories and proteins produced in Sweden are used for human consumption. ´

This approach to measuring productivity proved more effective at the national level than at the farm level. The indicator can be useful as a tool for a farmer who want to get a better understanding of how different agricultural practices impact the farm production in terms of food supply and to track changes in performance over time on an individual farm. However, the method is less suitable for comparing performance across farms, as different geographical areas have various conditions for agricultural production.

At a country scale, the indicator offers valuable insights into agricultural productivity and the food supply capacity. This information can be useful for evaluating land use efficiency and identifying potential actions to enhance national food supply. By adopting this new perspective, we gain a clearer picture of a country or region's food production potential, guiding efforts to enhance national food supply and illuminating the impact of different production decisions at both farm and national levels. However, to get an accurate understanding of food supply efficiency and sustainability, the indicator should be integrated with other measures that look at environmental, economic, and social factors. This comprehensive view is important to navigating the complexities of sustainable farming and making informed choices for our future food supply.

Acknowledgements

I extend my deepest gratitude to Alexander for his support and for giving me time to focus on my writing amidst our daily challenges and busy family life. Without his care and patience, this essay would not have been possible. I also want to thank Elin for her valuable guidance and helpful advice during the research process.

Appendix 1

Reference data for grain legumes
Total production of lupine beans, brown beans and other grain legumes that is not presented in the national official statistics, was calculated based on cultivation area and average yield drawn from several sources.

Table 18. The total production of lupine beans, brown beans and other legumes calculated from cultivated area and average yield taken from several sources.

	Cultivation area (ha)	Average hectare yields (kg/ha)	Total production (tonnes)
Lupine beans	197[1]	3500[2]	690
Brown beans	765[1]	1800[3]	1377
Other peas	4849[1]	4000[4]	19 396
Other common beans	174	1800[5]	315

1. (Karlsson 2021)
2. (Möller & Sjöberg 2019)
3. (Fogelberg 2008)
4. (Carlsson 2018)
5. Assuming same yield as for brown beans.

Information on area of use for exported cereals
The area of use for the exported cereals, presented in table 19, was based on the estimated percentage distribution between feed and food for each crop in a typical year, provided by Per Gerhardsson at Lanmätnnen[3]. The rye export varies greatly between different years depending on the total quantity of rye produced in Sweden. In years when large quantity of rye is exported, most of the rye exports are dedicated for whiskey production, according to Per Gerhardsson. Since the quantity of rye exported in 2020 was almost seven times larger than in 2021 (The Swedish Board of Agriculture 2022), it was assumed that the rye exports in 2020 were exclusively intended for whiskey production and thus do not contribute any macronutrients to the calculations. Hard liquor is not included as food in the calculation, hence the exported rye were excluded from the calculations. Further, barley exported for human consumption is mainly used as beer brew malt, according to Per Gerhardsson.

The total exported quantity for each cereal in year 2020 (presented in table 19) is based on net export shares taken from the cereal balance sheet for 20/21 (The Swedish Board of Agriculture 2022) multiplied by the total production of each crop 2020 (The Swedish Board of Agriculture 2020d).

[3] Per Gerhardsson, Purchasing manager for cereals at Lantmännen, interviewed by telephone 230409.

Table 19. Total exported quantity of cereals (in tonnes) and percentage of the export distributed by food and feed use

	Total exported quantity (tonnes)	Share exported for human consumption	Share exported for feed use
Wheat	862485	80%	20%
Rye	48055	100% (whiskey)[1]	0%
Barley	384067	90%	10%
Oat	221399	98%	2%

1. Rye used for whiskey production is not included in the proportion used for human consumption presented in Table 6.

Formula used for calculating the edible content of fodder maize

The utilization factor for green fodder maize presented in Table 3 represent an estimate of the edible content in the production of green fodder maize, based on the average hectare yields reported in the official agricultural statistics (The Swedish Board of Agriculture 2020d). Since yields of grain maize and green maize is reported with different water content in the agricultural statistics, the average hectare yield was recalculated into dry matter for both crops.

Unlike green fodder maize, maize kernels are removed in the harvest of grain maize. Therefore, the edible content of the total production of green maize was calculated according to the following formula:

$$UF_{Green\,maize} = Y_{Grain\,maize}/Y_{Green\ maize}$$

Where:

$Y_{Grain\,maize}$ = Average yields of grain maize, as kg dry matter per hectare

$Y_{Green\ maize}$ = Average hectare yield og green maize, as kg dry matter per hectare

$UF_{Green\,maize}$ = Edible content in the total production of green fodder maize.

Appendix 2

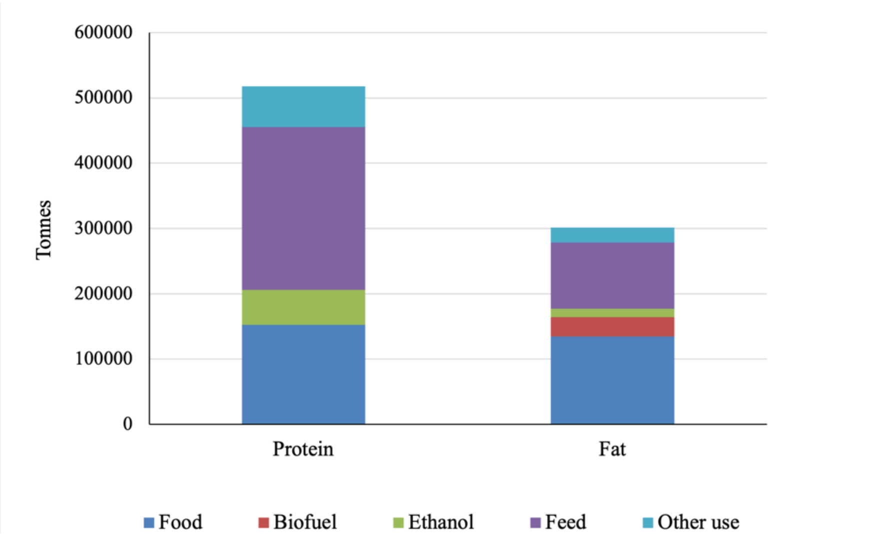

Figure 6. Quantity of edible fat and protein embedded in the total crop production in Sweden 2020, distributed by area of use.

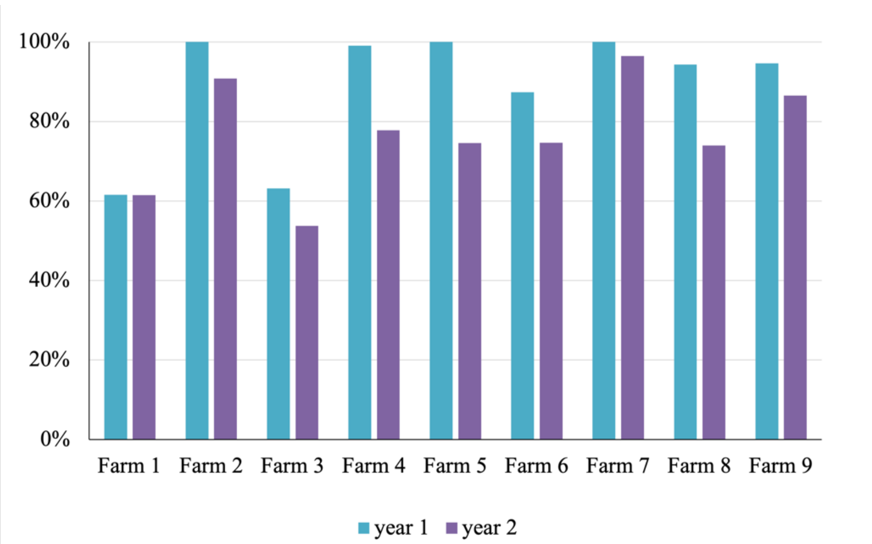

Figure 7. Proportion of cropland used for feed production on the case farms.

Publishing and archiving

Approved students' theses at SLU are published electronically. As a student, you have the copyright to your own work and need to approve the electronic publishing. If you check the box for YES, the full text (pdf file) and metadata will be visible and searchable online. If you check the box for NO, only the metadata and the abstract will be visible and searchable online. Nevertheless, when the document is uploaded it will still be archived as a digital file. If you are more than one author, the checked box will be applied to all authors. You will find a link to SLU's publishing agreement here:

- https://libanswers.slu.se/en/faq/228318.

☒ YES, I/we hereby give permission to publish the present thesis in accordance with the SLU agreement regarding the transfer of the right to publish a work.

☐ NO, I/we do not give permission to publish the present work. The work will still be archived and its metadata and abstract will be visible and searchable.