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Costs, Environmental Gains, and Potential for National Self-Sufficiency with Ecological Recycling Agriculture in Sweden—Calculations Based on Case Studies of 30 Farms

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ABSTRACT

The need for reduced climate impact in agriculture and an increased interest in self-sufficient food production in Sweden serves as the main background for the study. The study examined if conversion of Swedish agriculture following principles of Ecological Recycling Agriculture (ERA) could be a realistic alternative in addressing both those issues, and what the resulting price for that food would be. Case studies of 30 ERA farms were performed. These farms show substantially lower climate impact compared to the national average, through 75% lower commodity purchases and twice the amount of carbon sequestration in soil thanks to more ley cropping. An alternative diet including less meat and more grain, vegetables and dairy products was defined. Two different methods were used for matching production with consumption. The results are presented in scenarios where different combinations of the farms' staple food production are upscaled for a Swedish population of 10.5 million inhabitants. Results are presented in kg produced, hectares of arable land, CO_2 equivalents, kg of surplus N, and production costs per capita. It is shown that an 80–95% reduction in climate impact is possible, and that it is within range for Sweden to become self-sufficient in staple foods based on the available acreage of arable land by adopting Ecological Recycling Agricultural principles in a manner similar to the studied farms. However, diets need to change in a lacto-vegetarian direction. Production costs would be slightly higher for most products, but consumers' food expenses could be lower if they also change their diet. Possible political instruments are proposed to realize these scenarios.

Key words: climate impact, acreage need, nutrient balance, self-sufficiency, production costs, food consumption, ley cropping, carbon sequestration, organic, agriculture

INTRODUCTION

This study will be a follow-up study on the paper Sustainable Agriculture and Self-Sufficiency in Sweden—Calculation of Climate Impact and Acreage Need Based on Ecological Recycling Agriculture Farms published in 2022 (Granstedt & Thomsson, 2022). The present study includes additional farms, data from several more years, and, above all, economical studies. The economic consequences and possibilities for conversion are discussed as well as possible political instruments to realise this.

Food production contributes to global environmental changes and can be linked to virtually all major environmental problems, mainly decreasing biodiversity, climate impact, eutrophication and toxins in the environment. Globally, the food system accounts for 21–37% of climate emissions, the largest share of which occurs during production (Folkhälsomyndigheten, 2024), as well as being the largest contributor to loss of biodiversity. Agricultural production also contributes to eutrophication of seas, lakes and waterways, as well as an increased need for diversity in the agricultural landscape in certain parts of the country.

In Sweden, food accounts for about 25% of the total household climate impact. Of this, 64% is emissions from imported food and commodities such as imported and transported fodder, fertilisers, chemicals, and fuels used in the food system. If factors, now omitted, like changed land use, deforestation and soil losses are also considered, the climate impact of our food stands for about 40% (Cederberg et al., 2019).

This study focuses on reduced climate impact, production capacity, self-reliance in the food system and the economic and political possibilities for change in Sweden. The resulting scenarios for Sweden are generally characterised by their usefulness, when slightly modified, being able to become models for other countries and other circumstances. The UN climate conference in Paris 2015 (COP21) states that the limit of increase in global temperature preferably should be only 1.5 °C above pre-industrial levels. This UN climate conference was followed by Glasgow 2021 (COP26, 2021), and the most recent in Dubai 2023 (COP28) established guidelines for the need to decrease emissions of greenhouse gases to safeguard against the rise in global temperature.

The European Climate Law lays down directives for Europe's economy and society to become climate-neutral by 2050, setting the intermediate target of reducing net greenhouse gas emissions by at least 55% of 1990 levels by 2030. Sweden's Climate Act and Climate Policy Framework (Naturvårdsverket, 2025) state that Sweden should have zero net greenhouse gas emissions by 2045 at the latest. Thus, assuming equal distribution between sectors, the household food climate impact needs to be reduced by a factor of 10 within 20 years.

Furthermore, we wish to remind ourselves that the photosynthesis is the only single process which captures CO_2 and builds carbohydrates; everything else involves consumption and break–down thus releasing CO_2. Until the 1960s, Sweden was largely self-sufficient in its food supply. However, at that time, dependence on imported commodities was already much greater than earlier in the century when most of Swedish agriculture was driven by local renewable resources. Later, food habits changed to a doubled consumption of white meat (mainly chicken), and tripled vegetable consumption. The increased consumption of white meat is troublesome, from a systems perspective, since pigs, hens and chickens in today's industrialised system largely with grain and proteins that could be used for human food. The consumption of meat from grazing animals, beef and lamb, is at the same level, but the domestic production nowadays is only 54% for beef and 28% for lamb (Linderholm, 2018) and even lower for some horticultural products like salad and tomatoes. Even domestic products are indirectly imported to some extent in the sense that some of the fodder concentrate is imported, and this from mainly South Americana countries where the agricultural sector often results deforestation and soil degradation.

Agriculture practices developed in two directions during the first part of the 20th century (Formas, 2010). The Haber-Bosch method of producing mineral fertilizer nitrogen using fossil energy resulted in an agriculture no longer dependent on pasture cultivation with nitrogen-fixing legumes and forage-based animal husbandry that could transform pasture feed into animal manure. This resulted in:

- Entire regions of specialised mineral fertiliser-dependent cereal crop farms. The lack of animal husbandry and pasture cultivation has led to decreasing humus levels, lower organic carbon and deteriorating fertility properties, increasing dependence on chemical pesticides and loss of biodiversity in the cereal-dominated plain areas in the southern parts of Sweden (Jordbruksverket, 2019a).

Animal husbandry became concentrated in other regions, resulting in farms with high animal density dependent on purchased feed. An increasing number of animals in relation to individual farm's cultivated area resulted in a surplus of plant nutrients in the form of animal manure (Jordbruksverket, 2020). This nitrogen surplus has led to increased eutrophication of lakes, waterways and seas, and emissions of the greenhouse gas, nitrous oxide. The eutrophication of the Baltic Sea with fish death and dying seabeds is an example of the surplus of nitrogen and phosphorus. Attempts have been made to reduce the harmful effects by legislation concerning permitted animal density and rules for spreading stable manure. A study into the solution to these problems through an ecological cycle-based agriculture was carried out within the framework of the Baltic Sea project BERAS (Baltic Ecological Recycling Agriculture and Society) (Granstedt et al., 2008; Granstedt & Seuri, 2013).

Clarifications

- Following the Nordic guidelines, we use the term ecological as a synonym for organic,
- CO_2e is the used abbreviation for CO_2 equivalents (carbon dioxide equivalents), which equals GWP100 (100-year Global Warming Potential),
- ERA (e.g., ERA farms) is an abbreviation of Ecological Recycling Agriculture (defined below).

Hypothesis, Aim and Goal

The hypothesis is that by converting the Swedish agriculture following the principles of Ecological Recycling Agriculture (ERA), Sweden could become more or less self-sufficient in staple foods, and, at the same time, fulfil its climate goals.

The aim was to assess production and consumption patterns and investigate if a hypothetical conversion of Swedish agriculture similarly to the ERA case study farms could:

- substantially decrease climate impact,
- produce the staple food needs of the Swedish population,
- produce food for the population at same

cost.

The main goal was to:

- create a numerical hypothetical conversion of the agricultural system following ERA principles based on what the studied farms produce today,
- determine the amount of domestically produced after such a conversion, and, if we assume self-sufficiency, how that corresponds to the recommendations for lowered meat consumption suggested in the New Nordic Diet (Saxe et al., 2013) and the EAT–Lancet Commission (Willett et al., 2019),
- determine what other changes to our diet such a conversion requires if we assume Sweden to be more or less self-sufficient in staple food production,
- determine the climate impact of the production and consumption of staple foods in Sweden after such a conversion, compared to today's system,
- determine the cost of food produced in a converted agricultural system, compared to today's system.

Contribution

In contrast to on-going agricultural development with a conventional industrialised high-input system, the study presents an alternative picture of what sustainable food production could look like.

1. The focus is on Ecological (organic) Recycling Agriculture (ERA). It is a self-sufficient, productive agriculture that imports none or very little manure/fertilisers and animal fodder, uses no chemical pesticides, and produces more than one product category of food. The nutrients needed are supplied by legume–grass leys on a large part of the acreage, in combination with well-adapted animal stock and crop rotation.
2. 30 ERA farms in Sweden are documented, providing the data used for the calculations.
3. Carbon sequestration in soil is included in the climate impact calculations.
4. Food production and demand are matched for Sweden in scenarios with an alternative, more lacto-vegetarian, diet (staple foods only) for the Swedish population. Results for climate impact, nutrient balance, acreage needs, and kg of food produced/consumed are presented in different categories with production costs.
5. Policy measures for a transition to ERA agriculture are proposed and analysed.

MATERIALS AND METHODS

Ecological Recycling Agriculture

Ecological Recycling Agriculture (ERA) is based on the ecological principles of self-sustaining systems. These principles were developed by comparing on-farm studies focused on yearly nutrient flows at a macrolevel (crop and animals) and in the soils included in crop rotations over several years. Biodynamic farms with integrated crop and milk production producing their own fodder, dominated by coarse fodder, were compared to conventional specialised animal production farms with a high input of purchased fodder, and specialised conventional farms with crop production based only on artificial fertilisers in central and south Sweden (Granstedt, 1992). The concept of ERA was finally defined in the EU-financed project BERAS (Baltic Ecological Agriculture and Society) 2003–2006 (Granstedt et al., 2008) and in BERAS Implementation (Granstedt & Seuri, 2013). In short, ERA farms have:

- Diversified crop rotations with a large portion of perennial, deep-rooted, humus-building (C-sequestering), and nitrogen-fixating leys with legumes and grass.
- Integrated animal husbandry (mostly grazing animals transforming grass to protein and energy-rich meat and milk), adapted to the farm's own fodder production and thus more or less self-sufficient on-farm or on farms in close collaboration with crops and animal manure.
- Manure management and recirculation with least possible loss of organic matter and plant nutrients. The biodynamic farms make composts of straw and manure.
- Focus on soil health and humus building, with the use of biodynamic additives on the biodynamic farms.

The Research Steps

The research has been carried out in several steps in order to present results for a more or less self-sustained domestic staple food production in Sweden delivering enough food for a population of 10.5 million inhabitants. Details are presented in the following chapters. The steps performed were:

- Data collection on 30 Swedish ERA farms and statistics from average agriculture as provided by Statistics Sweden (2020).

- Calculation of acreage needs, climate impact, and nutrient balance per farm and per hectare.
- Definition of two target diets.
- Manual matching of production and consumption in several scenarios, study farms clustered into five production groups.
- Economic matching of production and consumption, the most cost-efficient farms are represented in the scenario.
- Possible policy measures are suggested, impact on production and consumption is calculated in a policy scenario.

Case Study Farms

Farms following ERA principles were sought all over the country. The most important priorities were to find ecological farms that are relatively self-sufficient in manure/fertilisers and animal fodder, as well as having a diversified production comprising both human food cropping and an animal husbandry well-adapted to the available acreage. External fodder purchases were set to a maximum of 15–20% of the livestock's protein needs. Many of the farms bought nothing but mineral fodder for their animals. Secondly, we made a concerted effort to find farms in all production regions of the country (Figure 1). Both the Swedish agricultural production and the population are situated largely in the southern third of the country, and this is also true for the study farms. The fertile southern plain is under-represented among the study farms, but so are the very northern agricultural districts, which is why we estimate the farm selection to be fairly representative for Swedish agriculture in terms of geography and production conditions.
Basic farm and production data were collected from 30 ERA farms of different sizes and production types in different parts of the country for the years 2019 to 2022 (Table 1). The data collected was acreage of arable land and natural pastures, crops, animals, manure systems, commodity purchases, and product sales, working hours, and number of employees. Statistical data was used for Swedish agriculture and agricultural production in general.
Solmarka farm, which has the largest production of eggs, poultry, and vegetables, falls within the limits for fodder purchase, but we adjusted the in-data by excluding the imported hen fodder used, about half of the total amount protein, in order to strengthen our focus on self-sufficiency. We estimate that this exclusion reduces egg production by 60%, meat production by 50%, and vegetable production by 20%. In the economic optimisation study both settings of Solmarka were included.

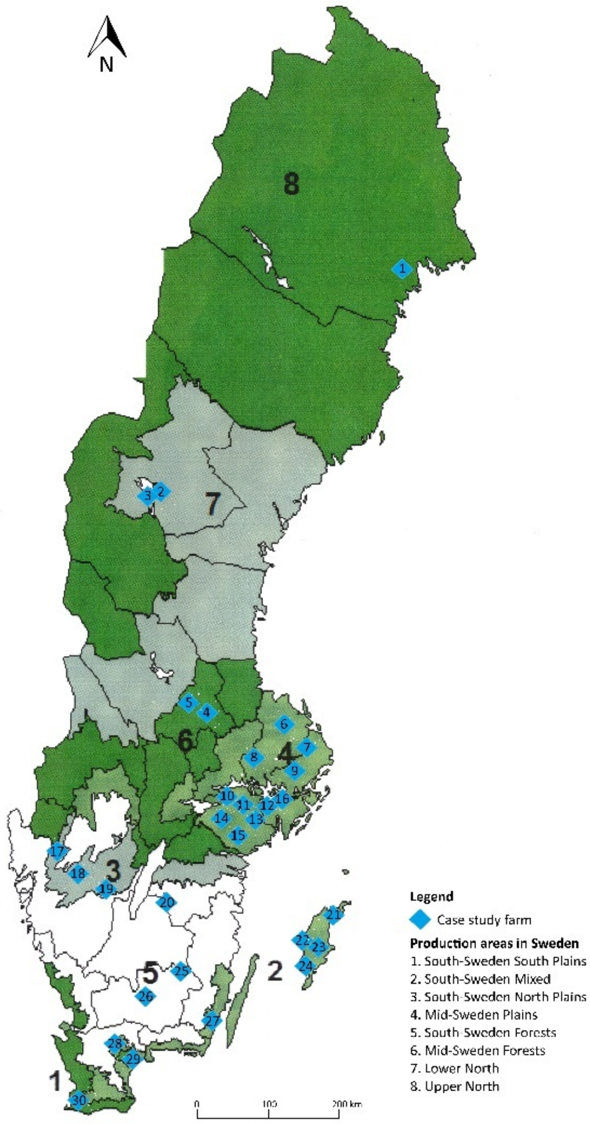


Fig. 1. Location of the study farms marked with numbered dots. Numbers correspond to the order in Table 1. Production areas in Sweden shown with different colours and large digits. After map from Jordbruksverket.

Table 1. The study farms and Swedish agriculture; years studied, acreage, animal density, location, and production. Average of years studied.

Study farms	Years studied	Arable land ha	Natural pastures ha	Share ley of arable land %	Animal density au [1]/ha	Production region [2]	Farm production [3]
Blomfeltsgården	2020–2022	152	7	73	0.45	8	milk, beef, oilseed
Fjöset	2019–2021	359	250	100	0.31	7	livestock, beef
Trappnäs	2019–2020	12	0	83	0.00	7	vegetables, ley (cropped by Fjöset)
Ingelsbo	2019–2022	60	30	71	0.59	6	milk, beef, bread grain
Björnens Eko	2019–2020	5	1	38	0.48	6	vegetables, pork, ley (cropped by Ingelsbo)
Östanå	2019–2022	50	10	80	0.63	4	milk, beef
Källingby	2019–2021	142	43	58	0.10	4	Beef, grain, beans, oilseeds
Resta	2019–2022	110	80	55	0.41	4	milk, beef, mutton, pork
Åsbergby	2020–2022	225	70	48	0.57	4	pork, beef, grain
Fräkentorp	2020–2022	143	38	71	0.68	4	milk, beef
Uppmälby	2019–2020, 2022	7	3	54	0.45	4	mutton, grain, vegetables, eggs
Nibble	2019–2022	118	16	79	0.48	4	milk, beef, livestock, bread grain, eggs, vegetables
Sörbro	2019–2022	87	15	72	0.37	4	goat milk and meat, beef, grain, eggs, vegetables
Tolfta	2020–2022	92	32	71	0.39	4	horses, beef, hay
Ullberga	2019, 2021–2022	90	33	73	0.48	4	milk, beef, bread grain
Yttereneby-Skilleby	2020–2022	271	30	73	0.34	4	milk, beef, livestock, bread grain, coarse fodder, manure
Gatan	2020–2022	145	5	41	0.49	3	milk, beef, bread grain
Markusgården	2019–2022	87	11	35	0.17	3	beef, heritage cereals, eggs
Bossgården	2022	3	3	78	0.33	3	vegetables, mutton
Älmås	2019	60	71	83	0.67	5	beef, livestock, vegetables
Alvans	2019	80	30	69	0.58	2	milk, beef
Buters	2019–2021	56	0	55	0.00	2	grain, vegetables, ley
Byssegårde	2020–2022	88	22	88	0.38	2	mutton, grain
Sigsarve	2019, 2021–2022	63	10	56	0.22	2	mutton, heritage cereals, lenses
Stig in Mörtelek	2019–2020, 2022	12	40	69	0.53	5	pork, mutton, beef, poultry, eggs, vegetables
Västregård	2019–2022	170	110	60	0.75	5	milk, beef, oilseed
Solmarka	2019–2020, 2022	122	25	49	0.66	2	milk, beef, poultry, eggs, vegetables, cereals
Källunda	2020–2022	64	20	47	0.30	5	pork, beef, heritage cereals, vegetables
Nöbbelöv	2019	230	53	90	0.84	2	milk, beef, bread grain, oilseed, sugar beets, vegetables
Ängavallen	2019, 2022	105	35	57	0.86	1	milk, beef, pork, mutton, grain, vegetables
Swedish agriculture	2019–2022	2,246,979	308,812	38	0.41		

[1] Animal units, 1 au = 1 dairy cow or 6 calves 1–6 months or 3 other cattle > 6 months or 3 sows incl. piglets or 10 slaughter pigs > 10 weeks or 1 horse or 10 sheep or goats > 6 months or 40 sheep or goats < 6 months or 100 hens > 16 weeks or 200 chickens < 16 weeks; [2] 8. Upper North, 7. Lower North, 6. Mid-Sweden Forests, 5. South-Sweden Forests, 4. Ss Mid-Sweden Plains, 3. South-Sweden North Plains, 2. South-Sweden Mixed, 1. South-Sweden South Plains; [3] Vegetables include vegetables, potatoes, and root crops.

Calculation of Climate Impact and Nutrient Surplus

Calculations of greenhouse gas emissions and nutrient balances are carried out following a

model built in Microsoft Excel. The same model was used to calculate average agriculture. The results are presented per farm and per hectare and year.
The calculations follow the method used in the Vera calculation tool distributed by the Swedish official extension service Greppa Näringen (Eng. Focus on Nutrients) administered by the Swedish Board of Agriculture. The calculation model in Vera builds on Berglund et al. (2009). Conversion factors for the greenhouse gases carbon dioxide, methane and nitrous oxide to carbon dioxide equivalents with a 100-year perspective, GWP100, based on IPCC (2014) are used.
Using this calculation method for emissions of methane from animal husbandry, which is a powerful but short-lived greenhouse gas, is questioned and further explored in Discussion, Section "Climate Impact Calculations".
The Vera model does not yet include carbon sequestration in soil. It is, however, gaining interest for mitigating global warming and improving soil fertility and resources-use efficiency (Kätterer & Bolinder, 2024). In order to get the full picture of the climate impact, and since a basic element of ERA farming is increased legume–grass ley cropping, which builds humus (sequestering carbon) in soil, inclusion of carbon sequestration in the calculations is one of the major issues of this study. Thus, here we calculate that the calculated climate impact is the difference between the summarised emissions of greenhouse gases from the use of external resources and the animal husbandry, and the carbon sequestration in soil.
Climate impact and Nutrient balance are calculated for every single study farm following the formulas:

Greenhouse gas emissions *(kg CO_2e)* = [kg $supply_1$ * CO_2e per kg $supply_1$]x + [no $livestock_1$ * kg CH_4 per $livestock_1$ * CO_2e per kg CH_4]y + [Σ kg N (purchased manure + on-farm produced manure + harvest remains) * EF1] * CO_2e per kg N_2O + [Σ kg N (manure released on pastures * EF3) + (manure released on pastures * EF4)] * CO_2e per kg N_2O

Carbon sequestration in soil (*kg CO_2e*) = [(kg dry matter of ley harvest * USH * PartC * $HumC_1$) + (kg dry matter of ley harvest * C/N ratio animal manure * $HumC_2$)] * CO_2/C ratio

Climate impact (*kg CO_2e*) = Greenhous gas emissions − Carbon sequestration in soil

Nutrient balance (*kg N, P, K*) = kg N, P, K in purchased animals, fodder, bedding, seeds, manure + kg N in atmospheric deposition + kg N fixated by legumes − kg N, P, K in exported products

x = purchased supplies (fodder, fertilisers, bedding, seeds, plastics, fuels), per year
y = livestock animals of different kind and age on the farm, average over the year
EF1 = emission factor for mineral and organic fertilisers, harvest remains, mineralised N from mulch = 0.001
EF3 = emission factor for manure released from cattle, pigs and poultry during grazing = 0.002
EF4 = emission factor for manure released from other animals during grazing = 0.001
CO_2e per kg CH_4 = 28
CO_2e per kg N_2O = 265
USH = under-surface harvest in relation to harvest = 0.66
PartC = part C in roots and harvest remains = 0.45
$HumC_1$ = humification coefficient for roots and harvest remains = 0.35
$HumC_2$ = humification coefficient for animal manure = 0.30
C/N ratio animal manure = 0.20
CO_2/C ratio = 3.6667 kg CO_2 per kg C
The background and sources of data are extensively explored in Section "The Research Steps" in Granstedt & Thomsson (2022). We have used the same figures and methods in this study.
Possible carbon sequestration in annual crops and in natural pastures is omitted due to lack of data for Nordic conditions, and it is assumed to be low. On the other hand, we did not include the loss of organic matter in organic soils on either the farms or in Swedish agriculture as a whole.
The single largest contribution to the farms' climate footprint is methane from the animals' digestion of feed. Methane is formed when the animals ruminate and will therefore contribute to the climate impact on farms with cows and other ruminants.

Consumption and Target Diets

A target diet, BERAS 2020, was designed and compared to the average food consumption in 2020 composed from statistics (Table 2). The BERAS 2020 diet is a more lacto-vegetarian focused diet developed from a diet presented in the BERAS project (Granstedt et al., 2005), based

on a consumer survey of 15 environmentally aware families in Järna, Sweden, 2004. Their meat consumption was 80–90% lower than average but very few were strict vegetarians.
The measure used is Total consumption, which is the total consumption of different raw foodstuffs for human consumption (Jordbruksverket, 2021). It includes both raw foodstuffs consumed in households and large-scale catering establishments, and the raw foodstuffs and semi-processed foodstuffs used in the food industry. Raw foodstuffs in imported processed foodstuffs are included, while raw foodstuffs in exported products are excluded. The calculation formula is:

Total consumption = Production of raw foodstuffs + import of raw foodstuffs and raw foodstuff content in processed food − export of raw foodstuffs and raw foodstuff content in processed food

Fish and fruit are omitted in the calculation since their production in Sweden today is on a small scale. Exports of foodstuffs are not included either since the aim was to establish the possibility of self-sufficiency in Sweden.

Table 2. Two alternative diets. Swedish average diet 2020, and BERAS 2020. Source: Swedish Board of Agriculture (total consumption) and BERAS.

Food product category	Target diets [1]		BERAS 2020 in relation to Sweden 2020
	Sweden 2020	BERAS 2020	
	Kg per capita, year		%
Grain products	63.2	90.0	143
Vegetables incl. potatoes	165.3	170.0	103
Milk and dairy products	337.5	400.0	119
Red meat, ruminants	25.1	10.0	40
White meat, monogastrics	52.0	5.0	10
Eggs	14.8	8.0	54
Vegetable oils	13.0	5.0	39
Sugar	36.9	5.0	14
Protein (excl. sugar), g/capita, day	91.8	83.9	91
Energy (excl. sugar), MJ/capita, day	9.2	8.6	94

[1] Target diet is the set total consumption of the different food categories.

Matching Production and Consumption

The last step of the calculations is matching the production and consumption defined in scenarios. This has been performed using two methodologies described below.

Manual Matching Using Farm Production Groups

For Manual matching the study farms were grouped into five production groups. Many of them have diversified production. Thus, the most dominant or the most productive production branch on the farm (kg/ha arable land) determined group placement. The production groups are:

- Grain;
- Dairy;
- Potatoes/garden products;
- Red meat (from grazers);
- White meat (from monogastric animals; pigs and poultry).

The results for each group are given in kg products of each product category, CO_2e, and kg N, P, K balance, all counted per hectare arable land. Natural pastures make only a small contribution to the total food production and were omitted in the calculations.
The production results for each farm group (average hectare yields of the farms in the group) were used to calculate the acreage needed to produce the quantity of foodstuffs defined in the target diets. Matching was performed by dividing the diet value, kg/capita, by the production (kg/ha) from each respective production group (grain/grain, milk/milk, etc.), resulting in ha/capita. Matching begins with the most frequent product categories, Grain and Dairy. Thereafter, the less commonly produced product categories Potatoes/garden crops, Red meat, and White meat are adjusted. Eggs and oilseeds are reported without matching.
Since the farms in all production groups have produce in several product categories, the product quotas will be overfilled, making the addition of an adjustment factor necessary to adjust the contribution of each production group. A step-by-step fine-tuning of the adjustment factor for the different production groups was conducted in an iterated process until the target diet was fulfilled. The results are given in hectares per capita, which multiplied by 10.5 million gives the total demand for arable land in the country for the scenario.
In parallel, the climate impact and the nutrient

balance were calculated in kg CO_2e per capita and in kg N-P-K-balance per capita. Additionally, actual attained production in each product category was reported since exact matching is often not possible.

Cost-minimising Matching Based on Single Farms Using SASM

In the second approach a special version of the Swedish Agricultural Sector Model (SASM) (Naturvårdsverket, 2018) is used to find solutions with a more exact matching and lower costs without using more acreage than available. SASM is usually used to find regional combinations of crops and numbers of livestock. In this study the structure of production data for individual crops and animals has been removed and replaced by production data for the 30 ERA farms. This special version of SASM is used to find cost-minimising mixes of these farms given the restriction that total production should cover the foodstuffs defined in the target diets.
Variants for the 30 farms have been created to obtain complete coverage of all regions in Sweden by recalculating the area requirement according to regional harvest data. When technology from a farm in one region is used in a region with different yields the needs for cropland, tractor hours, diesel and labour are adjusted in proportion to the differences in yields. The area of pasture is not adjusted.

Possible Policy Measures

The matched scenarios described in Section "Consumption and Target Diets" shows the environmental benefits and costs of changing production to ERA farms but not how to reach the goal. Trade is free, consumers buy products at the best price and producers sell to those who pay the most. We cannot close borders but we can introduce policies making it more attractive for farmers to apply ERA technology and for consumers to buy these products. Two policy measures have been analysed:

- Differentiated food VAT. 6% for ecological staple foods and 25% for other foods. Current VAT is 12% for all foodstuffs in Sweden (Verksamt).
- Amended agricultural subsidies (direct subsidies) directing benefits to land farmed consistent with ERA production.

Consumer behaviour is the key to alternative production. If consumers were willing to buy and pay a higher price for local ERA products there would be no need for other policy measures. Some consumers might do so if they were well informed of the environmental benefits but that is not the case for all. Differentiated VAT is one way to influence consumption. Today, the general VAT rate is 25% in Sweden, but VAT is reduced to 12% for food and to 6% for some products and services (Verksamt). Ecological food is more expensive than other food today, but that price difference would be less or disappear completely if the food VAT were differentiated to 25% for conventional food and 6% for ecological basic foodstuffs. It would even become an incentive for consumers to switch to more staple foods in their diet.
Differentiated food VAT makes it possible for farmers to receive a higher price for ecological products without raising the price for consumers. It also provides protection from imported products. Swedish ecological farmers would gain high international competitiveness. That is not the case for other Swedish farmers. However, it does not distinguish products from ERA farms from other ecological products. This could be achieved by changing the system for agricultural subsidies.
Today subsidies are mainly used to compensate agriculture for price reductions that took place in the 1990s, aimed at retaining agricultural land that would otherwise be unprofitable to farm, and also to avoid negative environmental effects from the existing production. None of this would be necessary if the subsidies were directed to ERA production. In its simplest version, it could be an area subsidy of SEK 4000/ha. A differentiation where pastures and climate-positive farms receive double the support compared to arable land on other ERA farms would be even more effective. A support level of SEK 6000/ha for permanent pasture and crops on climate-positive farms, and SEK 3000/ha for other ERA farms makes for the same total direct support as today.
The possible effect of the proposed policy measures has been calculated with the special version of the Swedish Agricultural Sector Model (SASM) described in Section "Cost-minimising Matching Based on Single Farms Using SASM". In these calculations trade is free. The Swedish ERA farms compete with products from other countries produced by today's production methods. Consumers are not expected to be willing to pay more for the Swedish ERA products than for the same imported product. However, they are expected to change the composition of their diet from today's diet with a large amount of pork and chicken to the BERAS diet.

RESULTS

In Section "Case Study Farms" the results for the farm case studies are presented and compared to Swedish average agriculture, for the years 2019–2022, calculated using the same method.
Section "Scenarios for Matching of Production and Consumption" presents the scenario results for the matching of production and consumption, including estimates of environmental impact when imported food is taken into account. Here two methodologies were used: (1) manual matching using production groups, and (2) economic optimisation of single farms using the SASM model.
Section "A Possible Policy Scenario" shows the results from the policy scenario. These results are not presented in the same diagram as the others since they differ methodologically. In the policy scenario, there is no matching of production to consumption. Instead, farmers optimise according to the prices that arise in competition with imported products produced by current production methods. Exports can also occur if profitable.

Case Study Farms

The following subsections present calculated climate impact and plant nutrient balance for the study farms. The results are compared to Swedish agriculture, which is mainly conventional. Results are given per hectare arable land and per hectare total farmland including natural pastures. The latter is derived from official environmental statistics and climate reports.

Climate Impact

The calculated climate impact for the individual study farms is shown in Table 3 (per hectare arable land) and in Table 4 (per hectare total farmland). The Emissions and Net climate impact (NET) are presented in two scenarios in order remove individual farmer's choices in the actual years: Fossil fuels and Renewable fuels, where all farms use either type of fuels. Average Swedish electricity is used in both scenarios. Several of the farms buy renewable electricity but its use is not widespread, and there is little difference since average Swedish electricity is dominated by water and nuclear power.
Figure 2 presents climate impact divided per emission source for the individual farms. Inclusion of the carbon sequestration in soil substantially affects the total result of climate impact from agriculture.
Figure 3 shows the average farm climate impact results per year for average Swedish agriculture 2019–2022, and on the study farms in GWP (Global Warming Potentials), kg CO_2e per hectare arable land. We present the study farm results for actual fuels used, and a scenario where it is assumed that all farms use renewable fuels. The average use of purchased commodities, including fuels, on the study farms is lower compared to the average Swedish agriculture, reflecting in 60% lower emissions, and 77% lower in the scenario with renewable fuels. which was the case on some of the study farms. The emission of methane from ruminant animals, on the other hand, is larger due to the larger number of grazing animals and the average portion of roughage in animal husbandry on the study farms. However, the net climate impact is substantially lower on the study farms, in average 74% and 85% respectively, compared to average Swedish agriculture when the carbon sequestration in soils, which is doubled on the study farms, is included in the calculation. This is due to a larger proportion of legume–grass leys in crop rotations.
Following the GWP* concept, discussed in Section "Climate Impact Calculations", would probably show that the farms are climate positive, i.e., the sequestration is greater than the climate impacting emissions.

Table 3. Climate balance including C sequestration on the study farms and for average agriculture 2019–2022, presented in Fossil and Renewable scenarios, where all farms use either type of fuels, average kg CO_2e per ha *arable land* and year.

Study farms	Carbon sequestration in soil	Scenario fossil fuels		Scenario renewable fuels	
		Emissions	NET	Emissions	NET
Blomfeltsgården	−1658	2383	725	2231	573
Fjöset + Trappnäs	−2666	1793	−873	1506	−1160
Ingelsbo + Björnens Eko	−1936	2930	994	2549	613
Östanå	−2248	2906	658	2571	323
Källingby	−1168	850	−318	687	−482
Resta	−1640	1215	−424	1121	−518
Åsbergby	−1068	2135	1067	1905	837

Fräkentorp	−2436	4528	2092	4225	1789
Uppmälby	−1511	2044	533	1562	51
Nibble	−1720	2176	456	1980	260
Sörbro	−1458	1657	200	1517	60
Tolfta	−1555	1159	−396	1028	−527
Ullberga	−2218	2167	−51	1943	−275
Yttereneby-Skilleby	−1923	1821	−102	1598	−324
Gatan	−1107	2572	1465	2321	1214
Markusgården	−697	1006	309	855	159
Bossgården	−770	1800	1030	1691	921
Älmås	−2344	4349	2004	3900	1555
Alvans	−1672	3263	1591	3025	1353
Buters	−1252	436	−816	196	−1056
Byssegårde	−2657	1769	−888	1608	−1049
Sigsarve	−575	1188	613	954	379
Stig in Mörtelek	−2360	2330	−30	2059	−301
Västregård	−2705	3873	1167	3522	817
Solmarka (original)	−1996	3065	1070	2765	769
Solmarka (modified)	−1996	2795	799	2495	499
Källunda	−1313	1369	55	1224	−89
Nöbbelöv	−2727	4385	1657	4026	1298
Ängavallen	−1793	3305	1511	3061	1268
Average	−1767	2318	551	2069	302
Weighted Average	−1569	2154	585	1946	377
Sweden 2019–2022	−864	2917	2053	2622	1757

Table 4. Climate balance including C sequestration on the study farms and for Swedish average agriculture 2019–2022, presented in Fossil and Renewable scenarios, where all farms use either type of fuels, average kg CO_2e per ha *farmland* (arable land + natural pastures) per year.

Study farms	Carbon sequestration in soil	Scenario fossil fuels		Scenario renewable fuels	
		Emissions	NET	Emissions	NET
Blomfeltsgården	−1588	2283	695	2137	549
Fjöset + Trappnäs	−1593	1071	−522	900	−693
Ingelsbo + Björnens Eko	−1312	1986	674	1728	415
Östanå	−1874	2422	548	2 143	269
Källingby	−897	652	−244	527	−370
Resta	−949	704	−246	649	−300
Åsbergby	−815	1629	814	1453	638
Fräkentorp	−1925	3577	1652	3338	1413
Uppmälby	−1114	1506	393	1151	37
Nibble	−1514	1916	401	1743	229
Sörbro	−1242	1413	170	1293	51
Tolfta	−1154	860	−294	763	−391
Ullberga	−1627	1590	−37	1425	−202
Yttereneby-Skilleby	−1731	1640	−92	1439	−292
Gatan	−1070	2486	1416	2244	1174
Markusgården	−622	898	276	763	142
Bossgården	−398	929	532	873	475
Älmås	−1074	1992	918	1786	712
Alvans	−1216	2373	1157	2200	984
Buters	−1252	436	−816	196	−1056
Byssegårde	−2119	1411	−708	1282	−837
Sigsarve	−496	1026	530	824	328
Stig in Mörtelek	−545	538	−7	475	−69
Västregård	−1642	2351	709	2138	496
Solmarka (original)	−1656	2544	888	2295	638
Solmarka (modified)	−1656	2320	663	2070	414
Källunda	−1001	1043	42	933	−68
Nöbbelöv	−2217	3564	1347	3272	1055
Ängavallen	−1344	2476	1132	2293	950
Average	−1289	1693	404	1511	222

Weighted Average	−1 185	1626	441	1469	284
Sweden 2019–2022	−760	2565	1805	2305	1545

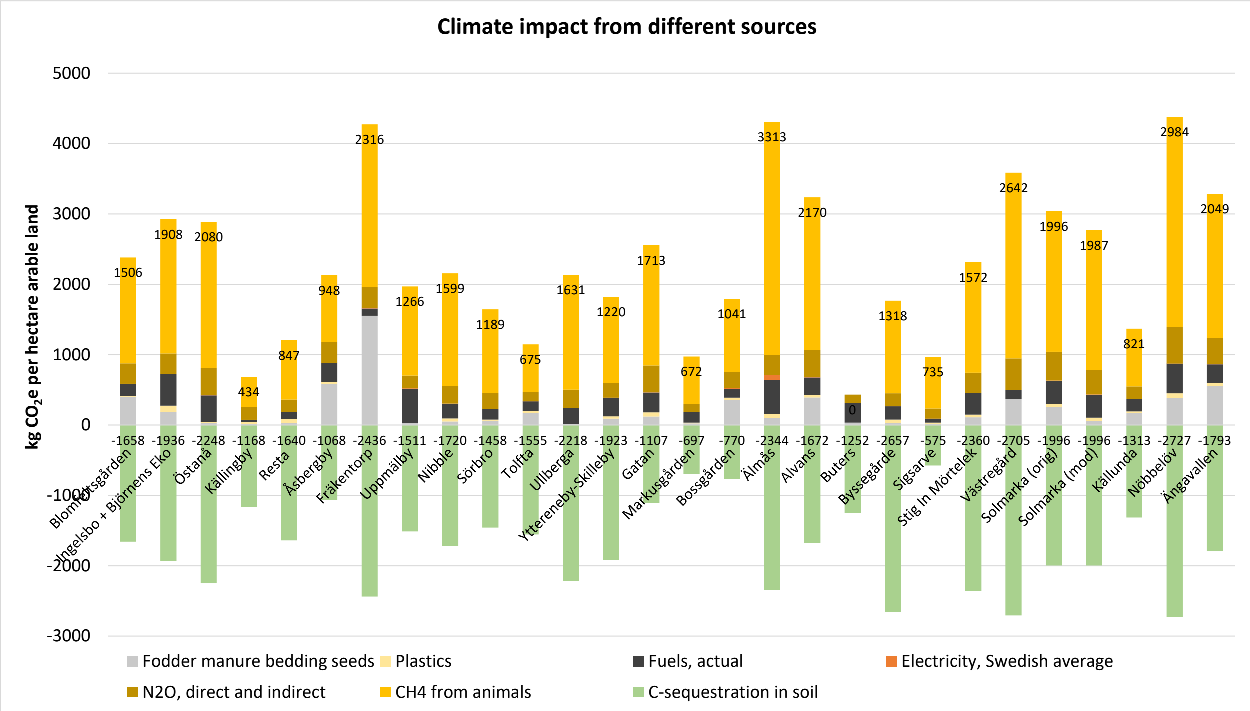


Fig. 2. Climate impact on the study farms from different sources in GWP (Global Warming Potentials), kg CO_2e per hectare arable land and year.

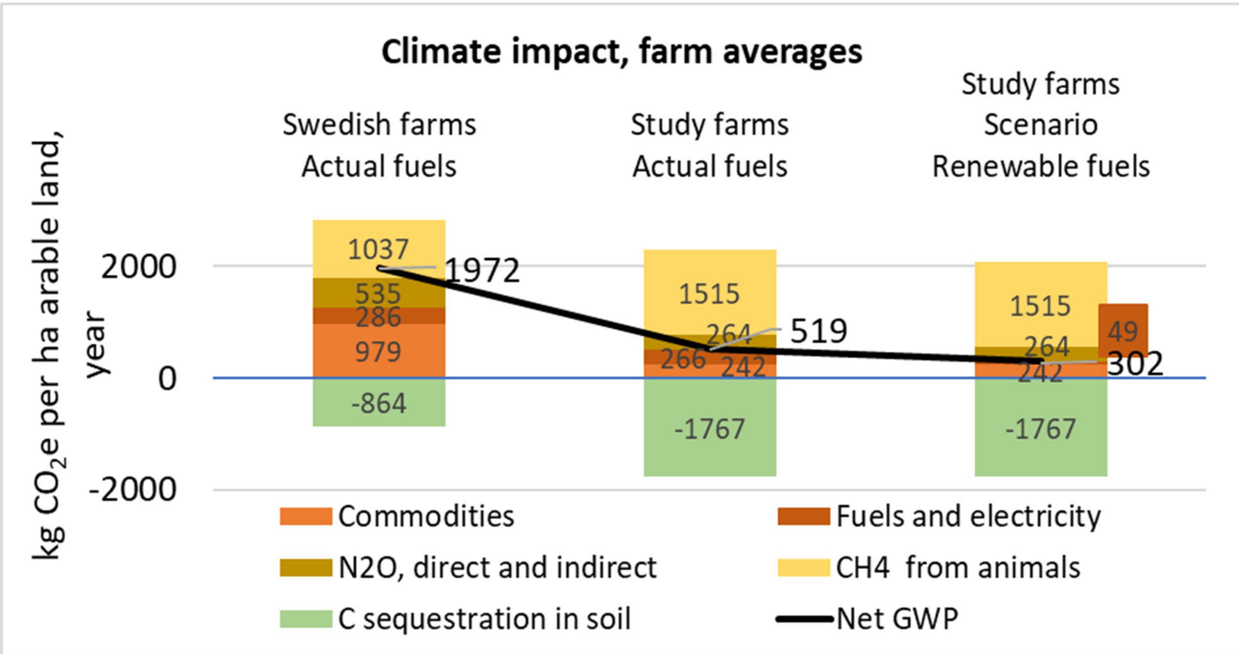


Fig. 3. Average climate impact for Swedish average Swedish farms and on the study farms, and a scenario for the study farms where only renewable fuels are used. GWP (Global Warming Potentials), kg CO_2e per hectare arable land, presented for Net GWP, and for Commodities, Fuels and electricity, N_2O (direct and indirect), CH_4 from animals, and C sequestration respectively.

Plant Nutrient Balance

Table 5 gives the plant nutrient balances for the individual study farms. The results show generally lower surpluses of both nitrogen and phosphorus compared to average agriculture.

Table 5. Plant nutrient balance on the study farms, kg nutrient per ha., calculated on arable land only and total farmland including natural pastures. The share of purchased fodder is calculated from protein needs for the livestock production. The share of purchased manure is calculated from kg N in purchased manure and in estimated kg N released from the farm animals.

Study farms	Farm plant nutrient balance kg per ha arable land			Farm plant nutrient balance kg per ha farmland			Fodder part purchased	Manure part purchased
	N	*P*	*K*	*N*	*P*	*K*	%	%
Blomfeltsgården	27	−1	−1	27	−1	−1	14	0
Fjöset + Trappnäs	68	−1	0	41	−1	0	0	0
Ingelsbo + Björnens Eko	61	−1	−3	42	−1	−2	6	0
Östanå	48	−4	−6	40	−3	−5	0	0
Källingby	31	−1	5	24	−1	4	1	49
Resta	58	−1	0	33	0	0	4	0
Åsbergby	53	−2	0	41	−1	0	17	0
Fräkentorp	69	0	8	55	0	6	38	0
Uppmälby	56	−3	−7	41	−2	−5	2	0
Nibble	34	−2	−4	30	−2	−3	6	0
Sörbro	44	−2	−3	38	−2	−3	3	0
Tolfta	24	3	1	18	2	0	6	48
Ullberga	57	−4	−5	42	−3	−3	1	0
Yttereneby-Skilleby	41	−2	−4	37	−2	−3	17	−10
Gatan	43	5	−3	41	5	−3	13%	42
Markusgården	20	−4	−5	18	−3	−5	2%	0
Bossgården	18	4	−12	9	2	−6	15%	1
Älmås	67	0	10	31	0	5	12%	22
Alvans	66	−1	−2	48	−1	−1	18%	0
Buters	−29	−6	−46	−29	−6	−46	no animals	100
Byssegårde	92	0	1	74	0	1	5%	0
Sigsarve	10	−3	−3	9	−2	−3	1%	0
Stig in Mörtelek	46	−2	−1	11	−1	0	6%	0
Västregård	71	0	3	43	0	2	17%	13
Solmarka (original)	61	−1	−5	51	−1	−4	14%	0
Solmarka (modified)	60	−4	−5	50	−3	−4	8%	0
Källunda	69	0	1	52	0	1	34%	0
Nöbbelöv	79	1	12	65	1	10	16%	20
Ängavallen	60	−2	16	45	−1	12	8%	12
Average	48	−1	−2	35	−1	−2	10%	10
Weighted Average	44	−1	1	33	−1	0	10%	9
Sweden 2019–2022	83	1	7	73	1	6	28%	70

Scenarios for Matching Production and Consumption

The results for matching production and consumption in Sweden, assumed to provide all staple food for the Swedish population of 10.5 million, are presented below in five scenarios. The two first scenarios represent results for the Sweden 2020 Diet, and the following three show results for the BERAS 2020 Diet. Both diets are described in Table 2.
The first scenario represents the Sweden 2020 Diet produced by average agriculture and imported food. In the following four scenarios the diets are produced by different combinations of the study farms.
The second, third and fourth scenarios show the results for manually matching the two target diets with the production of the study farms, grouped into five production groups as described in Section "Manual Matching Using Farm Production Groups". The fifth scenario presents results for the SASM optimisation of single study farms described in Section "Cost-minimising Matching Based on Single Farms Using SASM".

Food Production and Acreage Needs

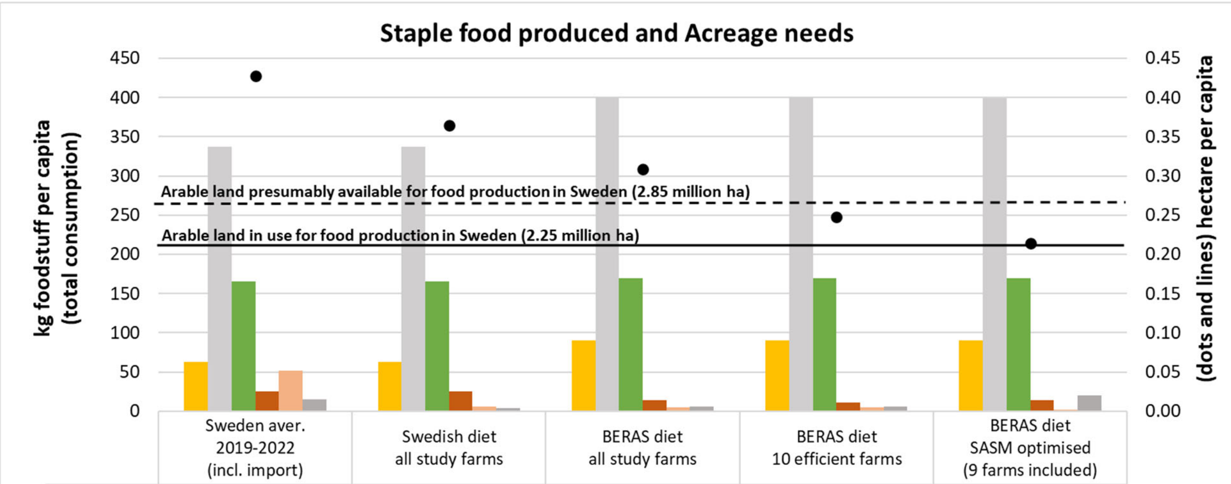
The acreage needed to meet the population's demand for food, i.e., the target diets, is of vital importance if a country wants to be self-sufficient. There are 2.55 million ha arable land in use in Sweden, of which 0.3 million ha is used for production of horse fodder, leaving 2.25 million ha for food production. That is 0.21 ha/capita. Historically, Sweden has had at most 3.5 million ha arable land in use, but that included the fodder for horses and oxen. It is estimated that it would be possible to reinstate about 0.6 million ha into production (Lantbrukarnas Riksförbund, 2019; Jordbruksverket, 2008), making a maximum of 3.15 million ha available, or 2.85 million ha for food production if we assume the number of horses remains equal to the present population. Figure 4 shows the amount of staple food the scenarios manage to produce, and the acreage of arable land needed. The acreage arable land in production in Sweden today is shown by the solid line. The dashed line represents the assumed possible acreage for food production.

The first scenario shows the Sweden 2020 Diet, the actual food consumption in Sweden in 2020. The acreage needed is estimated to be double the domestic used arable land since the country imports about 50% of the food.

The second scenario also shows the Sweden 2020 Diet, but produced by a combination of all study farms, when the production group methodology is applied. We conclude that in this scenario it is not possible to produce the set diet. Firstly, the acreage needed is far too high, and, secondly, the farms do not produce enough white meat and eggs. When the BERAS 2020 Diet is used as target diet, scenarios 3–4, the acreage needs decrease. Applying the matching of production group methodology, the acreage need is at a realistic level when only the 10 most efficient (productive) farms (2 in each production group) are used in the calculation. Using the SASM model for optimisation of single farms, the target diet can nearly be fulfilled by the acreage of arable land used in the country today. For all BERAS Diet scenarios the Red meat production is somewhat greater than the set diet of 10 kg per capita and year, while the White meat cannot be met in the SASM-scenarios. The reason is the higher number of grazing animals, and thus lower number of monogastric animals, on the study farms in general.

It should be noted that there are different combinations of study farms in all different scenarios.

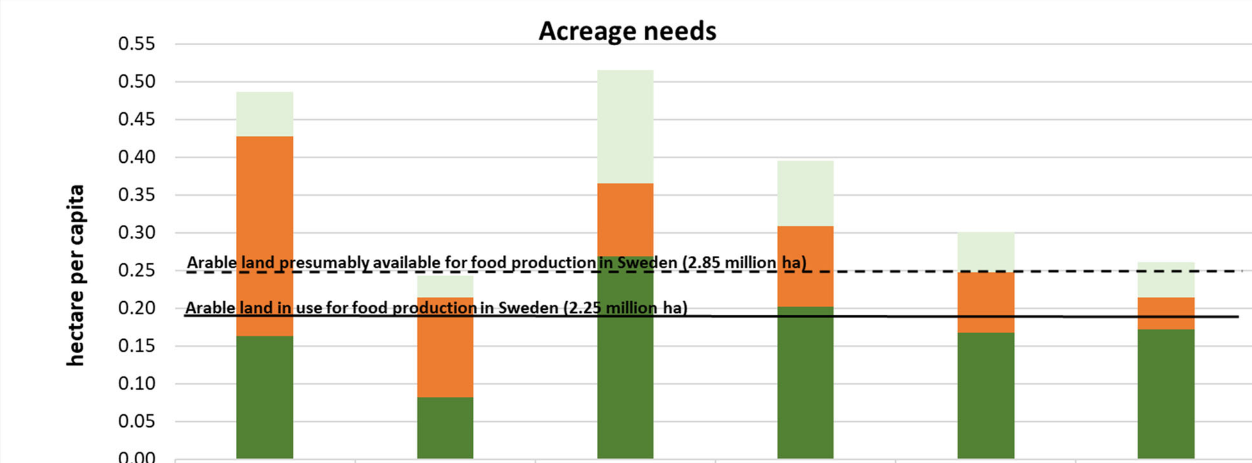
One of our main starting points is the need for increased ley cropping, to sequester more carbon rendering the soils more fertile and self-sustained. Figure 5 presents the proportion of legume–grass leys, field crops, and natural pastures showing substantially greater portions of both leys on arable land and permanent pastures for all scenarios compared to average agriculture. About 450,000 ha of natural pastures are in use in Sweden today, 0.043 ha/capita. presented. Some of those could be substituted by grazing on arable land, but then that arable land acreage would have to be increased. However, the acreage of natural pastures in use is increasing somewhat, and we judge the potential for larger increase both possible and desirable for increased biodiversity.



	Sweden aver. 2019-2022 (incl. import)	Swedish diet all study farms	BERAS diet all study farms	BERAS diet 10 efficient farms	BERAS diet SASM optimised (9 farms included)
Grain	63	63	90	90	90
Milk	337	338	400	400	400
Vegetables	165	165	170	170	170
Red meat	25	25	14	11	14
White meat	52	6	5	5	2
Eggs	15	4	6	6	20
arable land	0.43	0.37	0.31	0.25	0.21

Fig. 4. Food consumed in Sweden (2020) and acreage arable land needed when imported food is included (estimated value); compared to food produced in four scenarios with production from the study farms, up-scaled to produce food for the whole country. The arable land acreage needed (dots) is represented on the

right scale.



	Sweden aver. 2019-2022 (incl. import)	Sweden aver. 2019-2022 (domestic)	Swedish diet all study farms	BERAS diet all study farms	BERAS diet 10 efficient farms	BERAS diet SASM optimised (9 farms included)
natural pastures	0.06	0.03	0.15	0.09	0.05	0.05
field crops	0.27	0.13	0.10	0.11	0.08	0.04
perennial ley	0.16	0.08	0.27	0.20	0.17	0.17

Fig. 5. Acreage needs for perennial crops, annual crops, and natural pastures, in hectares per capita. Four scenarios compared to Swedish domestic production and Sweden including imports (estimated to be double the Swedish hectare needed).

Climate Impact and Plant Nutrient Balance

The climate impact of the scenarios is presented in two variants to remove individual farmer's choices of fuel. Thus, the total fuel consumption is assumed to be either of fossil origin, Figure 6, or renewable, Figure 7. For the latter, HVO, with 20% climate impact compared to fossil fuels, was used. Electricity is assumed to be according to the Swedish average in both cases.

The scenarios shown are the same as in Figure 5. In the first scenario, also including imported food, climate impact is estimated to be double that of domestic agriculture, since the country imports about 50% of its food. That is probably under-estimated, but not significant in the overall results. Fauré et al. report that about two-thirds of Greenhouse gas emissions occur abroad (Fauré et al., 2019).

We conclude that the scenarios when study farms produce food have substantially lower net climate impact due to lower use of commodities and greater C sequestration in soil. Comparing Figures 6 and 7 also make it clear that the choice of fuel is important for the climate impact, but it is only a part of the solution.

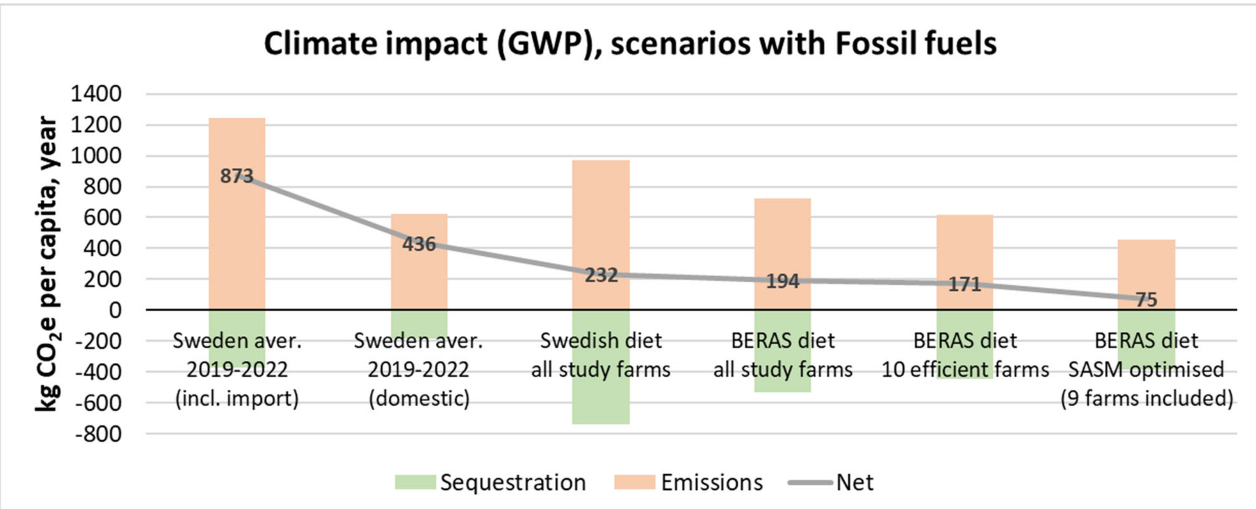


Fig. 6. Climate impact, Global Warming Potential, kg CO_2 equivalents per capita. Four scenarios, where all farms use fossil fuels, compared to Swedish domestic production and Sweden including imports (estimated to be

double the average agriculture).

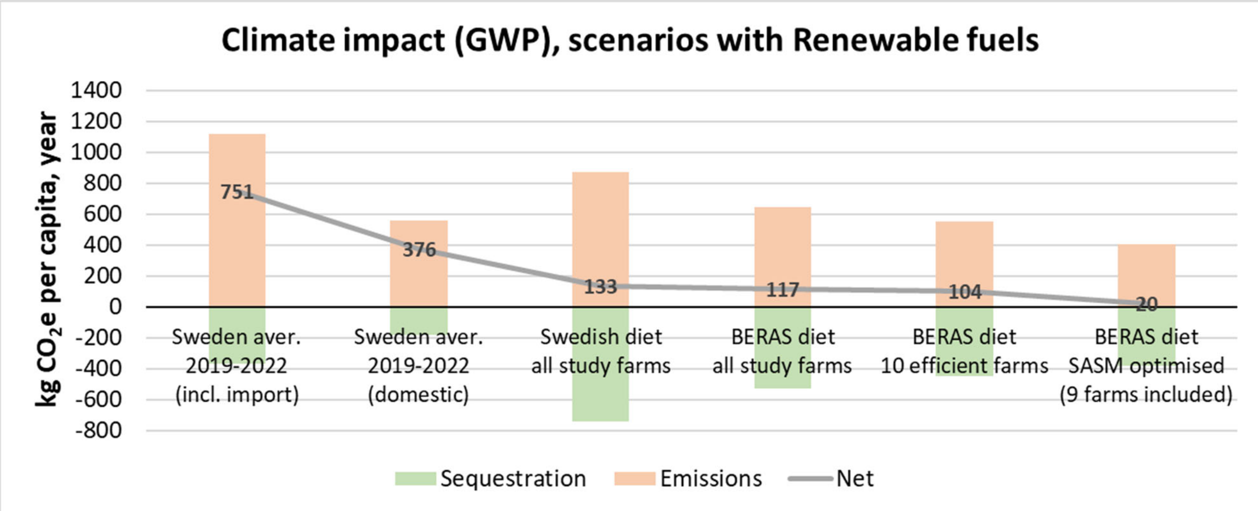


Fig. 7. Climate impact, Global Warming Potential, kg CO_2 equivalents per capita. Four scenarios, where all farms use renewable fuels, compared to Swedish domestic production and Sweden incl. imports (estimated to be double the average agriculture).

Often dairy cows and ruminants are claimed to have negative impact on the climate due to their methane emissions. Figure 8 presents the number of livestock in the scenarios, showing that all study farm scenarios have substantially larger numbers of cows and other ruminants, compared to average domestic farms. Thus, since the climate impact results presented above clearly show diminished climate impact for the scenarios, we conclude that dairy cows and ruminants are positive for the climate, when the increased cropping of legume–grass leys is included in the calculations.

Figure 9 presents the results for plant nutrient balances, showing that the BERAS Diet scenarios result in lower nitrogen surpluses compared to average Swedish agriculture, and thereby pose a lower risk of contributing to the eutrophication of lakes and seas. However, here it should be noted that the domestic Swedish average may seem at about the same level. In reality however, there are vast regional differences, with high surpluses in some animal-dense areas, and close to none on the grain cropping plains.

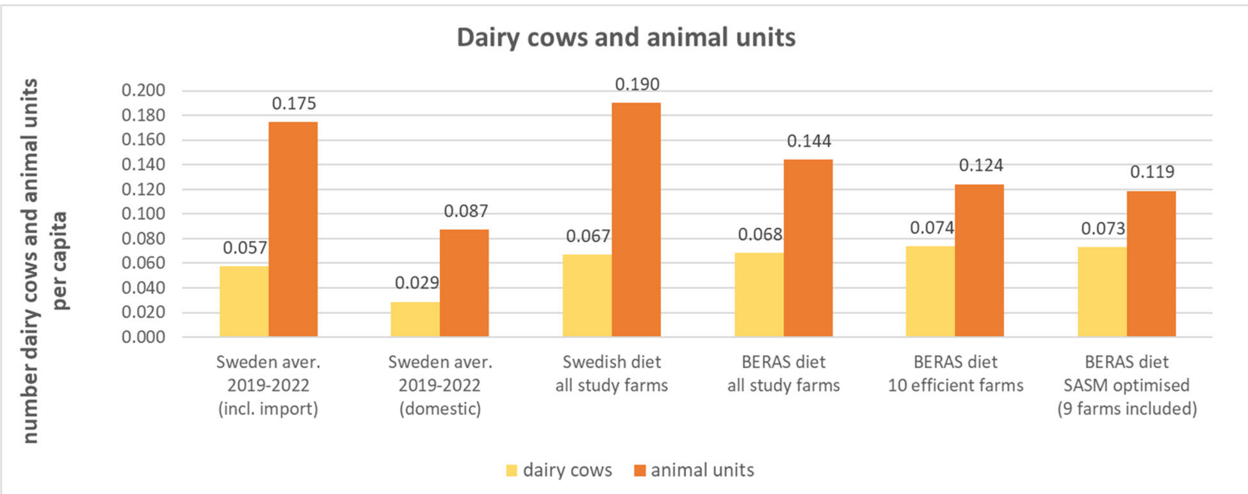


Fig. 8. Number of dairy cows per capita. Four scenarios compared to Swedish domestic production and Sweden including imports (estimated to be double that of Swedish domestic agriculture).

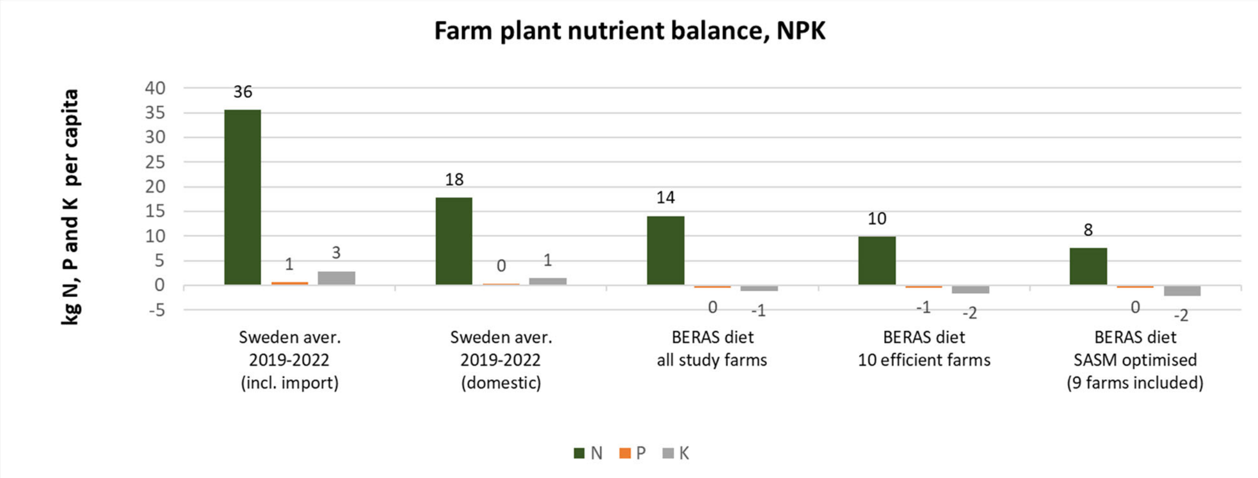


Fig. 9. Plant nutrient balance, kg N, P and K surplus per capita. Four scenarios compared to Swedish domestic production and Sweden including imports (estimated to be double that of Swedish domestic agriculture).

Production Costs

The production costs for agricultural products have been calculated in SASM. In the three manually matched scenarios a given farm structure is used. In the last scenario, SASM calculates a cost-effective combination of farms. In Figure 10 costs are compared to the costs of current agricultural production with and without imports. All costs are reported per person provided with food.

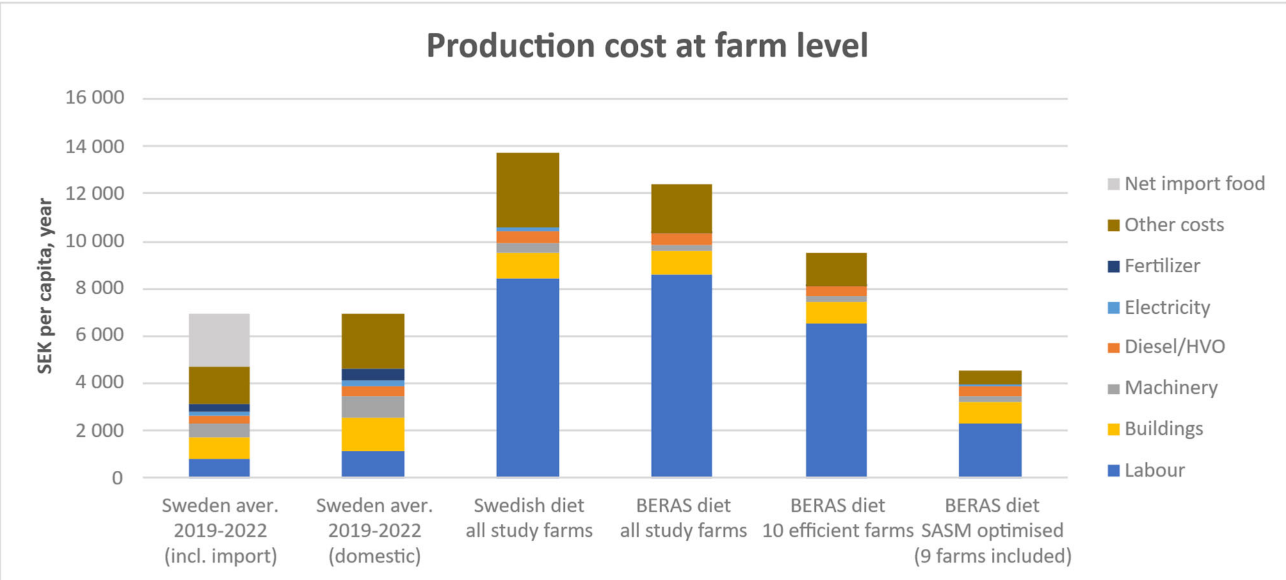


Fig. 10. Production cost of agricultural commodities per capita. Four scenarios compared to Swedish domestic production and Sweden inclusive import.

The most striking result is the large difference in the cost of labour for the production carried out on the study farms compared to labour costs in current production. There are a few differences in the calculation methods. The cost for the study farms is based on stated working hours combined with contractual wages, while the calculations for Sweden are based on data from the Swedish Agency for Agriculture's EAA calculation (Jordbruksverket, 2022), where the cost of the user family's working hours has been calculated at the same hourly cost as that of paid labour. There is also uncertainty in the estimate made by the farmers regarding the amount of working hours on their farms. The large difference in labour costs in the scenario optimised with SASM and the other scenarios with the study farms may be partly due to this uncertainty. In SASM, the farms with the lowest production costs are selected. This is not the case in the other scenarios.

Another important result is that cost of staple foods could be lower than today with food from

ERA farms and the assumed BERAS diet. Most products are more costly to produce but the fact that vegetables and grain are cheaper to produce than meat compensates for this. Calculated at farm level, the cost of staple food is SEK 2440 lower per person and year in the SASM optimised scenario than today. The key to the savings is that the altered diet provides a saving of SEK 4000 per person and year with current prices and that we avoid a large part of the costs for imported food and for imported means of production (fertiliser, plant protection, protein feed, etc.). Other costs in Figure 10 include among other things, plant protection, protein feed and processing costs for industrially produced feed. It is noteworthy that farmers' income for their own work would be more than doubled compared to today.

A Possible Policy Scenario

The calculation of the scenario with a proposed policy assumes that consumers on average have embraced the BERAS diet but not that they are willing to pay extra for local food from ERA farms. The proposed change with differentiated VAT on food allows farmers to obtain higher prices for ecological products than for conventional ones even when the prices are the same in the store. In addition, the proposed changes in agricultural subsidies make it more profitable to carry out ERA production than other organic production.

Given these policy changes, net imports of staple foods can be reduced by approximately half. Figure 11 also shows that consumer expenses for staple foods can be reduced by SEK 1570/person/year calculated at farm level. Savings at consumer level are difficult to calculate, but they are likely to be greater. The total cost for agricultural support would remain unchanged but farmers' income would rise, partly due to doubled remuneration for owners' or employees' working hours in production but also doubled working time. The other aspect is SEK 6.4 billion in higher profits, which leads to an increase in land rent of SEK 3000/ha for arable land. This increase in land rent is part of "Other costs" in Figure 11. It is a cost for consumers but a gain for landowners.

The proposed policy instruments would also provide significant environmental improvements. In Sweden the climate impact (GWP) from agriculture would be reduced from 436 to 106 kg CO_2e per capita if fossil fuels were used and from 376 to 51 kg CO_2e per capita if renewable fuels were used. In addition, our environmental impact in other countries would be reduced thanks to fewer imports. Since net imports are halved, our environmental impact in other countries could be halved. But we are also moving from importing meat towards importing vegetables, while exports are shifting from cereals to beef. Therefore the decrease is likely to be greater. Plant nutrient balances would also improve, with the surplus of nitrogen reduced from 18 to 11 kg per capita. Phosphorus and potassium are close to zero in the policy scenario.

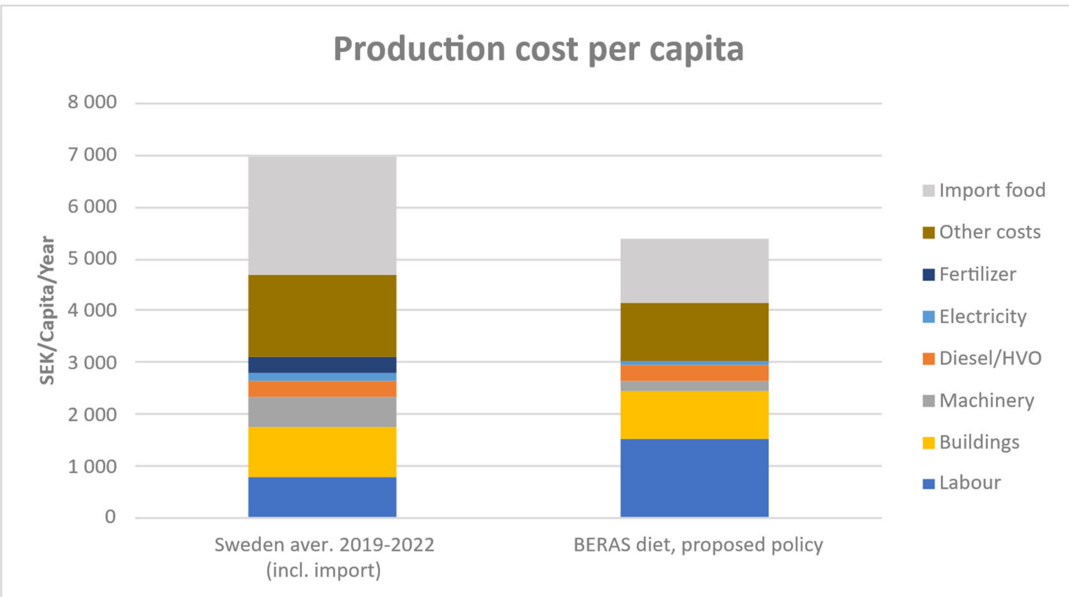


Fig. 11. Production costs of agricultural commodities per capita. BERAS diet with proposed policy compared to Sweden average 2019–2022 inclusive import.

DISCUSSION

Firstly, we would like to point out that the results presented should be interpreted with caution since only 30 farms are included, and only examined over the course of three years. Secondly, in the most promising scenarios reported, only 10 of the farms are included. Furthermore, it may be over-optimistic to assume that all farms in Sweden could be as productive as these.

However, we maintain that our study shows the potential for ecological recycling agriculture (ERA), and we dare to claim that our hypothesis was largely confirmed. These types of farms do exist, but only in small numbers since due to economic pressure the general development has been towards input-intensive production. One should also remember that the farm setups and production of today probably tell us little about their true potential. Most of them are under development and constantly trying new practices. Regenerative agriculture, adopted by some of the farms, indicates a positive future for a vital agriculture. Personally we have also observed an increased interest in a less capital-intensive type of agriculture.

Thus, in light of the serious situation of increasing global warming, and other threats to our environment, it is imperative to begin a rapid conversion of agriculture as a whole. Continuing the prevailing high-input agriculture development is not sustainable, or at least has many hidden dangers (van der Werf et al., 2020). We believe the direction provided by this study, showing good examples of farms that have adopted Recycling Ecological Agriculture (ERA) principles, and a consumption adjusted to their production, could serve as an archetype for future sustainable development.

Furthermore, even though average agriculture appears to show quite satisfactory results in our comparisons, in reality, regional differences are vast with almost no leys on the plains, and too many animals fed on "imported" feed (from other regions or abroad) in some regions, resulting in nutrient excess. Added to which, the increased ley cropping in Sweden from 32% of the arable land year 1981 to 47% of the arable land 2013 (Poeplau et al., 2015), which is about the same today, is due largely to an increased number of horses kept for leisure and sport activities. This 300,000 ha of arable land used for horses is not included in the study.

Acreage Needs and Changed Diets for Staple Food Self-Sufficiency in Sweden

In a global perspective, Sweden has enough acreage to feed a population of 10.5 million inhabitants. We have 0.21 ha/capita compared to a world average of 0.18 ha/capita (Our World in Data). Still, we import many products, above all meat and dairy products, while we export quite a lot of grain (Nordic Council of Ministers, 2023). Thus, we conclude that food habits of the Swedish population in general must be adjusted drastically if we want Sweden to be more self-sufficient in staple foods. And that probably is the case whether the agriculture goes in an ERA direction or continues the present input intensification. Of course we realise that it's not the easiest thing to accomplish in reality, but the Policy scenario presented in Section "A Possible Policy Scenario" may provide some ideas of measures that could support more "environmentally friendly" production and consumption, making it profitable for both producers and consumers.

Other attempts to promote more sustainable eating are, for example, presented by the EAT–Lancet report (Willett et al., 2019) and The Nordic Nutrition Recommendations 2023 (Blomhoff et al., 2023). Both support diets with less meat, and above all, less meat from grazing animals referring to LCA (Life Cycle Assessment) data, not taking carbon sequestration into account. This has been questioned in later years by researchers, e.g., (Van Selm et al., 2022; Karlsson, 2022) as well as the Swedish branch of WWF (the World Wildlife Fund for Nature) (WWF, 2015; WWF 2021) that now advocates meat from grazing animals. Something which our results support. Both soils and the climate require cropping of deep-rooted perennial crops. The combination of grass and legumes such as clover and lucerne are a prerequisite for self-sustaining agriculture, by building mulch (sequestering carbon), collecting nitrogen (Kjaergaard, 1994), and mineralising phosphorous. In order to utilize these ley products (hay and silage), there is a need for grazing animals, which in turn implies that we need to eat meat from these animals if we want to utilise these resources efficiently.

Our results point out possible levels of meat consumption, with substantially lower consumption of white meat (pigs and poultry) and halved red meat (grazing animals) consumption. Pigs and hens/chickens are present on only a few of the farms studied, and on a very small scale, which of course does not have to be the case for ERA farming in general. The number of eggs produced is more than doubled in the SASM scenario, compared to the other scenarios, since one dairy farm included also produces eggs from hens kept outdoors. This indicates that a larger egg production would be possible even if Swedish agriculture converted to ERA farming practices.

For dairy products, our results suggest that consumption can increase from today's 337 kg/capita to 400 kg/capita while imports of cheese and other dairy products can be replaced by domestic products.

All scenarios show an almost doubled or, in some cases, tripled use of natural pastures. An area of 460,000 ha of pasture lands qualifies for subsidies in Sweden today. There has been an increase in recent years (Nordic Council of Ministers, 2023), but Statistics Sweden (2000) also reports 709,000 ha of grazing lands were registered in the year 2000. Historically, there were more than one million ha of pasture lands in use (Goodla SLU), and some sources, e.g., (Jordbruksverket, 2019b), mention several million hectares. It seems possible to regain a good deal of the lost pastures. But this would entail the market placing a higher value, and/or political compensation, both on meat from grazing animals, and for the biodiversity services and recovered landscape obtained by keeping animals in abandoned meadows and forests.

Climate Impact Calculations

When it comes to climate impact calculations, there is some uncertainty both concerning calculation methods and the quality of data. We have used CO_2e, also referred to as GWP100, since it is the official method.

However, that calculation model is questioned by some researchers and is claimed not to be an appropriate measure concerning agricultural systems since e.g., methane emitted from grazing animals is short-lived and part of the natural system, not affecting global warming to the degree predicted earlier (Lynch et al., 2020; Allen et al., 2016). Lynch et al. (2020) suggest GWP Star: "GWP*, an alternative application of GWPs where the CO_2-equivalence of short-lived climate pollutant emissions is predominantly determined by changes in their emission rate, provides a straightforward means of generating warming-equivalent emissions.". Following the GWP* concept would have diminished the climate impact results in the study substantially, on average the study farms would have been climate positive. Furthermore, the result would also be that climate impact of grazing animals would not be a matter of high priority. We agree and have come to the same conclusion by introducing C sequestration into the global warming assessment, while at the same time recognising that adopting the GWP concept would make comparison to national statistics and goals complicated.

We judge the results to be consistent with the prevailing CO_2e method and rather conservative. The calculated value for carbon sequestration in Swedish average agriculture (760 CO_2e/ha arable land) is lower than the one given by Röös (2019). A recalculation of her results comes to 940 CO_2e/ha arable land. Thus, our model can be assumed to underestimate the sequestration.

As for greenhouse gas emissions, our model gives 6.7 million tons CO_2e for the whole country. Wirsenius (2019) reported 14 million tons CO_2e including transports and emissions from cropping on organic soils that our calculations omit. A recalculation of Wirsenius's data excluding the transport and organic soils, results in 9 million tons CO_2e.

Both of these probable underestimations partially compensate each other. The results are somewhat uncertain, but we judge them to work well as comparison between the ERA farms in the study and the mainly conventional average agriculture, are both calculated using the same method. The results clearly show a lower climate impact for the ERA farms.

Renewable fuels are often advocated as a solution. We show that it makes a difference but does not entirely solve the question of the food system's climate impact, (Figures 3, 6 and 7).

The Swedish Environmental Protection Board indicate a level of about 140 kg CO_2 equivalents per capita and year for food consumption as a goal for the year 2050 (Naturvårdsverket, 2025). We conclude that the scenarios using manual optimisation are below this target when renewable fuels are used. The SASM optimised scenario is well below the target in both cases. However, one should remember that we have not included transport and trade. And, again, in the two "best" scenarios only 10 farms were included in the calculation.

Nutrient Balance Calculations

When it comes to nutrient balances, the scenarios show lower nitrogen surpluses compared to average Swedish agriculture and, thereby, imply a lower risk for contributing to the eutrophication of lakes and seas. Additionally, the observed increased humus content in soils results in an increased capacity for nutrient and water retention and also immobilisation of nitrogen and phosphorus in soil organic matter.

Production Cost Calculations

All the scenarios imply higher production costs for each product seen separately, but a change in diet makes consumers' expenditure on food lower when technologies from the farms with lowest cost are used. Typically, ERA farms have lower costs for imported and fabricated means of production (fertilisers, plant protection products, protein feeds, etc.) but higher use of and higher costs for labour. The pattern is clear, but there is great uncertainty in the estimation of the cost of labour.

Most farmers tend to overestimate their work hours when asked. The large difference in labour costs in the scenario optimised with SASM and the other scenarios with the study farms may be partly due to this uncertainty, when some farmers overestimate more than others. In SASM, the farms with the lowest production costs are selected. This is not the case in the other scenarios.

Hourly cost has a methodological difference when calculating for present Swedish agriculture and the calculated scenarios with the study farms. The actual use of labour is only 12% higher in the SASM optimised scenario than today but the calculated cost is almost three times as high. Labour costs for the study farms are calculated according to contractual wages, SEK 235/h, independently if labour is hired or done by the farmer. Calculations for Sweden are based on data from the Economic Accounts for Agriculture, EAA (Jordbruksverket, 2022). Their estimated cost for hired labour is SEK 82/h. We have applied the same cost for the farmer's own labour. The low average cost per hour is partly due to an overestimation of time used but it is also a result of friends and relatives working unpaid or for a low wage. If contractual wages were used in the EAA calculation production costs would be SEK 1510/person higher in the scenario with import and SEK 2230/person higher if all food was domestic.

Another important factor is that the farms studied act according to the demand they experience in a market where most of the production is conventional. If all production came from ERA farms, the market situation would be different. In that case, they would have designed their product mix in a different way. Scaling up 30 farms to the entire market means that the costs are overestimated and that the possibilities of achieving self-sufficiency using the current arable area are underestimated. Moreover, in the last two scenarios, only the most productive farms are included. It is probably optimistic to assume that all farms in Sweden could be as productive as these.

We also believe that ERA production would be more cost efficient than today's production if both production systems had to pay for their negative environmental impact and were rewarded economically for their positive environmental impact. These calculations remain to be done in future research.

Possible Policy Calculations

Two policy measures have been analysed, differentiated food VAT and amended agricultural subsidies (direct subsidies) to direct the grants directly to land with ERA production.

The suggested system for direct payment is much simpler than the existing system. Yet it would be more efficient. Sweden would have higher self-sufficiency in food, farms would be more profitable, there would be more jobs in rural areas, climate impact of food production would be reduced as well as the risk of dangerous chemicals in nature and leaching of plant nutrients. In addition, biodiversity would increase in the agricultural landscape.

It looks like a simple win-win situation but it's not. There are losers. Today large multinational companies profit from providing farmers with production factors, fertilisers, plant protection products, protein feeds, seeds etc. These markets would almost disappear if agriculture converted to ERA production. Consumers who do not adopt new diets would have 12% higher food expenses and conventional farmers would lose their supports if they didn't convert to ERA production. All of actors will oppose any change directed towards ERA production.

Time is another factor in conversion. Consumers might adopt new diets relatively quickly but farm structure is locked into existing buildings. As is the industry surrounding the farmers. Some buildings were intended to be used for up to 40 years to come. Some of the existing buildings could be used for ERA production, but not all. To avoid capital losses in existing buildings full conversion to ERA production might take up to 40 years, though most capital losses will be avoided within a 20-year period.

Differentiated VAT could be implemented immediately but the system for agricultural subsidies must be changed gradually to avoid capital losses and temporary production losses. However, investment aid could be changed immediately so that it is only available to installations suitable for ERA production. In the plains, support could be given to investments for milk, beef, sheep and other products that result in an increased share of perennial ley. In forested areas and northern Sweden, priority could instead be given to facilities for the cultivation and handling of grain, oilseeds and protein crops. Investment in increased cultivation of kitchen produce and root vegetables would be supported throughout the country.

Other policy measures that could be considered are bans on the use of chemical pesticides and mineral fertilizers and firmer animal protection regulations regarding feed intake from grazing for ruminants and outdoor living for pigs and poultry. These policy measures are not included in the calculations. They are unnecessary if the other measures are implemented. ERA farms operate without use of chemical pesticides and mineral fertilisers. They also have greater feed intake from grazing for ruminants and outdoor living for pigs and poultry. However, if supports cannot be directed fully to ERA farms, these measures could be important.

Comparison between Previous and Present Study

In general the results of this study concur with the earlier published study (Granstedt & Thomsson, 2022) but a few differences in the setup slightly affect the results. However, the major conclusions drawn are the same.

The major difference is that economic studies have been included in the present study, giving broader insights into what a conversion to ERA farming would imply. It also has given us an opportunity to investigate and recommend possible policy instruments.

The input data has been increased in the present study. The number of study farms were 30 compared to 22 farms in the previous study. Also, input data from additional years has been included. In the present study, data from 3–4 years was collected from the majority of farms. The previous study comprised only 1 year of farm data.

Climate impact results point in the same direction, the ERA farms show substantially lower impact figures compared with average Swedish farms, but the difference is somewhat smaller. The study farms are reported to have 74% lower GWP in the present study, and 81% in the previous study (Granstedt & Thomsson, 2022).

The scenarios for matching production and consumption are developed, and fewer, in the present study, but results indicate the same trend. The economic optimisation model (SASM) (Naturvårdssverket, 2018) made it possible to find a combination of farms, by giving it the opportunity to choose the best producing farms, to better fulfil the target diet with lower acreage requirements than the manual optimisation was able to find.

The target diet (BERAS 2020) is slightly modified compared to the BERAS diet used in previous study (Granstedt & Thomsson, 2022). Both fulfil nutritional standards. The most important difference is that the consumption of dairy products was set to 400 kg/capita and year in the present study, compared to 380 and 250 respectively in the previous study.

Shortcomings and Uncertainties

We are aware of that we have been unable to include an assessment of a self-sustained energy supply system. There are initiatives with biogas plants on some of the farms, but we have not able to explore that option further. We also note that solar voltaic electricity production is gaining volume in Sweden but that too is a subject that must be investigated in coming research.

We suggest quite drastic dietary changes, but the time span and practical and social complications that would have to be solved, were not examined.

We are also well aware that the study is a case study with only a few farms assessed over several years. This suggests that the results be used more as a possible development direction than a well-documented prediction.

CONCLUSIONS

- Including carbon sequestration in soil in a climate impact assessment is a game-changer. Adding up only emissions, as most research and official reporting have done so far, results in erratic conclusions.
- A common conversion of all agriculture according to the principles of ERA-agriculture food production would result in an important carbon sink, and lowered risk for eutrophication of lakes and seas, while also eliminating pesticide use in the agriculture.
- The net climate impact is substantially less on the studied ERA farms, i.e. agriculture based on self-supportive circular principles, compared to Swedish agriculture in general. Largely, that is thanks to:
    - 75% lower use of external resources.
    - twice the degree of carbon sequestration and build-up of organic matter in soils due to ley cropping on a

greater portion of the acreage.

- Sweden could be self-sufficient in staple food production given the available acreage of arable land by adopting Ecological Recycling Agricultural principles in a similar manner to the studied farms.
    - However, this also demands quite a drastic dietary change to a more lacto-vegetarian diet among the Swedish population in general.
- Our calculations indicate that ERA production is slightly more costly than today's production, but:
    - Consumers' food expenses will be lower if as suggested, they simultaneously change to a diet with more vegetables and less white meat (pork and poultry).
    - The local economy is strengthened since a larger part of the expenditures is spent on labour at ERA farms, keeping the earnings in the local economy, whereas in present production, large sums of money are passed on out of farming communities to multinational companies trading in fertiliser, plant protection and feed.
- Two simply-designed policy instruments could lead to the conversion of all Swedish agriculture to ERA production without higher costs for consumers or tax-payers. The instruments presented are:
    - Differentiated VAT on food.
    - Redistribution of direct payments to ERA farms.

A combination of the two instruments could result in a self-sufficiency rate of about 85% in staple foods. The policy instruments would need to be more refined to reach 100% self-sufficiency but we believe it could be possible.

AUTHOR CONTRIBUTIONS

Conceptualization, A.G.; Data curation, O.T. & L.J.; Formal analysis, O.T. & L.J.; Funding acquisition, A.G.; Investigation, A.G.; Supervision, A.G.; Validation, O.T. & L.J.; Writing—original draft, A.G., O.T. and L.J.; Writing—review & editing, O.T. & L.J. All authors have read and agreed to the published version of the manuscript.

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Informed consent was obtained from all subjects involved in the study.

DATA AVAILABILITY STATEMENT

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CONFLICTS OF INTEREST

The authors declare no conflict of interest. The funders had no role in the design of the study; in the collection, analyses, or interpretation of data; in the writing of the manuscript, or in the decision to publish the results.

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