

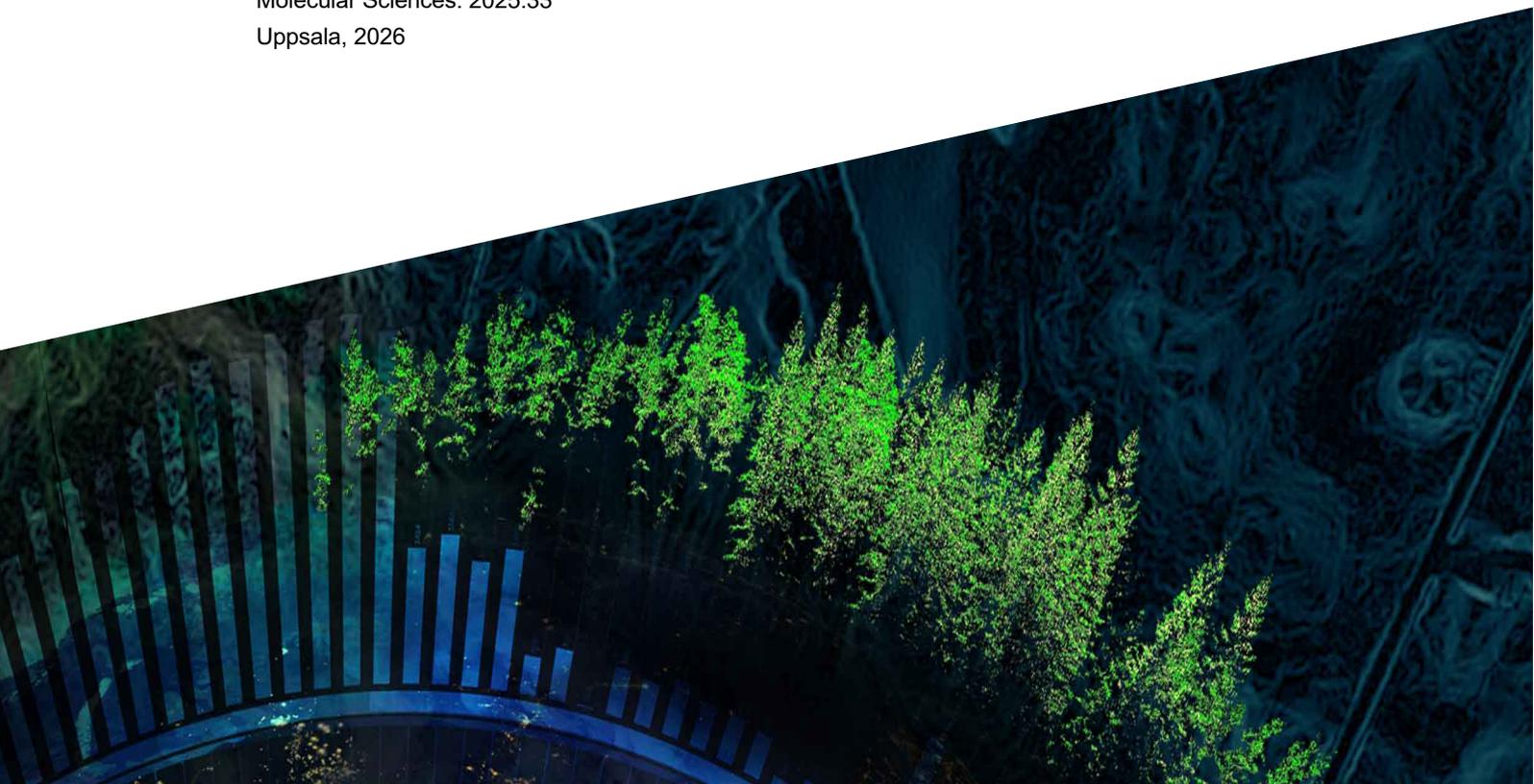


# Carbon Footprint and nutritional aspects of an upcycled food product based on slaughterhouse blood

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Degree project • 30 credits  
Swedish University of Agricultural Sciences, SLU  
Department of Energy and Technology  
Master's Programme in Sustainable Food Systems  
Molecular Sciences: 2025:33  
Uppsala, 2026



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**Credits:** 30

**Level:** A2E

**Course title:** Master Thesis in Food Science

**Course code:** EX0875

**Programme:** Master's Programme in Sustainable Food Systems

**Course coordinating dept:** Department of Molecular Sciences

**Place of publication:** Uppsala

**Year of publication:** 2026

**Title of series:** Molecular Sciences

**Part number:** 2025:33

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**Keywords:** Life Cycle Assesment (LCA), Rescued Blood, Upcycled food, Nutritional Assesment, Carbon Footprint

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## Abstract

In today's world, it is crucial to ensure sustainable food production and consumption while maintaining food security. Food waste from industrial production is a major problem that affects both food security and the achievement of a circular economy. While preventing food waste is the most preferable option, when it is not achievable, valorization through upcycling, can offer a more beneficial alternative compared to conventional recycling methods.

Slaughterhouse blood is one of the primary contributors to the total volume of edible by-products generated in the Swedish meat industry. However, this blood has great potential beyond its current use in biogas production as it is a rich nutrient source and has many functional properties.

This study was conducted in collaboration with the Axfoundation, where a bakery product called Black brownies was developed using rescued cattle blood as part of a food waste reduction initiative. The aim of the study was to calculate the carbon footprint of the new food product, evaluate the influence of different allocation methods on this carbon footprint value, identify its climate hotspots and assess its nutritional composition.

The carbon footprint was calculated using two different allocation methods for the burden of blood: as the full value of beef or as missed out biogas production, respectively. The scope of the study was from "cradle to bakery gate". The carbon footprint values were 7.5 and 1.5 kg CO<sub>2</sub>e per kg brownie respectively, for the first and second allocation method. Conventional chocolate cake was used as the reference product and had a carbon footprint of 1.7 kg CO<sub>2</sub>e per kg cake, but was calculated based on a recipe without dark chocolate. The production of the ingredients was the most significant hotspot in this new product. The carbon footprint was subject to several limitations, including assumptions made for the allocation of blood and data gaps regarding production conditions (baking of *kladdkaka* was used as a proxy).

One main nutritional difference was the significantly higher heme iron content in the blood-enriched brownie when compared to a regular chocolate cake, offering a novel way to introduce iron through a familiar sweet food like Swedish fika, for those who are not willing to eat blood based savory food.

*Keywords: Life Cycle Assessment, Rescued blood, Upcycled food, Nutritional Assessment, Carbon Footprint*

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# Abbreviations

CF	Carbon Footprint
CO <sub>2</sub>	Carbon dioxide
CO <sub>2</sub> e	Carbon dioxide equivalents
GHG	Greenhouse gases
GWP	Global Warming Potential
LCA	Life Cycle Assessment
LCI	Life Cycle Inventory
LCIA	Life Cycle Impact Assessment
SAFAD	Sustainability Assessment of Food and Diet

# 1. Introduction

Global food production continues to rise with the population growth, which has a significant contribution to greenhouse gas emissions and is responsible for other environmental problems. Despite rising food production, world hunger and malnutrition persist, with around 750 million people suffering from hunger all over the world in 2021 (De Boni et al. 2022). Therefore it is crucial to address food security and food production while keeping less pressure on the environment. To improve global food security it is necessary to develop new strategies by considering both economic and environmental concerns which address the challenges such as climate change, resource depletion, and protection of ecosystems and biodiversity (De Boni et al. 2022). Food losses and waste (FLW) have a significant impact on the process of reducing food security and also it represents 38% of energy consumption in the supply chain which creates a significant pressure to environmental sustainability (Nutrizio et al. 2024). Reducing FLW is considered as a key strategy to minimize production impacts, enhance food system efficiency, improve food security and nutrition, and promote environmental sustainability (De Boni et al. 2022, Dominguez Aldama et al. 2023).

Animal blood from slaughterhouses is a major byproduct with valuable functional and nutritional properties. It can be used as a food ingredient to enhance nutritional value, reduce food waste, and improve production efficiency and sustainability. In particular, the meat industry produces large amounts of wasted blood due to slaughtering of large numbers of animals (Chiroque et al. 2023). Despite the large quantities of blood produced, it remains underutilized as a food ingredient (Ofori and Hsieh, 2014). In cattle, approximately 4.5% of the animal's live weight is blood, and about 50% of this blood can be collected during the slaughtering process (ibid). Whole bovine blood contains 17.3% protein, 80.9% water, 0.07% carbohydrates, small amounts of minerals and fat (Chiroque et al. 2023). Among the blood proteins the most important is hemoglobin, which contains heme iron, which has a high absorption level about 20% to 35% to the body, making it useful to treat some types of anemia (ibid). Some researchers found that consuming foods incorporated with blood led to a 16% increase in hemoglobin levels (ibid).

In Sweden, approximately 13,000 tonnes of animal by-products were lost in 2020, with blood accounting for a significant portion of these losses. (*Livsmedelsförluster vid slakt av grisar och nötkreatur* n.d.). According to a survey conducted in three large slaughterhouses in Sweden, average cattle blood production was around 3500 tons in 2020 which is mainly used for biogas production (ibid). However, blood has significant nutritional potential due to its high protein and heme iron content (Chiroque et al. 2023).

Food upcycling or valorizing is a recognized strategy for repurposing the food that would otherwise be wasted during the manufacturing or processing of other products, thereby preserving the environmental, nutritional and financial resources used for the food production ([Thorsen et al. 2024](#)). There are two distinct roles of upcycled foods in resource preservation. One is alternative use, which involves redirecting edible food that would otherwise go to waste, thereby preserving the resources used to produce that food. The second is novel use, which refers to utilizing ingredients not commonly or currently considered edible, thus expanding the available base of food resources (*ibid*). The wasted blood has much potential in upcycling as a ‘novel use’ ingredient, which means converting waste into valuable products due to these nutritional and functional properties. Moreover, the use of slaughterhouse waste blood could be considered as a use of secondary raw materials in the food production as a solution for resource scarcity (Izgarishev, Izgarisheva & Ostroumov, 2018).

The food production and processing industry needs to manage its environmental performance to reduce environmental pressure and achieve a circular economy. To enhance environmental performance, it is necessary to assess the current situation and identify hotspots (Ahmad et al. 2019). Life Cycle Assessment (LCA) is a widely used comprehensive tool to measure environmental performance in both products and processes, and provides important information about the impact of using raw materials, energy, water etc (*ibid*). An LCA typically consists of goal and scope definition, life cycle inventory, life cycle impact assessment and interpretation (*ibid*).

Nevertheless, in the case of assessing the impacts and the earnings of food waste valorization and upcycling, a comprehensive understanding of different types of waste outputs and its uses in the food supply chain is required (Dominguez Aldama et al. 2023). In current agri-food LCAs many inconsistencies have been identified due to different allocation processes, mostly when there is no clear differentiation between co-production and waste generation (*ibid*).

An example for the inconsistencies arising from different allocation approaches in LCAs were shown in above mentioned systematic review. Among seven reviewed studies, significant variation was observed in how multifunctionality was addressed, even when assessing similar product systems. While three studies treated whey as a waste stream and framed the analysis as a valorization scenario, the remaining four studies classified whey as a co-product and applied different allocation methods. The results obtained were different based on the allocation used (Dominguez Aldama et al. 2023). This illustrates how methodological choices, particularly in allocation, can lead to different results and interpretations, even within comparable systems, thereby highlighting the importance of transparent and consistent allocation procedures in LCA studies.

## 1.1. Background

Several studies have explored the potential of using slaughterhouse blood as a food ingredient and have evaluated the nutritional value of various foods made from upcycled slaughterhouse blood. However, the environmental impact of these upcycled products has rarely been assessed in the literature. The concept of incorporating slaughterhouse blood into “black brownies” is both novel and underexplored from nutritional and environmental perspectives.

Ofori and Hsieh (2014) discussed the use of animal blood as a food ingredient for human consumption or for animal feed and the related consumer concerns (Ofori and Hsieh, 2014). This paper concluded that the incorporation of blood for human food or animal feed has only a minimal food safety risk regarding disease transmission such as transmissible spongiform encephalopathies (TSE), blood allergens and food-borne pathogens. The risks are comparable to those of other animal-based foods.

One study conducted to produce bovine blood enriched porridge powder to alleviate the anemia among children in Kenya showed that this blood enriched product was effective in reducing iron deficiency anemia (Andago et al., 2015). The study found that blood-enriched products had a prolonged shelf life if they were collected soon after slaughter and hygienically processed and dried. Otherwise, the product would deteriorate quickly. The authors argued that the use of blood powder can be upgraded to industrial level to address the problem of inadequate consumption of heme iron especially in vulnerable populations (ibid).

Another study, new sherbet like bar was developed by using the dried hydrolysate of red blood cells as an anti –anemic agent by incorporating full cream milk, sugar vanilla, citric and ascorbic acids (Izgarishev, Izgarisheva & Ostroumov, 2018). This study identified a key drawback of animal blood waste product when using black food albumin which is less digestible in the human digestive system due to the stable membrane of dried red blood cells. This study aims to develop a type of sherbet bar that includes dried hydrolysate red blood cells as an ingredient to mitigate the iron deficiency (ibid).

Previous studies have shown that blood can be used as a substitution for eggs in the bakery industries. Ockerman & Hansen (1988) emphasized that the use of blood plasma in bakery products has promising effects on foaming and leaving properties that can be used successfully as an egg substitute (Ockerman & Hansen 1988 p 242). The dark color of blood can make food products visually unappealing, although this can be mitigated through bleaching or iron removal. The book also discusses the environmental benefits of using slaughterhouse blood while providing economic benefits by maximum utilization of the by-product (ibid).

Another recent research has revealed that animal blood powder is a viable substitute for egg powder in baked goods like sponge cakes (Csurka et al. 2022). This study evaluated the techno-functional and sensory properties of blood-substituted sponge cakes, blood powders were found to enhance product texture (e.g., increased hardness and chewiness), stability, and moldability, making them suitable for functional food applications. Moreover, the sensory evaluation conducted revealed that there was no significant compromise in acceptability, despite the darker color and altered texture. In fact, the intensified cocoa flavor and rich visual appeal were perceived positively (ibid).

Notably, earlier foundational work by Ockerman and Hansen (1988) provided extensive insights into the functional properties of blood plasma in bakery applications, including its potential as an egg substitute. Although the publication is dated, it remains relevant due to the limited volume of recent empirical work on blood-based food applications in Western food contexts. The inclusion of such sources is thus justified in order to contextualize current innovations against the historical backdrop of blood utilization in food. However, it also highlights the lack of updated, comprehensive studies on the topic, especially those that integrate environmental, nutritional, and consumer acceptance dimensions.

Although several studies have explored the nutritional potential of slaughterhouse blood in food applications, the environmental implications of upcycling this by-product remain largely underexplored. Most of the previous studies are framed within public health, nutritional and safety aspects and product development contexts rather than the environmental and sustainability perspective (Andago et al., 2015, Izgarishev, Izgarisheva & Ostroumov, 2018, Csurka et al. 2022). These findings reinforce the suitability of blood-based ingredients not only from a nutritional standpoint but also in terms of product development. However, environmental assessment of such applications remains scarce which highlight the need for LCA undertaken in the present study.

This thesis addresses these gaps by assessing a novel blood-based food product (“black brownies”) from both environmental and nutritional perspectives. Unlike earlier studies that focus solely on nutritional enrichment or functional attributes, this research incorporates a cradle-to-gate LCA to evaluate the carbon footprint of the product, while also assessing and comparing the nutrient composition of the brownies, when substituting eggs with animal blood. The integration of sustainability assessment with nutritional profiling makes this research a novel contribution to the discourse on food waste valorization and circular food system innovations.

## 1.2. Study Framework

This study was conducted in collaboration with Axfoundation, which developed an upcycled food product using cattle blood waste from slaughterhouses as a prototype. The goal is to introduce this prototype to a commercial food producer capable of scaling it up for large-scale production. An LCA was carried out to evaluate the environmental performance of the product, aiming to explore the potential of using wasted blood as an upcycled ingredient and to contribute to reducing food waste within the cattle production supply chain. The prototype was developed in the foundation’s test kitchen by their staff. As the product is still in the prototype stage, specific production conditions have not yet been defined. Therefore, the production conditions of a typical Swedish chocolate cake (kladdkaka) were used for the LCA as its ingredient composition and preparation method was almost similar to the novel product. The intended consumer group remains to be defined in future stages of development.

### 1.3. Aim and Objectives

The aim of this study was to assess the climate impact and nutritional profile of an upcycled food product based on cattle blood. The specific objectives were to:

- estimate the carbon footprint of the bakery product “black brownies” at bakery gate, and to compare this with a reference chocolate cake product
- evaluate the influence of different allocation methods on carbon footprint values
- identify the environmental hotspots of the product’s lifecycle
- assess the nutritional composition

## 2. Materials and Methods

The study included two methods: LCA to assess the climate performance in terms of carbon footprint, and nutritional mapping to assess the nutritional profile. The primary objective was to evaluate the climate performance of an upcycled food product using a life cycle approach. Additionally, the nutritional composition, with a particular emphasis on iron content, was assessed using the Swedish Food Agency database.

### 2.1. Life Cycle Assessment

LCA was used to evaluate the climate impact of 1kg of “black brownies” produced, following the ISO 14040 and 14044 standards. LCA is a comprehensive and commonly used tool to measure the environmental impact of products and services. LCA quantifies the environmental impacts and the resource usage of a product or service throughout its entire life cycle (Garnett, Röös, Nicholson and Finch, 2016). Additionally, it provides a basis for identifying the critical phases of the life cycle and how to reduce the impact in a sustainable way (ibid). The LCA is based on the analysis of the systems which requires careful design choices regarding what to exclude and what to include in the analysis. However this method has an inherent uncertainty due to variables in data sources and design choices which can be more significant in agricultural production (ibid).

The standard LCA method consists of four major methodological processes and are completed in sequential order begins from the goal and scope definition, followed by life cycle inventory (LCI), life cycle impact assessment (LCIA) and end up with interpretation of results (Boakye-Yiadom et al. 2021).

The importance of the LCA is increasing as many companies want to assess their product’s environmental performances and ask from their suppliers (Boakye-Yiadom et al. 2021). Therefore it is very important to measure the current performance of the new food product as it can be claimed for the environmental impacts and also to identify the climate hotspots of the production.

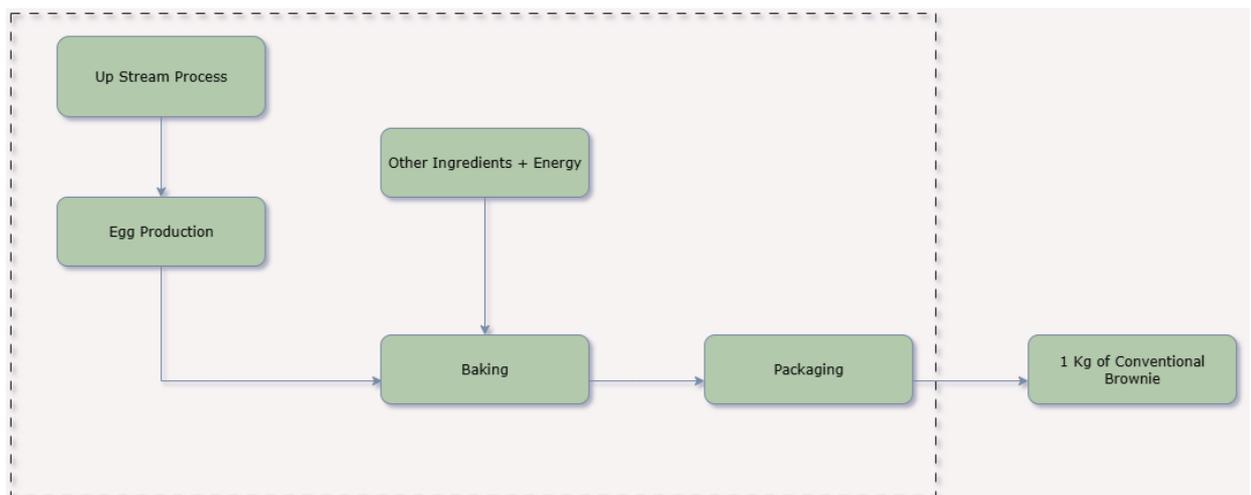
More details of the method are described below.

### 2.1.1. Goal and Scope Definition

In this phase functional unit and the system boundaries were defined. This study measured the carbon emissions of the upcycled food product named “Black brownies”, produced from by-product of cattle slaughtering using LCA and compared this with a conventional chocolate cake (Swedish Kladdkaka). The functional unit was 1kg of brownies produced. The system boundaries of this study were set from cradle to bakery gate which is illustrated below in Figures 1-3.

### 2.1.2. System Boundaries

The system boundaries for this study were set from cradle to bakery gate. The life cycle begins with the raw material extraction for all included processes. The life cycle boundary ends at the bakery gate, meaning that distribution, retail, consumption, and waste disposal were excluded from this assessment.



*Figure 1 System boundaries for conventional chocolate cake production.*

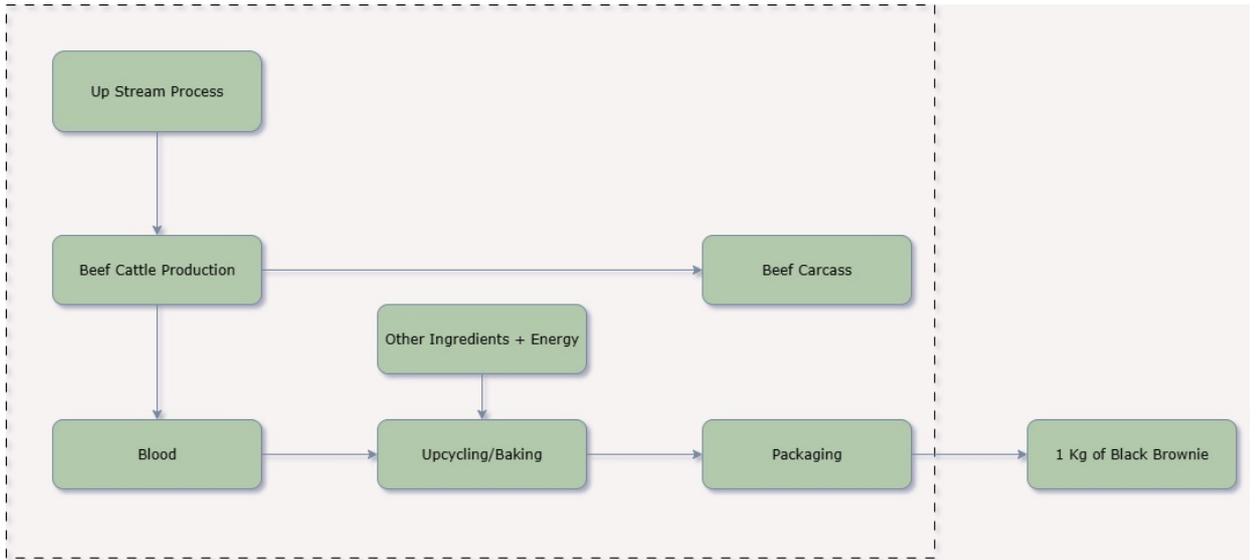


Figure 2 System boundaries when assigning beef impact value for blood.

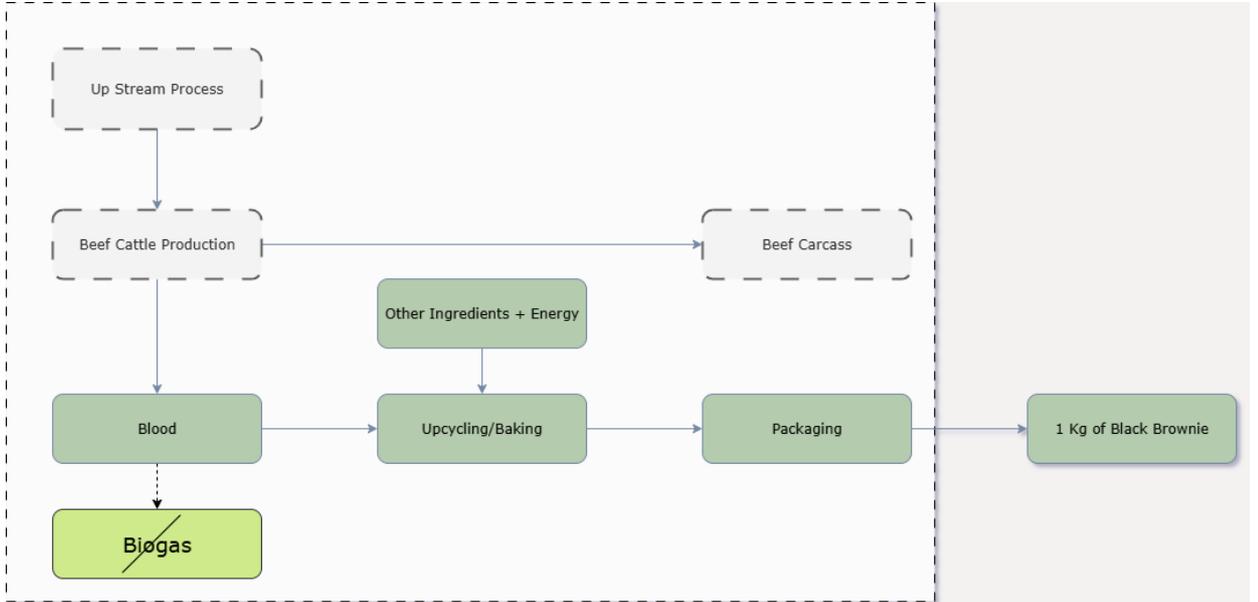


Figure 3 System boundaries when assigning lost biogas value for the blood. Unfilled boxes are processes that are not included in the system boundaries.

### 2.1.3. Scenario description

A carbon footprint assessment was conducted for the three scenarios described below and illustrated in Table 1. Recipes for the two products and the product specific carbon footprint data of the ingredients are shown in Table 2 and 3.

#### Scenario 1: Conventional Chocolate Cake

This scenario represents the standard chocolate cake (Swedish Kladdkaka) produced commercially using conventional ingredients. The system boundaries include the production of eggs and other ingredients (e.g., flour, sugar, cocoa, rapeseed oil), transportation of these ingredients to the bakery, the baking process, and packaging.

This serves as the baseline for carbon footprint comparison and allows for assessing the relative environmental performance of the new product containing upcycled blood against a more available, widely consumed alternative. It is crucial to have a baseline to quantify the potential benefits or trade-offs of incorporating blood in to this type of food product.

#### Scenario 2: Black Brownie (Beef value)

This scenario, represents the new product Black brownies, which replaced the eggs of conventional cake with upcycled slaughterhouse blood. The impact of blood was valued by mass-based allocation of beef production. The climate impact per kilogram of beef was multiplied by the standard carcass weight and then divided across the total carcass weight, including blood. This assigns a proportional share of the cattle-rearing impacts to blood based on its mass fraction in the carcass.

The system boundaries include the production of blood (valued as impact of beef), production of other ingredients, transportation of other ingredients to the bakery except the blood transportation from slaughterhouse to the bakery, the baking process, and packaging. In this scenario blood impact was derived by adjusting the beef impact value for the total carcass weight including blood weight.

#### Scenario 3: Black brownie (Lost biogas)

This scenario is similar to Scenario 2 in terms of the ingredient composition, but here the slaughterhouse blood impact was valued as ‘lost biogas’. This reflects a substitution approach, in which the environmental impact of blood is represented by the lost potential CO<sub>2</sub> savings that would have been achieved if the blood had been used for biogas production. In other words, the avoided emissions from producing biogas are considered the environmental burden of blood in this scenario.

The system boundaries include the production of blood (valued as lost biogas), production of other ingredients, transport of ingredients to the bakery except the blood transport from the slaughterhouse to the bakery, the baking process, and packaging. This scenario enables the assessment of trade-offs between different valorization pathways for slaughterhouse blood.

Comparison of scenario 2 & 3 demonstrates how the allocation choices influence on the environmental performance of product.

*Table 1 :Scenario description*

Included processes	<b>Conventional chocolate cake</b>	<b>Black brownie, Beef Value</b>	<b>Black brownie, Lost Biogas</b>
Production of blood, valued as beef		x	
Production of blood, valued as lost biogas			x
Production of eggs	x		
Production of other ingredients	x	x	x
Transport of ingredients to bakery	x	x*	x*
Baking	x	x	x
Packaging	x	x	x

\*transport of blood from slaughterhouse to bakery not included.

Table 2: Recipe for 1 kg of conventional chocolate cake and product specific carbon footprint data for included ingredients

Ingredients	Amount(g)	CF(kgCO <sub>2</sub> e/kg ingredient)	References
Whole Eggs	170	1.3	SAFAD
Sucrose	460	1.0	SAFAD
Rapeseed oil	170	2.3	SAFAD
Wheat flour	150	1.0	SAFAD
Cacao	50	1.2	SAFAD

Table 3: Recipe for 1kg of Black brownies and product specific carbon footprint data for included ingredients

Ingredients	Amount (g)	CF (kg CO <sub>2</sub> e/kg ingredient)	References
Cattle Blood*	202	30	Modified SAFAD <sup>1</sup>
Cattle Blood**	202	0.12	GASUM biogas <sup>2</sup>
Sugar	316	0.9	SAFAD
Rapeseed oil	215	2.3	SAFAD
Wheat flour	63	1.0	SAFAD
DarkChocolate (50%)	126	1.2	SAFAD
Cacao	76	1.2	SAFAD
Vanilla	1	13	ECOINVENT
Salt	2	0.4	SAFAD

<sup>1</sup>Modified SAFAD-The beef impact value was adjusted for additional weight of blood per carcass.

<sup>2</sup><https://www.gasum.com/sv/gasum/leveranskedja/biogasanlaggningar/skovde/>

\*when valued as beef

\*\*when valued as missed biogas production

#### 2.1.4. Allocation Procedure

Initially, the study intended to use economic allocation for slaughterhouse blood by calculating its economic share out of all outputs in Swedish beef production, thereby assigning the proportionate share of environmental impact to the blood. However, it was not feasible due to the unavailability of reliable economic data on slaughterhouse blood. Given uncertainties in the economic value of slaughterhouse blood and the lack of transparent market data, this study adopted the following substitutional methods.

In one scenario, the impact of beef was used as an alternative value for blood. This value was taken from the SAFAD datasheet, and corrected for the additional weight of blood per carcass.

For the other scenario the missed biogas opportunity approach was applied, where the potential climate savings from biogas production typically derived from slaughterhouse blood were considered as an environmental cost. In this case, since the blood is diverted from biogas production to food production, the loss in CO<sub>2</sub> savings was interpreted as the environmental impact of the blood. The CO<sub>2</sub> savings value was obtained from the website of a Swedish biogas plant “Gasum” in Skövde.

Gasum, which is a biogas plant adjacent to one of the largest slaughterhouses in Sweden, using slaughter waste as a main substrate. Gasum reveals on their website a yearly conversion of 40,000 tons of waste into biogas and biofertilizers, corresponding to a climate savings of 5000 tons of CO<sub>2</sub>. If assuming a flat ascription of climate savings per ton of waste, one ton withdrawn blood would lead to 0.12 tons missed out climate savings from the biogas plant. Although more detailed modelling approaches exist, such as those based on volatility solid contents refined by seasonal biogas yield variation and chemical inhibition effects (Otero et al.2021), these require data not available for the present contexts. The simplified producer-based method used here offers transparency and relies on real-world Swedish data, which strengthens its practical relevance.

These two methods were applied to blood based Black brownies to estimate the climate footprint.

#### 2.1.5. Data Types and Sources

Life cycle inventory (LCI) is the second phase of the standard LCA method which includes all the inputs and outputs associated in order to produce one functional unit of the product at each stage within the system boundaries (Garnett, Rööös, Nicholson and Finch, 2016).

This study primarily relied on secondary data, which was collected from sources such as Sustainability Assessment of Food and Diet (SAFAD) and Ecoinvent 3.1 database. The data for the climate impact of Swedish beef production was obtained from the SAFAD report which

includes all the inputs and outputs of beef production in the Swedish context. These sources were used to obtain information related to the impact of ingredients, general production processes, energy use, water consumption, and background emissions data. The carbon footprint values for all the ingredients except vanilla were obtained from the SAFAD database. SAFAD has region specific life cycle inventory data which ensures that values are representing production status, agricultural practices, and energy sources specific to Sweden. Therefore this is highly relevant for this study, as the product prototypes were developed within Sweden. Blood transportation from the slaughterhouse to the bakery was excluded from the study due to data unavailability. Since the prototype was produced in Axfoundations test kitchen, processing data such as energy use and water use were modeled based on Swedish kladdkaka production as a representative proxy. This includes typical bakery operations like mixing, baking, cooling, and packaging.

Primary data was collected directly from Axfoundation, specifically regarding the recipe composition and output quantities of the upcycled food prototype. Since the product is still in its prototype stage, detailed processing data was not available. Therefore, data from Swedish kladdkaka production in SAFAD was used as a representative proxy for processing and packaging related impacts. It was assumed that the production processes for Swedish kladdkaka closely resemble those of the prototype.

### 2.1.6. LCA Modelling & Data Interpretation

The LCA modelling for this study was conducted using Microsoft Excel, where a cradle-to-gate system boundary was applied for 1 kg Black brownies. Excel served as a platform for organizing input data, calculating emissions, and comparing scenarios across different allocation methods and ingredient combinations. Key data points included ingredient quantities (e.g., blood, vegetable oil, sugar, flour, dark chocolate, cocoa powder..etc), their respective carbon footprint values (in kg CO<sub>2e</sub> per kg of ingredient), and additional emission factors for processing and packaging.

For each scenario, emissions were calculated by multiplying the mass of each ingredient by its emission factor and summing the contributions from all life cycle phases. Allocation approaches for blood based versions on beef value and missed biogas production were incorporated through separate calculation columns to observe variations in climate impact. This spreadsheet-based model provided a transparent, adaptable framework for tracing emission sources, testing assumptions, and comparing alternative formulations of the product.

### 2.1.7. Limitations of the study

This study was performed with several challenges and limitations that should be acknowledged. The environmental impact of handling and preparing blood for food use, such as collecting, freezing and storing, was not included in this assessment. It was a biggest challenge to reach out to the slaughtering houses to obtain information regarding blood collection, storing and economic value of the wasted blood. Specifically, it was assumed that all processes from the extraction of blood up to its delivery to the bakery were equivalent to those for the preparation, packaging, and transportation of offal used as an ingredient in the *blood pudding* dataset within the SAFAD database. This proxy was considered a reasonable approximation but may not fully represent actual industrial practices related to edible blood processing.

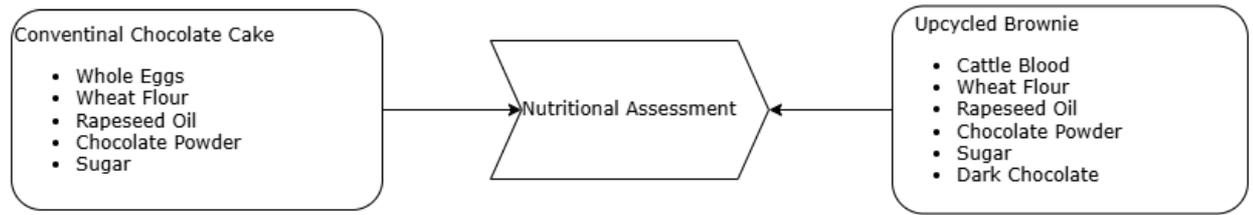
Another challenge was selecting a suitable proxy product which is similar to brownie production, to obtain the information about production, packaging and transportation related emissions. Therefore another assumption was made as Swedish kladdkaka production, packaging and processing emissions were similar to the novel food product. This may not actually represent the precise processing conditions of the novel production process.

Another limitation was that the reference brownie recipe differed from the black brownie not only in the main ingredient (eggs vs. blood) but also in several other ingredients, notably the inclusion of dark chocolate in the blood brownie.

Finally, allocation of environmental burdens to blood as a by-product of animal slaughter posed methodological challenges, as there is no universally agreed-upon approach for such allocation, and different methods (e.g., economic vs. mass-based) can significantly influence the outcome of the assessment.

## 2.2. Nutritional assessment

Nutritional composition was determined by entering the full ingredient list into the Swedish Food Agency's database, which generated an output spreadsheet used for further analysis. Using this data, the nutritional value of the recipe was calculated, and the final nutritional composition was standardized per 100 grams of the product. The analysis was conducted for both conventional chocolate cake and blood based Black brownies.



*Figure 4 Illustration of nutritional assessment.*

Figure 4 illustrates the overview of the nutritional assessment approach conducted in this study. It shows the ingredient composition of a conventional chocolate cake with that of an upcycled brownie formulation. The conventional chocolate cake made out of whole eggs, wheat flour, rapeseed oil, chocolate powder, and sugar, whereas the upcycled brownie replaced eggs with cattle blood and included dark chocolate as an additional ingredient which was absent in conventional chocolate cake.

## 3. Results

This section includes the results of the carbon footprint (CF) assessment conducted for the food prototype developed from surplus slaughterhouse blood and the results of the nutritional assessment of the product.

### 3.1. Carbon footprint

The carbon footprints are presented per the functional unit of the study which is 1kg of the food product. It is important to understand that the results are approximate estimates, indicating potential climate impacts rather than providing precise values or exact outcomes. These values are subject to variation based on data sources, boundary definitions, and allocation choices.

*Table 4: Recipe and contribution from each ingredient to the total carbon footprint (CF) for 1 kg of conventional chocolate cake*

Ingredients	Amount (g)	CF (kg CO <sub>2</sub> e per kg ingredient)	Contribution to CF from each ingredient (kg CO <sub>2</sub> e)
Whole Eggs	170	1.3	0.22
Sucrose	460	1.0	0.46
Rapeseed oil	170	2.3	0.39
Wheat flour	150	1.0	0.15
Cacao	50	1.2	0.06
Total CF from ingredients			1.3

Table 4 shows the recipe formulation and the total contribution for CF from each ingredient for the 1kg of conventional chocolate cake. The total contribution for the CF from all the ingredients was 1.3 kg CO<sub>2</sub>e per kg of cake.

Table 5: Recipe and contribution from each ingredient to the total carbon footprint (CF) for 1 kg of black brownie

Ingredients	Amount (g)	CF (kg CO <sub>2</sub> e per kg ingredient)	Contribution to CF from each ingredient (kg CO <sub>2</sub> e)
Cattle Blood*	202	30	6.06
Cattle Blood**	202	0.12	0.02
Sugar	316	0.9	0.28
Rapeseed oil	215	2.3	0.49
Wheat flour	63	1.0	0.06
DarkChocolate (50%)	126	1.2	0.15
Cacao	76	1.2	0.09
Vanilla	1	13	0.01
Salt	2	0.4	0.001
Total CF ingredient			7.1*, 1.1**

\*when beef value, adjusted for the larger output of edible product, was used as the impact of blood

\*\*when missed biogas production was used as the impact of blood

Table 5 presents the recipe formulation and the total carbon footprint (CF) contribution from each ingredient for 1 kg of black brownie under the two allocation approaches applied to cattle blood: the beef value scenario and the missed biogas scenario. The total CF contribution from all ingredients was 7.1 and 1.1 kg CO<sub>2</sub>e per kg of cake, respectively.

Table 6. Carbon footprint for each allocation scenario and prototype [kg CO<sub>2</sub>e per kg brownie]

Life Cycle Phase	Conventional Chocolate Cake	Black brownie, Beef value	Black brownie, Lost biogas
Production of Ingredients	1.3	7.1	1.1
Baking	0.3	0.3	0.3
Packaging	0.1	0.1	0.1
Total	1.7	7.5	1.5

Table 6 demonstrates that the ingredient production stage contributed the largest share of emissions in all three scenarios. The BeefValue scenario in black brownie had the highest overall carbon footprint (7.5 kg CO<sub>2</sub>e per kg), primarily due to the high impact attributed to blood when

valued as a co-product of beef production. Whereas, the Lost biogas scenario in blood brownie attributed to lowest carbon footprint (1.5 kg CO<sub>2</sub>e per kg) and the conventional chocolate cake (1.7 kg CO<sub>2</sub>e per kg) also had a substantially lower carbon footprint value. The baking and packaging stages had a minor contribution to total emissions across all scenarios.

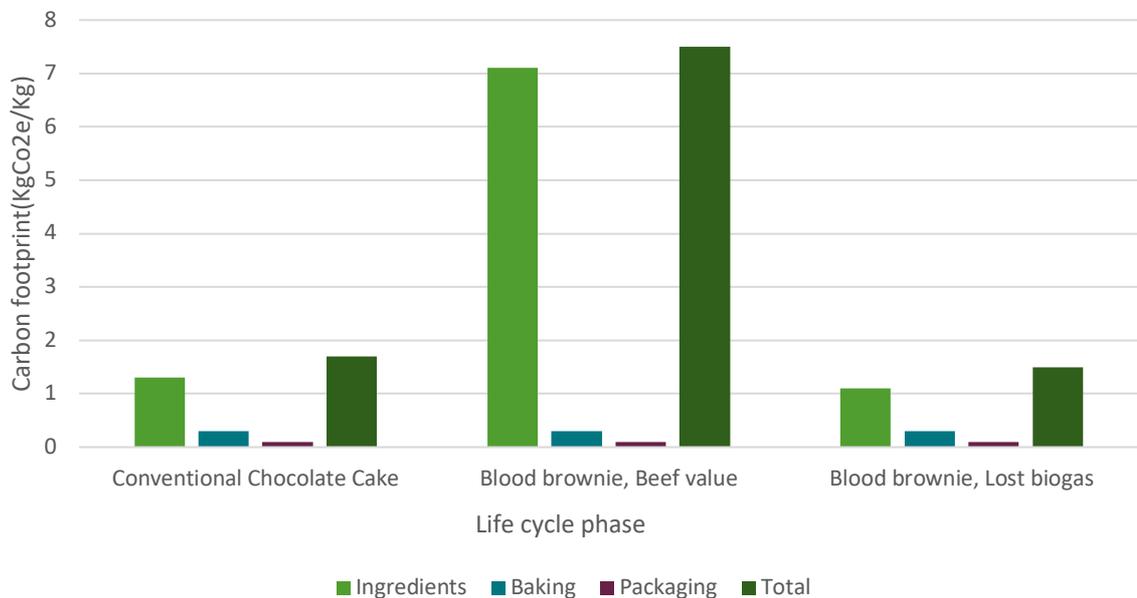


Figure 5 Carbon footprint of a conventional chocolate cake and two black brownie scenarios per kg of the product

Figure 5 illustrates the contribution of different life cycle phases to the total carbon footprint (kg CO<sub>2</sub>e per kg product) for conventional chocolate cake, blood brownie with beef value allocation, and blood brownie with lost biogas. Ingredients production is the dominant phase in all scenarios, with notably higher impacts for the blood brownie, beef value scenario.

### 3.2. Nutritional Assessment Results

The nutrient composition of the product was assessed by using data from the Swedish Food Agency's database, where all nutrient values are provided per 100 grams of the food product. To assess the nutritional impact of incorporating blood as a replacement for eggs in conventional brownies, two sets of calculations were conducted. These calculations aimed to compare the changes in nutritional content resulting from the substitution. The results are presented below.

Table 7: Nutritional composition of the conventional chocolate cake and black brownie (per 100 g)

Nutrient	Conventional chocolate cake	Black brownie
	Amount (100 g)	Amount (100g)
Energy (kcal)	592	576
Fat, total (g)	38	36
Protein (g)	6	7
Carbohydrates, available (g)	54	54
Fiber (g)	3	4
Sugars, total (g)	46	46
Total saturated fatty acids (g)	7	7
Total monounsaturated fatty acids (g)	20	19
Total polyunsaturated fatty acids (g)	8	8
Folate, total ( $\mu\text{g}$ )	27	9
Vitamin A (RE/ $\mu\text{g}$ )	61	11
Beta Carotin ( $\mu\text{g}$ )	5	5
Phosphorus, P (mg)	124	84
Iron, Fe (mg)	2	10
Calcium, Ca (mg)	29	18
Potassium, K (mg)	189	167
Magnesium, Mg (mg)	49	47
Sodium, Na (mg)	36	84
Cholesterol (mg)	85	48

Table 7 shows the nutritional comparison of black brownies and conventional chocolate cake.

Since the nutritional data included values with different units (e.g., grams, milligrams, and micrograms), it was not feasible to represent them on a single chart using their original scales. Therefore, the values were normalized by setting the highest value among all nutrients to 100, and scaling the rest proportionally.

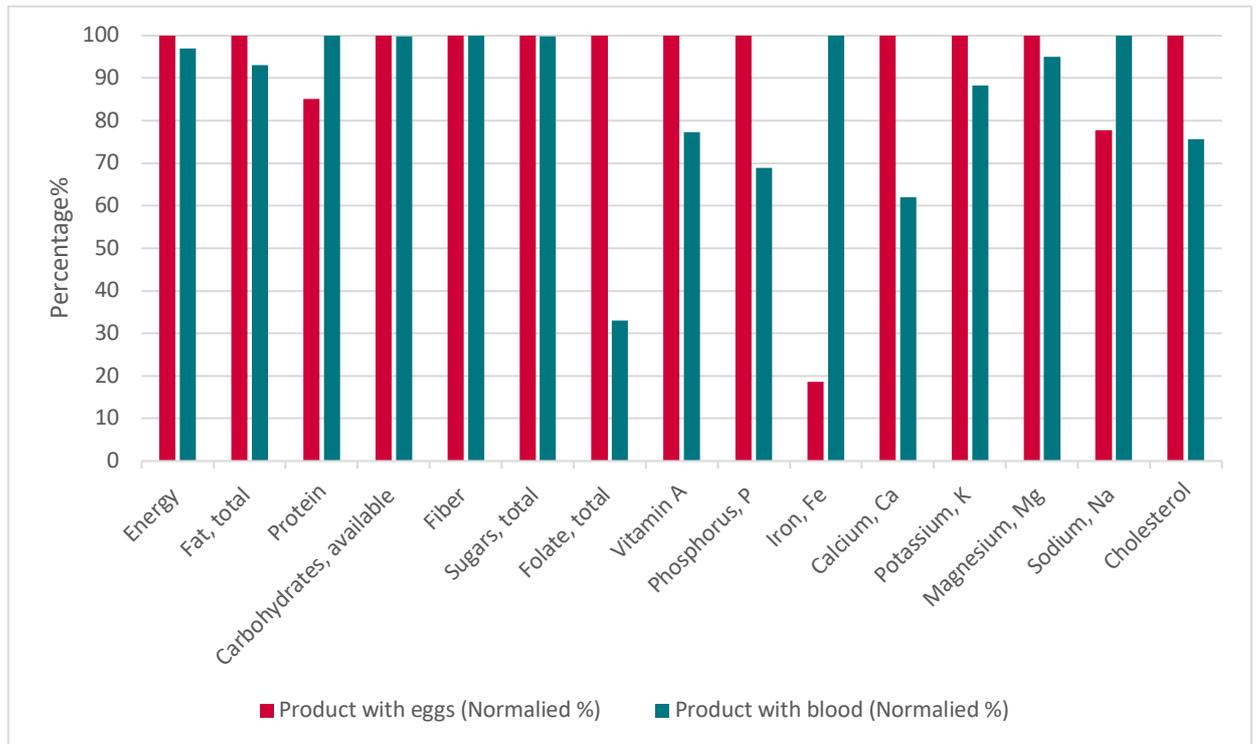


Figure 6 Relative comparison of nutritional values in the two products. Values are normalized to a scale where the highest value is set to 100.

Figure 6 illustrates a normalized comparison of nutritional values between the two products, where the highest value is scaled to 100. The Black brownie demonstrated a notably higher iron and somewhat higher protein content compared to the conventional cake scenario, attributable to the naturally high levels of these nutrients in blood. In contrast, the folate, calcium and phosphorous content was lower in the Black brownie formulation. Other key nutritional components, including fat, carbohydrates, fiber, sugar, and total energy, showed comparable values across scenarios.

## 4. Discussion

### 4.1. Carbon Footprint Analysis

This study aimed to assess the carbon footprint of the Black brownie by evaluating the outcomes under two different allocation approaches for rescued cattle blood and compare those results with conventional chocolate cake.

The carbon footprint analysis emphasized that ingredient phase was the dominant contributor to emissions across all three scenarios, which is compatible with previous LCA studies showing that agricultural production and raw material extraction typically account for the majority of environmental burdens in food products (Espinoza-Orias et al., 2011). The relatively low impact from baking and packaging stages across all scenarios aligns with broader evidence showing that agricultural production dominates the carbon footprint of food systems, accounting for approximately 70% of total emissions, while processing, packaging, and other supply chain stages accounting only for the remaining 30% (Crippa et al., 2021, Espinoza-Orias et al., 2011).

Among the three assessed scenarios, the highest carbon footprint (7.5 kg CO<sub>2e</sub> per kg brownie) was obtained when beef impact value was used for the blood, which is obvious due to the large climate impact of beef. While, the lowest footprint (1.5 kg CO<sub>2e</sub> per kg product) was observed under the lost biogas scenario. The conventional cake had a carbon footprint of 1.7 kg CO<sub>2e</sub> per kg. This result can largely be affected by the differences in recipe composition between the blood brownie and the conventional chocolate cake since the ingredient compositions differ in types and amounts considerably in the two products. The blood brownie contains dark chocolate which is carbon-intensive ingredient, and not present in the conventional cake and therefore can add extra emissions to the blood brownie. In addition, the brownie recipe uses higher quantities of certain ingredients, such as rapeseed oil than in conventional cake, which has a relatively high carbon footprint and contributes to elevate the carbon footprint. These recipe variations already cause to place the higher impact level for blood brownie than the conventional cake, even before considering cattle blood allocation. Therefore these variations was not primarily result from the eggs- blood substitution, but also due to variations in recipe composition. These value could be much lower for blood brownie if the ingredient composition were same as in conventional cake. However, addition of these extra ingredients such as dark chocolate could improve the desired sensory qualities of the blood brownie.

When blood was assigned a large share of beef production emissions in the Beef value scenario, the total footprint rises sharply to 7.5 kg CO<sub>2e</sub>, with cattle blood becoming the dominant

contributor. Whereas, assigning a minimal burden to blood in the Lost biogas scenario reduces the total footprint to 1.5 kg CO<sub>2e</sub>. This illustrates that allocation choices have a great impact on the climate profile of the blood brownie, but also higher-impact ingredients and higher quantities of oil play a significant role in making the final results. Across all scenarios, baking and packaging contribute very little, reinforcing that variations in emissions originate primarily from the ingredients and, in the case of the blood brownie, from the allocation method applied to cattle blood.

#### 4.1.1. Allocation Results and Its Implications

The carbon footprint (CF) results showed clear variations across the different allocation scenarios, underscoring the significant influence of allocation choices on the environmental performance of the product. These findings are consistent with existing literature, which shows that the choice of allocation method can lead to widely varying LCA outcomes in co-product systems (Kyttä et al., 2021).

Among the three assessed scenarios, the highest carbon footprint (7.5 kg CO<sub>2e</sub> per kg product) was observed in the scenario where the impact of blood was based on the impact value of beef, which is expected given the substantial climate burden associated with beef production. In this scenario blood was allocated a share of the environmental burden consistent with that of beef. This also illustrates that when a co-product was attributed with high economic value (in this case blood was treated as same as beef), the environmental burden of the product increased accordingly.

In contrast, the scenario which used the lost CO<sub>2</sub> savings from missed biogas production for the impact of blood, resulted in a lower carbon footprint. This reflects a different framing, in which the blood was considered as a substrate for energy generation than a co-product of food production. This result was based on a key assumption when utilizing CO<sub>2</sub> savings data from GASUM: that blood have comparable biogas generating potential per kg as the mix of substrates processed by GASUM and used in their climate saving calculations. These differences in CF values resulted under different allocation scenarios, highlights that how allocation choices can change the environmental interpretation of a product.

Olofsson and Börjesson (2018) emphasize that allocation of residuals can strongly affect LCA results, with burden-sharing approaches often escalating the impacts of unavoidable by-products. This observation is directly showed in the BeefValue scenario, where assigning beef's upstream emissions to blood resulted in an incredibly high carbon footprint. Furthermore, Lostbiogas scenario aligns closely with the guidance of Olofsson and Börjesson (2018), who argue that residuals should be assessed in terms of the functions or services they replace in alternative valorization pathways. By modeling blood as if it would otherwise be directed to biogas production, the Lostbiogas scenario reflects this consequential perspective, where the environmental impact of blood is represented as the foregone climate benefits of biogas production. This approach avoids unfair allocation of full environmental burden of beef to blood

and provides a more balanced estimate of its role in the product system, consistent with circular economy principles that prioritize waste utilization and avoided emissions.

This study reflects the broader concerns raised by Dominguez Aldama et al. (2023), who highlight the complexities and inconsistencies in life cycle assessments of agri-food systems, particularly in the interpretation of multifunctionality and the differentiation between waste and co-products. They emphasise the importance of understanding the nature of input substrates and the context of their valorization within supply chains, which directly influences the environmental outcomes of LCA studies, as revealed in this study.

#### 4.1.2. Assumptions and Their Effect on Reliability

While the analysis offers important insights, its reliability was restrained by several underlying assumptions. Processing, packaging, and transport emissions were assumed to mirror those of Swedish *kladdkaka*, which may not accurately reflect variations specific to blood brownie manufacturing. Additionally, the modelling did not account for potential variations in energy use or food safety protocols specific to blood-handling operations. These simplifications were necessary due to data unavailability but introduce uncertainty that should be acknowledged when interpreting the results. Uncertainty in LCA studies often results due to variability in data, choice of methods, and assumptions made in the inventory stage, which can significantly affect results (Barahmand and Eikeland, 2022)

#### 4.1.3. System Implications of Valorization of Blood

The recent study by Scherhauser et al. (2020), which conducted a comparative environmental assessment of various valorization pathways for food production side-flows, including animal blood, provides valuable context for this study. Both studies emphasize that upcycling these side-streams into food ingredients can offer climate benefits, particularly when they replace conventional, high-emission ingredients and are processed using renewable energy sources. This thesis strengthens their observation that the allocation method plays a major role in determining environmental outcomes.

Though Scherhauser et al. highlighted that cooling and long-distance refrigerated transport as significant contributors to GHG emissions, it was less significant with compare to processing related emissions. In this study, transportation and cooling of the blood were excluded due to limitations in real situational data. Accordingly, the climate benefits reported here are more likely representative of localized or small-scale production contexts, which requires no energy-intensive

logistics. This exclusion creates a key limitation and demands the need for future research combining comprehensive life cycle inventory data.

However, according to the waste management hierarchy, valorisation into food products is considered more favourable than recycling options such as anaerobic digestion, as it retains more of the material's original value and supports circular economy principles. Scherhauser et al. emphasize that when valorization involves complex or energy-intensive processing, other alternatives which are bottom in the waste hierarchy such as anaerobic digestion may prove more environmentally advantageous. This nuance is reflected in this study's findings as well: although upcycling slaughterhouse blood into a brownie mix showed climate benefits under specific assumptions, those benefits are highly dependent on the energy mix, allocation approach, and exclusion of burdens like cooling and transport.

Moreover, both studies highlight methodological and economic uncertainties that limit the scalability of these valorization strategies. As with Scherhauser et al., this thesis was constrained by a lack of specific cost data and relied on assumed processing conditions, including generic emission factors. The true climate impact and commercial viability of valorizing animal blood thus remain sensitive to what products are actually displaced on the market, the infrastructure available, and country-specific factors such as energy policy and food regulation.

Overall, these insights demand for a context-dependent and cautious approach to valorization within the circular economy framework. While the upcycling of slaughterhouse blood has potential as a way to sustainable food system and circular economy, its implementation must be guided by robust LCA data, supportive policy instruments, and energy-efficient processing systems to minimize the environmental trade-offs and maximize the net benefits.

## 4.2. Nutritional Assessment

The results of the nutritional assessment were presented as a comparison between two product versions, one with Black brownie and the other one with conventional chocolate cake. Each assessed per 100g of product.

The nutritional comparison between the conventional and Black brownies disclosed that both products were widely comparable in terms of macronutrients, including energy, fat, protein, and carbohydrate content. This stipulates that substituting eggs with slaughterhouse blood does not substantially alter the basic nutritional profile of the product.

Importantly, the Black brownie offered a distinct advantage in its higher iron content, reflecting the presence of bioavailable heme iron, which was 10 mg per 100g in the Black brownie and it was substantially higher compared to conventional cake which had iron content of 2 mg per 100g. According to EU regulation No 1169/2011, the daily reference value for iron is 14 mg. 100 g of this product contains more than 70% of daily reference intake of iron, which makes this product capable of claiming as “high in iron”. This represents a significant improvement from a public health perspective as this product was derived from rescued blood. In Sweden iron intake in young girls at high school level was found to be low (Warensjö Lemming et al., 2018) which

creates a significant potential for this upcycled food product when consumed occasionally as part of a balanced diet.

Moreover, the Black brownie had lower cholesterol content than the conventional brownie, which could be viewed positively from health perspective, particularly in relation to cardiovascular diseases.

However, the Black brownie showed some nutritional trade-offs including lower levels of certain nutrients such as vitamin A, folate, calcium and potassium which are naturally rich in eggs. These trade-offs suggest that while blood can replace eggs in terms of functionality and most nutritional components, additional strategies may be needed to ensure a balanced nutritional profile.

Blood is not only a nutrient rich ingredient, but also it contributes to functional properties in the formulation (Csurka et al., 2022). It has good binding, foaming and emulsifying properties, which reduces the requirement for additional additives. Therefore these properties increase the potential of the product as a sustainable and nutrient-rich replacement to conventional egg based baked items.

The substitution of eggs with cattle blood led to a nutritionally distinct profile, with both advantages and trade-offs. Given the enriched profile of iron, address the common nutritional deficiency particularly among vulnerable groups such as children, adolescents and pregnant mothers in many countries including Sweden. Also high protein content supports energy and muscle development. However, this substitution resulted in low folate content, likely due to absence of this nutrient in blood, compared to its abundance in egg yolk. Therefore, it is essential to give attention to potential nutritional trade-offs, such as folate, vitamin A which may need to be compensated through recipe modification.

Generally, these results show that slaughterhouse blood can enhance the nutritional profile of baked products, particularly in iron while having similar energy and carbohydrates levels as egg based products. Also has the functional properties that replicate the functional roles of eggs in baking, such as emulsification and binding (Csurka et al., 2022).

Even though blood has a vast potential in enhancing nutritional requirements in humans while achieving the environmental and economic aspects, still most people are reluctant to consume blood containing foods particularly in low-income regions where iron deficiency is prevalent (Chiroque et al. 2023). This may be due to socio- cultural barriers and concerns about food safety aspects. However studies have shown that there is no additional risk associated with animal blood in terms of transmitting pathogens, exposure to blood allergens since those risks are similar with other foods of animal origin (ibid).

It becomes evident that developing safe, nutritious, environmentally friendly, and consumer-acceptable food products from side streams such as slaughterhouse blood is a challenging task, yet it aligns well with the principles of the circular economy. As emphasized by recent research (Stübler, Heinz & Aganovic, 2020), the success of this kind of product is heavily depend on the appropriate development, better marketing strategy (includes education and transparency) along with clear regulatory framework. This study demonstrates that upcycling slaughterhouse blood into a food product may be a more beneficial approach than conventional recycling, particularly

in terms of enhancing nutritional value. Additionally, it has the potential to reduce the overall carbon footprint by optimizing emissions from other ingredients and incorporating renewable energy in the production process.

However, consumer acceptance to this kind of product is strongly depending on the contextual factors such as region, educational level, social and political background (Stübler, Heinz & Aganovic, 2020). According to this study the major motivation of the consumers to buy these products is to support local farmers while having positive effect on the environment and economy. These findings suggest that some consumer groups are willing to support circular bioeconomy initiatives if they understand the environmental benefits and feel they are contributing to local economies and sustainability goals. This aligns well with the behavior of Swedish consumers, who are generally highly aware of environmental and sustainability issues and are more likely to respond positively to upcycled food products that support these values. Thus, effectively communicating the reduced carbon footprint and high nutritional quality of the product could play a key role in enhancing consumer willingness to adopt novel, upcycled food solutions.

Collaboration between regulators and industry stakeholders is essential to implement the measures such as proper labelling, development of new techniques for blood collection and storing to reduce the contamination of blood in the manufacturing stage. It is also necessary to increase the awareness of the public to eliminate unfounded concerns about foods containing blood. Therefore, innovation in the food industry should be encouraged to develop blood-based food products, and sensory acceptance studies should be conducted to evaluate consumer responses to these novel formulations such as surveys and taste panels.

## 5. Future Research

This study opens the path for new research with actual emission data related to the collection, storage and transportation of blood, preferably collecting primary data from slaughterhouses in Sweden. It will yield more precise estimates under real-world production conditions. Choosing more relevant and improved allocation methods for blood will enhance the accuracy of future LCA.

Moreover, market and consumer research should be conducted to explore the consumer acceptance and perception towards this type of blood based product since cultural, religious, and psychological factors may significantly affect consumer acceptance and market viability for these products. Further research should be conducted to evaluate the bioavailability of iron from the blood in this product and to assess the consumer acceptance through consumer surveys, taste panels..etc.

Microbiological examination should be conducted to determine the shelf-life and safety of blood-based formulations. Ultimately, integrating food-grade blood into mainstream food systems could offer a promising pathway to reduce food waste, lower environmental impact, and enhance nutrient availability in a resource-efficient manner.

## 6. Conclusions

The current study evaluated the carbon footprint of a novel Black brownie formulated using slaughterhouse-derived blood, assessed from a cradle-to-bakery gate perspective for 1 kg of the final food product, which resulted in a climate footprint of approximately 7.5 and 1.5 kg CO<sub>2</sub>e per kg when employed in two allocation scenarios for blood. The two allocation approaches applied respectively were: using the impact value of beef and accounting for lost climate savings from missed biogas production. The reference product scored 1.7 kg CO<sub>2</sub>e per kg, but was based on a recipe without dark chocolate. The carbon footprint revealed that the included ingredients were the primary climate hotspot. Other life cycle stages were modeled using proxy data from Swedish kladdkaka production, due to similarities in processing and ingredient composition, and turned out to have a low overall impact.

The nutritional assessment demonstrated that this novel product contained 10 mg of iron per 100 g which corresponds to 70% of daily reference value. Although it is not intended as a nutritionally suitable product, its relatively high iron content indicates that it can provide a valuable contribution to dietary iron intake when consumed occasionally as part of a balanced diet.

Additionally, the study found that eggs in the brownie formulation could potentially be replaced with slaughterhouse blood, provided it is handled and stored under safe and hygienic conditions. However, nutrient trade-offs were identified; for instance, folate, vitamin A content was relatively low and would require fortification to optimize the product's nutritional profile. This study demonstrates that food grade blood can be a sustainable, nutrient-dense ingredient that promotes circularity and reduces food waste.

## References

- Ahmad, S., Wong, K.Y. & Ahmad, R. (2019). Life cycle assessment for food production and manufacturing: recent trends, global applications and future prospects. *Procedia Manufacturing*, 34, 49–57. <https://doi.org/10.1016/j.promfg.2019.06.113>
- Andago, A., Imungi, J., Mwangi, A., Lamuka, P. & Nduati, R. (2015). Development of a Bovine Blood Enriched Porridge Flour for Alleviation of Anaemia among Young Children in Kenya. *Food Science and Quality Management*, 39, pp.73-83.
- Barahmand, Z. and Eikeland, M.S., 2022. Life cycle assessment under uncertainty: a scoping review. *World*, 3(3), pp.692–717. <https://doi.org/10.3390/world3030039>
- Boakye-Yiadom, K.A., Duca, D., Foppa Pedretti, E. & Ilari, A. (2021). Environmental Performance of Chocolate Produced in Ghana Using Life Cycle Assessment. *Sustainability*, 13 (11), 6155. <https://doi.org/10.3390/su13116155>
- Chiroque, R.G.S., Cornelio-Santiago, H.P., Espinoza-Espinoza, L., Moreno-Quispe, L.A., Tirado, L.R.P.- & Nieva-Villegas, L.M. (2023). A Review of Slaughterhouse Blood and its Compounds, Processing and Application in the Formulation of Novel Non-Meat Products. *Current Research in Nutrition and Food Science Journal*, 11 (2), 534–548
- Crippa, M., Solazzo, E., Guizzardi, D., Monforti-Ferrario, F., Tubiello, F.N., and Leip, A., 2021. Food systems are responsible for a third of global anthropogenic GHG emissions. *Nature Food*, 2, pp. 198–209. <https://doi.org/10.1038/s43016-021-00225-9>
- Csurka, T., Varga-Tóth, A., Kühn, D., Hitka, G., Badak-Kerti, K., Alpár, B., Surányi, J., Friedrich, L.F. & Pásztor-Huszár, K. (2022). Comparison of techno-functional and sensory properties of sponge cakes made with egg powder and different quality of powdered blood products for substituting egg allergen and developing functional food. *Frontiers in Nutrition*, 9, Article 964041. <https://doi.org/10.3389/fnut.2022.964041>
- De Boni, A., Ottomano Palmisano, G., De Angelis, M. & Minervini, F. (2022). Challenges for a Sustainable Food Supply Chain: A Review on Food Losses and Waste. *Sustainability*, 14 (24), 16764. <https://doi.org/10.3390/su142416764>

- Dominguez Aldama, D., Grassauer, F., Zhu, Y., Ardestani-Jaafari, A. & Pelletier, N. (2023). Allocation methods in life cycle assessments (LCAs) of agri-food co-products and food waste valorization systems: Systematic review and recommendations. *Journal of Cleaner Production*, 421, 138488. <https://doi.org/10.1016/j.jclepro.2023.138488>
- Espinoza-Orias, N., Stichnothe, H. and Azapagic, A., 2011. The carbon footprint of bread. *The International Journal of Life Cycle Assessment*, 16(4), pp.351–365.
- Garnett, T., Rööß, E., Nicholson, W., & Finch, J. (2016). Environmental impacts of food: an introduction to LCA (Foodsource: chapters). Food Climate Research Network, University of Oxford
- Izgarishev, A.V., Izgarisheva, N.V. & Ostroumov, L.A., 2018. Development and study of food product with anti-anemic agent based on farm animal blood. *Foods and Raw Materials*, 6(1), pp.56. Available at: <http://jfrm.ru/> [Accessed 23 February 2025].
- Kyttä, V., Roitto, M., Astaptsev, A., Saarinen, M. and Tuomisto, H.L., 2021. Review and expert survey of allocation methods used in life cycle assessment of milk and beef. *International Journal of Life Cycle Assessment*, 27, pp.191–204
- Livsmedelsförluster vid slakt av grisar och nötkreatur (n.d.). <https://webbutiken.jordbruksverket.se/sv/artiklar/ra2218.html> [2025-02-20]
- Malta, D., Petersen, K.S., Johnson, C., Trieu, K., Rae, S., Jefferson, K., Santos, J.A., Wong, M.M.Y., Raj, T.S., Webster, J., Campbell, N.R.C. & Arcand, J. (2018). High sodium intake increases blood pressure and risk of kidney disease. From the Science of Salt: A regularly updated systematic review of salt and health outcomes (August 2016 to March 2017). *The Journal of Clinical Hypertension*, 20 (12), 1654–1665. <https://doi.org/10.1111/jch.13408>
- Nutrizio, M., Dukić, J., Sabljak, I., Samardžija, A., Fučkar, V.B., Djekić, I. & Jambrak, A.R. (2024). Upcycling of Food By-Products and Waste: Nonthermal Green Extractions and Life Cycle Assessment Approach. *Sustainability*, 16 (21), 9143. <https://doi.org/10.3390/su16219143>
- Ockerman, H.W. and Hansen, C.L., 1988. Animal by-product processing. VCH. Available at: <https://cir.nii.ac.jp/crid/1130000797467934208>
- Olofsson, J. and Börjesson, P., 2018. Residual biomass as resource – life-cycle environmental impact of wastes in circular resource systems. *Journal of Cleaner Production*, 196, pp.997–1006. <https://doi.org/10.1016/j.jclepro.2018.06.115>
- Scherhauer, S., Davis, J., Metcalfe, P., Gollnow, S., Colin, F., De Menna, F., Vittuari, M. & Östergren, K. (2020). Environmental assessment of the valorisation and recycling of selected food production side flows. *Resources, Conservation and Recycling*, 161, 104921. <https://doi.org/10.1016/j.resconrec.2020.104921>

- Stübler, A.-S., Heinz, V. & Aganovic, K., 2020. Development of food products. *Current Opinion in Green and Sustainable Chemistry*, 25, p.100356. Available at: <https://doi.org/10.1016/j.cogsc.2020.100356>.
- Swedish University of Agricultural Sciences (SLU) (n.d.). *SAFAD – Sustainability Assessment of Foods and Diets*. Available at: <https://safad.se/> [Accessed: 7 February 2026].
- Vergé, X., Maxime, D., Desjardins, R.L. & VanderZaag, A.C. 2016. Allocation factors and issues in agricultural carbon footprint: a case study of the Canadian pork industry. *Journal of Cleaner Production*, 113, 587–595. <https://doi.org/10.1016/j.jclepro.2015.11.046>
- Warensjö Lemming, E., Moraeus, L., Petrelius Sipinen, J. and Lindroos, A.K. (2018). Riksmaten ungdom 2016–17: Näringsintag och näringsstatus bland ungdomar i Sverige – Resultat från en matvaneundersökning bland ungdomar i årskurserna 5, 8 och 2 på gymnasiet. *Livsmedelsverkets rapportserie nr 23*. Uppsala: Livsmedelsverket.

## Popular science summary

As the world's population grows, it increases the demand for food. But producing food takes a cost on our environment since it uses up huge amounts of resources and releases greenhouse gases that cause climate change. Also it causes to other environmental issues such as biodiversity loss, eutrophication and air pollution. In addition to that, large amounts of food and animal by-products go to waste due to industrial production. Animal blood is one of those by-products from slaughterhouses, which is usually thrown away.

This study focused on an upcycled food product (similar to Swedish kladdkaka) made out of rescued cattle blood, in environmental and nutritional aspects. Instead of using egg powder, which is common in baking, the recipe was changed to include blood as an ingredient.

To perform this task I used a method called Life Cycle Assessment (LCA), which measures the environmental impact of a product from production to finished product; starting with the raw materials, and ending at the bakery gate. The results showed that when the blood assigned with lost CO<sub>2</sub> savings of missed biogas production, the product had the lower carbon footprint. In contrast, using beef impact value instead of blood caused the highest impact because beef production is known to have high climate impact.

From the nutritional perspective this blood-based product has a rich profile in iron which makes it beneficial for children, adolescents and pregnant women. In contrast it has less folate, vitamin A and some minerals content compared to regular egg based product, which should be improved by recipe modification.

However, this study has several limitations such as difficulties of finding reliable and transparent data sources in slaughterhouses which hinder the impact allocation for blood, and the emissions related to actual processing, packaging and transportation could not be found since this is a prototype. Therefore future research is needed to be conducted to avoid these limitations and obtain more precise insights.

## Acknowledgements

I would like to express my heartfelt gratitude to my family for their love, support, and encouragement throughout this journey. A special thanks to my friends for their motivation and companionship, which kept me going during challenging times.

I am also deeply thankful to my supervisors, Ingrid Strid from SLU and Maria Lundesjö from Axfoundation for their valuable guidance, constructive feedback, and continuous support, which have been instrumental in completing this thesis. This achievement would not have been possible without their support and presence by my side. Finally, I would like to express my heartfelt gratitude to Veronika Öhrvik for giving me this opportunity to contribute to their meaningful work in advancing sustainability in food production.

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