A longitudinal sustainability investigation of lunch menus in Swedish primary schools

Trends in composition and impacts

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A longitudinal sustainability investigation of lunch menus in Swedish primary schools. Trends in composition and impacts

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Abstract

School meals form an important part of public catering and have the potential to act as a powerful sustainable development lever. This study investigated the composition and sustainability of school lunches in Swedish primary schools across 71 municipalities between 2019 and 2025 using menu data extracted from three school menu databases. In total, 10 sustainability indicators, covering both environmental and social sustainability were evaluated using the SAFAD tool. The impacts were assessed against relevant planetary boundaries.

Based on the most frequently served menu combinations, it was found that animal-source dishes remained the dominant, and expanding, school lunch option. Animal-source dishes constituted 65% of primary (first option) offering, with meat and poultry serving increasing by 3 and 4 percentage points, respectively, over the investigated period. Conversely, a nearly 8 percentage point decrease in vegetarian options in school menus was noted based on estimated portions served. The inclusion of both environmental and social sustainability indicators allowed to investigate the trade-offs associated with different animal-source protein options, such as poultry-related animal welfare concerns. It was further found that school meals trespass four of the six studied planetary boundaries: carbon footprint, extinction rate, nitrogen input and phosphorous input and that the provision of milk as a part of the school lunch exacerbates the impacts, pushing cropland use beyond the safe planetary limit.

Keywords: menu analysis, planetary boundaries, school meals, sustainable public catering, Sweden

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Abbreviations

Abbreviation	Description
N	Nitrogen
NNR	Nordic Nutrition Recommendations
P	Phosphorous
PHD	Planetary Health Diet
SAFAD	Sustainability Assessment of Foods and Diets
SDGs	Sustainable Development Goals
SFA	Swedish Food Agency (*Livsmedelsverket*)

1. Introduction

Food systems account for more than a third of anthropogenic greenhouse gas emissions (Xu et al. 2021) and are a key driver of losses in biosphere and ecosystem integrity, among other transgressions of the planetary boundaries (Rockström et al. 2025). Increasing the sustainability of agri-food value chains therefore requires systemic change at every level, from production through consumption to waste management (Willett et al. 2019). Given the projected need to feed over 10 billion people by the mid-2080s (United Nations 2025) and the limited scope for expanding sustainable resource use (Willett et al. 2019), changing individuals' diets is paramount to a more sustainable food system. While the details of a sustainable diet are context-dependent (Food and Agriculture Organization of the United Nations & Bioversity International 2012), but substantial research support that it should be rich in plant-based foods (Willett et al. 2019; Rockström et al. 2025). This dietary shift should be accomplished by a stark reduction in meat consumption. As meat intake tends to rise with income (Clonan et al. 2016), the economic development of developing and emerging countries, combined with the consumption levels in high-income countries, will increase the demand for meat if left unchecked. Meat consumption is associated with higher environmental impacts than plant-based dishes (Poore & Nemecek 2018). Although demand for meat is levelling off or declining in some high-income countries (Clonan et al. 2016), a far greater reduction is still required to lower environmental impacts and improve health outcomes (Steenson & Buttriss 2021). The Nordic Nutrition Recommendations (NNR) reflects this: their latest edition incorporates environmental considerations alongside health criteria and outlines a primarily plant-based diet with limited animal-source products, with an increased potato and legume consumption alongside reduced poultry intake being recommended mainly for environmental reasons, while red meat reduction is recommended on both health and environment grounds (Blomhoff et al. 2023).

Achieving widespread dietary change requires overcoming barriers rooted in individuals' choices and socioeconomic circumstances, which makes dietary transition at the individual level a significant challenge (Fernqvist et al. 2024). One setting where change can be achieved more efficiently is the public meals sector, where food procurement, meal planning and preparation are delegated to public authorities. Policy-driven sustainability initiatives in settings such as hospitals, elderly care, and schools therefore have the potential to drive systemic change by potentially influencing the food habits of millions of individuals. School meals are of particular interest, as they represent a significant and consistent part of a student's dietary intake over many years. Given their contribution to short and long term health and socioeconomic benefits (Eustachio Colombo et al. 2020; Lundborg et al. 2022; Springmann et al. 2025), as well as to long-term habit formation (Livsmedelsverket 2026a), they could be harnessed in a food systems transition. It is therefore of interest to understand their impacts and how these have changed over time.

Sweden's public catering sector provides a suitable case study. The country has a long history of school meal provision, and of the roughly three million public meals served daily, around two thirds are served in educational settings (Livsmedelsverket 2025b; a). A free and nutritious school meal is legally mandated in primary schools (SFS 2010) and is often provided free of charge in secondary schools as well. Although responsibility for school meals rests with municipalities, national guidelines developed by the Swedish Food Agency (SFA) and based on the NNR guide menu planning and the wider organisation of school meals (Livsmedelsverket 2026a). First published in 2015 and subsequently updated (Livsmedelsverket 2019; 2026a), these guidelines emphasise the "eco-friendly" dimension of school meals. Yet while they establish a framework for more sustainable meals, gauging their success remains a challenge.

Direct measurement of school meals' impacts is difficult. Only 43% of municipalities currently have an environmental policy addressing the climate-related impacts of primary school's food on the purchasing level (Livsmedelsverket 2025b). This share of municipalities has grown in the last three years by nearly 10 percentage points (Livsmedelsverket 2022). While no national targets for climate impact of meals have been set, the average goal of municipalities with own targets is 1.9 kgCO_2e per kilogram of purchased food (Livsmedelsverket 2022). Existing analyses of the diets of Swedish minors (Jacobsen et al. 2025; Lindroos et al. 2025) have therefore relied on national dietary recall surveys (Warensjö Lemming et al. 2018a; Bjermo et al. 2024; Moraeus et al. 2024). These show that the diets of both four-year-olds and adolescents transgress most planetary boundaries (Jacobsen et al. 2025; Lindroos et al. 2025), reflecting a high intake of animal-source products and discretionary foods and a below-recommended intake of vegetables, fruit and fibre (Warensjö Lemming et al. 2018b; a; Moraeus et al. 2024). Such surveys capture the whole diet rather than school meals specifically. The closest school-specific evidence comes from the pre-school setting, where the impact from meat consumption was lower than at home but offset by higher dairy (Jacobsen et al. 2025), as subsidised milk accompanies the school lunch (European Commission 2025). Generally, school meals have also been associated with greater nutritional density, and to children's intake of vegetables and seafood, than food consumed in other contexts (Eustachio Colombo et al. 2020).

One way in which schools can contribute to greater provision of vegetables is through the provision of vegetarian options, including plant-based meat alternatives. In a study of 76 Swedish municipalities, more than 90% of municipalities reported daily availability of vegetarian alternatives in public catering, though meat-based meals still formed more than half of the available options (Wollmar 2025). The authors noted how the vegetarian options can be employed as a carbon footprint reduction tool. At the same time, municipalities' efforts to provide more sustainable meals in the educational setting, for example through provision of vegetarian alternatives, have been met with considerable criticism. Political figures have claimed that schools impose vegetarianism on students against their preferences and needs (Karlsson 2026). Some students describe vegetarian alternatives as less appetizing and filling (Hallands Nyheter 2026), and parents have echoed this, arguing that on days when only vegetarian meals are served, additional food is needed to ensure adequate energy intake, while schools have pointed to the environmental impact of food and called for shared responsibility (SVT Nyheter 2026). With little empirical data available, it is difficult to judge whether these claims reflect what is actually served, rest on personal beliefs, or are tied to the approaching 2026 general election. Despite the prominence of this debate, little is in fact known about the composition and sustainability of Swedish school meals or how they have changed over time.

Bridging this gap calls for a data source that captures school meals directly and over time. While national survey data is helpful for gauging the impact from actually eaten meals, the brief observational window of the standard recall method (Bailey 2021), limits longitudinal generalisability of results and observation of trends. An alternative is to utilise weekly menus that municipalities and individual schools publish (Sjölund 2021). While this method is less helpful for gauging the impacts of actual dietary intake, it provides a proxy by estimating the impacts of the intended meal offering, and thereby the impact of providing lunch, rather than eating it, in a longitudinal manner across many kitchens. A multi-indicator approach is especially valuable here, as it reveals impact trade-offs (Ran et al. 2024), that remain hidden when a single metric, such as carbon footprint is used in isolation. By applying such an analysis to an extensive dataset of Swedish primary school menus, this thesis provides a longitudinal, multi-indicator sustainability assessment of school meals in Sweden.

1.1 Aim

The aim of this thesis is to investigate the sustainability of Swedish primary school meals over the period 2019-2025. To this end, the thesis addresses the following research questions:

- How have the environmental and social sustainability impacts of offered lunches changed over the study period?
- How do these impacts compare with the planetary boundaries for food systems?

- How has the composition of Swedish primary school lunches and the balance of animal- and plant-based dishes served changed over the same period?

2. Methods

The following chapter outlines the methodological approaches employed in the study. An overview of data collection methods is provided, along with relevant definitions employed in the thesis, followed by data treatment strategies. The chosen sustainability indicators are introduced, and municipality selection criteria are justified. The chapter concludes with an overview of the sustainability profiling and menu analysis procedure.

2.1 Data collection and study scope

Menu data spanning from 2019 to 2025 were collected from Swedish municipalities via three school meal databases: Skolmaten, Matilda, and Mashie. Menus were fetched on a weekly basis, on Mondays throughout the collection period. Kitchens were categorised according to the educational institution's level (pre-school, primary, or upper secondary). The scope of this study was limited to primary schools (*grundskolor*), corresponding approximately to ages 5/6 to 15/16 as this is a mandatory education stage (SFS 2010), and represents the largest share of Swedish student population. The kitchen data was cleaned to remove healthcare and eldercare services, as well as adult education institutions, after-school care and uncategorisable entries. Kitchens that were featured in the database on several occasions due to misspellings or changes in spelling convention were merged.

After cleaning, 3065 kitchens in 235 municipalities (81% of Swedish municipalities) remained (Figure 1), though no academic year in the studied period captured the full breath of municipalities present in the database (Table 1). The number of individual kitchens is potentially larger as some municipalities reported a single menu for all educational institutions. As such, an estimation of the number of pupils served by the kitchens is difficult. An estimation of data coverage was made using the number of students enrolled in each municipality as a proxy (Table 1). These municipalities include up to 88% (n=803 747) of the Swedish primary school student body, based on average student numbers from Skolverket during academic years 2018/19-2024/25.

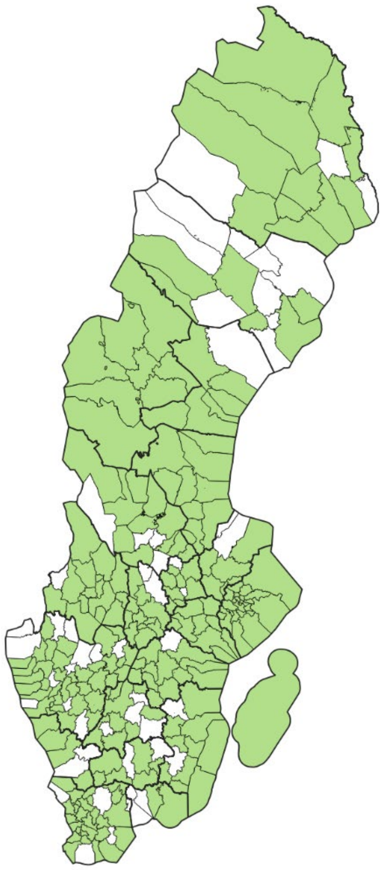

Figure 1. Overview of the geographic spread of the 235 municipalities included in the dataset. Municipalities in green are featured in the database.

Table 1. Overview of menu entries, number of primary schools and municipalities represented in the database per academic year.

Academic year	Number of menu entries	Number of primary schools	Number of municipalities
2025/26	61659	356	43
2024/25	171503	425	52
2023/24	213772	454	54
2022/23	684227	2692	221
2021/22	920415	2661	208
2020/21	692250	2560	193
2019/20	702443	2594	194
2018/19	21465	161	12

2.2 Menu and meal definitions

A typical school lunch in Sweden consists of a hot dish, accompanied by a salad buffet, bread and spread, as well as water or milk (Patterson & Schäfer Elinder 2015). Alternatives may be available for the hot meal, including vegetarian options or different meat and fish dishes (Figure 2). In this thesis, a menu is defined as the entire food offering available at lunch, and is generally communicated in a weekly format, as depicted in Figure 2. In the context of daily impacts, a menu represents all the possible alternatives served at a school on a particular day. A menu entry designates an individual dish listed as a choice in the menu. In Figure 2 therefore, the menu for the 18th of March consists of three menu entries: the vegetarian meal, the meal of the day, and the alternative meal of the day, each of which is further explained in the menu text.

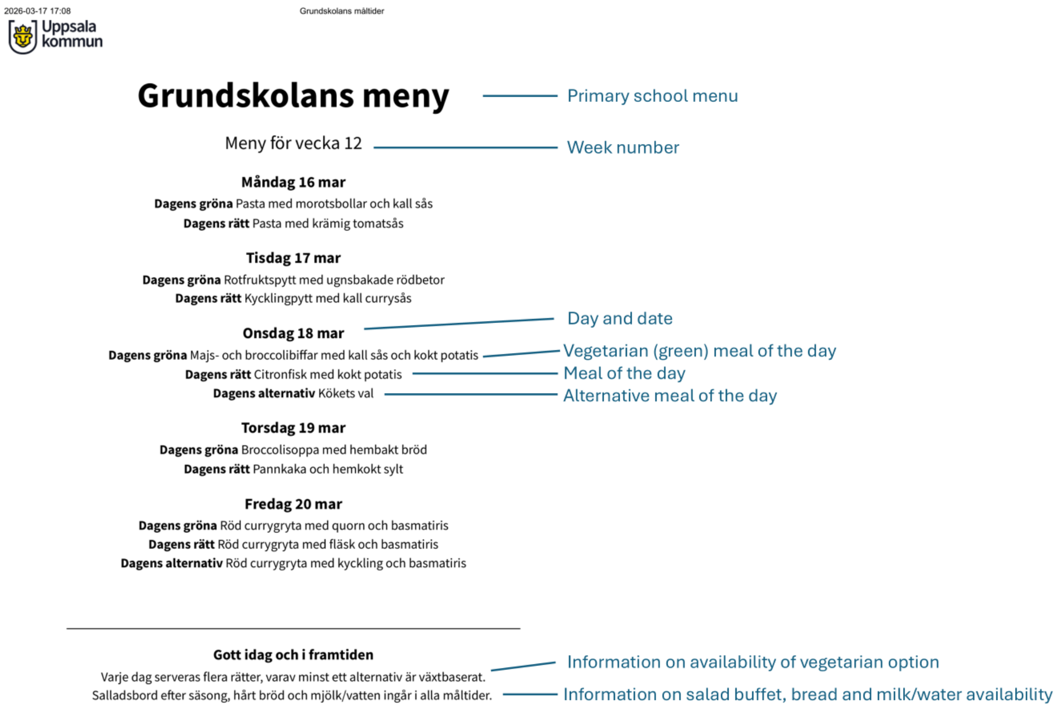

Figure 2. Example primary school lunch menu from Uppsala municipality (Uppsala kommun 2026). Translations and explanations of the menu sections are marked in blue.

In this study, the focus will be on the hot meal component of the lunch. Though the salad buffet may change seasonally, it is not possible to determine the precise composition based on the information featured on school menus. Thus, salad, bread, and accompanying beverages are treated as a constant here. To determine the size of a school lunch portion, data from a survey on food waste in Swedish primary schools and pre-schools was used (Livsmedelsverket 2025c). Median plate waste (20 g) and serving waste (17 g) amounts per person were added to the median amount of food consumed (279 g) to obtain a more accurate estimation of how much food, and therefore impact, can be attributed to a meal. Thus, for the purposes of this study, a school lunch portion, including salad, bread and spread but excluding beverages, is 316 g.

2.3 Menu data treatment

The cleaned database featured 7 296 363 individual menu entries representing individual lunch dishes as well as side options depending on how individual kitchens' reporting conventions. 3 467 734 of these entries were reported by kitchens of primary schools. As it is common for multiple schools in the same municipality to have the same menu, the number of unique menus could be reduced to 667 955. To increase the feasibility of analysing such a large number of menus, the menu data was subjected to normalisation, during which, words indicating preparation method, taste and coordinating conjunctions were removed. Specifications of food item type (e.g. "baguette" or "levain") were grouped together (in this case, as "bread"). Furthermore, uninformative menu entries (e.g. "kitchen's choice" or "summer holiday") and menu entries containing words that occurred on less than 50 occasions in the database were removed.

Further cleaning was done by consolidating dish names (e.g. "vegetarian lasagna" and "lasagna with vegetarian filling"), removing of redundant information (e.g. removing the term vegetarian from dishes which were vegetarian by default, e.g. vegetarian lentil stew), and by assigning consistent terms to menu items (e.g. "vegetarian" and "veg" were assigned the term "vego"). The last normalisation level further consolidated the naming of common dishes, removed flavour or herb descriptions, consolidated relevant dishes by protein type and normalised different spelling conventions. Following this treatment, the number of normalised menus was 316 998, and the number of unique words featured in the normalised menus was 46 295.

2.4 Menu item classification

For descriptive statistics of schools meals, the classification used by Jacobsen et al. (2025), based on SFA's classification, was used. Jacobsen et al. (2025) divided menu entry items into 10 categories: bread, grains, cereals, rice and pasta; dairy; fruits and nuts; meat; pizza, pies and hamburgers; poultry and eggs; seafood; sweets and snacks; vegetables; and other. This classification system was deemed broad enough to be employed for menu data, which, based on initial observations, varied widely in level of detail both in and between kitchens. By employing a broad system, it was possible to classify menu entries with a great level of detail, e.g. "Fiskgratäng, potatis och gröna ärtor" (fish gratin, potatoes and green peas) as well as less descriptive ones, e.g. "fiskrätt" (fish dish). For the benchmarking purposes of this thesis, this level of classification was deemed sufficiently detailed, however, for a granular composition analysis, a more detailed classification would be warranted, as this classification groups many commonly featured side dishes such as couscous, pasta, and bulgur into the same category of bread, grains, cereals rice and pasta. Likewise, the variety of vegetable dishes is reduced as tuber, and legume dishes, such as potato soup and chickpea stew, both fall into the vegetable category. Moreover, other than distinguishing between poultry and seafood, all other types of meat products fall into a general meat category, thus on a descriptive level, pork, beef and game meat appear the same. In this analysis, the plate model (*Tallriksmodellen*) used by the SFA (Livsmedelsverket 2026b) was employed to estimate the proportions of dish components. The plate model is based on the SFA's nutritional recommendations, which in turn are based on the NNR's recommendations. The plate model recommends a portion to be composed of 20% the main protein source, 40% of carbohydrate-rich components, and 40% of vegetables. As this study does not directly focus on nutrition, some amendments were made to the plate model to better allow assessing components and their impacts. Where possible, the simplified menu entries were divided into a main component, characterised either by being a protein source, or by dish nomenclature, and side components. There were given weights of 20% and 40% of the portion (Figure 3). In cases where this division was not possible (e.g. soups), the entire hot meal was assumed to account for 60% of the portion. The other 40% was attributed to the salad buffet and bread. In order to account for the milk served alongside lunch, a per student daily average of 0.12 kg of milk was used (Westerberg et al. 2023) in addition to the components of the plate model.

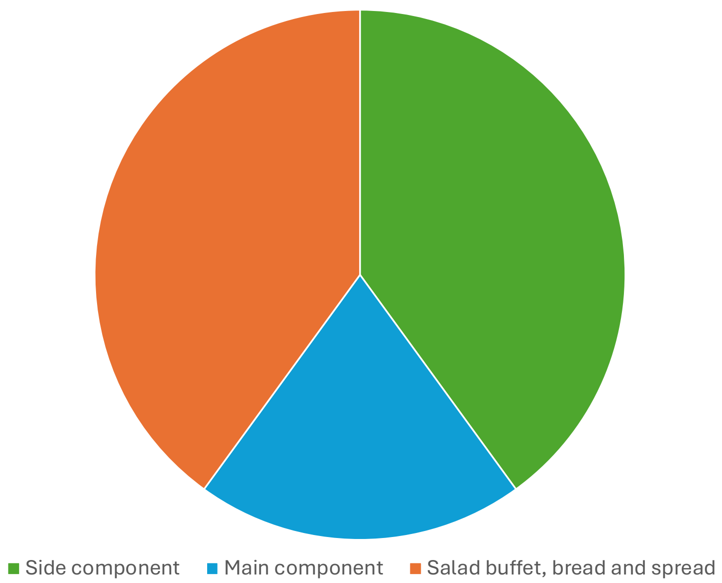

Figure 3. An amended version of the SFA's plate model showing the division of meal components used in this study

2.5 Sustainability indicators

For the purposes of this study, sustainability impact estimation was done using the SAFAD (Sustainability Assessment of Foods and Diets)-tool developed by Röös et al. (2025). The SAFAD tool incorporates ten sustainability indicators, enabling a more comprehensive impact assessment than approaches which focus on a single indicator, such as carbon footprint. The eight environmental indicators included in the tool are: carbon footprint, cropland use, new nitrogen (N) input, new phosphorus (P) input, blue water use, pesticide use, biodiversity loss from land use and ammonia emissions. Moreover, the tool incorporates two social sustainability indicators: animal welfare and antibiotics use. The SAFAD-tool encompasses both raw commodities (crops, terrestrial livestock and aquatic products, and novel foods) and composite dishes. European Food Safety Agency's (EFSA) recipes of foods and dishes were used to obtain a representative picture of sustainability impacts in the European context. For composite dishes, the reverse yield factor approach was employed to dissect these into their constituent parts. The geographic origin of foods and commodities was accounted for by using trade data from FAOSTAT and Eurostat. The SAFAD-tool additionally allows for a country-specific estimation of foods and dishes. In the case of Sweden, the SFA's food recipe database was used for obtaining impacts pertaining to a standardised Swedish diet. Thus, the tool lends itself well for this study.

In this study, the main and side elements of dishes were labelled with SAFAD codes to enable the determination of sustainability impacts. The menu items which had a direct match with a composite dish in the SAFAD database (e.g. spaghetti bolognese) could be directly mapped to the SAFAD code of the whole dish. Dishes that had no direct match were encoded by finding the best suited match in the SAFAD database for the main and the side component. Owing to the scale of the dataset, menu item classification and SAFAD code allocation were performed in order of normalised menu entry frequency until a representative coverage of 80% of the dataset was reached. A similar classification was done for the elements assumed to have a constant impact - salad buffet, bread, spread and beverages - to enable the estimation of the impact of the total meal.

2.6 Municipality selection

Sustainability profiling was performed on data from highly centralised municipalities, i.e. municipalities in which the same lunch menu was served in all reporting schools on a given day. This was done due to both practical constrains related to project duration and analytical feasibility, as well as incomplete database coverage. In decentralised municipalities, profiling could only have been done for individual schools and days as the schools featured in the database did not cover the entirety of the municipality's student body. To determine which municipalities to perform sustainability profiling on, the menu entries across the schools in each municipality featured in the database were compared. For this purpose, a similarity score was calculated in SQLite by matching schools' menu entries' SAFAD codes (for whole dish, main and side) to each other in each municipality on each day on which menu data was available. Entries for which SAFAD codes were not present were removed from analysis. Scores ranging from 0 to 1 were obtained, where 0 indicates no match between daily menu items in different schools and 1 indicates a perfect match. Thus, a higher score indicates a higher centralisation of school menu planning in a municipality. For this study, municipalities with a similarity score of ≥ 0.9 (n=71 municipalities) were included in the final analysis (Figure 4). This threshold was chosen to allow for inclusion of municipalities that share a common menu with some deviations. This was done after performing a manual check on Uppsala municipality (similarity score 0.934), in which all municipally-run schools have the same school lunch menu (Uppsala kommun 2026), where discrepancies occurred due to individual schools altering on which day a menu item was served during a week, and due to the inclusion of some privately-run schools' menus in the database. From each included municipality, the school with the highest number of valid SAFAD entries was selected as a representative for the municipality. The full list of municipalities and representative schools included in analysis can be found in Appendix 1. The menu data from these schools was then subjected to sustainability profiling.

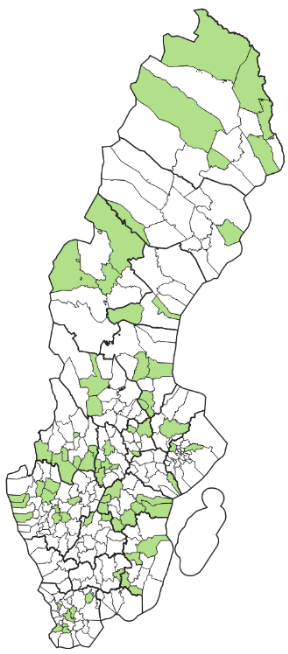

Figure 4. The 71 municipalities included (green) in sustainability profiling

2.7 Sustainability profiling

2.7.1 Consumption pattern estimation

In order to determine the sustainability profile of the meals served in the selected municipalities, an estimation of consumption patterns was done. The extracted menu data was weighted to approximate the contributions of different meal options to a municipality's daily impacts. Based on the number of dishes available on a day in the representative school, and on the position of a dish in the menu (indicated by the menu index number), each meal option was attributed a weight (Table 2) to estimate which proportion of the municipality's students chose the meal. Both the number of available dishes and menu index were assigned after the removal of entries without SAFAD codes to ensure that only valid menu entries were included.

Table 2. Weights allocated to menu options based on the menu index of the dish and the total number of options available on a given day.

option nr	1 option	2 options	3 options	4 options	5 options	6 options
1	1	0.6	0.5	0.4	0.2	0.167
2		0.4	0.3	0.25	0.2	0.167
3			0.2	0.2	0.2	0.167
4				0.15	0.2	0.167
5					0.2	0.167
6						0.167

To account for student absence, a 90% attendance was assumed in analysis.

2.7.2 Per student impacts

To allow for comparison between municipalities and years, and benchmarking to planetary boundaries, the functional unit of per student per lunch impact was determined. The weighted (in terms of attendance and menu weight) impacts of each menu entry were obtained for each indicator. To capture the full per student per lunch impact, the impacts of each menu entry served at a representative school on a given day were summed. For temporal evaluation of impacts, the yearly averages and standard deviations were calculated across all dates for each year from 2019 to 2025. Additionally, per student per lunch impacts were calculated for each municipality across the whole study period.

The average per student per lunch impacts were benchmarked against the planetary boundaries for climate change, land-system change, nitrogen cycling, phosphorous cycling, freshwater change and biodiversity loss proposed by Willett et al. (2019). The global yearly boundaries were converted into daily per capita figures by dividing the boundaries by a world population of 8.2 billion individuals (United Nations 2025). To facilitate comparison, daily per capita boundaries were transformed into per student per lunch boundaries (Table 3) using the recommended 30% share of the school lunch in a student's daily nutritional and energy intake (Livsmedelsverket 2026a) as the conversion factor.

Table 3. Planetary boundaries, based on Willett et al (2019), adjusted to yearly, daily and per lunch per capita boundaries, including uncertainty ranges

Earth system process	Control variable	Global boundary, per year	Global daily per capita boundary	Daily school lunch boundary per capita
Climate change	Carbon footprint	5 Gt CO_2e (4.7-5.4)	1.67 kg CO_2 (1.57-1.80)	0.50 kg CO_2 (0.47-0.54)
Land system change	Cropland use	13 Mkm^2 (11-15)	4.34 m^2 (3.68-5.01)	1.30 m^2 (1.10-1.50)
Nitrogen cycling	Nitrogen application	90 Tg (65-130)	30.1 g (21.72-43.43)	9.02 g (6.52-13.0)
Phosphorous cycling	Phosphorous application	8 Tg (6-16)	2.67 g (2.00-5.35)	0.802 g (0.601-1.60)
Freshwater change	Blue water use	2500 km^3 (1000-4000)	835 dm^3 (334-1336)	250 dm^3 (100-401)
Biodiversity loss	Extinction rate	10 E/MSY (1-80)	3.34E-12 E/MSY (3.34E-13 - 2.67E-11)	1.00E-12 E/MSY (1.00E-13 - 8-02E-12)

The relationship between indicators was assessed using Spearman's correlation coefficients (r). Correlation analysis was performed on the daily per student per lunch level (n=42 103). The non-parametric approach was chosen to accommodate for non-normal distributions and zero-value entries. Analysis was performed in Microsoft Excel using the "rank.avg" function for indicator value ranking and the "correl" function for determining the r values from the ranked data. The correlation levels employed previously by Jacobsen et al. (2025) were used to describe relationships between indicators.

To compare the municipalities across all 10 indicators, hybrid normalisation was performed. The municipal per lunch per student averages ($x_{i,j}$) for the six indicators for which planetary boundary values had been established by Willett et al. (2019) – carbon footprint, cropland use, blue water use, nitrogen application, phosphorous application, and biodiversity loss – were mapped into three risk zones using piecewise linear transformation:

$$S(x_{i,j}) = \begin{cases} \dfrac{x_{i,j}}{B_{\text{safe},j}}, & \text{if } x_{i,j} \le B_{\text{safe},j} \\ 1.0 + \dfrac{x_{i,j} - B_{\text{safe},j}}{B_{\text{upper},j} - B_{\text{safe},j}}, & \text{if } B_{\text{safe},j} < x_{i,j} \le B_{\text{upper},j} \\ 2.0 + \dfrac{x_{i,j} - B_{\text{upper},j}}{B_{\text{upper},j}}, & \text{if } x_{i,j} > B_{\text{upper},j} \end{cases}$$

Where $B_{\text{safe},j}$ denotes the safe zone boundary and $B_{\text{upper},j}$ denotes the upper uncertainty boundary for indicator j. Hence, normalised values $S(x_{i,j}) \le 1.0$ fell into the safe space for humanity, values between 1.0 and 2.0 fell into the uncertainty zone, whereas values greater than 2.0 exceeded the upper uncertainty threshold.

The indicators without established planetary boundaries – ammonia emission, pesticide use, antibiotic use, and animal welfare were normalised using the cross-municipality averages for each indicator:

$$S(x_{i,j}) = \frac{x_{i,j}}{\bar{x}_j}$$

Where $\bar{x}_j$ represents the cross-municipality per student per lunch average impact for indicator j. Here, a normalised value of 1.0 represents average municipal performance, whereas values above it denote trespassing the cross-municipality average. Heatmaps were constructed using R (version 2025.09.2+418).

2.7.3 Composition of menu items

In order to investigate the composition of the school lunch menus over time, the Jacobsen main and side classifications were coalesced to create a single entry for each menu combination, formatted as "Jacobsen main + Jacobsen side". This resulted in 31 unique combinations. To capture the most representative menu combinations, the top 10 combinations in terms of serving frequency were subjected to a descriptive analysis. This frequency tracking was performed for both the nominal menu text, and the modelled number of portions served to investigate whether changes in menu planning translated to shifts in practice. The nominal menu text-based analysis was performed by obtaining yearly counts for the menu combinations in all municipalities. The portions-based analysis was performed by calculating the number of portions served using the menu option weight, assumed attendance and municipalities' primary school student population, and then obtaining the cumulative count.

To visualize longitudinal shifts across the 2019-2025 study period, the annual percentage shares of the top 10 combinations were plotted using 100% stacked area charts.

2.7.4 Impact contribution of menu combinations

The top 10 most frequent menu combinations were subsequently subjected to an impact contribution analysis to evaluate their contribution to each environmental and social sustainability indicator of the SAFAD tool. This analysis was performed by calculating the total impacts of the menu combinations for all studied municipalities across the investigated years. To obtain the total impact, the number of portions served was calculated by multiplying the menu option weight, the assumed attendance, and the municipality's primary school student population. The number of portions served was then multiplied by each corresponding SAFAD indicator value, standardized to a 316 g portion.

To allow for longitudinal comparison, the relative contribution of each of the top 10 menu items was calculated by dividing the cumulative impact of each combination by the total impact of all menu combinations for the period 2019-2025 for each indicator. The menu items' contribution to each sustainability indicator was visualised using a 100% stacked bar chart to allow for cross-indicator comparison and identification of sustainability trade-offs.

2.8 Menu structure analysis

To characterise the availability of alternatives and the structure of menus, an analysis of the representative schools' menu entries was performed. First, the number of dish combinations per day was determined to estimate the availability of alternatives. The menu indices and total number of valid options for each unique date and school combination (n=42 103) were used to categorize school days by the number of options available to students.

Then, to capture the order in which menu alternatives were presented, the main component, mapped via the Jacobsen et al. (2025) classification, was ranked based on the menu index of the dish combination it appeared in. The main component was selected as the primary unit of analysis here since it consistently indicated whether a dish was based on animal-sourced products or plant-based alternatives. By determining the relative share of each main component across each respective option index, an estimation of how animal-based and vegetable-based meals are positioned in school menus could be made. This analysis was limited to the first three menu indices (option 1-3), as serving occasions on which more than three options were available were rare, and thus not considered to be representative.

3. Results

In this chapter, the analytical findings of the study are presented. The per capita environmental and social sustainability impacts of school meals are quantified and benchmarked against established planetary boundaries where relevant. Then, the relative contribution of different dish combinations to each impact category is evaluated, followed by the results of menu composition and structure analysis.

3.1 Per capita dietary sustainability impacts

The modelling of average per capita impacts per lunch (Figure 5) revealed generally large variation in average per capita impacts, indicated by the standard deviation values.

Carbon footprint averaged to 0.79 kgCO_2e per student per lunch, or 2.62 kgCO_2e per student per day when extrapolated using the 30% nutritional and energy recommendation, between 2019 and 2025. The lowest carbon footprint occurred in 2019 (0.76 kgCO_2e per student per lunch) and the highest in 2025 (0.81 kgCO_2e per student per lunch). Cropland use reached a per student per lunch average of 0.94 m^2*year (3.15 m^2*year per student per day) and ranged between 0.92 m^2*year (2019) and 0.96 m^2*year (2025). Blue water use was the lowest in 2024 at 34 dm^3 per student per lunch and highest in 2023 at 38 dm^3 per student per lunch, averaging to 37 dm^3 per student per lunch, or 122 dm^3 per student per day.

Nutrient inputs showcased high stability over the study period. The average nitrogen input was 13.3 g per student per lunch (44.4 g per student per day), and average phosphorous input was 1.34 g per student per lunch (4.49 g per student per day). The lowest yearly average was 12.9 g (2019) and 1.33 g (2024) and highest was 13.6 g (2020) and 1.36 g (2020) for nitrogen and phosphorous respectively.

Ammonia emission averaged at 0.003 kg per student per lunch (0.010 kg per day), varying between 0.00289 kg (2019) and 0.00308 kg (2025). Pesticide use was the lowest in 2024 at 0.0908 g.a.i. and peaked in 2020 at 0.0940 g.a.i, with an average of 0.0925 g.a.i per student per lunch (0.308 g.a.i per student per day). Average biodiversity loss exhibited little change across the years, averaging to 1.66E-13 E/MSY per student per lunch (5.54E-13 E/MSY per student per day), and varying between 1.61E-13 (2019) and 1.70E-13 E/MSY (2025) per student per lunch.

The social sustainability indicators, antibiotic use and animal welfare had a per student per lunch average index value of 1.11 and 0.88 respectively, or 3.70 and 2.94 per student per day. Per student per lunch antibiotic use ranged from 1.05 in

2021 to 1.17 in 2025, while animal welfare ranged from 0.78 in 2019 to 0.94 in 2025.

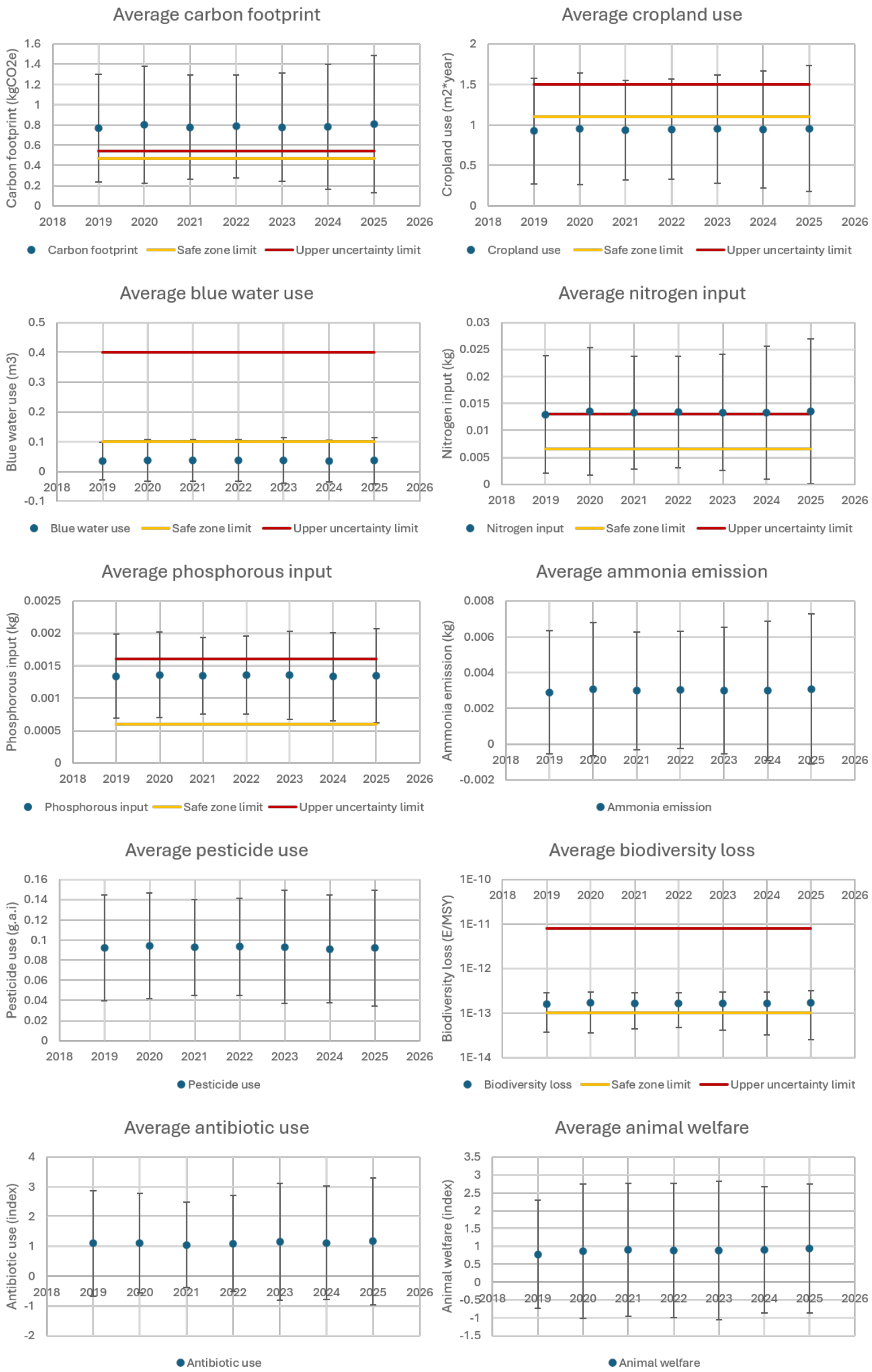

Figure 5. Overview of sustainability impacts across the years (blue), the minimum and maximum values, safe zone boundary (yellow, if relevant) and planetary boundary (red, if relevant) per student per lunch.

In both figure 5, and in figure 6 below, the per student per lunch averages are compared to the planetary boundaries for relevant indicators. Whereas figure 5 presents the yearly averages for each indicator separately, figure 6 showcases the normalised overall average per student per lunch impacts for each of the six indicators, allowing for comparison between indicators' relative impacts. Carbon footprint transgressed the boundaries of both the safe space and uncertainty zone, landing firmly in the high-risk zone. Nitrogen application also passed the upper uncertainty threshold. The other measured nutrient, phosphorous, had a lower relative impact, but still firmly reached the uncertainty zone. Extinction rate landed close to the lower boundary of the uncertainty zone, slightly trespassing it.

The only two indicators which remained in the safe operating space for humanity were blue water use, and cropland use. The former had the largest safety margin, using less than half of the allocated sustainability impact.

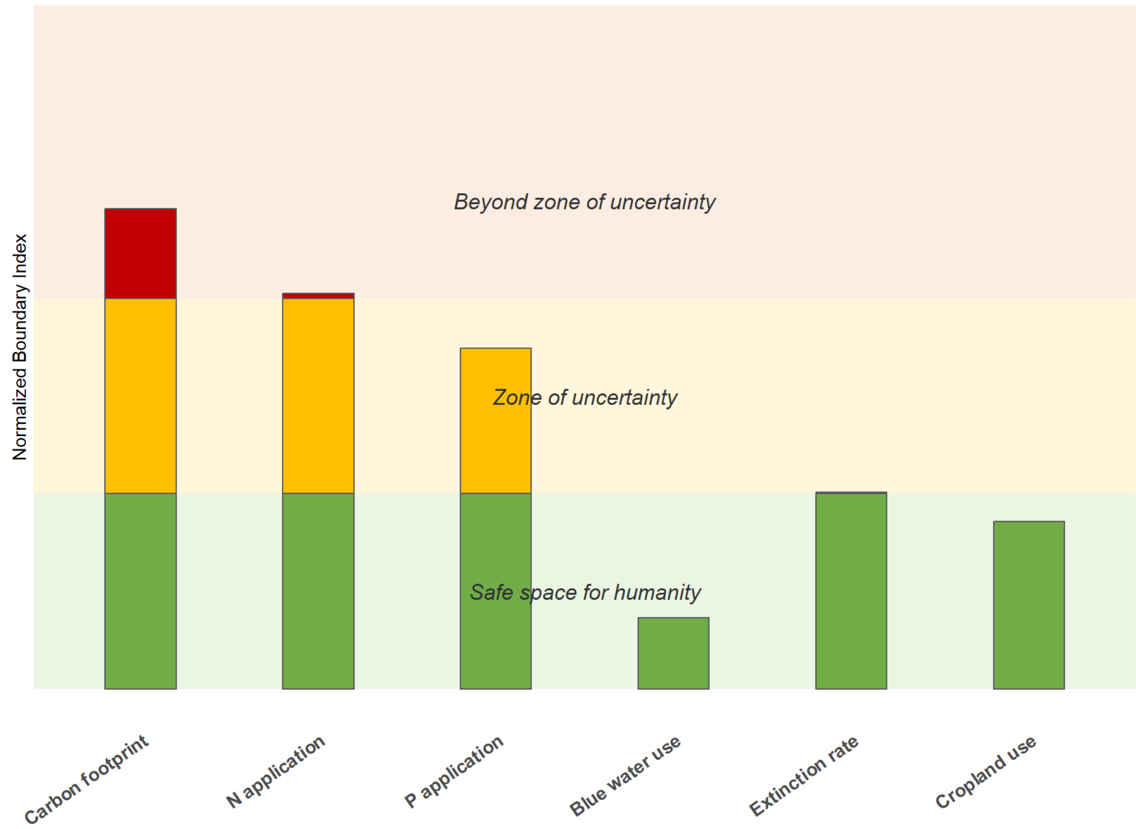

Figure 6. Overview of the average environmental sustainability impacts, benchmarked against lunch portion-adjusted planetary boundaries

Spearman's correlation analysis was conducted to assess between-indicator relationships. All pairwise analyses revealed positive correlations (r between 0.10

and 0.97) between indicators. Most indicators had strong positive correlations (r≥0.7) to multiple other indicators (Table 4). In particular, cropland use was found to be in a strong positive cluster with carbon footprint, nitrogen and phosphorous inputs, ammonia emission, pesticide use, biodiversity loss, and antibiotic use. Carbon footprint, the major proxy indicator in sustainability assessments, was strongly correlated to cropland use, nitrogen input, and ammonia emission. Of the social sustainability indicators, antibiotic use exhibited strong correlations with cropland use, nitrogen and phosphorous inputs, as well as ammonia emissions and pesticide use. The two indicators which exhibited a relatively more independent behaviour were blue water use and animal welfare, with neither having strongly positive correlations with any of the analysed indicators.

Table 4. Spearman's correlation coefficients between sustainability indicators. Colour mapping indicates the correlation strength: dark blue – strong positive correlation (r≥0.7), medium blue – moderately strong positive correlation (0.5≤r<0.7), light blue – weak positive correlation (0.3≤r<0.5), white – correlation strength below 0.3, n=42 103.

Indicator	Carbon footprint	Cropland use	Blue water use	Nitrogen input	Phosphorous input	Ammonia emission	Pesticide use	Biodiversity loss	Antibiotic use	Animal welfare
Carbon footprint	1.00									
Cropland use	0.75	1.00								
Blue water use	0.42	0.54	1.00							
Nitrogen input	0.79	0.97	0.54	1.00						
Phosphorous input	0.65	0.88	0.68	0.86	1.00					
Ammonia emission	0.74	0.94	0.52	0.94	0.85	1.00				
Pesticide use	0.62	0.89	0.65	0.85	0.92	0.86	1.00			
Biodiversity loss	0.64	0.89	0.49	0.87	0.75	0.84	0.75	1.00		
Antibiotic use	0.56	0.81	0.50	0.75	0.80	0.82	0.83	0.65	1.00	
Animal welfare	0.38	0.40	0.10	0.39	0.40	0.48	0.38	0.37	0.53	1.00

Overall, a large degree of inter-municipality variation was observed for the indicators (Figure 7), both in terms of planetary boundary indicators and average impact metrics.

Among the indicators benchmarked against planetary boundaries, carbon footprint exhibited the greatest degree of planetary boundary transgression, with 97.2% of municipalities included in the analysis falling beyond uncertainty zone. Meanwhile, no municipalities landed in the safe zone for humanity. Nitrogen input followed the same pattern, with more than half of municipalities, 56.3%, having normalised average nitrogen input values which trespassed planetary boundaries beyond uncertainty, while no municipalities landed in the safe zone. Two indicators, phosphorous input and biodiversity loss, were characterised occupying the uncertainty zone (relative impact value between 1.0 and 2.0), the former to the extent of 95.8% and the latter completely. Additionally, as seen by the small variation in relative impacts at 0.02, biodiversity loss was highly stable across municipalities. Blue water use and cropland use were the best-performing indicators in terms of impact in relation to planetary boundaries: 100% and 88.7% of municipalities respectively landed in the safe operating space for humanity.

For the indicators without established planetary boundaries, ammonia emission, pesticide use, antibiotic use and animal welfare, comparison was performed by determining relative impact in comparison to the average per-indicator emission. For all indicators, more than half of the municipalities (52.1-57.7%) had average emissions below the per-indicator average. In three impact categories, ammonia emission, antibiotic use, and animal welfare, impact hotspots were observed. A small number (1-2) of municipalities exceeded the average impact by more than 200%.

Overall, Torsås and Vårgårda municipality had the highest compliance to planetary boundaries and lowest relative impacts, While Övertorneå municipality had the lowest compliance.

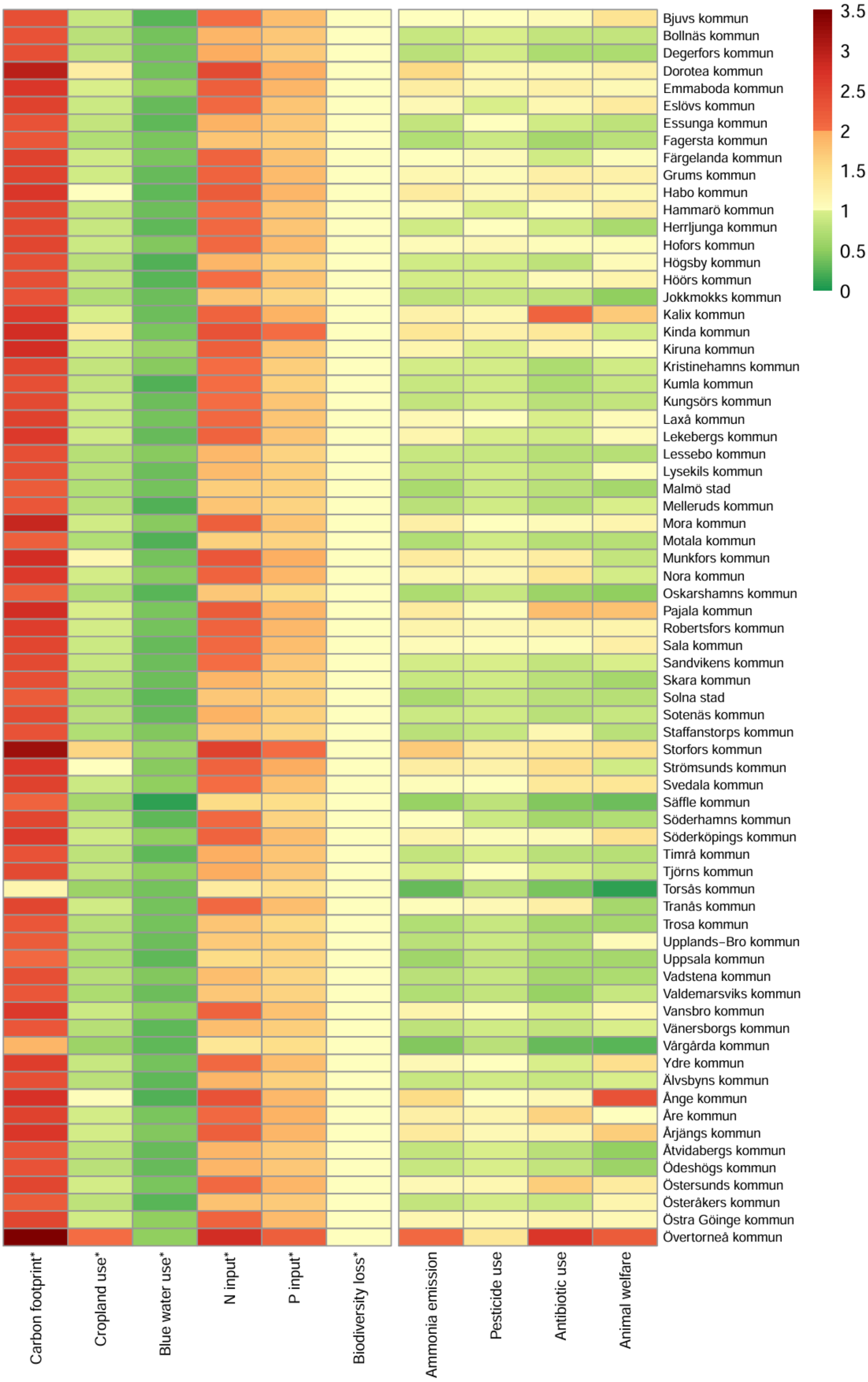

*Figure 7. Heatmap depicting the average impacts per municipality (n = 71) across the 10 studied indicators. The indicators marked with * are normalised against planetary*

boundaries (safe space boundary=1.0, upper uncertainty boundary=2.0), whereas indicators lacking a boundary are normalised against the cross-municipality average impact per indicator. Colour mapping: green shades (<1.0) – safe space for humanity/below cross-municipality average; yellow/orange shades (1.0-2.0) – zone of uncertainty/100%-200% of the cross-municipality average; red shades (>2.0) – beyond zone of uncertainty/more than 200% of the cross-municipality average.

The results depicted above take into account the hot meal, salad buffet and bread with spread. However, the intake of milk is excluded. If the average daily per student milk consumption of 0.12 kg is taken into account, the sustainability impacts are exacerbated (Figure 8). Notably, at 1.11 m^2 per lunch per capita, cropland use exceeds the lower uncertainty threshold of 1.10 m^2 and is pushed into the zone of uncertainty.

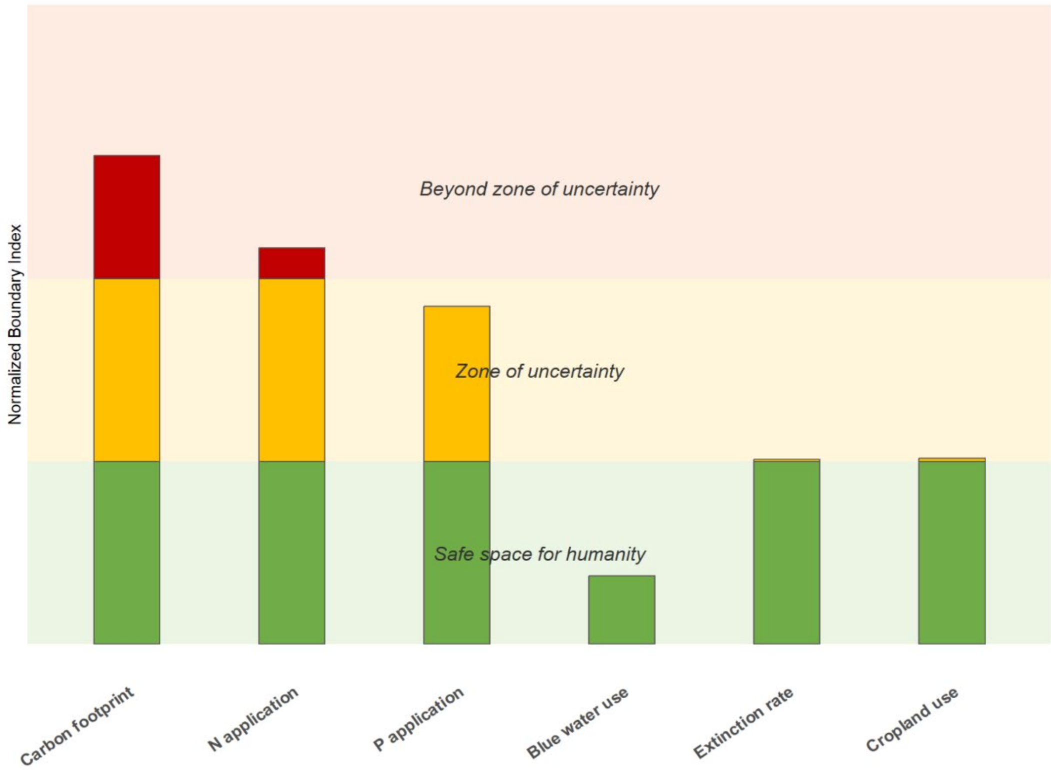

Figure 8. Overview of environmental impacts from school lunches, including milk, benchmarked against planetary boundaries adjusted to a school lunch serving

3.2 Menu composition in the studied primary schools

An analysis of the top 10 most frequently occurring menu combinations, which represent 91.5% of the lunch portions served, reveals some changes from 2019 to 2025 in what is served to Swedish primary school students. In terms of nominal changes observable in published menus (Figure 9), it can be observed that the share of meat dishes has slightly increased by approximately five percentage points, while the share of vegetarian options has decreased by approximately 6 percentage points. The share of seafood decreased slightly (0.12 percentage points) and of poultry product-containing dishes increased by approximately 1.4 percentage points.

To unveil whether the trends in nominal menu composition are reflected in actual food consumption, menu composition based on the modelled portion numbers (based on menu item weight, assumed attendance and student number) were obtained (Figure 10). These results revealed a four percentage point increase in the share of poultry dishes in students' diet (from 8% to 12% of the top 10 items served). The share of vegetable-containing dishes decreased by nearly eight percentage points through the studied period. Meat-containing dishes underwent an increase of approximately three percentage points between 2018/19 and 2025/26. The share of seafood remained relatively constant, peaking at 12.81% in 2020, and generally oscillating between 10 and 11%.

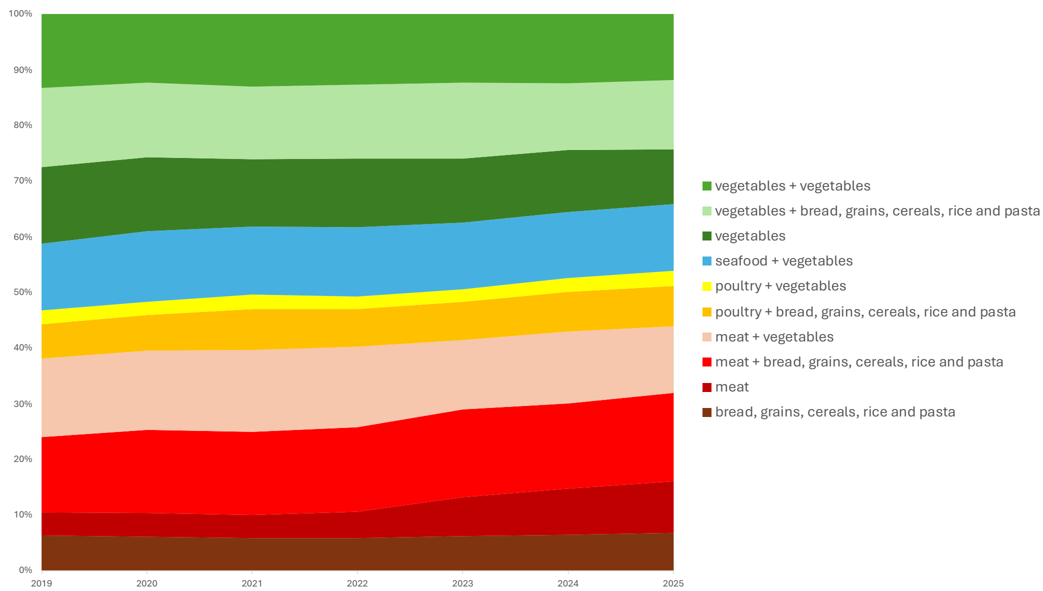

Figure 9. Composition of top 10 most frequently served menu combinations according to published menus

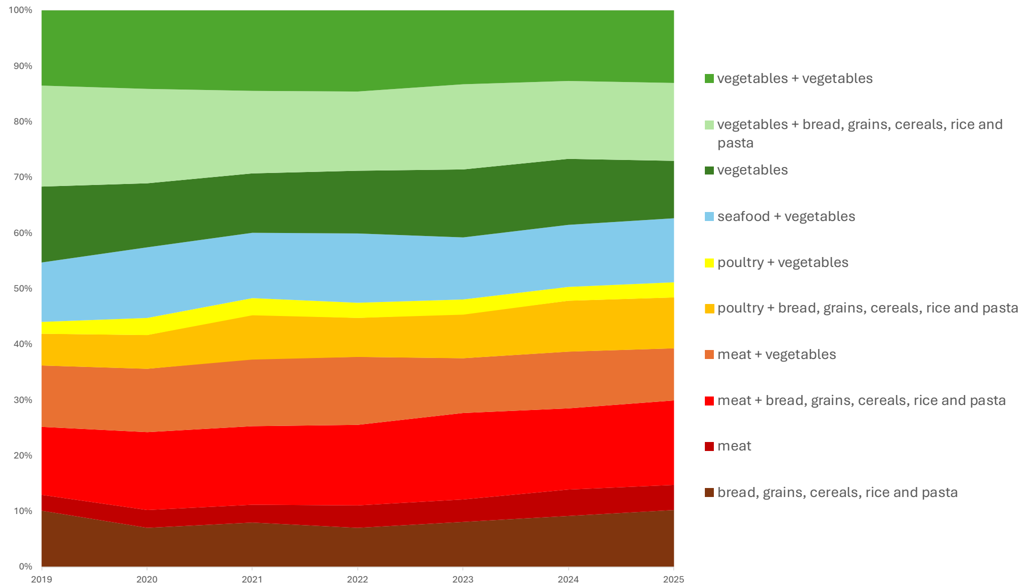

Figure 10. Composition of the top 10 most frequently served menu combinations according to estimated portions served

3.3 Contribution to dietary sustainability impacts

In order to estimate the contribution of different categories of menu items to the sustainability impacts of dishes served in Swedish primary schools during the period under investigation, the percentage contributions of the top 10 most frequently served dishes to the eight environmental sustainability and 2 social sustainability indicators were obtained (Figure 11).

Animal-based product-containing meals, driven by meat, were the principal contributors to environmental impacts, as well as to antibiotics use. Meat-containing menu items were responsible for 33 (animal welfare) to 74% (ammonia emissions) of the per-indicator impacts. On the other hand, poultry-based dishes had generally low impacts across indicators, except for animal welfare, where poultry dishes accounted for 60% of estimated impact. Vegetarian dishes had the smallest contribution to animal welfare indicators, while seafood dishes had a low contribution across categories, with the lowest impact in all categories except for carbon footprint and animal welfare.

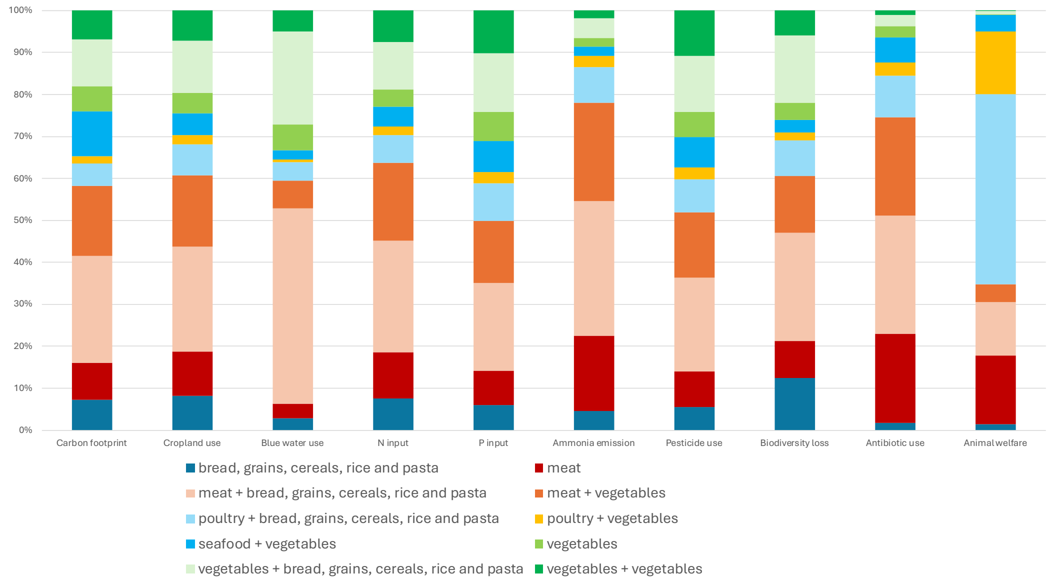

Figure 11. Contribution of the 10 most frequently served menu items to the sustainability impacts

3.4 Menu structure

To gauge the menu structure and availability of alternatives in the 71 municipalities selected for analysis, an analysis of the menu options was performed. In total, the analysis covered 42 103 school days (each day is treated as a unique serving occasion). It was found that days with one option were most common, occurring on more than half of the total valid serving occasions (Table 5), followed by days with two options (41.6%) and three options (3.6%). Days with four or more options were rare, representing 1.5% of the total.

Table 5. Summary of the number of options available across all school days with valid entries in the 71 municipalities included in analysis.

Number of available options	Total days	Percentage share
1 option	*22451*	53.3%
2 options	*17508*	41.6%
3 options	*1519*	3.6%
4 options	477	1.1%
5 options	118	0.3%

6 options	30	0.1%

To further analyse the composition of menus, an estimation of the share of main components listed as option 1 in the menus was performed (Table 6). It was found that animal based main components are the dominant option one, with the share of meat, seafood and poultry products as main element reaching nearly 65% of the total main elements listed as the primary menu option, while vegetable-based mains accounted for approximately 25% of the primary mains. In contrast, vegetable-based mains dominate in the secondary option category (57%), while animal-based mains are less commonly observed, accounting for approximately a third of the secondary mains. As for tertiary options, the shares of animal-based mains and vegetable-based mains are much more closely matched (44% and 40% respectively). Bread, grains, cereals, rice and pasta are relatively consistent, regardless of which main dish option they are.

Table 6. Share of main component (according to the Jacobsen et al. (2025) classification) as option 1 in the analysed menus

Jacobsen main	**Share as option 1**	**Share as option 2**	**Share as option 3**
meat	38.64%	19.26%	27.94%
vegetables	24.60%	57.00%	40.73%
seafood	16.02%	6.36%	6.53%
poultry	10.69%	5.18%	9.68%
bread, grains, cereals, rice and pasta	6.65%	7.18%	6.81%
pizza, pies and hamburgers, etc	2.98%	4.81%	7.88%
sweets and snacks	0.24%	0.06%	0.09%
dairy	0.19%	0.16%	0.32%

4. Discussion

In this chapter, the empirical findings of this thesis are interpreted and contextualised to answer the set research questions. The sustainability impacts of school meals are discussed in relation to the broader dietary habits of Swedish children and benchmarked against global planetary boundaries. Findings concerning the menu structure and composition are compared to nutritional guidelines and media narratives to evaluate alignment with policy and the accuracy of public discourse. The menu planning operations and their implications are addressed, followed by a reflection on the methodological limitations of this study.

4.1 Sustainability impacts of school lunches

In this study, it was found that dishes which include meat are a large driver of environmental impacts across most of the indicator categories. Similar results were reported by Jacobsen et al. (2025) and Lindroos et al. (2025) in their broader analysis of the dietary impacts of Swedish pre-school children and adolescents respectively.

In contrast to previous findings, seafood containing dishes were found to have lower social sustainability impacts than expected. This could be a consequence of the centralised municipal meal planning selecting seafood types with lower antibiotic and animal welfare impacts. However, methodological differences are another possible source of this discrepancy in findings. The studies by Lindroos et al. (2025) and Jacobsen et al. (2025) considered all food groups separately, while in this study, composite dishes were analysed for their sustainability impacts. Specifically, in the case of seafood-containing dishes, the dishes featured in the top 10 most frequent menu items were a combination seafood and vegetables. Considering that the main component was given a share of 1/5 of the dish, the high impacts on social welfare aspects may be diluted by the lower impacts of the vegetable-based side components, as well as the salad buffet and bread. While this approach constrains the ability to gauge the impacts of each food group separately, it also provides insights into how, if consumed in moderate quantities, and paired with dishes with lower impacts, high impact dishes can be consumed in a more sustainable manner.

The longitudinal data showed an increase in poultry serving. While from the perspective of environmental impacts, poultry may seem as a more environmentally friendly alternative to red meat, the social welfare aspects decrease its overall sustainability (Röös et al. 2025). Thus, as the concept of a just food system is becoming increasingly more relevant (Rockström et al. 2025), the case of poultry, especially chicken meat, highlights the importance of considering indicators in a more holistic manner beyond the proxy of the carbon footprint.

A systematic evaluation of relationships between the 10 indicators using Spearman's correlation revealed cropland use as the primary impact driver, with strong positive correlations to all other indicators except blue water use and animal welfare. In contrast, carbon footprint was strongly correlated to three indicators – cropland use, nitrogen input and ammonia emission. Moreover, cropland use was more strongly correlated to both blue water use and animal welfare than carbon footprint. These findings partially align with previous research (Jacobsen et al. 2025), in which the same correlation cluster was observed for carbon footprint, while cropland use had weaker correlations to other indicators than observed here. Nevertheless, both the previously published findings and this thesis found that land use and greenhouse gas emissions serve as unsuitable proxies for animal welfare metrics. Thus, while carbon footprint and cropland use are correlated to each other and several other indicators, serving as helpful benchmarks in sustainability assessments, they are not a perfect fit, and are not suitable for non-physical indicators such as animal welfare.

4.2 Swedish primary school lunches in the context of planetary boundaries

In the context of planetary boundaries, the sustainability impacts of primary school lunches present a slight divergence from the broader trends seen in the dietary impacts of Swedish children. As mentioned above, the diets of Swedish pre-school children and adolescents breach five of the six investigated planetary boundaries, with only blue water use remaining within the safe zone (Jacobsen et al. 2025; Lindroos et al. 2025). In this study, only four of these boundaries were breached, namely carbon footprint, biodiversity loss, N input and P input. This discrepancy indicates that school lunches perform somewhat better in terms of sustainability than the food consumed outside the school context. Explanation for this may be rooted in the composition of diet in these two contexts – while school meals restrict the intake of discretionary items such as soft drinks and snacks, these are more readily available in the general food environment, increasing the environmental impacts of children's diets.

However, the consistent trespassing of carbon footprint, biodiversity loss, as well as N and P input indicates that school lunches remain tied to high-impact agricultural inputs, reflecting the high reliance of school menus on animal-sourced protein which requires heavy fertiliser inputs for feed production. Additionally, when the average per student per lunch carbon footprint is extrapolated to carbon footprint per kilogram of food served (2.48 $kgCO_2e/kg$), the average goal set by Swedish municipalities is overshot, especially considering that the goal of 1.9 $kgCO_2/e/kg$ is set at the point of purchase.

Moreover, the inclusion of milk as a part of the school lunch increases the baseline impacts of school lunches. Relative to plant-based beverages, cow milk has a higher sustainability impact across all ten categories considered in this study than a locally-available plant based drink such as oat milk (Röös et al. 2025). This creates a constant sustainability impact that is difficult to lower in the context of the current school milk provision schemes in the European Union (European Commission 2025). Furthermore, as Jacobsen et al. (2025) noted, the localised reductions in impacts in the school setting from a lower meat consumption (versus in the home setting), can be offset by the relatively higher consumption of milk in schools. This, combined with the finding that meat availability in schools has increased over time, further exacerbates the total impacts of school lunches.

In contrast to the planetary boundary transgressions observed for climate change, biodiversity, nitrogen, and phosphorous indicators, the cropland use figures were unexpectedly low. During the investigated period, the average per capita cropland use for the meal (excluding milk) remained consistently in the safe zone for humanity when compared to the downscaled, per-capita-adjusted planetary boundary. This finding was surprising, as previous literature has identified a positive correlation between carbon footprint and cropland use, both in the specific case of livestock products (Röös et al. 2013), and in terms of general dietary intake of Swedish children (Jacobsen et al. 2025). Moreover, the latest global-scale modelling of planetary boundaries places land-system change in the uncertainty zone (Rockström et al. 2025). While a strong positive correlation was observed in this thesis between carbon footprint and cropland use. an explanation for the discrepancy in boundary transgression may be found in the methodology used for modelling the impacts. Every menu combination included a baseline salad buffet, assumed to consist of mixed vegetables, such as tomatoes and cucumbers. In the Northern European context, the energy-intensive yet land-efficient cultivation of these vegetables in greenhouses can partially explain the decoupling between carbon footprint and cropland use. Additionally, common menu item combinations like seafood plus vegetables or vegetable-only entries further add to this trend. Marine seafood, which is most commonly served in schools, is associated with zero cropland use, but high energy requirements, while vegetable production is spatially efficient. Finally, an explanation may be found in the uncertainties – the uncertainty zone for carbon footprint is narrower than that of cropland use, which may provide an additional reason for the lower-than-expected results.

4.3 Composition of school meals

The composition analysis of the top 10 most commonly served school lunches reveals a discrepancy between what is served to students and the public perception of school meals. The analysis reveals that the share of vegetarian options available in primary schools has decreased, while an increase in meat and poultry options has occurred. This contrasts with public perceptions of school meals, in which the purported increase of vegetarian dishes has become a common topic of debate. The results of this study underline the lack of empirical evidence to support these claims.

As such, the current Swedish primary school catering system is not in alignment wider policy or environmental goals. The NNR-recommended decrease in meat consumption and compensation thereof with increased plant-based and sustainable fish consumption (Blomhoff et al. 2023) cannot be observed in Swedish school lunches. Similarly, the dietary goals set in the context of planetary boundaries are not mirrored by the current school lunch (Willett et al. 2019; Rockström et al. 2025) as animal proteins remain an important part of the school lunch and dominate over vegetarian options.

As such, the claims of forced vegetarianism in schools (Karlsson 2026) seem anecdotal. Based on the observed menu composition, it appears that the nominal presence of vegetarian options forms the basis of the criticism, rather than their actual prevalence or likelihood of being chosen over meat-based alternatives.

4.4 Menu structure

Analysis of the menu structure revealed that in the 71 municipalities considered here, the most common lunch consisted of a single meal alternative, in which an animal product-based component was the most common main dish. Where more alternatives were available, the vegetarian option was commonly presented as the secondary option.

This situation indicates that the default option available for Swedish primary school students is animal based, most commonly mammalian meat. In the context of choice architecture, a default nudge (Thaler et al. 2010) could arise as students, having a set and constrained amount of time to make choices in selecting their lunch, may gravitate towards the most prominent option. Thus, even when vegetarian alternatives are available, their position in the menu may discriminate against the chances of these being chosen by students.

Exceptions to this trend exist, for example, Uppsala municipality consistently lists the vegetarian ("green") option first in the menus (Uppsala kommun 2026). While beyond the scope of this study, it is of interest to investigate whether this menu presentation tactic translates into an increased popularity of vegetarian dishes. Naturally, dish acceptance plays a role in this, but by strategically presenting vegetarian dishes with a high acceptance rate in the menus, an increased consumption of this may be achieved, as was observed when highly accepted dishes with a lower environmental impact were presented in canteens concomitantly with dishes with higher environmental impacts (Flynn et al. 2025).

4.5 Menu design centralisation in the context of sustainable school lunches

In this study, the analysis was limited to municipalities with a high degree of menu centralisation (≥0.9). While this methodological approach restricted the coverage of the Swedish primary school student population and therefore the generalisability of results, the implications of centralisation as a municipal policy tool are worth considering in the context of school lunches.

Regardless of the sustainability impacts, centralised municipalities have an advantage over decentralised ones in several aspects. Firstly, as exemplified by this study, municipalities with a centralised menu planning system lend themselves better to analysis, allowing to keep track of changes in menu composition and associated impacts with greater ease, which in turn allows for a better understanding of each municipality's strengths and weaknesses. Thus, changes can be implemented faster. Similarly, changes made in a centralised municipality are far reaching, affecting every student in a municipal school network.

However, the high degree of centralisation can also have important drawbacks. Depending on municipal priorities, sustainability-related goals may be subservient to budgetary constraints, leading to bulk-purchasing of low-cost, high-impact ingredients and therefore a lock-in in terms of impacts across the municipality. Moreover, centralised menu planning leaves little room for individual innovation in school kitchens. Additionally, menu acceptance may vary largely across a municipality, depending on local cultural differences or kitchen team competencies, potentially leading to low-impact dishes being chosen less.

Thus, while centralisation can leverage change more rapidly, the sustainability of such changes is dependent on the individual in charge of effecting change and the policies governing their actions.

4.6 Limitations

The impacts reported here may be skewed towards underrepresenting the actual environmental and social sustainability impacts of school lunches due to methodological limitations. Firstly, the data normalisation included heavy pruning of the menu texts. While necessary for enabling classification of the main and side element, certain elements of school meals had to be omitted from the normalised menus. Examples include dips and sauces which did not constitute a main or side element (e.g. while bolognese sauce was retained, a yoghurt sauce was removed) and side elements with less assumed significance (such as jams). Additionally, concessions on data complexity had to be made during the classification process. This was the case for menu entries with no direct SAFAD match, whether they were composite meals (such as "korv stroganoff") or single ingredients (such as “haddock”). In these cases, the closest proxy was chosen, resulting in differences in impacts due to deviations from actual recipes or ingredients. Nevertheless, this approach allowed to obtain a conservative baseline approximation of school lunch impacts.

Furthermore, the weights applied to menu options may have led to over- or underestimations of the per-capita and total impacts associated with school lunches in cases where multiple alternatives were available per day. It is estimated that 95% of Swedish adolescents are omnivores (Warensjö Lemming et al. 2018a), thus allocating a weight of 0.6 or lower to the first option (predominantly animal-product based dishes), may have led to underestimation of the impacts of meat dishes while overestimating the impact of vegetables or starch-heavy components, if those were reported as the primary option. In line with this, the results may further be affected by the presumed attendance of 0.9. This number was chosen mainly to reflect absence from school. However, an overestimation could have been made, since previous research indicates that 28% of students enrolled in middle school in Sweden abstain from eating school lunch, with not eating school lunch becoming more common with increasing age (Eustachio Colombo et al. 2020). While a sensitivity analysis was not conducted in this project, these variables are likely to affect the uncertainty of the observed results.

Another limitation relates to the data collection method. As visible in section 3.2, the databases through which menu data was obtained provide uneven data coverage over the years, with the majority of entries being from the period 2019/20-2022/23. Data density before and after these academic years is much lesser, leading to an over-representation of the mid-period and the impacts generated during this time. Additionally, the peak data coverage period coincides with the COVID-19 pandemic and may thus include short-term strategic decisions made during this time period to cope with disturbances in supply chains as well as changes in students’ physical attendance. Thus, the trends observed in this study may not necessarily represent the operational reality across the selected municipalities. Future studies would benefit from a greater equality in the temporal distribution of data. However, in practice, this data disparity indicates that municipalities have moved from using these databases to alternative, less-centralised record-keeping practices. Therefore, achieving a greater data density in the future requires an investigation into how individual municipalities are currently reporting their school menus.

5. Conclusions and further research directions

This study provided an analysis of school lunch menus in highly centralised Swedish municipalities. The composition and sustainability impacts of lunch options offered in 71 municipalities were determined. Based on the results of this analysis, several conclusions can be drawn.

Firstly, despite extensive press coverage regarding a shift to vegetarian lunch options, animal-source proteins continue to dominate the primary option slot. Secondly, the increase of poultry as an animal-source protein in school lunches presents a dilemma between lowering environmental impacts and exacerbating animal welfare concerns. Overall, while school lunches appear to perform better than food consumed outside the school context, they still consistently breach four of the planetary boundaries: carbon footprint, biodiversity loss, N input and P input.

Finally, while this study covers the highly centralised municipalities, the impacts cannot be generalisable to the entirety of Sweden.

To further investigate the sustainability of Swedish school meals, several lines of research are suggested. Firstly, an analysis of the decentralised municipalities should be undertaken to reveal whether the trends observed in this study hold true across the country. Additionally, it would be of interest to decouple the impacts of the main and side dishes in this dataset to allow for a more detailed investigation into the sustainability profiles of the school menus. Furthermore, it would be of interest to further delve into the effects of menu structure to understand whether the positioning of a menu item in a school lunch menu affects the choice of the student in the canteen.

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Popular science summary

Public meals, such as those served in schools and hospitals, represent an important part of a country's food strategy and exemplify its priorities in terms of public health and sustainable development. Meals served in schools have an especially important part to play in sustainable development, as not only are they served to children for a large part of their formative years, but they also play an important role in the formation of future habits, including eating habits.

In Sweden, school meals are served free-of-charge to all primary school students. Menu planning is taken on by individual municipalities but follows national recommendations. In recent years, and in light of increasing concerns about the environmental impacts of food provision, recommendations have begun to highlight the importance of increasing the environmental sustainability of food, for example through integrating more environmentally friendly plant-based options. Simultaneously, there has been an increase in criticism against the inclusion of more vegetarian options in school lunches.

In this context, menus from municipalities across Sweden were investigated to determine the environmental and social sustainability of the meals offered in primary schools. A database of food items and their impacts was used to estimate the sustainability of school food.

It was found that the claims of vegetarian options being forced on students are largely unfounded, as meat continues to be a major default option and vegetarian dishes have decreased in availability of the recent years. Furthermore, Swedish school food still has major sustainability challenges to overcome. Currently, the lunches served in school have impacts in several areas which are greater than the planet can sustain. Moreover, it was found that some dishes, such as poultry-based dishes, have lower environmental impacts than other meat options, but higher impacts on animal welfare. This establishes important dilemmas for menu planners and policymakers in determining what is truly a sustainable meal.

Appendix 1

Overview of the 71 municipalities, with the SAFAD code-based similarity scores, included in the sustainability profiling

Swedish name of municipality	**Similarity score**
Älvsbyns kommun	1
Ånge kommun	1
Åre kommun	1
Årjängs kommun	1
Åtvidabergs kommun	1
Bjuvs kommun	1
Degerfors kommun	1
Eslövs kommun	1
Essunga kommun	1
Färgelanda kommun	1
Herrljunga kommun	1
Högsby kommun	1
Kinda kommun	1
Kristinehamns kommun	1
Laxå kommun	1
Lekebergs kommun	1
Lessebo kommun	1
Lysekils kommun	1
Malmö stad	1
Melleruds kommun	1
Munkfors kommun	1
Nora kommun	1
Oskarshamns kommun	1
Österåkers kommun	1
Robertsfors kommun	1
Säffle kommun	1
Skara kommun	1
Söderhamns kommun	1
Solna stad	1
Staffanstorps kommun	1
Storfors kommun	1
Timrå kommun	1
Torsås kommun	1

Tranås kommun	1
Trosa kommun	1
Vadstena kommun	1
Vänersborgs kommun	1
Vansbro kommun	1
Ydre kommun	1
Fagersta kommun	0.998
Kiruna kommun	0.998
Motala kommun	0.998
Ödeshögs kommun	0.998
Höörs kommun	0.997
Upplands-Bro kommun	0.997
Hofors kommun	0.996
Vårgårda kommun	0.995
Jokkmokks kommun	0.992
Kalix kommun	0.992
Hammarö kommun	0.989
Pajala kommun	0.988
Kumla kommun	0.985
Kungsörs kommun	0.983
Östra Göinge kommun	0.983
Sala kommun	0.981
Söderköpings kommun	0.981
Tjörns kommun	0.975
Mora kommun	0.973
Valdemarsviks kommun	0.967
Bollnäs kommun	0.963
Övertorneå kommun	0.958
Emmaboda kommun	0.946
Svedala kommun	0.945
Grums kommun	0.941
Uppsala kommun	0.934
Sotenäs kommun	0.928
Strömsunds kommun	0.918
Habo kommun	0.914
Dorotea kommun	0.907
Östersunds kommun	0.904
Sandvikens kommun	0.903

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