Climate impact of ultra-processed foods in the Swedish diet

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Abstract

The climate impact associated with food consumption is large. The size of the impact depend on the type of food and how it is produced. Food systems are currently changing and urbanization and increased affluence of consumers have led to an overall increase in food consumption and a rise in consumption of processed foods globally.

In this thesis, the climate impact of the Swedish diet was analysed, based on type of food and degree of processing. The NOVA framework was used to classify food groups into unprocessed or minimally processed foods, culinary ingredients, processed foods or ultra-processed foods (UPF). National statistics on food consumption was combined with a dataset with greenhouse gas (GHG) emissions associated with foods, based on life-cycle assessment of foods on the Swedish market. For a comparison of Swedish data to other settings, a literature search was done to capture studies on UPF and environmental impacts.

Our analysis show that the largest contribution of GHG emissions from the Swedish diet comes from foods categorised as unprocessed or minimally processed. The food groups that contributed most to climate impact were ‘Meat&Eggs’ and ‘Dairy’ in unprocessed or minimally processed foods and ‘Meat&Eggs’ and ‘Discretionary foods ’ in UPF.

A literature search rendered six papers relating climate impact to the degree of food processing based on the NOVA classification. In one paper, there was a higher climate impact of a diet higher in UPF than a diet higher in less processed foods, while two other papers found no association of degree of processing and climate impact of the diet. Also in the food-based analyses, results were inconsistent on the role of UPF on climate impact. The study results reflect the climate impact associated with the dietary pattern of the studied populations. Some of the differences between studies may also be due to methodology, as the authors used different ways to control for energy intake.

Our conclusion is that the least processed foods contribute more to the climate impact of the Swedish diet than the foods categorised as UPF. The NOVA classification is not well aligned with a food science view of what food processing is and not suitable for analysis of climate impact of diets. More information on the energy use in different food processing steps is crucial for investigating and reducing the climate impact of food processing.

Keywords: climate impact, culinary ingredients, diet, food consumption, food processing, greenhouse gas emissions, minimally processed foods, NOVA, ultra-processed foods

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Abbreviations

CH_4	Methane
CO_2	Carbon dioxide
EU	European Union
FFQ	food frequency questionnaire
GHG	Greenhouse gases
HCFC-22	hydrochlorofluorocarbon R-22
IPCC	Intergovernmental Panel on Climate Change
LCA	Life cycle assessment
NOVA	A system for classification of degree, place and purpose of food processing (not an acronym)
N_2O	Nitrous oxide
UPF	Ultra-processed foods

1. Introduction

Globally, the food system is a major contributor to greenhouse gas (GHG) emissions, water use, land use, and loss of biodiversity. Current food consumption in Sweden is not sustainable, as per capita consumption exceeds the planetary boundaries for GHG emissions, application of nutrients and cropland use (Moberg *et al.* 2020). The largest potential to reduce climate impact from the food system lies in a shift to a more plant-based diet, reducing the consumption of meat and dairy (IPCC 2022).

Diets high in vegetables, fruits, whole grains, fish, low-fat dairy and legumes and low in red and processed meats, sugar-sweetened beverages, sugary foods, and refined grains are associated with a lower risk of chronic disease (USDA 2020). In many cases, whole foods such as vegetables, fruits, legumes and whole grain products contain more dietary fibre and more micronutrients than highly processed foods such as fast food, snacks, cakes and ice cream. The UN Food and Agricultural Organization together with the World Health Organization recommend both more plant-based foods and minimally processed foods (World Health Organization 2019). However, trends towards more convenience foods speaks against minimally processed foods as the sole option to animal sourced foods. Responding to a demand for plant-based options, products to use as alternatives to meat and dairy have been developed, and they are often highly processed.

There is not one single way to classify degree of food processing, as methods of processing varies widely. NOVA is the most used framework to define degree of food processing (Sadler *et al.* 2021). It was also in the NOVA framework that the term ultra-processed foods (UPF) was coined (Monteiro *et al.* 2016). Describing the environmental impact of processed foods is relevant to foresee the full impact of the ongoing dietary transition and the implications of a future transition towards a more plant-based diet.

1.1 Aim and delimitations

The aim of this study is to assess the climate impact (total GHG emissions) of food consumption in Sweden by foods that are classified as unprocessed or minimally processed foods, culinary ingredients, processed foods or UPF according to the

NOVA classification. Previous literature of climate impact of UPF will also be reviewed.

This study uses national statistics on direct consumption of categories of foods. Because statistics on consumption of individual foods was not available, classification of single foods with the NOVA-classification was not possible. A decision to limit the scope of the thesis to climate impact was justified by the fact that this is an overall important impact and the most frequently available measurement of environmental impact. For example, water use would have been interesting to include, but as only water use in agriculture was included in the database used to perform the analyses, this did not seem appropriate for a study on food processing.

The scope of the literature review for this study is the environmental impact, with a focus on climate impact, of ultra-processed foods and does not attempt to review the extensive literature on UPF and health or on how the concept is understood and perceived by different actors.

2. Background

This thesis focuses on climate impact of food consumption, with a particular focus on the concept of UPF. This section describes climate impact of food consumption and food processing in general, and some trends in the food system that underlies the emerging of this concept.

2.1 Climate and environmental impact of food systems

The food system is a major contributor to GHG emissions, water use, land use, and loss of biodiversity globally (Poore & Nemecek 2018; Willett *et al.* 2019). It is estimated that about one third of global GHG emissions caused by human activities can be attributed to the food system (Crippa *et al.* 2021). The estimation from the Intergovernmental Panel on Climate Change (IPCC) is that 21–37% of the global anthropogenic GHG emissions are related to the food system (IPCC 2019).

The method used for assessing the climate impact per unit food is often life cycle assessment (LCA) reporting the impact of different steps in production. The impact of all activities such as enteric fermentation from ruminants, soil emissions, energy used for manufacturing of agriculture inputs, machinery, irrigation, transport, storage and food processing is accounted for and aggregated, and gives the total GHG emissions per unit of food (Notarnicola *et al.* 2017).

The largest contribution to the climate impact from the food system comes from agriculture, land use and land use change and from keeping of livestock in particular (Crippa *et al.* 2021). Agriculture is also the most energy demanding part of the food system, using a third of the food sector´s energy within the European Union (EU) (Monforti-Ferrario *et al.* 2015). Energy use during industrial processing accounted for 28% of the food sector´s energy us in the EU while, as an example, the final disposal accounted for only about 5% of the energy use in the food sector (Monforti-Ferrario *et al.* 2015).

Animal source foods have the highest climate impact per kilo. In the Swedish diet GHG emissions are highest from beef and lamb (about 35 kg CO_2-equivalents per kilo bone-free weight), followed by cheese with about 10 kg CO_2-equivalents per kilo. Cereals and fruits and vegetables have an impact of less than 2 kg CO_2-equivalents per kilo (Moberg *et al.* 2020).

2.2 Food processing

The purposes of processing foods are multiple: increased edibility, palatability and to increase storage time. Throughout history food processing techniques have improved food safety by prevention of microbiological spoilage and food security by increasing storage time and by allowing for the production of more food from a commodity (Forde & Decker 2022). The latter resulting in less waste of crops and animal products. Traditional processes developed in households such as salting, drying, fermenting today takes place in processing plants. Figure 1 shows food processing as the second step in a food supply chain and the different dimensions used to conceptualize processed foods; the extent of change, the nature of change, the place of processing and the purpose of processing (Sadler *et al.* 2021).

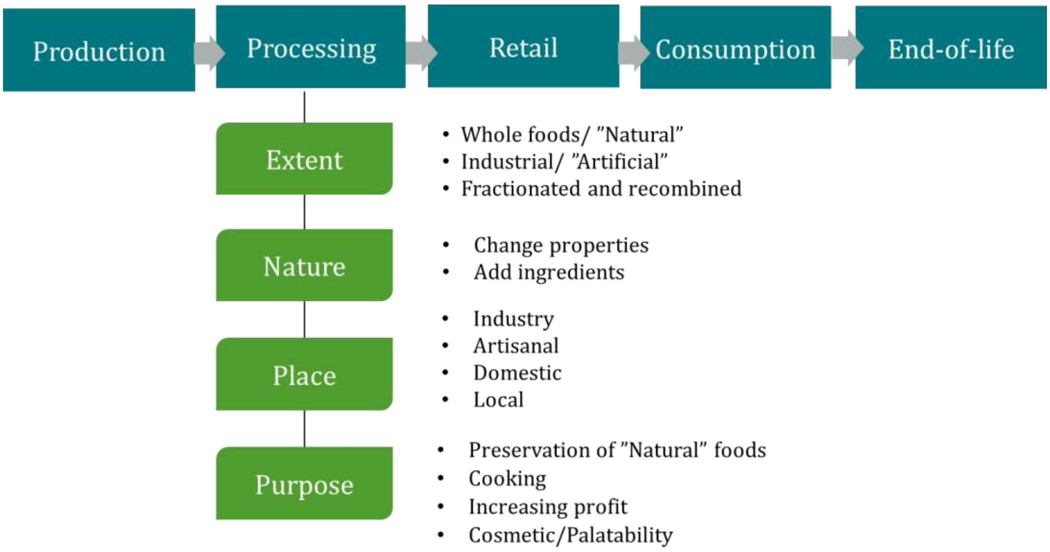

Figure 1. An example of a food supply chain (horizontal in blue) combined with the dimensions in the conceptualisation of processed foods (vertical in green) adapted from (Sadler et al. 2021).

Several frameworks have been used to classify foods according to their degree of processing (Crino *et al.* 2017). The NOVA food classification system is used in this study because it is the most widely used (Sadler *et al.* 2021). NOVA was initially developed to follow the nutrition transition in Brazil from traditional diets high in dietary fibre to a diet with more foods high in refined grains, fats and sugars (Monteiro *et al.* 2010). The NOVA classifies food into four categories depending on degree of processing and where the food is processed (Table 1). The NOVA classification has been applied by scientists all over the world to classify diets and assess health outcomes. A large and growing body of evidence associates UPF with negative health outcomes (Pagliai *et al.* 2021).

Table 1. Explanations and examples of unit operations and foods by the NOVA classification

Category	Explanation[1]	Example of unit operations[2]	Examples of foods in this study
NOVA 1: Unprocessed or minimally processed foods	Edible parts of plants or animals, also fungi, algae and water.	Cleaning, cutting, peeling, drying, freezing, pasteurization, fermentation and packaging are acceptable.	Coffee, Fresh and frozen vegetables, Fresh and frozen meat and fish, Fruits, Flour, Milk, Natural yoghurt, Pasta, Rice, Tea
NOVA 2: Processed culinary ingredients	Obtained from category 1 by pressing, refining, grinding etc.	Extraction, purification, cooking, refining, milling, hydrolysis and enzyme processes are acceptable.	Butter, Salt, Seasonings, Starch, Vegetable oils
NOVA 3: Processed foods	Products made from group 2 and group 1 with the purpose of increasing durability or modify sensory quality (2-3 ingredients).	Baking, deep-frying, salting, pickling, smoking may be acceptable, depending on place of preparation industrial or at home.	Beer, Canned fruits and vegetables, Crispbread, Flour mixes, Frozen potato products, Hard cheese, Pickled herring
NOVA 4: Ultra-processed food	Industrial formulations of ≥5 ingredients.	Hydrogenation, curing, hydrolysis, interesterification, smoking, extrusion, and fractionation are associated with ultra-processed products.	Buns, Cheese spreads, Chocolate, Flavoured yoghurt, Ice-cream, Jam, Processed meat, Soft bread, Soft drinks, Sauces

[1](Monteiro *et al.* 2019), [2](Knorr & Augustin 2021)

The concept UPF has been criticised for making use of the neutral term food processing, long used in food science, for a classification of a nutritional impact (Knorr & Augustin 2021). The classification does not align with the way the food industry classify processing (Forde & Decker 2022). Some foods classified as minimally processed by NOVA has a high number of processing steps. One example is the production of fresh milk which requires at least five unit operations before it is packaged: filtration, separation, blending, homogenization, pasteurization (Forde & Decker 2022), but is classified as minimally processed by NOVA (Monteiro *et al.* 2019).

2.3 Food system changes affecting the climate impact from processed foods

Phenomena such as urbanization, population growth and increased income of consumers are key drivers in the food system (Béné *et al.* 2019). They increase the demand for food overall, for processed foods and animal-based foods. Wasteful behaviour can also be added as a contributor to an increased demand for food (Bodirsky *et al.* 2020). The dietary transition is a concept used to describe the change from relying on a few whole foods as staple foods to the use of more convenience foods, high in sugar, salt and fat. This transition is associated with a rise in overweight, obesity and non-communicable diseases. When countries are becoming richer, populations demand a wider variety of more processed, higher value convenience products (Baker *et al.* 2020). Trade policies, internationalization and growing concerns for food safety contributes to an increasingly globalized food trade and food systems that are ‘supermarketized’ (Béné *et al.* 2019). This nutrition transition is however, not similar in all places and countries (Baker *et al.* 2020).

The total environmental impact of a processed food product relates to primary production of the ingredients (for example wheat, maize, sugar cane, meat) and to impact from the processing (energy use) (Fardet & Rock 2020). In food processing, a large proportion of energy consumption comes from thermal processes (Ladha-Sabur *et al.* 2019). Powders such as instant coffee and milk powder, fried foods such as French fries and crisps and bread were the most energy intensive food groups at the manufacturing stage (Ladha-Sabur *et al.* 2019). Convenience foods can be more energy intensive to produce but require less energy for storage and preparation in retail and in the household. Dried food products are more energy intensive in production but are lighter at transport and have long shelf life. This means that it is important to do LCA of the whole food chain to be able to evaluate total impact and where energy can be saved. Monforti-Ferrario *et al.* (2015) report high demand of energy in the production of refined products and of products of animal origin, relative to for example vegetables and cereal products.

The environmental impact of processed foods in relation to unprocessed foods has not been extensively investigated. A recent report summarizes the data on environmental impact of food products that may be classified as UPF (Anastasiou *et al.* 2022), and there are some examples of studies on climate and water footprint of diets high in UPF. These studies will be presented and discussed in this thesis.

3. Methods

This section describes the management of data on food consumption and climate impact, the classification of foods according to degree and type of processing and the literature review performed to find previous assessments of climate impact associated with UPF consumption.

3.1 Data on food consumption and climate impact

Consumption data was downloaded from the Swedish Board of Agriculture (2022). This national statistics, the 'direct consumption' refers to the total quantity of food reaching households, restaurants and public catering establishments in Sweden. Methods to calculate and estimate the direct consumption varies between food groups but the data is based on national production and trade. Waste at storage and retail was accounted for in these statistics. Consumption statistics used in this study cover a mean of the years 2017-2021 (Swedish Board of Agriculture 2022).

The food consumption data was used to update the dataset used in Moberg *et al.* (2020). This dataset included information on environmental impact of foods from production to retail in Sweden used in an analysis to benchmark the Swedish diet in relation to environmental targets (Moberg *et al.* 2020). This dataset was based on the data developed for an analysis of the impact of climate taxes in Sweden (Moberg *et al.* 2019). Moberg *et al.* (2019) used import statistics to find the country of origin of the foods sold in Sweden and averages were based on the largest production countries to correct for import from transit countries where the food was not originally produced. The GHG emissions per kg or litre of foods were multiplied with the amount of food sold on the Swedish market. The total GHG emissions in these datasets include average emissions of carbon dioxide (CO_2), methane (CH_4), nitrous oxide (N_2O) and the hydrochlorofluorocarbon R22 (HCFC-22) associated with food production and in transport up to retail (Moberg *et al.* 2019). In the 2020 publication, the energy use in greenhouses and the fertilizer use for certain crops were updated (Moberg *et al.* 2020). Land specific input data was primarily taken from *The World Food LCA Database* (available through the Ecoinvent database version 3.5). If no value from that database was available, data was taken from peer reviewed LCA studies or LCA reports (Moberg *et al.* 2019). Standard values from carefully chosen literature was used as a proxy for emissions from packaging and electricity use in processing. Production of seeds and seedlings, production of mineral phosphorous and potassium fertilizer, production of pesticides and energy use for wholesaler and retail storage was not included (Moberg *et al.* 2019). Data were adjusted for allocation of by-products in production systems with multiple outputs. Waste and losses in the production chain was also accounted for (Moberg *et al.* 2019).

Some data in the Moberg *et al.* (2020) dataset was of higher detail than the official statistics (Swedish Board of Agriculture 2022), as it was obtained by personal communication with industry representatives in 2017. To update these numbers, the same ratio between food groups was assumed. For example, the official statistics give one number for the total of citrus fruits. In data from 2011-2015 lemons, lime and grapefruit was 22% of total citrus (Moberg *et al.* 2020). This percentage was used to separate different types of citrus in 2017-2021 consumption data. Similar calculations were made for bananas and melons, and for data on apples and pears. Data from Moberg *et al.* (2020) was used for berries as this data separated fresh and frozen berries of different types. Also for a combined value for fish, crustaceans and molluscs, data from 2011-2015 was used. An assumption was made that 35% of fermented milk such as yoghurt was flavoured with for example fruit, berries, sugar or sweetener (Nilsson *et al.* 2022).

3.2 Classification of degree of processing

Each food or food group as it appeared in the official statistics was assigned to one of four categories according to NOVA (Monteiro *et al.* 2019). See Table 1 for examples and Appendix 1 for a full list. Some food groups consist only of one type of food such as carrots classified as unprocessed or minimally processed (NOVA 1) or salt classified as a processed culinary ingredient (NOVA 2). When a food group could be expected to contain majority of foods from one of the NOVA categories, the whole food group was in most cases classified accordingly. For example the food group pasta contains both pasta sold raw which would be in the minimally processed foods, and pasta as in ingredient in a ready-to eat pasta salad, which would be classified as UPF (NOVA 4). Pasta was assumed to contain mostly unprepared pasta (Nilsson *et al.* 2022) and was hence classified as NOVA 1. Spices and mustard was classified as NOVA 2 (Juul & Hemmingsson 2015). Sauces such as ketchup and mayonnaise were classified as NOVA 4 despite also sometimes being used as ingredients in cooking.

The categorization of bread, fermented milk products and processed meats was less straightforward. Bread belongs to processed foods (NOVA 3) if it is unpacked and freshly made, for example bought directly from a small bakery. Most bread in Sweden is however packed and sold in retail, and in this study soft bread was classified as UPF (NOVA 4). Crisp bread is not mentioned in guides to classification but based on our interpretation of the intention of NOVA, crisp bread was classified as NOVA 3. Natural (unsweetened) fermented dairy products belongs in the category unprocessed or minimally processed (NOVA 1), while a sweetened fruit yoghurt is an ultra-processed food (NOVA 4). In the official statistics, fermented milk products are presented by fat content and not in subgroups by natural/unsweetened or flavoured/sweetened. Nilsson et al. (2022) was used to estimate the market share of fermented milk product with fruits and berries and that new food group was classified as NOVA 4. Smoked and cured meats belong to processed foods (NOVA 3) or UPF (NOVA 4). In this study both unmixed cured meats and provisions, including for example ham and mixed cured meats and provisions, including for example sausages and paté was classified as NOVA 4. Hard cheese was classified as NOVA 3 and processed cheese (cheese spreads) as NOVA 4. Alcoholic beverages made from fermentation of NOVA 1 foods; beer and wine were classified as NOVA 3 (Monteiro *et al.* 2016) while liquor was classified as NOVA 4.

3.3 Data analysis

GHG emissions as CO_2-equivalents were presented for the following food groups (for a full list, see Appendix 1):

1. Cereals (bread, flour, pasta, rice)
2. Greens (fruits, vegetables, root vegetables, legumes, nuts)
3. Meat and eggs (fresh and frozen meat, ham, sausages)
4. Fish and seafood (fresh and frozen fish and crustaceans, canned fish, caviar)
5. Dairy (milk, cheese, fermented milk, cream, butter)
6. Beverages (coffee, tea, beer, wine, soda, mineral water)
7. Discretionary foods (sweets, honey, confectionery, bund, pastry, snacks)
8. Other products (vegetable fats, mixed soups, sauces and salt)

The GHG emissions in different food groups were then presented in the four NOVA categories. In addition, the contribution of individual greenhouse gases was presented separately to identify differences in GHG contribution by degree of food processing. The gases CH_4 and N_2O originate mainly from agriculture (emissions from enteric fermentation of ruminants and emissions from manure). HCFC-22 is a short-lived gas in the atmosphere. It is associated with fish consumption due to the use of HCFC for refrigeration on some fishing vessels. The contribution of CO_2 to the total GHG may come from primary production, processing or transport. The following factors were used for conversion to CO_2 equivalents: 27 (CH_4); 273 (N_2O) and 2106 (HCFC-22) according to the method used by IPCC (2022).

Sensitivity analysis was made for the diverse groups ‘Soft bread’ and ‘Corn flakes, roasted rice, cheese doodles, popcorn’ by classifying these as NOVA 3 instead of NOVA 4.

3.4 Literature review

A number of plausible search strings were tested, with words such as ‘climate’, ‘carbon footprint’ or ‘environment’. However these searches were too narrow to find a number of the papers identified as relevant before the search. Thus, the final literature search was made to capture all types of spelling of UPF and to limit the search to food related publications. A search was made 2023-04-27 in Web of Science with the search string:

> ("ultra processed" or "ultra-processed" or "ultraprocessed" or "UPF") and "food"

No limitation on language was set and only original papers or reviews were evaluated. The hits were downloaded to Excel and evaluated for inclusion by title. For a few of the search hits, the abstract was used to assess the publication for inclusion. Only papers that presented results, or reviewed papers on results on associations between UPF and climate impact were included.

4. Results

In this section, the results of the analysis of climate impact of categories of foods by the NOVA-classification are presented, as well as the outcome of the literature review.

4.1 Swedish food consumption

The consumption of different food groups, as a mean of kg or litres year 2017 to 2021 is shown in Table 2. Most beverages (beer, wine, soda, mineral water, fruit juice) are expressed in 1000 litres, while grounded coffee and tea leaves are presented in tonnes. ‘Greens’ is the largest one in tonnes followed by ‘Dairy’. ‘Discretionary foods’ is a mix of foods that are based on for example foods in ‘Cereals’ (buns) and ‘Greens’ (potato crisps).

Table 2. Swedish yearly food consumption (mean 2017-2021). Data from the Swedish Board of Agriculture (2022)

Food group	Consumption (tonnes)
Cereals	852660
Greens	2283420
Meat&Eggs	913060
Fish&Seafood	136880
Dairy	1279860
Beverages[1]	1775200
Coffee and tea	82720
Discretionary foods	631040
Other	352140

[1] Beverages other than Coffee or tea, consumption expressed in 1000 litres

4.2 Climate impact by NOVA-classification

The climate impact by degree of processing is presented in Figure 2, showing the contribution from the greenhouse gases CO_2, CH_4, N_2O and HCFC-22.

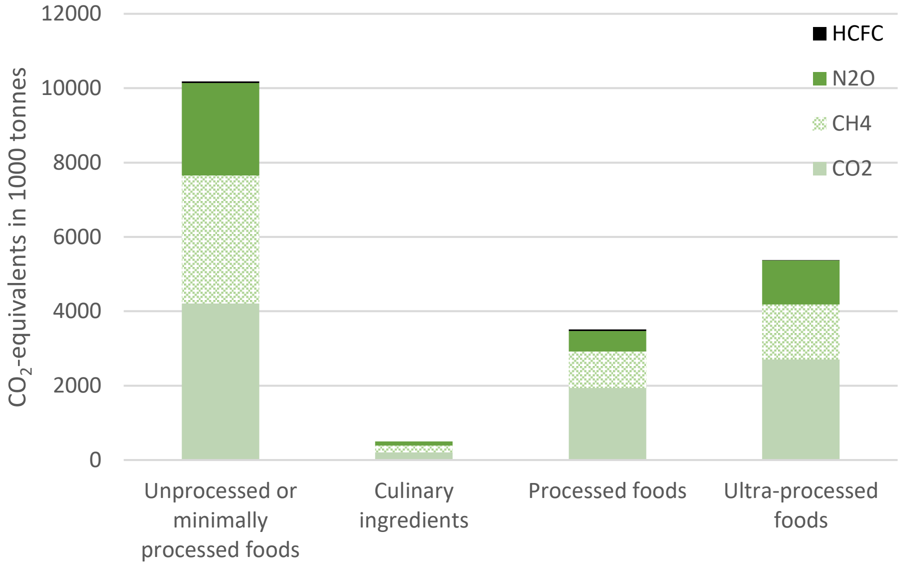

Figure 2. Climate impact of food consumption in Sweden by degree of processing, showing the impact of different greenhouse gases.

Climate impact from the foods at retail in Sweden is dominated by the category unprocessed and minimally processed foods. If processed foods and UPF are combined, their climate impact is about the same as for unprocessed or minimally processed foods. Few foods are classified as culinary ingredients, and thus the impact from this category is small.

In unprocessed and minimally processed foods, the contribution from CH_4 is of similar size as CO_2, while N_2O contributes slightly less (Figure 2). For processed foods and UPF, the contribution of CO_2 to total GHG emissions is of similar size as CH_4 and N_2O combined. HCFC, associated with fish and seafood is a minor contributor to climate impact in all categories of food processing.

4.3 The contribution of food groups to climate impact

The classification of foods by the NOVA framework results in groups of different sizes and different types of foods. The contribution of different food groups to climate is presented in Figure 3-6. In processed and minimally processed foods the food groups ‘Meat&Eggs’ and ‘Dairy’ contribute the most to climate impact (Figure 3). CH_4 is a large contributor to climate impact of these food groups.

Culinary ingredients include few foods. ‘Dairy’, which in this category includes sour cream and yoghurt for cooking and butter, is the main contributor to GHG emissions (Figure 4). Also in processed foods, the main contributor is ‘Dairy’, which in this category means cheese (Figure 5). The main contributors to climate impact in the UPF are ‘Meat&Eggs’ and ‘Discretionary foods’ (Figure 6).

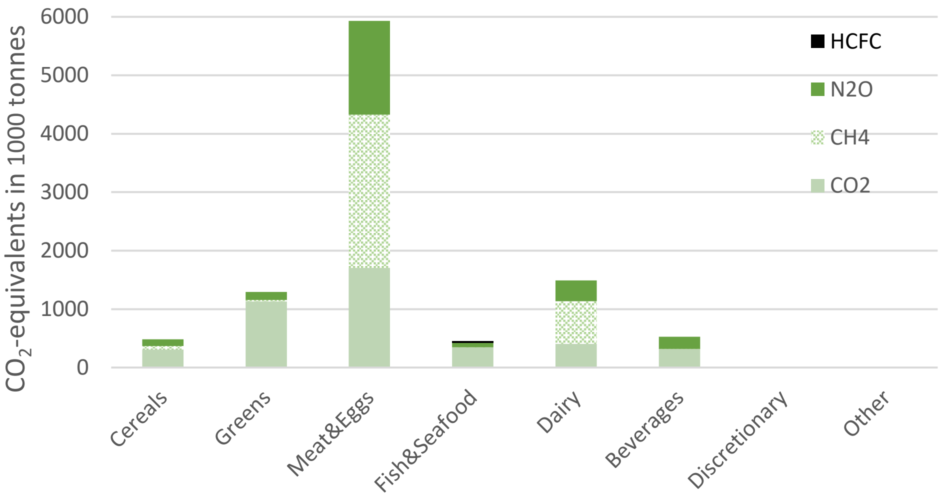

Figure 3. Climate impact of unprocessed or minimally processed foods consumed in Sweden, showing the impact of different greenhouse gases by food groups.

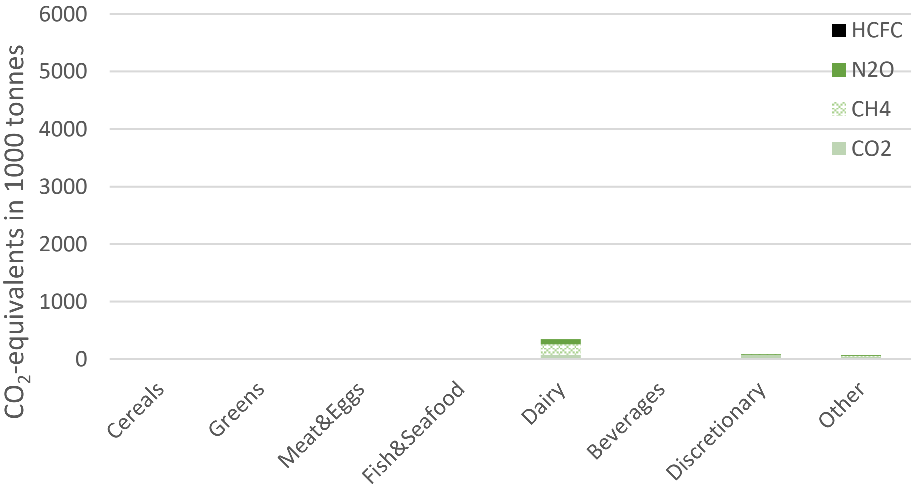

Figure 4. Climate impact of processed culinary ingredients consumed in Sweden, showing the impact of different greenhouse gases by food groups.

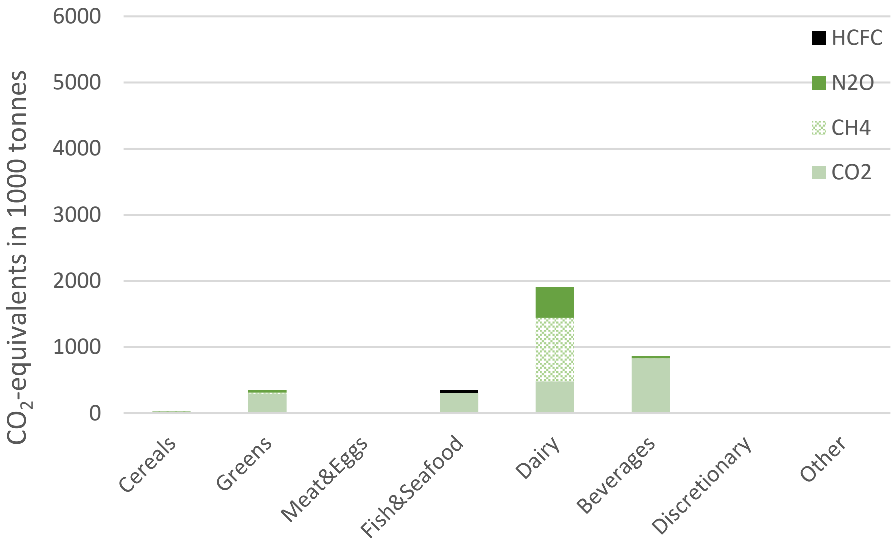

Figure 5. Climate impact of processed foods consumed in Sweden, showing the impact of different greenhouse gases by food groups.

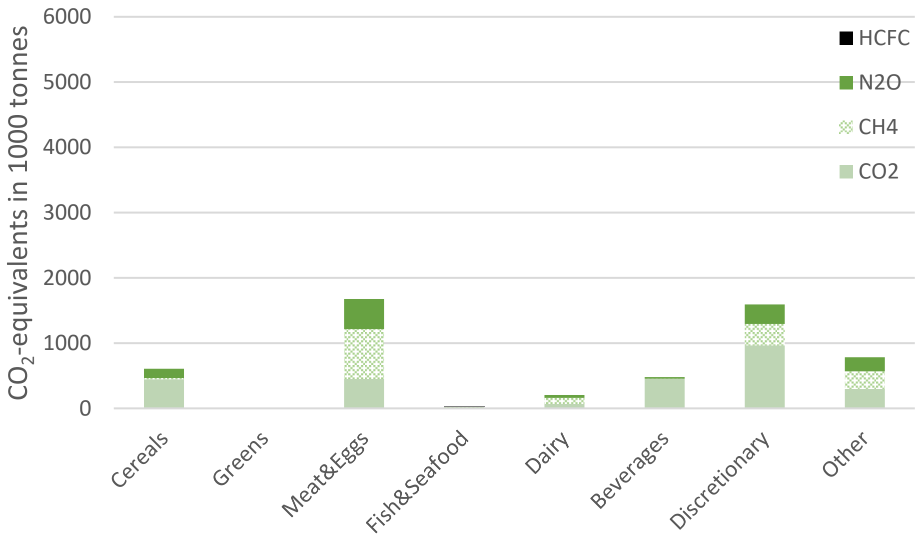

Figure 6. Climate impact of ultra-processed foods consumed in Sweden, showing the impact of different greenhouse gases by food groups.

4.4 Sensitivity analysis

To find out how sensitive our analysis was of classification of foods to NOVA categories, ‘Soft bread’ and ‘Cornflakes, roasted rice, cheese doodles, popcorn’ were put in NOVA 3 instead of NOVA 4. The reason for choosing these groups was that these diverse foods are difficult to classify and they may affect the outcome due to the high consumption. These groups together make up 590 000 tonnes of CO_2-equivalents. The results of this sensitivity analysis is presented in Figure 7 where the climate impact of processed foods and UPF is more similar in size than in the analysis presented in Figure 2. However, this does only result in slight changes in the 'Cereals' group of the graphs in Figure 5 and Figure 6 (data not presented).

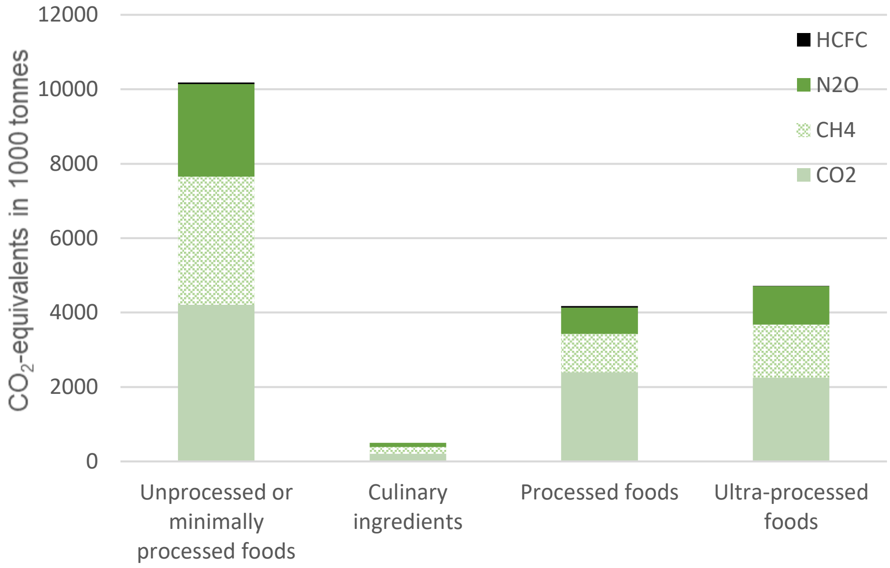

Figure 7. Climate impact of food consumption in Sweden by degree of processing, showing the impact of different greenhouse gases. This figure is showing an alternative NOVA classification of some of the cereal foods.

4.5 Literature review

The search rendered 1675 hits. Based on type of publication, 230 hits were removed before downloading: 138 (dataset only), 47 (proceedings of meetings), 45 (abstracts), 30 (editorial material), 1 (letter), 1 (patent). This resulted in 1444 original or review papers, reports or unspecified material downloaded and evaluated for inclusion based on the title. Papers in English, Portuguese and in Spanish appeared in the search. The abstract was read for 33 of the hits, when the title did not give enough information for evaluation. The majority of papers was excluded because they had the scope to describe the consumption of UPF, or to relate it to health outcomes. Some papers were interesting for a general discussion on UPF and sustainability, but did not present data on the relationship between UPF consumption and any environmental impact and was thus not included in this study (Gibney 2019; Baker *et al.* 2020; Seferidi *et al.* 2020; Capozzi *et al.* 2021; Leite *et al.* 2022; Macdiarmid 2022).

Six papers, some including more than one type of analysis, were found to relate degree of food processing to environmental impacts and they are summarized in Appendix 2. These studies all included climate impact as one of the studied environmental stressors. All six papers used NOVA to classify degree of food processing. Three papers reported an analysis of diet, where the focus was environmental impact by categories of food processing according to NOVA (Garzillo *et al.* 2022; Vellinga *et al.* 2022; Kesse-Guyot *et al.* 2023). Three papers reported a food based analysis of association of degree of processing to environmental impact (Berardy *et al.* 2020; Aceves-Martins *et al.* 2022; Vellinga *et al.* 2022). One paper analysed the environmental impact by stages of food production (Kesse-Guyot *et al.* 2023). One paper was a time series analysis of degree of food processing in the food purchases in certain regions over 20 years, linking this to the GHG emissions from foods during the same period (da Silva *et al.* 2021).

Garzillo *et al*. (2022) and da Silva *et al.* (2021) used different methodology to study UPF and environmental impacts in Brazil. Da Silva *et al*. (2021) performed a time series analysis of GHG emissions from the diet during 1987-2018. Food purchases in metropolitan areas were used as a proxy for diet. GHG emissions from diet increased by 183% over this time. Simultaneously, UPF became more common. Meat products classified as UPF was the main contributor of GHG emissions per 1000 kcal in the UPF category during this time. Most types of UPF foods increased, for example ready-to-eat meals, milk-based products, sweets, sweetened beverages, cakes and cookies. Among the minimally processed foods, GHG emissions from cereals other than rice, poultry and eggs increased, while rice, beans and milk contributed less to GHG emissions over time. Although several parallel changes in the diet took place, the authors attribute the increased GHG emissions from the diet to the dietary transition and the increase in products classified as UPF (da Silva *et al.* 2021).

Garzillo *et al.* used more specific consumption data, namely from the Brazil National Dietary Survey with interviews of more than 32 000 participants. Two dietary recalls of 24 hours were used. Data for assessing climate and water footprint was from a national database of 569 foods. The authors analysed the climate and water impact by quintiles of contribution of UPF to total energy intake, and did so in five strata of the population (Garzillo *et al.* 2022). The quintiles of UPF contribution were not associated with GHG emissions in this study. This was explained by a lower intake of meat in the groups with high UPF in their diet. A higher intake of UPF was associated with a higher water footprint, and this was due to a higher energy intake (Garzillo *et al.* 2022).

In France, the national dietary survey with three 24 hour dietary recalls was used to capture consumption (Kesse-Guyot *et al.* 2023). Foods were categorized and presented in quintiles of percentage of contribution of foods from NOVA 1, 2, 3 and 4. Data on 14 environmental pressure indicators were used for some foods but for most foods only GHG emissions, land use, water use and energy demand were presented. Data came from the database *Agrobalyse* with more than 2000 foods. In this study, the higher impact of UPF intake on environmental stressors was explained by higher energy intake in diets with high contribution of UPF (Kesse-Guyot *et al.* 2023). After adjustment for energy intake there was no association between quintiles of UPF and GHG emissions. In the French population, the effect of GHG emissions of UPF is outweighed by the high meat consumption among consumers of a diet with a high contribution of minimally processed foods (Kesse-Guyot *et al.* 2023). That water use was higher for a diet of less processed foods, compared to a diet high in UPF can be explained by the high consumption of fruit and vegetables, non-alcoholic beverages and red meat by consumers whose diets were classified as less processed. Kesse-Guyot *et al.* (2023) also analysed the environmental impact by stages of food production. They found that the environmental pressure from foods mainly occurred from agricultural production. Food processing and packaging contributed more to environmental impacts in diets rich in UPF, than for diets low in UPF (Kesse-Guyot *et al.* 2023). Interestingly they also found that in France, the climate footprint of packaging was higher among consumers who had a lower consumption of UPF. There was no obvious explanation to this, but the limitation of data on packaging was mentioned in the paper.

Vellinga *et al.* (2022) used a national dietary survey with two 24-hour dietary recalls to assess the climate and water footprint from the Dutch diet according to categories of processing. Data on GHG emissions and blue water use was available for 265 foods, and in all other cases, a value from a similar food was used. Diets with a high percentage of UPF contributed more to climate footprint than did diets high in minimally processed foods, as expressed per 2000 kcal (Vellinga *et al.* 2022). On the other hand, diets high in UPF had a lower water footprint. The authors also performed a food-based analysis of impact per 100 gram foods and found that emissions of GHG were higher for UPF than for foods classified as minimally processed or processed foods (Vellinga *et al.* 2022). Water footprint was lower for UPF than for minimally processed or processed foods. They did not analyse foods separately based on origin, for example cereal-based foods or dairy.

A food based analysis of climate impact by degree of processing was also performed for commonly eaten foods in the UK (Aceves-Martins *et al.* 2022). A database of 4912 foods, with GHG emission data for 153 foods was available for the analysis. When data on CO_2-equivalents was not available, a value from a similar food was used. Aceves-Martins *et al.* (2022) found that GHG emissions were lower for more processed foods than for unprocessed foods as assessed per 100 kcal of foods. Foods with vegetable-based protein had lowest GHG emissions across the NOVA-categories.

The Adventist health cohort includes more than 96 000 adults in the religious group Adventists living across all states of the US and in Canada. Berardy *et al*. (2020) classified the food items in the food frequency questionnaire (FFQ) based on NOVA. In this particular FFQ of 200 items, there were detailed questions on for example meat-analogues and breakfast cereals, resulting in many items classified as UPF. Per serving, climate impact was highest for the food items classified as UPF, while land use was highest for processed foods. Water consumption was highest for minimally processed foods (Berardy *et al.* 2020). Overall, in the study, meats and dairy had a high climate impact, while plant-based meat-analogues had low climate impact and land use, although they were associated with higher water consumption than meat.

5. Discussion

In this section the results of the analysis is discussed in light of findings from the literature review. The strength and weaknesses of the study are then put forward. This section concludes with a discussion on the NOVA framework for classification and on the policy implications of our findings.

5.1 Results in light of previous findings

The analysis shows that the largest contribution of GHG emissions from the Swedish diet comes from foods classified as unprocessed or minimally processed. A closer look at the contribution of different food groups shows the large contribution of ‘Meat&Eggs’ and ‘Dairy’ to overall climate impact of the Swedish diet, confirming previous research (Moberg *et al.* 2020; Hallström *et al.* 2022). Within the category UPF the food group ‘Discretionary foods’ contributed on a similar level as ‘Meat&Eggs’ to the climate impact. The contribution of different greenhouse gases was presented to be able to see differences between the categories of processing. The contribution of CO_2 was slightly larger in the UPF than in the unprocessed or minimally processed foods, which could indicate a larger contribution to the total GHG emissions from processing steps rather than primary production, also seen by Kesse-Guyot *et al.* (2023). CH_4 and N_2O contributed similarly, indicating the strong relation to food origin even in the UPF category. The contribution of HCFC was negligible in all NOVA categories.

In the six papers found in the literature review, consumption of UPF was not consistently associated with lower or higher climate impact than less processed foods. Garzillo *et al.* (2022), Vellinga *et al.* (2022) and Kesse-Guyot *et al.* (2023) share similar methodology of population based dietary intake, classified into NOVA categories and databases of environmental impact of foods, building on the evidence of LCA studies. Analyses based on consumption indicated that UPF was not associated with a higher climate impact than less processed foods (Garzillo *et al.* 2022; Kesse-Guyot *et al.* 2023) or that there was a higher climate impact of a diet higher in UPF than a diet higher in less processed foods (Vellinga *et al.* 2022). Food based analyses showed higher climate impact of UPF per portion (Berardy *et al.* 2020), and per 100 grams of foods (Vellinga *et al.* 2022) but lower climate impact of UPF foods per 100 kcal (Aceves-Martins *et al.* 2022). As these studies did not separate between processed and unprocessed foods of different origins, these results are difficult to interpret.

The differences between results may be due to differences in food consumption patterns. In a diet where many foods fall into the category UPF, the climate impact associated with UPF will be high. Also in a dietary pattern where many foods of animal origin are classified as UPF, there will be a strong association between climate impact and UPF. As described by da Silva *et al*. (2021) the UPF consumption increased parallel to a rise in climate impact from foods during a time period in Brazil. The climate impact of the consumption of unprocessed or minimally processed meat was stable during the period, whereas the impact from ultra-processed meat and other animal-source UPF products increased (da Silva *et al.* 2021). In France, higher intake of UPF in the diet was associated with higher energy intake (Kesse-Guyot *et al.* 2023). A diet with relatively high intakes of minimally processed foods contained more meat, which balanced out the higher climate impact of a diet high in UPF, which was seen in analysis unadjusted for energy intake (Kesse-Guyot *et al.* 2023). Thus, the results of the studies reflect the climate impact associated with the dietary pattern of the population.

Some of the differences may also be due to methodological choices. All studies used NOVA classification and they had a similar way of calculating GHG emissions. However, the authors used different ways to control for energy intake and some adjusted for other variables such as socioeconomic status of low-or high consumers of UPF.

We found that the highest climate impact of foods in the Swedish diet originated from the minimally processed food category, which can be explained by the fact that several meat and dairy products are classified as NOVA 1. Plenty of cereals and vegetables and fruits are also classified as NOVA 1, but they contribute less due to their generally low climate impact (Poore & Nemecek 2018). Our results are not fully comparable to any of the analyses found in the literature search because we used statistics on the total quantity of food reaching households, restaurants and public catering establishments to represent consumption. In studies using dietary surveys (Garzillo *et al.* 2022; Vellinga *et al.* 2022; Kesse-Guyot *et al.* 2023) adjustments for energy intake and socioeconomic factors can be made. Several papers showed opposite directions of the degree of processing and impact on climate and the impact of water (Berardy *et al.* 2020; Vellinga *et al.* 2022). This shows that it is important to study several environmental impacts in relation to food processing.

5.2 Strength and limitations of this study

The strength of the study is the extensive database that was used for analysis. The climate impact estimations include all steps up to retail and include the foods consumed in Sweden, also imported foods (Moberg *et al.* 2020). Consumption data was taken from official statistics ensuring quality controlled data, accurate at national level (Swedish Board of Agriculture 2022). However, it is a limitation that some foods of special interest in the discussion of UPF, for example plant-based alternatives to dairy products and plant-based alternatives to meat, are not separate categories in the statistics.

NOVA classification was made on the basis of food categories. Thus, it was not possible to distinguish between individual foods with differences in processing and packaging. Information of particular brands of foods would have made it possible to check ingredients before classification. Some foods are difficult to classify even if the ingredients list is known, as place of production or sale is essential for classification, as in the example of bread (Sadler *et al.* 2021). It is not the first time the food groups in the statistics from the Swedish Board of Agriculture have been classified according to NOVA (Juul & Hemmingsson 2015) and overall, the information about the foods was sufficient to classify them for the purpose of this study. The most difficulties occur in choice of classification into processed foods or UPF. We were able to show that our result of which foods contributed most to climate impact was robust to the change of two large food groups where there was likely a mix of items that should be classified as processed foods and UPF.

The analysis was performed on climate impact up to retail level, which means that some issues were naturally left out. As discussed by Ladha Sabur *et al.* (2019), capturing energy use in every step of the food chain is necessary as some foods such as those classified as UPF may require more energy in production, but less energy for storage and cooking (Ladha-Sabur *et al.* 2019). Home cooking probably has a small impact overall on energy use and climate impact but the impact seems to vary considerably for different foods (Frankowska *et al.* 2020). Waste up to retail was considered, but more specific consumption data linked to information on household waste of different products would allow an in depth analysis about UPF and waste. Foods classified as UPF could be less prone to waste in retail and at household level, as they often have a long shelf-life (Forde & Decker 2022). On the other hand, many alternatives in the supermarket shelves may cause more waste at retail level, and overconsumption of palatable foods may lead to metabolic food waste. Food processing is key to develop smart use of by-products in food production (Capozzi *et al.* 2021). The implications of this on the climate impact of UPFs will not be known without more specific studies of supply chains.

5.3 NOVA classification of degree of processing

In general, there is an agreement between different classification tools to what is unprocessed and processed foods (Crino *et al.* 2017). The classification by NOVA had lower agreement with the other frameworks (Crino *et al.* 2017), indicating a different intention and scope of the NOVA compared to the other frameworks. Sadler *et al*. (2019) found a lack of scientific evidence behind the criteria for assigning categories of foods according to degree of processing, for all eight reviewed frameworks, which included NOVA. For example, there was no clear approach to how purpose of processing was applied in the frameworks, even when explicitly included as an important dimension. The classification was not systematic, and inconsistencies were found between publications using the same model for classification (Sadler *et al.* 2021). Furthermore, it is generally challenging to categorise a degree of processing when there are many types of foods in combination with many types of processes. The NOVA classification does not tell us the degree of processing as in number of processes that has occurred in producing a type of food and in that sense it is not well aligned with a food science view of what food processing is (Forde & Decker 2022). NOVA does not seem to be the optimal framework to assess degree of food processing for evaluating climate impact of foods. This is also not what NOVA was developed for.

5.4 Conclusions and policy implications

Our conclusion was that the foods classified as unprocessed or minimally processed contributed more to climate impact of the Swedish diet than did processed foods or UPF. This supports the idea that the origin of food is more important for climate impact than the degree of processing. To reduce climate impact of food production, a shift from a high dependence on animal sourced foods while increasing the amount of plant-based foods is the most effective to reduce emissions (IPCC 2022). This could, in practice mean an increase in dependency on highly processed plant-based foods. Plant-based foods, produced as alternative to meat and dairy differ in their composition but often have a much lower climate impact than meat and dairy (Berardy *et al.* 2020; Carlsson Kanyama *et al.* 2021; Berardy *et al.* 2022; Shanmugam *et al.* 2023). If food processing is increasingly seen as something inherently negative (Meijer *et al.* 2021), this may hinder the development of nutritionally sound products with low environmental impacts (Messina *et al.* 2022).

The climate impact of foods that are classified as UPF should not be ignored, only because it is not the largest contributing category. The environmental impact of discretionary foods such as confectionary and snacks and beverages such as soft drinks is significant (Moberg *et al.* 2020; Anastasiou *et al.* 2022). Reducing them would reduce the UPF in the diet and reduce climate impact, if not substituted with other foods with high climate impact. Choosing a type of bread that would not be classified as UPF (for example one baked at home or at a local bakery) would probably have a very small impact on GHG emissions. As two case studies show, the larger scale of bread production may have advantages of being more energyefficient, while local smaller bakeries cause less emission during transport (Sundkvist *et al.* 2001; López-Avilés *et al.* 2019).

Some have argued for including UPF into dietary guidelines as choosing whole foods is often good both for health and environmental sustainability (World Health Organization 2019), while others argue that mentioning UPF in guidelines is confusing and counterproductive (Forde & Decker 2022). Vellinga *et al.* (2022) attempted to assess nutritional quality, environmental impact and consumer food cost in the Dutch diet. Their conclusion was that the NOVA concept was not suitable for such overall evaluation. We are in the midst of a dietary transition towards higher consumption of convenience foods, of which many of them are UPF (Baker *et al.* 2020) and the consumption of UPF is high in the EU (Mertens *et al.* 2022). Health outcomes have been central to these discussions for long and the question remains whether the UPF concept is useful for guiding people to a healthy and sustainable diet.

To assess the climate impact of a processed food, information is needed both on the impact of production of the ingredients and the energy-use during food processing, packaging and transport. To be able to compare foods by type or degree of processing, mapping of the whole food supply chain for different types of foods is necessary. It is therefore discouraging that data on energy use in food processing was found to be so outdated (Ladha-Sabur *et al.* 2019). Some numbers indicate that energy consumption in the food industry sector in the EU is decreasing, in absolute terms and per production unit value (Monforti-Ferrario *et al.* 2015). This is promising and there are several ways to reduce climate impact through increasing efficiency (Nikmaram & Rosentrater 2019). More information on the energy use in different food processing steps is crucial for investigating and reducing the climate impact of processed foods, whether they are called UPF or not.

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Populärvetenskaplig sammanfattning

Maten vi äter påverkar klimatet. Hur stor denna påverkan är beror på matens ursprung och hur den är producerad. Globalt sett så har flera faktorer lett till att allt mer mat produceras och allt mer processad mat finns tillgänglig. Nästan all mat vi äter är processad på något sätt, till exempel hackad, kokt, inlagd eller frusen. Det finns ingen entydig definition av vad processad mat är, eller vad som ska räknas som mycket eller litet processad mat.

Ett sätt att kategorisera processad mat är systemet NOVA. Det togs fram för att visa både på hur mycket, var och varför maten hade processats. I NOVA ingår fyra kategorier; icke-processad eller minimalt processad mat, processade ingredienser för matlagning, processad mat och ultraprocessad mat. NOVA har ofta använts i studier om mat och hälsa, men har också kritiserats. Kritiken handlar bland annat om att NOVA inte stämmer överens med hur man ser på olika processer inom livsmedelsforskningen. Det är också svårt att använda NOVA i praktiken.

Eftersom många processer i livsmedelsindustrin är energikrävande kan man tänka sig att livsmedel som är processade i hög grad skulle bidra till växthusgasutsläpp. Det ville vi undersöka i den här studien. Vi använde direktkonsumtionen av livsmedel för att uppskatta hur mycket mat som konsumeras i Sverige. Siffrorna för konsumtion kombinerades med information om växthusgasutsläpp från olika typer av mat. En sökning i en biblioteksdatabas genomfördes också för att hitta andra studier som undersökt klimatpåverkan av ultraprocessad mat.

Resultatet är att den största klimatpåverkan i den svenska kosten kommer från icke-processad eller minimalt processad mat. Det beror på att kött, ägg och mjölkprodukter som hamnar i den kategorin har relativt stor klimatpåverkan. Om man slår ihop processad mat och ultraprocessad mat så har de tillsammans ungefär lika stor klimatpåverkan som icke-processad eller minimalt processad mat. Inom kategorin ultraprocessad mat hade drycker och godis, kakor, glass och snacks lika stor klimatpåverkan som kött och ägg.

Sex studier om klimatpåverkan av ultraprocessad mat hittades i litteratursökningen. De visade olika resultat om huruvida graden av processning hade någon betydelse för klimatpåverkan från maten. Det kan bero på att matvanorna skiljer sig åt mellan länderna som studerats (Brasilien, Frankrike, Nederländerna, Storbritannien och USA). Metoderna att studera kopplingen mellan ultraprocessad mat och klimatpåverkan skiljde sig också vilket kan påverka resultaten.

Slutsatsen från studien är att i Sverige har mat som är mindre processad en större klimatpåverkan än ultraprocessad mat. NOVA är inte ett bra sätt att dela in livsmedel för att undersöka klimatpåverkan från bearbetning av mat. Istället behövs mer information om energianvändningen i de olika processerna för att framställa mat. Med den informationen kan man undersöka hur klimatpåverkan från processad mat kan minska.

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Appendix 1

Table A1. Classification of food categories into NOVA by food groups ('Cereals', 'Greens', 'Meat &Eggs', 'Fish&Seafood', 'Dairy', 'Beverages', 'Discretionary foods' and 'Other'). Table continues to page 41.

Food group	Foods/Food category	NOVA
Cereals	Wheat flour	1
	Rye flour	1
	Mixed flour from wheat and rye	1
	Rice	1
	Oats	1
	Pasta	1
	Mix from flour or starch	2
	Crispbread and flatbread	3
	Gruel powder	4
	Corn flakes, roasted rice, cheese doodles, popcorn	4
	Soft bread (excluding crisp bread)	4
Greens	Carrots	1
	Other roots	1
	Cucumbers	1
	Onion	1
	Leek	1
	Cauliflower	1
	Cabbages (white, red, brussel sprouts, kale, broccoli, napa cabbage)	1
	Lettuce	1
	Tomatoes	1
	Other vegetables	1
	Oranges, tangerines, clementins etc.	1
	Lemons, lime, grapefruit etc.	1
	Grapes	1
	Almonds and nuts, fresh and processed	1
	Apples, fresh	1
	Pears, fresh	1
	Cherries, peaches, plums and other fresh stone fruits	1
	Bananas	1
	Melon, kiwi and other fruits	1

	Strawberries, fresh	1
	Raspberries, fresh	1
	Other berries, fresh	1
	Strawberries, raspberries, black currant, blueberries, lingonberries and other berries, chilled	1
	Raisins, figs, dates and other dried fruits	1
	Squash drink and juice of vegetables, fruits, berries, natural or concentrated	1
	Potato, fresh	1
	Canned and prepared vegetables	3
	Fruits and berries, prepared in cans or in other packaging	3
	Chilled and deep frozen potato products	3
	Canned potato	3
	Powder for mashed potatoes or turnips	4
Meat and eggs	Home slaughter of veal, pork and mutton	1
	Beef including veal, fresh and frozen	1
	Pork, fresh and frozen	1
	Mutton, fresh and frozen	1
	Poultry meat, fresh and frozen	1
	Reindeer meat, fresh and frozen	1
	Game meat	1
	Edible offal	1
	Eggs	1
	Cured meats and provisions, unmixed (*In Swedish: skinka, kassler och andra oblandade charkuterivaror*)	4
	Cured meats and provisions, mixed (*In Swedish: korv, pastejer och andra blandade charkuterivaror*)	4
	Canned meat (excluding meat soups)	4
	Frozen meat products and frozen ready-cooked food containing meat	4
Fish and seafood	Fish, crustaceans and molluscs	1
	Canned herring	3
	Other canned fish (excluding caviar and fishballs)	3
	Crustaceans and molluscs, prepared or canned	3
	Caviar and other products of roe	4
Dairy	Milk	1
	Fermented milk, natural (yoghurt etc.)	1
	Cream	1
	Milk powder	1
	Sour cream and yoghurt for cooking	2
	Butter	2
	Hard cheese	3
	Processed cheese	3
	Cheese, others	3
	Fermented milk, sweetened (yoghurt etc.)	4

Beverages	Mineral water and soda water, without sugar or flavouring	1
	Light beer, <2.25 % alcohol	3
	Beer, 2.25 - 3.5% alcohol	3
	Beer >3.5 %	3
	Wine	3
	Soda, cider etc.	4
	Spirits	4
	Coffee, roasted powder	1
	Tea (processed leaves)	1
	Coffee and tea extractions, e.g. instant coffee	1
Discretionary foods	Sugar and sugar-based products	2
	Honey	2
	Biscuits	4
	Buns	4
	Pastries	4
	Jam, marmalades, mashed fruits and jellies, cooked	4
	Other prepared potato products (potato crisps)	4
	Cocoa powder, drinking chocolate and chocolate sauces	4
	Chocolate and confectionary	4
	Ice cream including mix containing fat	4
	Ice cream not containing fat	4
Other	Cooking oil	2
	Potato starch	2
	Spices, including mustard	2
	Salt	2
	Cooking margarine excluding low-fat margarine	4
	Low-fat margarine	4
	Soups and clear soups containing vegetables, berries, fruit, fish and meat	4
	Sauces, including mayonnaise and other prepared products for flavouring	4

Appendix 2

Table A2. Summary of studies evaluating environmental impacts of UPF in consumption data or databases of foods commonly eaten. Result of literature review. Table continues on page 43.

Country	Consumption data	Environmental data	Type of analysis	Summary of results
Brazil (Garzillo *et al.* 2022)	National dietary survey, 2x24 h recall (n=32886) of children and adults.	GHGE and water footprint in a database of 569 sources of footprints.	Association between diet footprints and quintiles of the contribution of UPF to total energy intake. Adjusted for energy and SES.	No association UPF intake and GHGE. A higher dietary contribution of UPF was associated with a higher water footprint.
Brazil (da Silva *et al.* 2021)	Food purchases in metropolitan areas.	GHGE, water footprint and ecological footprint.	Time-series analysis 1987-2018.	GHG emissions from diet increased by 183% in Brazil during 20 y and this was attributed to the increased consumption of UPF.
France (Kesse-Guyot *et al.* 2023)	National dietary survey 3x24 h recall (n=2121) of adults.	GHGE, land use, water use and energy demand for 2,497 foods in a database.	Impact by stages of processing and by quintiles of contribution of foods in processing categories. Adjusted for energy intake.	No association between quintiles of UPF and GHGE or land use and a negative association for water and energy demand.

Table A2 Continued from page 42

The Netherlands (Vellinga *et al.* 2022)	National dietary survey, 2 x 24 h recall (n=4313) of children and adults.	GHGE and water footprint available for 265 foods in a national database.	Impact by 100g foods in a food based analysis. Consumption of UPF compared to MPF as expressed in % of 2000 kcal.	Climate impact was higher while water footprint was lower for UPF foods than MPF or processed foods as assessed per 100 g. Diets with high % UPF contribute more to climate footprint and less to water footprint than diets high in MPF as assessed per 2000 kcal.
The United Kingdom (Aceves-Martins *et al.* 2022)	No intake data. 4912 foods from national database of commonly eaten foods.	GHGE from a national database, CO_2e available for 153 foods, in all other cases, a value from a similar food was used.	Impact by processing categories, presented per 100 kcal.	GHGE was lower for UPF than for MPF per 100 kcal. Foods with vegetable-based protein had the lowest GHGE across FP-groups.
The US and Canada (Berardy *et al.* 2020)	Dietary intake based on an FFQ of about 200 foods in an adult cohort in US and Canada (n=96000).	Global warming potential, land use and water consumption available for 198 foods.	Processing of food was evaluated per serving.	UPF had the highest GHGE per serving, land use was highest for processed foods and water use was highest for MPF.

Abbreviations: FFQ, food frequency questionnaire; FP, food processing; GHGE, greenhouse gas emissions; MPF, minimally processed foods; SES, sociodemographic variables; UPF, ultra-processed foods.

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