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Circular food strategies for the Gothenburg circular economy action plan

Master's thesis in the Master's Programme
Infrastructure and Environmental Engineering

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ABSTRACT

Resource efficiency can reduce material demand and support the economy of cities. Circular economy actions can support the reduction of the economic gap between linear metabolism and circular metabolism of a city. Gothenburg aims to improve its food sector by implementing circular action across its food value chain. The thesis analyses the food metabolism of Gothenburg, identify suitable circular strategies relevant to the city based on the circularity pillars and model how the selected strategies affect the metabolism change in the production, consumption, trade and waste stages of the food chain. The results of the three modelled actions shows that import dependency on identified food products could be reduced although in some cases dependency shifted from one product to another. The actions could also support more circular food flows in Gothenburg through increased local production, changes in consumption and redistribution of surplus food. Through action alley farming, oat bread production reduced bread imports by 18 percent resulting in additional wheat imports. Action dietary change reduced modelled school meat demand but also increased imports of identified plant-based products. In centralized retail surplus redistribution, the estimated 6 percent increase in surplus capture rate at redistribution centres directed more food to people, that could potentially reduce the amount sent to waste treatment, while also reducing the import dependency of redistributed food products. The results indicate that the selected actions could contribute to more circular food flow in Gothenburg even though trade dependency is not eliminated. The selected actions show potential to support substitution, extend the use of surplus retail food and improve the resilience of the food system.

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Preface

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Finally, I would like to thank my family for the encouragement and care given throughout this journey.

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Raveena Nath

List of abbreviations

AR	available resource
CN	Combined Nomenclature
DE	domestic extraction
DMC	domestic material consumption
DMI	domestic material input
FW	Food waste
LP	local production
MFA	material flow analysis
ROC	rest of the country
ROW	rest of the world
RQ	research question
SDG	Sustainable Development Goals
UCM	Uppsala City Mission

1 Introduction

1.1 Background

Global economy is consuming ever more natural resources and still fails to deliver acceptable human development (United Nations Environment Programme, 2024). The material resource extraction is expected to increase to 160 billion tonnes by 2060, not aligning with the sustainable development goals (SDGs) (United Nations Environment Programme, 2024). Cities alone accounts for 75 percent of resource consumption in the world (UNEP, 2024). Also, the total global urban material consumption is expected to reach 90 billion tonnes by 2050, resulting in an average urban domestic material consumption of approximately 14 tonnes per capita by 2050. Urban consumption is increasing as cities grow, even faster than urban population growth. This will have serious effects in the global resource consumption and environment impacts (IRP, 2018).

Using resource efficiently can reduce the material flow and increase the efficiency, improving well-being of human and boosting the economy through concepts of circular economy such as dematerialisation which is the use of fewer materials for products or services and re materialisation which is the reuse or recovery of materials for new products or services (United Nations Environment Programme, 2024). Circular economy is a system where nature is regenerative and materials are not wasted, through processes such as recycling, maintenance, reuse, refurbishment and remanufacture (Ellen MacArthur Foundation, n.d.). While dematerialisation and re materialisation are concepts to address resource efficiency, value gap provides an economic outlook that captures the total economic value possible through circular economy (Circle Economy, 2025). For Sweden, it is 19 percent, meaning that there is currently a loss of SEK 600 billion per year due to linear economy (Circle Economy, 2025). There arises the need for analysing Swedish cities where these gaps will be more prominent and relevant to be reduced. For analysing the metabolism changes of cities, the Swedish research institute, RISE focus on important value concepts. These includes value created, value captured, value not created, value lost and overconsumption, which can be looked at for value generation, economic resilience and improving resource efficiency (Circle Economy, 2025). Circular economy in cities are carried out by minimising waste, providing services for efficient use of natural resource across value chain, optimising reuse and through better design of infrastructure (OECD, 2025).

Urban metabolism helps us to understand how cities consume and addresses the problems associated with urbanisation sustainably (IRP, 2018). Urban metabolism studies the multitude of interrelated exchange processes that shapes the urban environment (Broto et al., 2012). It guides policy making and assess trends in resource use, that highlights value chains where interventions are most needed (OECD, 2025).

Food is an important sector to be considered for global environmental sustainability (Guibrunet & Sánchez Jiménez, 2023). The sector contributes to one third of greenhouse gas emissions globally mainly through agriculture and land use (Crippa et al., 2021), making it the biggest sector contributing to environmental footprints (Guibrunet & Sánchez Jiménez, 2023). Food production system brings about

exploitation of resources such as land, fresh water and forest (Colombo et al., 2019). In an urban system, food is especially important to consider as it has one of the largest flows of materials, with cities alone consuming 70 percent of all globally produced food (UNEP, 2025). Often urbanisation results in increased consumption of resource demanding food, reducing the demand for lower impact ones (Colombo et al., 2019). Consumption beyond nutritional needs and unnecessary food waste production are two of the biggest issues that affect food resource use efficiency (Circle Economy, 2025). Sustainable resource management is based on the notion that waste is a resource (Papargyropoulou et al., 2014). Yet, food waste represents the largest fraction of municipal solid waste, accounting 38 percent globally while only 6 percent undergoes resource recovery (Cook et al., 2026). Therefore, it is important to assess, analyse and understand the food system metabolism in cities to develop and implement some of the best actions to support a sustainable urban food system.

1.2 Aim

The aim of the project is to assess the impact of the implementation of circular actions in the metabolism of Gothenburg food value chain towards a circular economy action plan, by modelling the selected actions, thereby, helping Gothenburg municipality to understand the magnitude of the resource use changes and how the metabolism of the city is affected.

1.3 Research question

The thesis aims to answer the following research questions:

1. What is the metabolism of food value chain in Gothenburg?
2. Which circular actions can be identified and explored to strengthen the circular metabolism of food value chain in Gothenburg?
3. What are the effects of selected actions in the metabolism of the food value chain in Gothenburg?

1.4 Scope

The thesis is carried as part of a larger on-going DUT research project: ECLECTIC - Enabling Circular Economy action plans for small and medium-sized Cities. The system boundary defined is Gothenburg, while the time boundary is set to 2022 as material flow data is made available for the particular year. Within the Gothenburg system boundary, local production represents production within the city, while national and international trade represent material flow entering from the rest of Sweden and from outside Sweden, respectively. The study covers the overall food flow of Gothenburg population, but the modelled scenarios are limited to selected food products and population. Within the resulting scope, the Municipality of Gothenburg is the main stakeholder involved, grounding the selection of circular actions to its practicality in the city. The study evaluates the changes in the food metabolism of Gothenburg's food value chain through selected actions and hence the economic cost and environmental impact of actions are outside the scope of this thesis.

2 Theoretical background

2.1 Circular economy and urban metabolism

Circular economy can be described as a regenerative system that minimises resource inputs, waste and energy losses by slowing, closing and narrowing material loops through methods such as lifetime extension, repair, reuse, refurbishing and recycling (Geissdoerfer et al., 2017). Circular economy concepts can help to tackle global challenges through waste prevention, dematerializations and regeneration, while also addressing societal needs. Achieving circular economy requires a good understanding of how the city functions. Urban metabolism concepts can support this.

"Urban metabolism is the quantification of the inputs, outputs and storage of energy, water, nutrients, materials and wastes for an urban region" (Kennedy et al., 2011). "Cities transform raw materials, fuel, and water into the built environment, human biomass and waste" (E. H. Decker et al., 2000) making cities act like an organism but with more complex structure, like an ecosystem (Girardet, 1992). This is the concept of urban metabolism. Study of urban metabolism helps to understand city needs at a given time (Franz Oswald, 2003). It supports sustainable development through a shift from linear metabolism to circular metabolism where cities transform from consumption and waste generation to reuse and reducing waste helping to reduce ecological pressure (Kennedy et al., 2011) (Girardet, 1992). The five urban quality criteria mentioned by Oswald and Baccini in (Franz Oswald, 2003) is the main design pillars identified for urban metabolism for cities. These includes diversity, flexibility, self-sufficiency, resource efficiency and identification.

Urban metabolism also provides a basis for material flow analysis. Cities are studied as a metabolic process in which energy and material flows are analysed, and material inputs are transformed into useful energy, physical structure, and waste (E. H. Decker et al., 2000). It deals with scientifically valid sustainability indicators such as energy efficiency, material cycling, waste management and infrastructure in urban systems (Kennedy et al., 2011). Thus, urban metabolism provides a framework for understanding the cities, while material flow analysis can be used for measuring metabolic change within the city when these flow changes. Quantification helps identify a linear system and support the shift to a circular system.

2.2 Food system

A food system includes its elements such as environment, people, inputs, processes, infrastructures, institutions and its related activities such as production, processing, distribution, consumption of food, in addition to the output of these activities (Level Panel of Experts on Food Security, 2017). Food system is relevant to consider as it is increasingly becoming important for policy makers for supporting SDG goals such as eradicating hunger, health, wellbeing and transition to sustainable cities goal and it is also an important sector to hold a share in the environmental impacts of cities (Guibrunet et al., 2025). Circular economy in food system can be achieved through reuse, recycling and waste management, especially from surplus food, by products, and organic waste because often the food system is linear (Geissdoerfer et al., 2017). Food system circular strategies can be framed as actions that can be implemented to improve resource efficiency, self-sufficiency and reducing waste. MFA can be used to

quantify urban food flow and when combined with life cycle assessment, these flows can be used to analyse the environmental impacts of food waste, unsustainable diets, and food injustice (Guibrunet et al., 2025).

In Sweden, food consumption is reported unsustainable particularly due to the consumption of meat, dairy and processed foods with around 7 percent equivalent to SEK 20 billion (Circle Economy, 2025). Food production contributes to several environmental pressures including greenhouse gas emissions such as methane from ruminants, nitrous oxide from nitrogen fertilization (Jörgen Larsson, 2015) as well as land use, freshwater use, acidification and eutrophication (Poore & Nemecek, 2018). Furthermore, Sweden is largely dependent on imports for several food categories while considerable amount of food waste are also generated in the food system (Livsmedelsverket; Jordbruksverket, 2025) (Johan Hultén & Martin Villner, 2024). These pressures highlights the need to analyse the food system to identify appropriate actions based on the MFA analysis. Measures identified in (Circle Economy, 2025) such as "consumption according to societal needs" can be used as a basis to formulate circular actions. "Maximising value capture upstream" will be relevant for food system to increasing the local food production, improving resilience and self-sufficiency whereas, "minimising value loss downstream" can be achieved by reuse of wasted food through sharing platforms, reduction in price etc. Food waste in Sweden is at SEK 33 billion annually with only SEK 1.5 billion recovered. The RISE suggested measure of maximising value recovery (Circle Economy, 2025) can be supported at the city level through waste recovery actions such as composting and anaerobic digestions. Identifying such intervention of circular action require understanding of the urban metabolism across the food value chain. (Guibrunet et al., 2025) uses urban metabolism nodes such as production, imports, exports, processing, wholesale, retail, consumption, food loss and waste in the food value chain of cities to analyse important urban food flow.

Building on these concepts of urban metabolism and circular economy, circular actions can be identified and used to support reduction of resource flow through the food system and possibly decrease the associated climate impact from greenhouse gas emissions from land use, fertilizers, livestock and supply chain (Michael A. Clark, 2020). Although international trade contributes to the stability of food inputs into the system, including inputs for domestic production, dependency on the continuous flow of imported food creates risks in the food system (Livsmedelsverket & Jordbruksverket, 2025). Therefore, it is important to reduce the dependency on national and particularly international imports to minimise the food flow, while examining the potential of efficient use of resources through identified circular actions.

2.3 Relevance of selected actions

Circular actions are essential to support transition to resource efficient system by implementing targeted and coordinated sustainability actions that reduces resource use and its associated environmental impact while increasing sustainable consumption and production, thereby supporting the decoupling of human well-being from increased resource consumption and environmental pressure (United Nations Environment Programme, 2024). Actions implemented within food system initiatives

can support sustainable food system transformation, while implementing multiple actions strengthens the local initiatives (Lam et al., 2022).

Agroforestry

Agroforestry is an agriculture system where trees and shrubs are deliberately integrated with crops or livestock or both on same land to harness synergies between biodiversity that brings about multiple environmental benefits (Sagastuy & Ternell, n.d.). Agroforestry is increasingly recognised as a land use strategy that combines sustainable agriculture method with climate change mitigation (Edris et al., 2025). Agroforestry has the potential to improve food security through crop diversification, nutritional benefits, stable production and secured farmers income. A lot of indigenous food found in the forest and woodland are not completely used by the food system. These have more health benefits than staple crops in monoculture system (Dawson et al., 2013). European agroforestry system is expected to be 20 to 30 percent more productive than monoculture due to reasons such as that it can withstand extreme weather conditions, supports microbes that helps in the growth of crops and trees, create healthier soil conditions by improving the fertility of soil and can even provide fodder in case of agrosilvopastoral system. In many cases, it also has a good cost benefit ratio (Dawson et al., 2013). Combining crops with trees or woodlands can provide more healthier food to the food system along with increasing the income of farmers from additional production. Beneficial inputs to food system from agroforestry includes food for human which includes fruits, berries, nuts etc, food for animals which is fodder and important raw materials such as fibre, timber and energy (Sagastuy & Ternell, n.d.). Agroforestry is a system already in existence in various forms from a very long period of time with a significant proportion of land already in such forms in Europe and globally (Burgess & Rosati, 2018). Wood pastures and hedgerow systems are such systems which has high value for nature and climate (Burgess & Rosati, 2018). Such a system like alley farming brings sustainable food production along with environmental benefits. Agroforestry thus becomes an important strategy to analyse for Gothenburg's food system.

Alley farming

Alley farming is widely practiced in Sweden. Examples include alley cultivation at Lönnstorp research station located in southern Sweden, oats and apple cultivation in Uppland, a historical region in eastern Sweden, alley growing vegetables in Sörmland in central Sweden (Jordbruksverket, 2024). Lönnstorp research station is an agroecological experiment field that cultivates fruits, for example, varieties of apples, cherry plum, elderberry, sea buckthorn, blueberry, and others together with crops such as spring barley, rye, clover ley, sugar beet, field bean, autumn rapeseed, winter wheat and clover ley in a crop rotation of eight years. It has been found that establishments for this type of farming culture was difficult. However, the station is in an ongoing research phase and final success of the project is yet not concluded. The farm in Uppland that grows cereals such as spring rye, peas, oats, autumn wheat along with suitable fruit trees such as apples, pears, sea buckthorn, medlar and hazelnuts shows good harvest especially in the alley farming of oats and apples.

Diet change plan

Dietary change strategy involves shifting the consumption pattern to adapt to more sustainable eating habits that brings both health and environmental benefits (Willett et al., 2019). It is a strategy that Gothenburg is already working on. There exists several projects and initiatives in Gothenburg focusing on sustainable food culture that encourages increased consumption of plant-based food and promote eating habits based on locally produced foods, among other measures, with the aim of reducing the environmental impacts associated with food consumption (Fermskog & Dahlin, 2022). When Gothenburg conducted a carbon dioxide equivalent emission for different purchasing categories in the spending analysis during the year 2021, even though Food & Meals category was the tenth largest category in terms of spending, it had the highest climate impact per krona. Focusing health and sustainable food culture, Gothenburg is involved in promoting more plant-based food, more whole grains in diet, increased use of sustainable seafood that is farmed in ways that do not compromise marine ecosystem and resources. All these promoted using locally produced ingredients to create meals that support healthier and more sustainable eating habits (Göteborg & Co, 2026). Project Switch, an EU collaborative project between various stakeholders is built around three mission which are, increasing whole grain consumption, promoting plant-based foods and enabling sustainable seafood choices (SWITCH FOOD HUB, 2024). There are various other sub projects within this project. One such is the project Green switch. The goal of this project is to normalise plant-based food consumption in private and public kitchen to stay within planetary boundaries while improving public health. The initiative involves chefs from public and private kitchens to develop nutritious and affordable plant-based meals that are also appealing by means of communication through menu and interactions with people (Switch Food Hub Sweden, 2024). In such an experiment conducted by Switch, the share of plant-based choices increased from 1.7 percent to 38.1 percent (Sarasini, 2024), suggesting that these initiatives has the potential to promote more plant-based choices. Diet change strategy is important to consider for Gothenburg, as it has the potential to support these ongoing initiatives thereby influencing a shift towards more plant-based diet.

Diet change in public school lunches

In ongoing research project OPTIMAT, a study was conducted in four primary schools in Uppsala municipality (Elinder et al., 2020). School lunches were redesigned to become climate friendly by reducing meat and dairy and increasing pulses and cereals. In addition to reducing greenhouse gas emissions by 28 percent, this action slightly reduced the purchasing cost of lunch while maintaining the nutritional requirements, also without significantly reducing food consumption.

Food sharing

Food waste is considered a global issue with roughly one third of all food produced being lost, resulting in both economic and environmental impact (Rosenlund et al., 2020). The EU ranks redistribution of surplus as the next best strategy when food waste cannot be prevented (Sundin et al., 2022). Food sharing is therefore relevant as it can support sustainability by addressing environmental, economic, and social issues relevant to many stakeholders (Sundin et al., 2022). Although redistribution through food banks have been supporting people in need for long, the concept has only recently been connected to waste prevention strategy, paving way for the rise of many internal redistribution units (Bergström et al., 2020). Sharing food through food banks involves redistribution of surplus food instead of diverting it to landfill. The study (Bergström et al., 2020) shows that food donated to socially exposed people resulted in the largest reduction of greenhouse gas emissions of redistributed food.

In Sweden, approximately 135 kilograms per person of food waste is generated in 2022, majority of it in non-household sectors of the food value chain, therefore a major responsibility for reducing food waste is expected from the non-household sectors (Johan Hultén & Martin Villner, 2024). This is particularly relevant for retail as a large portion of surplus food from retail are fit for human consumption (Eičaitė et al., 2022). In a study conducted in a municipality owned large food bank system, it showed that retail surplus food redistribution has the potential to support food insecurity through reducing food waste (Sundin et al., 2022). Hence retail sector is important to consider even though its contribution to food waste is low compared to other major sectors. In Gothenburg, surplus food collection system is handled by several actors leading to inefficiencies in the system. Related reports identifies this issue and proposes investigating more efficient logistics to improve the redistribution of surplus food (Kristina Fermskog; Jonas Dahlin, 2022). A common wider platform for coordination and efficient use of resources, supported by well-organised infrastructure, quality-assurance systems, trust between actors, and supportive legislative framework is thus important (Irmelin Gram-Hanssen, 2016), highlighting the relevance of a centralised redistribution system, especially for retail surplus redistribution in the city.

Redistribution of retail surplus through centralised food bank system

Uppsala city mission (UCM) is a redistribution system that brings many actors together. This redistribution centre is acting like a centralised food bank system coordinating between charities, food kitchen to caters including hand over food from each of these internal units. It consists of a food bag centre that collects surplus from retail and transport it to the food bag centre where it is received and sorted. Some amount of the surplus is transported to a unit called soup kitchen while some remains in the food bag centre, where it is stored and prepacked before it is transported and distributed to charity centres or handed through give aways. Remaining food at food bag centre becomes waste that is disposed as food waste. One part of food received at soup kitchen is stored and used in caters for daily meals while the other part is donated to charities and handed through give away. Furthermore, part of the surplus give aways are transported to food kitchen and charities that serve food. The cooked meals from soup kitchen are also distributed to cater fairs, daily meals and take aways. Internally this system is even more complex, yet it is a well-coordinated infrastructure compared to many non-centralised initiatives that functions small. In

2020, the system redistributed 237 tonnes of surplus food, of which 78 percent could be consumed and only 22 percent was identified as combined waste from the system and final consumption (Sundin et al., 2022). This shows significant potential of centralised redistribution systems to reduce surplus food waste generated at retail.

3 Methodology

The method section describes how the three research questions are addressed. Figure 1.1 illustrates the research process carried out, methods and data used for answering the three research questions. The first research question is addressed in the first section of methodology, 3.1, assessing the baseline of food metabolism in Gothenburg. This section also includes a case study on Gothenburg, how the obtained material flow data is organised and how the indicators are selected. The second research question is addressed in the second section 3.2, which describes how the circular strategies are selected, what are the preliminary and final list of strategies and how the actions were formulated from the selected strategies. The last section, 3.3 addresses the last research question, which is about the modelling of actions and assessing the effects of the metabolism change in Gothenburg.

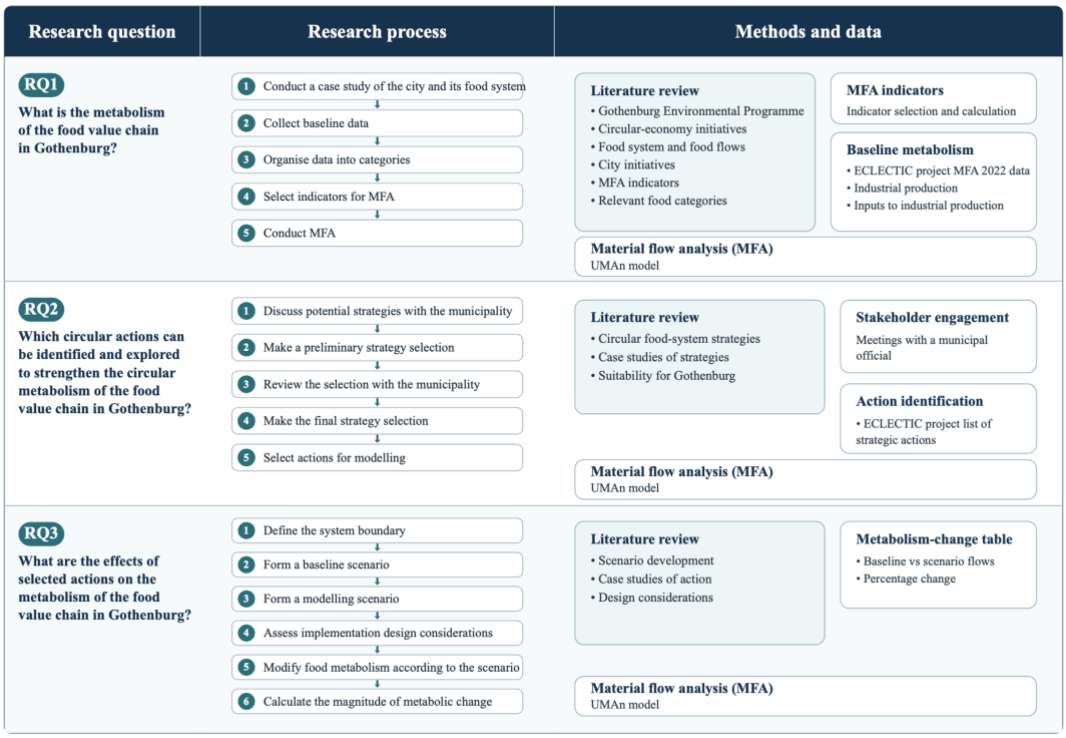


Figure 1.1 Research framework

3.1 Food system in Gothenburg (RQ1)

This section describes the methodology used to address RQ1, which examines the material flow of the food value chain in Gothenburg.

3.1.1 Case study

Gothenburg is Sweden's main seaport that lies along the Göta River estuary and is situated on Sweden's southwest coast (Britannica Editors, 2025). It is the second largest metropolitan area consisting of thirteen municipalities (Rosado et al., 2016). The population of Gothenburg in 2022 was 596,841 and is exceeding the Sweden's national average since 2000 (Business Region Göteborg, 2025) . Gothenburg is a

growing city with increasing number of residents, jobs and companies and is considering resilience and flexibility in its urban planning (Göteborgs Stad, 2022). The port of Gothenburg has an important role in global trade and industrial competitiveness (Port of Gothenburg, 2026).

The city is involved in environment and climate program 2021- 2030 that aims for the transition to an ecologically sustainable city by 2030 (Göteborgs Stad, 2024). This programme provides basic policies for Gothenburg municipality to take action, especially in circular economy. Gothenburg municipality see circular economy as having the potential to reduce unsustainable resource extraction and contribute to a sustainable consumption. They are involved in achieving circular goals such as waste prevention and developing circular models (Göteborgs Stad, 2024). Gothenburg was also selected as one of twelve frontrunner cities and regions within Circular cities and region initiatives (CCRI) launched by the EU. With this project, Gothenburg aimed to move from being a traditional linear customer to a circular one by 2030 and fostered collaborations with various stakeholders for this transition (Göteborgs Stad, n.d.-a).

Gothenburg is the leading logistic hubs in Nordics with around 20 percent of Sweden's foreign trade handled by the Port of Gothenburg (Business Region Göteborg, 2025). Being a transport hub, trade flow in Gothenburg, that is imports and exports per capita are larger than for the whole Sweden (Kalmykova et al., 2015). Gothenburg's industrial processes are also big compared to other cities in Sweden (Rosado et al., 2016). It's large industrial sectors and significant Scandinavian port contributes to large material flow and emissions (Kalmykova et al., 2015). It has the most resource intensive metabolism and also support other external system (Rosado et al., 2016). A large percent of the domestic material production o Gothenburg constitutes of exports(Kalmykova et al., 2015). However, urban metabolism pattern of Gothenburg shows a stable and matured trend (Rosado et al., 2016).

The current food production and consumption in Gothenburg causes several environmental issues and even health impacts (Fermskog & Dahlin, 2022). Many resources flow in food system is linear in Gothenburg. Local production and consumption proportions are very low and very small portion of fuel produced from waste are used by the city (Fermskog & Dahlin, 2022). This shows the city's food system is mostly linear and needs a transformation. Gothenburg municipality is tasked with proposing plans for a sustainable food system, especially in food supply and waste management. Gothenburg municipality plans to switch to a more sustainable food supply system, to increase local food production and local supply and also looking from a system perspective and not just as an environmental issue (Fermskog & Dahlin, 2022). This tend to bring more resilience and less vulnerability to the city.

According to the climate programme, climate footprints from food purchases should be reduced to 1.3 kg CO2e/kg by 2030. To achieve the goal of sustainable food purchasing and waste reduction, Gothenburg city serves environmental meals in public meals with more vegetables and legumes, sustainable fish, seasonal and eco labelled raw materials. (Göteborgs Stad, n.d.-b). Gothenburg's waste plan 2030 also targets to manage food waste. The edible food waste from municipal operations should be reduced to a maximum of 30 grams per meal by 2030, while at least 70 percent of generated food waste should be directed to nutrient recovery, biogas production or equivalent service (Göteborgs Stad, 2021).

Gothenburg city runs a lot of business for a sustainable food system that includes purchases, land management, planning, managing waste, supervise agriculture and food operations, in addition to supporting local business contacting citizens (Fermskog & Dahlin, 2022). The city has already been involved in several local food projects and initiatives such as locally produced food for kitchen, Angered Farmstead and other urban rural Gothenburg projects (Dymitrow et al., n.d.). Gtohenburg municipality has also mapped the food system to understand the flow of food resources. The results shows that knowledge about circularity and sectoral collaboration and innovations are important to bring about a change in the food system.

Gothenburg city has the potential to build a sustainable food system. The city has direct control over food purchases in public services, food inspections and information check, indirect control through influential urban planning and land use (Fermskog & Dahlin, 2022) . Gothenburg case also highlights that future food system should give importance to self-sufficiency, strengthen food security through agriculture land and become a resilient urban food system (Fermskog & Dahlin, 2022).

3.1.2 Material flow analysis

The material flow data for the city of Gothenburg for the year 2022 was generated in the ECLECTIC project following the Uman method (Rosado et al., 2014). The data has 1218 numbers of different products in CN4 and CN2 aggregation. It includes MFA indicators such as domestic extraction (DE), domestic material consumption (DMC), available resources (AR), national and international trade values in tonnes. Other data provided were inputs into the industries and industrial production within industries. Total trade was estimated by adding national and international trade values. Thus, total imports and exports were obtained.

The material flow data is organised to analyse food categories separately. Food system considered in this project includes all edible food products and beverages except tobacco products. At first, edible food was separated from non-edibles. Further categorization of edible food was done in order to distinguish between the type of food products. Edible foods were categorised into twelve different product categories. These includes meat, vegetables, fruits, fats and oils, cereals and starch, fish and seafood, beverages, dairy and egg, sugar and confectionaries, condiments and spices, oilseeds and products and nuts. For example, category meat includes edible meat of bovine animals, swine, sheep, goat, horses, asses, mules, rabbits etc., either fresh or chilled, sausages, prepared meat and other edible parts of animals suitable for human consumption.

MFA indicators were selected to understand Gothenburg's food flow, as they simplify complex data, enable performance to be assessed across different dimensions, and help identify trends. (Singh et al., 2009). For this, various food indicator were derived through literature review. The paper (Rosado et al., 2016) provides urban metabolism indicators for Swedish cities including Gothenburg. Most of the food indicators for Gothenburg have been derived from this literature, as it analyses the same system boundary, which is urban cities, especially for Gothenburg. Indicators were also adapted through various other literature review.

3.2 Selection of strategies and formulation of actions (RQ2)

This section describes the methodology used to address RQ2, which focus on the identification of circular strategies and exploration of circular actions.

3.2.1 Selection of strategies

Identification of actions was done using a co-selection process with the municipality official of Gothenburg. A total of three meetings were conducted, until a preliminary set of strategies were selected by the municipality. During the first meeting with the official, discussions were carried out to identify what Gothenburg needs to address now and what is important to prioritize within the project agenda. Since the Gothenburg municipality is interested in its food system, a material flow analysis was carried out to understand the baseline food flow in Gothenburg. During the subsequent meeting with the official, the MFA baseline values of Gothenburg along with derived indicators were presented. Through an understanding of the baseline, discussion then examined the criteria of four pillars of circularity for the selection of strategies. A literature review has been conducted to understand the circular food strategies that can address the four pillars of circularity. A list of various circular strategies, which is part of ongoing research were obtained from ECLECTIC project. This included list of strategies for various sectors. From this list, strategies that aligns with the four pillars of circularity were selected. This list of preliminary strategies were presented at the next meeting with the municipality official. Each of the strategies were presented and enquired about its current relevance in the food system of Gothenburg, existence of limitations to any of the strategies and about the local initiatives aligning with the presented list. Finally, a preliminary selection was carried out based on its current importance and adaptability in the Gothenburg city, as discussed during the meeting with the municipality official.

Since all the preliminary ones are relevant for Gothenburg, a final selection of three strategies was carried out based on the importance of the strategy at various urban metabolism nodes of food value chain, a concept used in (Guibrunet et al., 2025) for studying the urban food flows in cities as mentioned before in section 2.2. The strategies were selected so as to address different urban metabolism nodes across the food value chain. For example, production stage addresses strategies involving farming practices, consumption stage by changing habits and food waste stage by strategies for reducing food waste.

3.2.2 Action formulation

Actions are formulated based on the four pillars of circularity and the possibilities associated with the selected strategy. The purpose of action formulation is not to identify the best possible action in Gothenburg, but to explore the potential change in the food metabolism through the four pillars. Furthermore, different actions were studied to understand its relevance, ease of implementation and potential to improve the food system in Gothenburg.

Strategy agroforestry is widely practiced in different forms around the world and to arrive at the best farming practice for Gothenburg, it was classified according to one of the major approaches of classification from (Nair, 1993). From this classification,

the most suitable form of agroforestry for Gothenburg was further assessed through a literature review, considering existing farming practices and agricultural initiatives in Gothenburg and Sweden. The three most important ones chosen from this classification were studied for its adaptability and potential benefits while contributing to the main purpose of increased food production in Gothenburg resulting in the selection of one. The actions were also selected based on the possibility of direct involvement by the municipality in the implementation and relative ease of monitoring. For example, diet change actions in public kitchen can be directly controlled by the municipality. Furthermore, ongoing projects and initiatives relating to diet change plan was also investigated to understand the ease of implementation. Food sharing action was formulated based on a literature review conducted. For this, all the five stages of the food value chain were investigated (Johan Hultén & Martin Villner, 2024) to formulate an action around the most relevant stage of food value chain that can potentially reduce food waste in addition to its adaptability in Gothenburg city. When the suitable sector was decided for developing action, further investigation was carried out to arrive at a more specific action.

3.3 Modelling actions (RQ3)

This section describes the methodology used to address RQ3, which describes the modelling approach for the three circular actions and assessing the effects of the selected actions in the food metabolism of the food value chain in Gothenburg.

Modelling was carried out through a sequence of various steps. First, each selected action was identified at the relevant stages of food supply chain to understand its influence in the food value chain. The baseline conditions required for implementing the actions were then established. MFA indicators that may be affected by the action are analysed, followed by the identification of the affected products or sectors. Then, the corresponding baseline is formulated, and food flows are quantified. Building on the four circularity pillars for each strategy, scenario was developed to achieve the intended change in Gothenburg's food metabolism. The modelled scenario was compared with the baseline to quantify changes in food flows and MFA indicators. This change in metabolism was estimated by using a metabolism change table including different flow stages, MFA indicators, baseline and scenario values for the corresponding indicator such as DE, imports and exports, calculated change in flows and percentage change. The calculations were carried out to estimate the maximum implementation potential of each modelled action. While estimating the potential metabolism change, the main criteria was to reduce dependency on external system. Hence, reduction of international imports were first priority followed by reduction of national imports and then increasing exports if possible.

3.3.1 Alley farming

Baseline formation

The baseline condition is represented by the existing agriculture system in Gothenburg and the domestic extraction in the MFA data represents the baseline food production. Alley farming is introduced into Gothenburg's agriculture system as an additional farming practice to the conventional methods. The additional production from alley farming is subjected to contributing to the existing domestic extraction of

the city and influencing metabolic change in the food value chain. To understand the availability of agricultural land in Gothenburg, a literature review was conducted. Municipality officials were further contacted through emails to enquire about the agriculture land owned by municipality. From the retrieved information, since conversion of small, leased horse farms to cultivable land was a possibility, area of this land was investigated to allocate land for alley farming. It was found that a large percent of the studied farms in Gothenburg were small and that small farms were mainly horse farms (Wästfelt & Zhang, 2016). From this understanding, an assumption was made that at least 50 percent of the horse farms in the agriculture land leased by municipality are small ones. Further, the size of the farm were investigated. All kind of small farms in Gothenburg are less than 20 hectares (Wästfelt & Zhang, 2016). Gothenburg municipality has also published small horse farm of size 4 ha for lease. Therefore, an average of these values were assumed as the size of small farms within the agricultural land of municipality.

Scenario development

Gothenburg's climate zone was investigated, and a literature review was conducted to compile a list of crops and fruit tree species suitable for alley farming under the identified climatic condition. Food production zone within the climate zone was investigated through a digital zone map from (Riksförbundet Svensk Trädgård, n.d.). Crops and fruit tree species that falls under the same production zone as Gothenburg's was noted and a final list of species were formed. This list was analysed with the MFA data of Gothenburg to map the priority ones. Selection was such that it contributes to relevant metabolic changes to the city's food value chain and is well suitable for Gothenburg's agriculture system.

With the allocated land area, alley farming was designed based on the design considerations adapted from (Sagastuy & Ternell, n.d.). The actual area for cultivation of the selected cereal crop and area lost to growing of fruit tree was estimated. Total production of the selected food products were calculated from the observed yield and actual land area estimated. Yield for food products were retrieved from area and harvest for Västra götaland in the year 2023. For alley farming, mean yield increase of the cereal crop with wind protection is considered from (Sagastuy & Ternell, n.d.). Food production by alley farming is then compared with conventional method to assess relative productivity.

Quantifying metabolism change

The additional food products produced from alley farming is added to Gothenburg food value chain. For this, the MFA and industrial production data was analysed. Domestic consumption is kept unchanged, while the trade and industrial production was subjected to change. Then, a metabolism change table for cereal crop and fruit was created. For cereal crop, this flow table includes flow of cereal crop through different stages such as Extraction, industrial production, distribution- retail and wholesale and trade. The cereal crop CN4 code was checked for in the industrial production data to find the industries through which flow occurs. The first order production is the manufacture of grain mill products. CN4 code for the selected cereal crop is not available in this industry. But it includes products with very low values of the cereal crop, such as in CN4 1001 wheat and meslin; and CN4 1107 malt which could make quantification more complex. Hence this industry is not considered in this

metabolism change for the cereal crop. Other industries related to cereal crop are the manufacture of bread, rusks, biscuits, wholesales of grains, seeds and animal feeds, retails with food. Hence, MFA for Gothenburg was analysed to check the products involving the cereal crop, which is also significant for Gothenburg's food metabolism change. Cereal crop associated food products with high international imports were analysed to reduce the value of international imports. CN4 1905 Bread, pastry and others is the food product which has the highest international imports relating to the cereal crop. Therefore, the extra cereal crop produced is added to produce more oat bread. Further, oats bread production was estimated using literature values. The additional fruits produced are similarly added to the food value chain by analysing the MFA for the selected fruit.

3.3.2 Diet change in public school meals

Baseline formation

For modelling diet change plan, an investigation of public kitchen in the city of Gothenburg was carried out. While this included public schools, elderly care and others, public schools were selected for modelling. The available data for public schools were also more reliable than for elderly care and other municipal food services. Independent schools were not considered, as their food purchasing can be from providers not under municipality (Food Agency, 2023). Design considerations such as number of pupils, age groups involved and number of days were calculated from the annual report from literature reviews.

School lunches were inspected from weekly lunch menu which is published online in the Gotëborgs Stad website. For the compulsory school lunches, the data was organised into four school areas, which were Centrum Primary Schools, Hisingen Primary Schools, Nordost Primary Schools and Southwest Primary Schools. Schools with grade F-9 were selected. From this selection, three random schools were selected to investigate the last ten weeks menu. This was repeated for other three school areas as well (*Food in Primary School*, 2026). Similarly, weekly school lunch for upper secondary schools were inspected from the last 10 weekly menu of five randomly selected schools on the website (*Food in High School*, 2026) . If the menu for any day was missing, the entire week was excluded and replaced with the most recent fully available menu week. It was assumed that all public schools have similar meal pattern.

To determine the current meat consumption in public schools, a literature review was carried out. However, data on amount of food portion in lunches served in public schools could not be retrieved. Hence a calculation was made to determine the food amount, especially amount of meat served per year. An equation was formulated and calculation was carried out. See Appendix A.2 for equation used. For this calculation, the amount of meat was estimated from an assumption that public schools serve only the guidelines recommended amount of meat. An assumption on the daily nutritional share of lunch was also used.

Scenario development

Based on the information of the current ratio of meat to fish to plant based meals, a new ratio is formulated. A literature study with an assessment of dietary guidelines were conducted for the formation of the new ratio, to ensure the protein requirements in the

meals served. For determining the amount of meat consumed with the new menu, the same equation is used, but with the new ratio for number of days served.

For protein replacement, MFA data was inspected to find the best replacement food products within the CN4 level. Out of this, CN4 0708- Fresh leguminous vegetables are excluded as these are fresh with higher water content and low protein concentration than dry legumes which are usually high in protein and fibre (Food and Agriculture Organization of the United Nations, 2025). The protein replacement was further distributed between the selected plant-based protein of dry leguminous vegetables and Soya bean. From literature review, it was found that on a survey conducted on Swedish adult population, Pulses, legume vegetables and mixed meals with legumes were more frequently consumed than sprouts and soy products (Steib et al., 2020). The survey also provides information on average intakes of various legumes based on the percentage of people surveyed. This data was used to determine the weighted average for leguminous vegetables and soya bean. However, plant-based protein cannot fully replace meat by the same amount. Hence, a replacement factor is derived for legumes and soy. As recommended by a Finnish student meal recommendation, 100g of meat contains 20-30g of protein while legumes have 10-16g and soy has 15-16g (National Nutrition Council, 2019). From these values, replacement factors were derived. The amount of legumes or soy replacing meat is calculated using the estimated replacement factor and percentage distributed. See calculations in Appendix A.2.

Similarly, reduced meat was redistributed into different meat products. Firstly, from the MFA data, meat products were selected based on the types that suits school lunches. The available school lunch menu from five different schools from both compulsory schools and upper secondary schools were once again inspected to check types of meat product served. The most identifiable meat found in lunch menu includes poultry, sausages, minced meat, prepared or preserved meat. Beef and pork products were least mentioned and specifically did not appear in the menu. Therefore, this modelling excludes CN4 relating to beef and pork products. Based on the observed frequency for other commonly appearing meat in the menu, the reduced meat quantity was distributed to the most frequently identified meat products. Swedish dietary guidance encourages reducing red and processed meat (Food Agency, 2023). Since sausages are processed meat, they were assigned a smaller share in the reduction distribution making it consistent with this guidance. Thus, based on these findings, redistribution percentages are assumed for all the meat products that will be reduced. The amount of meat products reduced is calculated.

Quantifying metabolism changes

The effects of metabolism in the food system was calculated from the metabolism change table. The table was adjusted to assess the intended metabolism change within meat and replaced plant-based proteins and their corresponding changes in the MFA indicators. Selected meat category with CN4 0207, 1601 and 1602 was affected in its domestic material consumption (DMC) resulting in a substitution affect in the selected plant-based replacements CN4 0713, 1201 products. Quantification was done for the metabolism changes from this model based on baseline domestic material consumption (DMC) and New DMC. Difference between the two scenarios and percentage change was calculated.

3.3.3 Redistribution of retail surplus through centralised food bank system

Baseline formation

The existing retail surplus food redistribution system in Gothenburg, involving several actors, was modelled as a non-centralised baseline. To obtain Gothenburg specific total retail food waste, a Swedish per-capita retail food waste coefficient was identified from (Johan Hultén & Martin Villner, 2024). Assuming that Swedish average of retail food waste is suitable for Gothenburg city, this value is used to obtain the total food waste generated by the Gothenburg retail stores.

The percentage of retail surplus actually reaching redistributions are derived from an existing non-centralised redistribution in Sweden. This percentage is assumed to be the same for Gothenburg retail stores as outlets of these retail stores exists in Gothenburg as well. All the retail wastes reaching the non-centralised redistributions are treated as edible (Caldeira et al., 2019). Thus, the total retail surplus reaching at the non-centralised redistributions are estimated by multiplying the total retail waste generated in Gothenburg with the percent of surplus reaching redistribution. However, there could be loss at the redistribution centres because of several reasons such as short expiry dates, sometimes leading to waste simply moving from retail to redistributions, serving kitchens not able to use all the donated food within time, especially while using fruits and vegetables that needs to be used within one day of delivery at the donation centres (Irmelin Gram-Hanssen, 2016). Hence, there is some food waste generated at the redistribution centres before the surplus reaches people in need. This loss is obtained through a literature review. (Eriksson & Strid, 2013) reports that only 60 percent of the food donated through such initiatives reaches to people in need. Therefore, a 40 percent loss of surplus at redistribution centre is adapted in the non-centralised system and the food reaching human is estimated. Food waste at retail and redistribution is calculated to estimate the total loss in the non-centralised redistribution system.

Scenario development

Centralised food redistribution modelling is done based on an existing Swedish non-profit organisation in the Uppsala city called Uppsala city mission (UCM). This organisation is working as a centralised system for redistribution of surplus from retail to other similar organisations and initiatives including charity and public kitchen (Sundin et al., 2022) and hence was used to represent a similar centralised system model in Gothenburg. Since the UCM study states that the facilities are common in a Swedish context, modelling values are derived from the generalisable results of this study.

To estimate the percentage of retail surplus reaching the centralised redistribution in Gothenburg, UCM redistribution was used as a representative system. The total food waste generated in the Uppsala retail and total input into the UCM redistribution was investigated. Total input into the UCM redistribution is obtained from (Sundin et al., 2022). Total food waste generated in the Uppsala retail is estimated by multiplying the Uppsala population with the retail food waste generated per person in Sweden in the year 2020. Year 2020 is used since the value for the total input into the UCM redistribution was obtained for this year. Finally, the percentage of retail surplus

reaching the centralised redistribution is calculated from these two values. This percentage is assumed to be the same for Gothenburg in the year 2022 and the retail surplus reaching the centralised redistribution is derived for that year. However, there is loss of food within the system while moving through different organisations. This loss is adapted in the model by assuming the losses estimated from the UCM system to be same for Gothenburg. Thus, total surplus that could actually be redistributed to people was calculated. All the food that has gone wasted in the system were added together to give the total waste generated by the centralised redistribution for Gothenburg.

Quantifying metabolism change

Food metabolism changes were calculated from the difference of baseline and the modelled centralised redistribution scenario. The corresponding percentage change is quantified. Since the action affects the downstream flow of food chain, material flow indicators such as DE, DMC, imports and exports will remain unchanged. The retail waste generated in the city remains same while the food waste directed to the waste treatment reduces.

The increased redistribution of food is assumed to substitute an equal amount of food input to the city. Hence, food products in the redistributed surplus was investigated. (Sundin et al., 2022) gives information on the kind of food redistributed through food bags with their percentage composition. This is assumed to be same for the non-centralised redistribution in Gothenburg. All the food products identified were listed with their percentage composition and were mapped to their corresponding CN4 codes. Oil and fats are not included in the list as further details on the type of oil and fats could not be identified. Products with very low quantities were reported to be contributing nothing to the composition (Sundin et al., 2022) and therefore, these products were eliminated from the list. For some food redistributed, their CN8 code was checked to list it under the same CN4 code. For example, zucchini was not listed in the CN4 0709 label, but it falls under the same code when its CN8 codes was checked. While mapping kidney beans, the weight was checked to confirm if fresh or dry as their codes can differ. A smaller weight comparable to that of a commercially available dry packet was found and hence assumed to be canned and classified under CN4 2005. The percentage composition of food products under the same CN4 code are added up. After mapping, the amount of food products that is redistributed is calculated from the additional redistributed amount calculated from the model and their corresponding added percentage composition. The substitution was carried out by replacing the international imports with the amounts of food redistributed.

4 Results and Discussion

4.1 Food flow in Gothenburg

4.1.1 Food flow indicators

A total of nine different indicators were adapted from the literature. These includes domestic material consumption (DMC), domestic extraction (DE), domestic material input (DMI), imports, exports, dependency on rest of the country (ROC), dependency on rest of the world (ROW), dependency on local production and physical trade balance. Domestic material consumption is chosen as it helps to understand the amount of total food that goes to final consumption in Gothenburg (Rosado et al., 2016). Domestic extraction is chosen to understand the amount of food that is produced locally in Gothenburg (Rosado et al., 2016), whereas domestic material input is chosen to understand the total amount of food materials available to the city through trade and local production, which is calculated as the sum of domestic extraction and total imports (Eurostat, 2025). Imports are chosen to understand the food dependency of Gothenburg on national and international system while exports are chosen to understand the support given by Gothenburg to other exogenous system (Rosado et al., 2016). Dependency on rest of the country and rest of the world were adapted from (Rosado et al., 2016) to understand the share of material input that comes outside (Rosado et al., 2016). ROC was calculated from the ratio of national imports to DMI, while ROW was calculated from the ration of international imports to DMI. A higher value of this ration will indicate higher import dependency. Dependency on local production is an indicator that is derived from the MFA indicators mentioned by (Eurostat, 2025) and as inspired from the dependency indicators in (Rosado et al., 2016). This indicator was derived to understand the share of local food production in the total material input of Gothenburg. It was calculated from the ratio of DE to DMI. To understand the deficiency or surpluses in the Gothenburg food flow, indicator physical trade balance was derived from (European Commission, 2001). It was calculated by subtracting exports from imports. A positive value will indicate surplus food while a negative value will indicate deficiency in food flow.

4.1.2 Analysis of Gothenburg food flow

Food consumption in Gothenburg shows high consumption values for meat, vegetables, fruits and fats and oil. Meat is the highest consumed food in Gothenburg with a value of 99 kg per capita while vegetables are the second largest consumed with a value of 89 kg per capita. Food categories such as cereals and starch, fish and seafood and beverages are moderately consumed. Cereals and starch, fish and seafood and beverages show similar values ranging between 35 to 37 kg per capita. Among the lowest consumed food categories are dairy and eggs, sugar and confectionaries, condiments and spices, oilseeds and products and nuts. See Figure 4.1. The highest consumed food in Gothenburg is prepared or preserved meat from Meat category and Citrus fruits. It is important to reduce the amount of prepared or preserved meat consumption as Swedish dietary guidance also encourages reducing red and processed meat (Food Agency, 2023) which is also a part of prepared and preserved meat.

Compared to other cities like Mexico, Milan, London and Cape town, Gothenburg is among the lowest consuming cities. Gothenburg's food consumption of 463 kg per capita was comparable to Mexico City with 469 kilogram per capita and Milan 472 kilograms per capita but lower than Cape Town having 535 kilograms per capita and London having 635 kilograms per capita. Meat consumption is similar to London and Cape town which shows relatively higher consumption than other two cities. Vegetables and fruit consumption is high for Mexico and Milan which can be seen in Gothenburg also. Gothenburg shows a mixed pattern of consumption as compared to these cities.

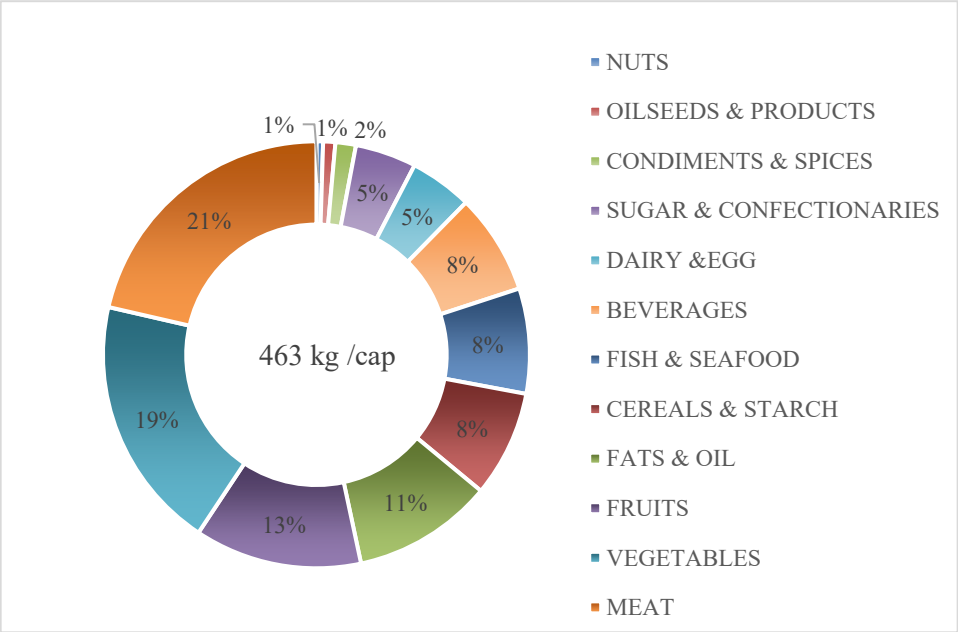


Figure 4.1 Food consumption share per capita

Domestic material input shows the total input into Gothenburg food system while domestic extraction gives what amount of that food is produced locally. Meat is not produced locally in Gothenburg. Meat consumption is highly dependent on imports from external sources. Vegetables, cereals and starch, fish and seafood and dairy products are produced locally in Gothenburg. Out of the 89 kilograms per capita of demand for vegetables, only 21 kilograms per capita are produced locally. Rest of the city's demand are satisfied from imports. Approximately 25 percent of Gothenburg's vegetable demand is satisfied through local production, while the remaining is supplied through imports. Demand for cereals and starch and fish and seafood is almost same around 37 kilograms per capita. However, cereals are more locally produced than fish and seafood and therefore fish is more import dependent. For fats and oil, material input is almost double the consumption. What is remaining is not accounted to be exported. This could be to data inconsistency. Similarly, sugar and confectionaries show double material input than demand of 21 kilogram per capita. But here, this category also exports 17 kilograms per capita internationally. See Figure 4.2. Overall, it is seen that Gothenburg has a potential to reduce dependency by improving local production of vegetables and cereals, considering suitable land area availability.

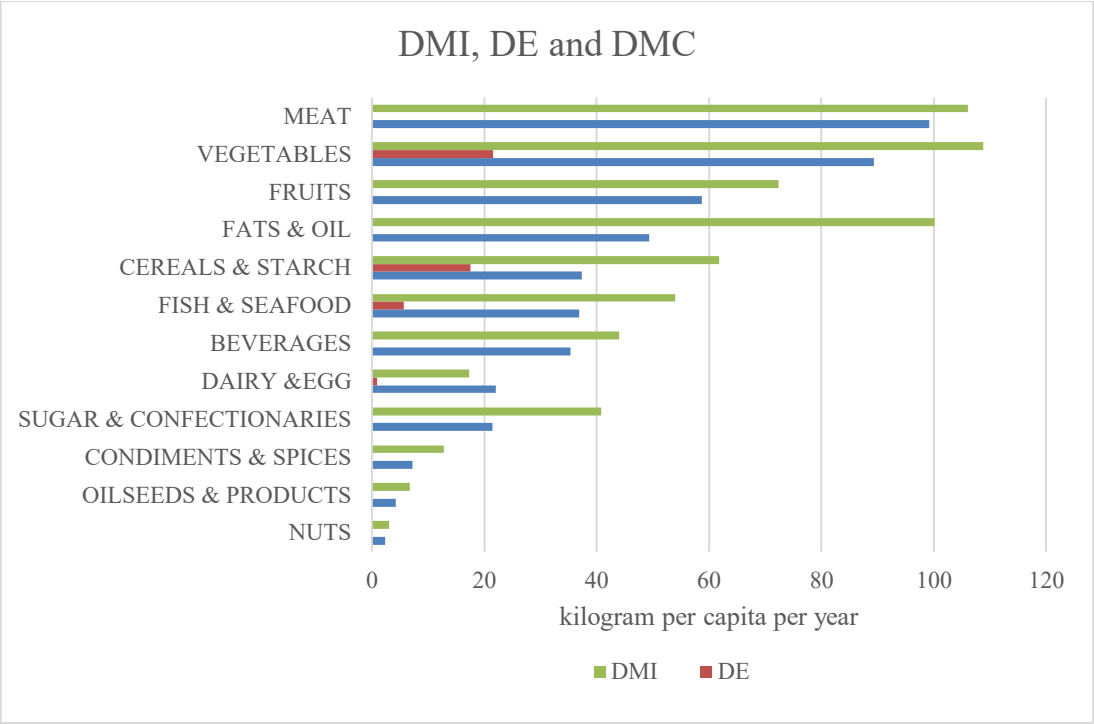


Figure 4.2 Food material input, domestic extraction and domestic material consumption by food category (kilograms per capita per year)

Gothenburg's food system is mainly import dependent. Food categories such as meat, fats and oil, fruits, beverages, sugar and confectionaries, condiments and spices, oilseeds and products and nuts are fully import dependent. Meat, vegetables and fats and oil are the highly imported categories. However, when it comes to international import, vegetables overtake meat by 84 kilograms per capita compared to 52 kilograms per capita of meat. This is because meat imports are balanced between national and international imports showing similar values. See Figure 4.3. Fish and seafood, despite being an important part of Swedish food, remain dependent on international imports, as local production and national imports are insufficient to meet Gothenburg's demand.

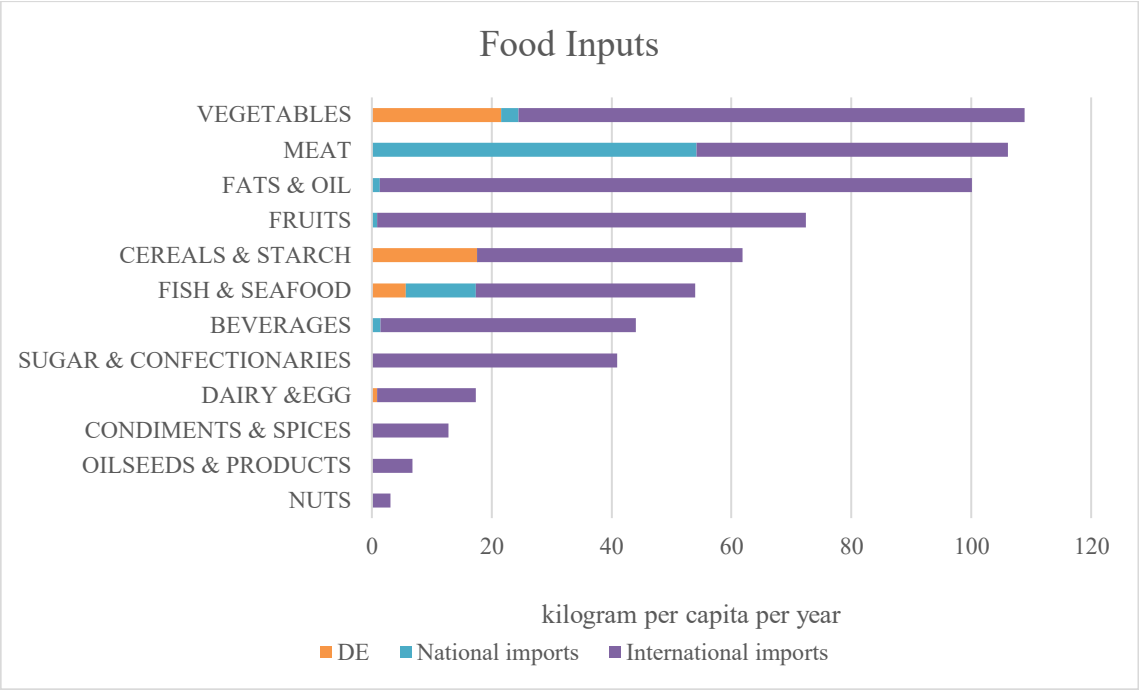


Figure 4.3 Food inputs by food category (kilograms per capita per year)

The graph in the Figure 4.4 shows different source of food inputs into the city. It shows dependency of different food categories on rest of the country, rest of the world and on local production. Gothenburg's food flow is mainly connected to international imports rather than national or local production. Most food categories are fully dependent on the rest of the world while remaining categories have at least 50 percent dependency. None of the categories are fully locally dependent. Local production contributes to food categories such as vegetables, cereals and starch, fish and seafood, and dairy and eggs. However, meat shows a different pattern with slightly higher than 50 percent dependency on rest of Sweden and the remaining dependency on the rest of the world. Condiments and spices and oils seeds and products are fully dependent on rest of the world. However, their domestic material consumption is low with larger flow categories such as vegetables and meat.

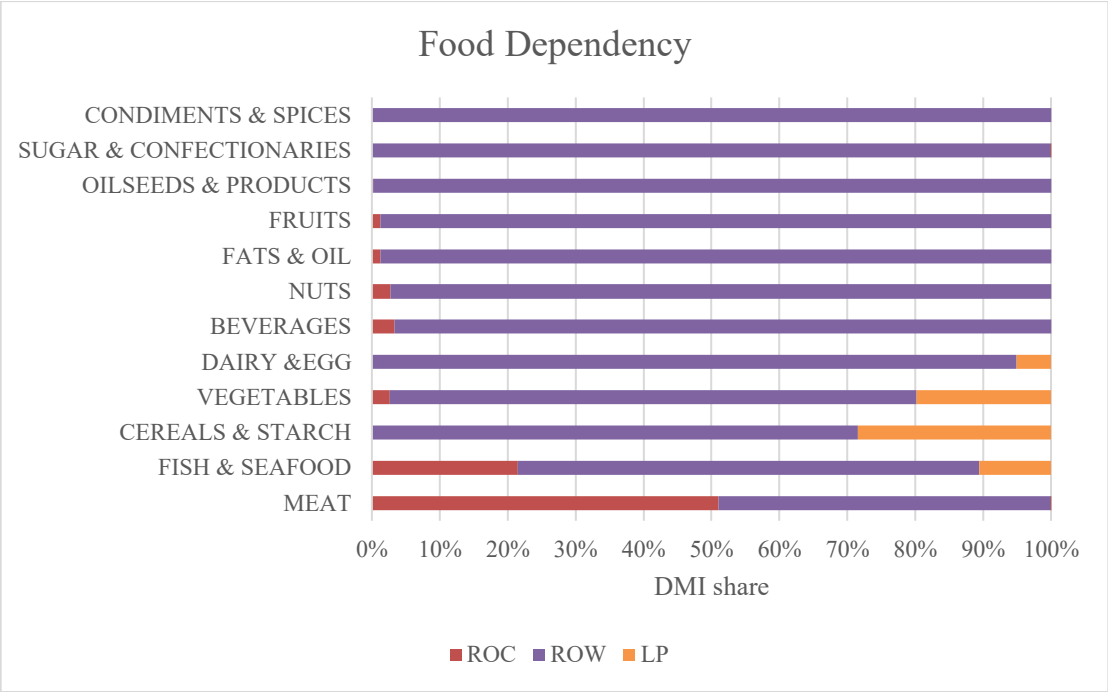


Figure 4.4 Food dependency on local production, national imports and international imports by food category (% of DMI)

Table 4.1 presents the trade balance for different food categories by showing the difference between imports and exports. The positive values for total and international trade indicates a high import, mainly by international imports. Cereals and starch is the only category with a negative national trade balance, indicating that national exports exceeds national imports. However, its total and international trade balances remain positive, indicating that imports from international sources exceed exports.

Table 4.1 Trade balance

Trade balance			
Food category	**Total trade**	**International trade**	**National trade**
Nuts	3.1	3.0	0.1
Oilseeds & products	6.7	6.7	0
Condiments & spices	11.0	11.0	0
Dairy & egg	16.0	16.0	0
Sugar & confectionaries	23.7	23.7	0
Cereals & starch	31.2	37.9	-6.7
Fish & seafood	35.8	32.8	3.0
Beverages	38.7	37.2	1.5
Fruits	71.4	70.5	0.9
Vegetables	76.5	74.6	1.9
Fats & oil	99.5	98.2	1.3
Meat	105.2	51.0	54.2

Priority food category Figure 4.5 represents the food categories which are most important to consider in the action in order to bring about changes in the food system metabolism of Gothenburg. Meat is the category with high share in DMC as well as high import dependent. Vegetables have high DMC share but shows a lower dependency on imports than fruits, fats and oil and fish and seafood. Sugar and confectionaries and dairy and eggs show high import dependency, but their DMC share is low. DMC share for cereals and starch, fish and seafood and beverages are almost similar in range. However, cereals and starch have lower dependency than others. Overall, it is seen that all the food categories are on the upper quadrant of the graph reflecting a highly import dependent food system.

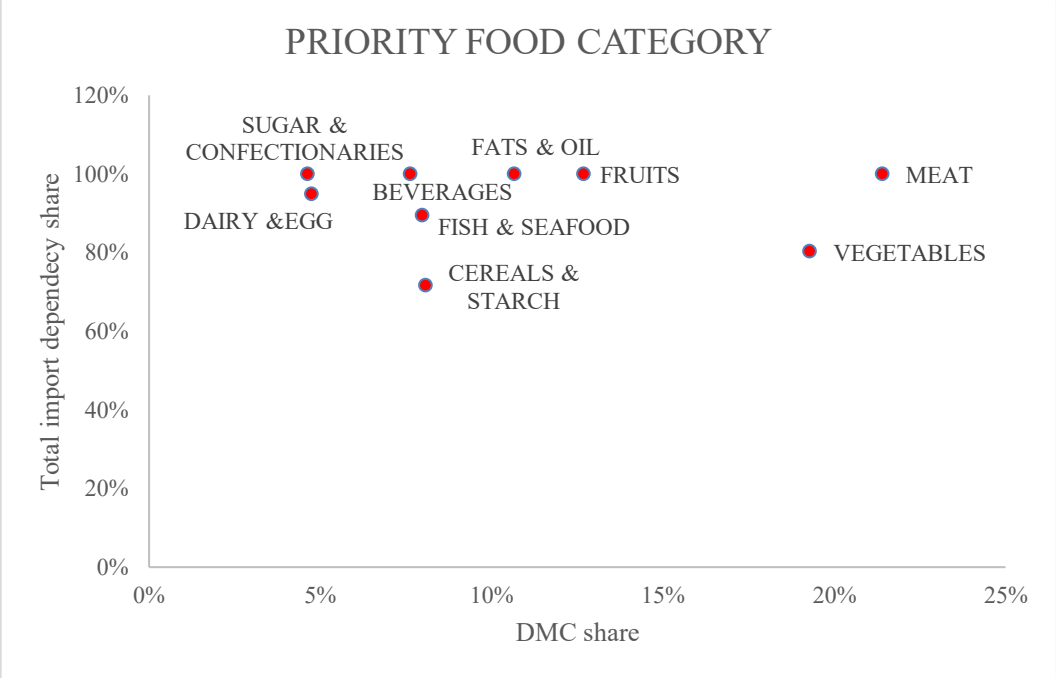


Figure 4.5 Prioritisation of food categories by DMC share and total import dependency

It can be inferred from the baseline MFA analysis that, meat and vegetables are important food to consider in the action as these have high food flows combined with high import dependency. Cereals and starch are another important food category to consider as they are the staple food that has moderate consumption and shows some potential in supporting exports, mainly at the national level.

4.2 Selection of strategies and action formation

4.2.1 Selection of strategies

An initial meeting held with the municipality official helped understand that Gothenburg is interested in focusing on its food system. The official also highlighted the importance of addressing food system through four pillars of circularity, which are closing loops, lifetime extension, resilience and substitution. Circular strategies are required to reduce the linear flow of materials through closing the loop, slowing resource loops, narrowing resource loops (Bocken et al., 2016) and regeneration (Konietzko et al., 2020). Hence, these four pillars were kept as the basis for the selection of circular food strategies for improving resource efficiency of Gothenburg food system. A literature review helped understand the importance of the four pillars in the metabolism of food system. In a food system, closing loop can be addressed through recycling food waste for nutrients, composting to produce fertilizer, anaerobic digestion to produce biogas and so on. Lifetime extension is possible through food redistribution, preservations and repurposing wasted food (FAO, 2024) (Bocken et al., 2016). Narrowing loop can be addressed through substitution of food by low impact alternatives and food waste reduction while resilience can be achieved through focus on seasonal and local food (FAO, 2026) (Bocken et al., 2016). Gothenburg specific suitable strategies such as these can work together to form a resilient and resource efficient food system in Gothenburg.

The preliminary set of strategies proposed based on the pillars of circularity includes agroforestry, vertical farming, greenhouse rooftop, diet change plan, food sharing platforms and anaerobic digestion. Strategies such as vertical farming, rooftop greenhouse and agroforestry were chosen for it supports to increase local production and improve resilience of the city, an important goal mentioned by the municipality official. The ownership of 3000 ha of agriculture land by the Gothenburg municipality (Göteborg Stad, 2019a) made these farming strategies important to consider as it can increase local production within the city. It also create added value from available urban and peri urban spaces. In addition to this, there exists various test fields, research and discussions on vertical farming and greenhouse rooftop (Drottberger et al., 2023) which makes it a developing sector important to consider in cities. When it comes to agroforestry, it widely exists in Europe years back (Sagastuy & Ternell, n.d.) and therefore implementation is expected to be more practical than other strategies. These three urban farming strategies helps with the circularity pillars of resilience, substitution and creates added values in the food system. Establishing food sharing places, another strategy put forward is considered as an effective waste reduction strategy as food sharing culture is seen to be already existing in Sweden as an implemented waste reduction strategy. Here, food is recirculated through initiatives such as open pantries and food rescue platforms which occur both digitally and physically (Bergström et al., 2020). It also contributes to value retention in the food system metabolism through lifetime extension as well as bring resilience by providing food to needed people. Diet change plan is another important chosen strategy at consumption stage as it supports narrowing the loop by reducing the resource input, increasing resilience (FAO, 2026) by reducing the flow of high impact food (Elinder et al., 2020) and reduced imports of such food categories. Anaerobic digestion is an important waste recovery strategy chosen for its importance in value recovery through recirculation of nutrient and energy into the system (FAO, 2024), thereby closing the loop.

From another meeting conducted with the municipality official, it was confirmed that Gothenburg is seeking metabolic changes to strengthen circularity, by improving resilience, substitution and reducing waste. The official also mentioned that all proposed strategies are considered equally important for the city, in addition to stating importance of procurement, supply chains, and market dynamics as these are major contributors to the city's metabolism. Anaerobic digestion was excluded as it is a waste recovery strategy that is neither expected to prevent waste generation nor bring a relevant change in the Gothenburg's food metabolism as much as other chosen strategies. Moreover, from the food system analysis of Gothenburg, the city is highly import dependent. This is also same for the food products that could be locally grown in Gothenburg agricultural land. This indicates that city needs to make use of its own available resources and agricultural characteristics to build a more resilient food system. Within production stage, vertical farming, greenhouse rooftops and agroforestry was given importance. However, agroforestry has been selected for two reasons. One is its added ecological benefits that vertical farming or greenhouse rooftop lacks in comparison and secondly because of the availability of the municipality owned land that has been dedicated for agriculture purpose. It also states that this dedicated area can creates opportunities for Gothenburg to grow crops and produce more food on the city's land (Göteborgs Stad, n.d.). It was considered important to make use of the existing dedicated land resources rather than developing new infrastructure. It was also found from the food system analysis that Gothenburg has high DMC share for meat, large trade imbalance with almost full import dependency. Diet change plan is a very relevant strategy at the consumption stage, as it is expected to change consumption pattern and can effect trade. This strategy helps to shift from highly dependent food category to more locally produced food categories, thereby improving resilience in the food metabolism, in addition to narrowing the loop. Also, it does not make use of land, and implementation is relatively simple and adaptable. Food sharing strategy can support the reduction of food waste generated by the food system through redistribution. Hence the strategy is used to intervene at the waste stage.

4.2.2 Formation of actions

Corresponding to the three selected strategies, three actions were developed. To arrive at the best action within agroforestry, a categorisation was done. Major categorization of agroforestry are agrisilviculture, silvopastoral, agrosilvopastoral. others include multipurpose tree lots, apiculture with trees and aquaculture with trees. Within agrosiliviculture includes multipurpose trees on croplands, alley farming and home gardens. From this classification, the most important forms for Gothenburg were alley farming, forest garden and silvopasture. These are already practiced in Europe (Burgess & Rosati, 2018). Alley farming which is the cultivation of crops in alleys in between rows of trees is chosen as the first action due to its studies benefits and relevance in Sweden. A well-designed alley farming increase local production through diversified production by addition of food producing trees or shrubs (Sagastuy & Ternell, n.d.). These trees which acts as windbreaks also increases the yield based on different crop type. Gothenburg's own agroforestry test environment at Angereds Gård is already implementing alley farming where trees and shrubs are planted together with agricultural crops (Västra Götalandsregionen., 2024). Alley farming is considered the most relevant type for Europe due its overall increase in

production (Sagastuy & Ternell, n.d.) and wider research and implementation in Sweden (Jordbruksverket, 2024). Thus, alley farming is a relevant and potential agroforestry method to model in Gothenburg which also aligns with the city's interest in sustainable land use practice.

For diet change plan strategy, based on the ongoing initiatives as described in section 2.3.2, especially the project, Green switch, the action was formulated. The project focused the importance of public kitchen in moving towards a sustainable food culture. Gothenburg City serves around 20 million lunches per year in schools, elderly care, conferences, events, and representation (Kategoriplan Livsmedel Och Måltider, 2023). Also, primary School Administration is one of the largest buyers within Gothenburg City's Food & Meals category, accounting for 23 percent of the spend(Kategoriplan Livsmedel Och Måltider, 2023). This inspires to model an action based on public school meals where children are offered more plant-based choices. This will also encourage them to make sustainable eating choices from childhood that can build a habit in them. Thus, the action chosen is to replace meat by plant-based proteins in public school lunches.

For food sharing strategy, five sectors in the food value chain studied were agriculture and fisheries, food industry, retail, restaurants and households. Among this, retail was found to be more important sector for food redistribution. SDG 12.3, global food waste reduction target highlights the need to halve retail and the consumer level food waste by 2030 (United Nations, 2015). Although retail is where least wastage occurs, (Sundin et al., 2022) it is yet an important stage for recovering edible food waste. Retail shops are also the most common donor among all other sectors for both redistribution and food-serving in the Nordic food redistribution system (Irmelin Gram-Hanssen, 2016). This might reflect the potential of retail surplus to donate with quality and assurance as it is still well packed with expiry dates.

Sweden is reported to lack national guidelines with inefficiently managed food redistribution organisations, while having great potential for redistribution (Sundin et al., 2022). This also points at agreements prohibiting retailers to sell goods to unregistered buyers (Fredrik Wikström, 2024), hindering cooperation between actors in the redistribution system. There is also a lack of common data sharing platform for organisation that could help support food waste strategies (Fredrik Wikström, 2024). There arises the need for a centralised platform for sharing of data, easy negotiation for small charities with retailers who mostly functions as large scale organizations. The main goal for the second phase of the Nordic food redistribution project is to develop a common platform for redistribution, framing food banks to take the role as food redistribution centres (Irmelin Gram-Hanssen, 2016). It defines food banks as "organisation that facilitates redistribution for several food-serving actors by running logistics and often storing large quantities of food at a centralised warehouse". This helps bring more retailers into redistribution as their concerns with efficiency can be solved through reliable pickups, traceability and quality assurance (Irmelin Gram-Hanssen, 2016). Regional food banks can function as operators which connects retailers to charity organizations through guidelines, agreements and logistic coordination (Irmelin Gram-Hanssen, 2016). Uppsala City Mission (UCM), a Swedish non-profit organization functions as a regional system operator which can act as a centralized system for other organizations. Since this organization can represent a centralized system, functioning in Sweden and is reported to have generalizable

structure for other parts of Sweden (Sundin et al., 2022), such a system is decided to model for Gothenburg. This action also supports increased job opportunities in collecting, sorting, storage, packing and distribution areas. For example, Göteborgs Stadsmission's Matcentralen, a surplus food redistribution centre receives and redistributes large quantities of surplus food through logistics operations, where they also offer work training to people outside labour market (Göteborgs Stadsmission, n.d.). This potential of the action to create employment was also a priority mentioned by the municipality during the discussion of selection of strategies. Hence, the third action formulated is redistribution of retail surplus through a centralized food bank system.

4.3 Modelling of actions and metabolism change

4.3.1 Alley farming

Baseline

Gothenburg municipality owns 3000 hectares of land dedicated to agriculture usage (Göteborg Stad, 2019b). While 75 percent of the land is classified agricultural land, 25 percent is pastureland. This agriculture land includes cultivated areas in addition to leased plots for purposes other than agriculture and few vacant plots (Göteborgs Stad, 2023). However, from enquiry through emails, it was understood that there were almost no availability of plots for new cultivation and that municipality make available only one farm and few patches of land each year. In a study on the peri urban agriculture land in Gothenburg, it was found that food producing agriculture land were increasingly used for recreational horse activities (Wästfelt & Zhang, 2016), displacing food cultivation possibilities in the city. However, Gothenburg municipality identifies the possibilities of converting small horse farms to food cultivation land upon the expiry of their contract (Göteborgs Stad, 2023). Total number of horse farms leased by the municipality are 72 (Göteborgs Stad, 2023) and the assumed number of small horse farms that have a possibility of conversion into cultivable land are 36. The modelled area for small horse farms are 12 hectares, resulting in a total of 432 hectares of land availability for alley farming.

Scenario

Preliminary selection of suitable crops for alley farming was based on suitability for Gothenburg's temperate climate. Temperate zones were found to be mostly diverse for dry plains and moist forest. Gothenburg has more moist forest conditions than dry plains. Gothenburg's climate is categorized with distinct seasons, that obtain rainfall throughout the year mostly occurring during summer and autumn season with an average precipitation of 998mm (Gothenburg climate, n.d.). Seasonal crops have greater importance in setting an agroforestry system here, since short growing seasons can limit the species productivity. Another important factor considered for the selection of crops were its suitability in Gothenburg agriculture production Zone. According to the statistics of Sweden (SCB), Swedish agricultural area is divided into 8 production zones (Dahrendorf, 2022). Out of the 8 zones, Gothenburg was identified to be ranging from Zone 2 to Zone 3. In a particular case study conducted in an alley farming site at Uppland in Sweden, they grow oats along with apple trees (Sagastuy & Ternell, n.d.). The area is classified as Zone 3, which is similar to Gothenburg's zone range. Therefore, it was inferred that these crops can be grown in Gothenburg agriculture land as well. Further analysing the MFA data, cereals

category ranks the second largest domestically extracted food category in Gothenburg and the only category with a negative national trade balance, as national exports exceeds national imports. However, cereals are dependent on imports from rest of the world. This indicates an established cereal production system within the city and a potential to substitute international imports through additional local production. Gothenburg's consumption for oats and apples were among the highest in the MFA, with no identified local production for apples. These considerations support the selection of oats with apple trees as one of the suitable and alley crop combination that may have relevant impact in improving local production and reducing import dependency.

The design consideration in alley farming is such that to maximize the microclimate benefits, maximum width of alley, which is the area for main crop is kept 10 times the height of tree (Sagastuy & Ternell, n.d.). The average heigh of a semi dwarf apple tree is 12 to 20 feet. Pictures from the alley farming cultivation of oats and apples in Uppland, Sweden also suggests dwarf sized apple trees (Sagastuy & Ternell, n.d.). Thus, width of alley calculated is 40 meters. For the tree spacing, a 3m tree row width is assumed, representing average of the recommended 2–4 m non-cultivated strip for alley-cropping systems (Sagastuy & Ternell, n.d.). The calculated land loss in alley farming compared to conventional farming is 7 percent of total land available. The actual land area available is estimated to be 402 hectares for oats and 30 hectares for apples. Yield for oats is 5040 kg per hectare while for apples it is 4431.3 kg per hectare (Swedish Board of Agriculture, 2025). Mean yield increase for oats is 6 percent (Sagastuy & Ternell, n.d.) and the estimated yield increase of oats in alley farming is 5342 kg per hectare. Thus, the total oats produced is 2147 tonnes along with 134 tonnes of apples. When compared to conventional farming method, amount of oats produced by alley farming is found to be 1.4 percent less due to the 7 percent reduction in the total land which is then allocated for apple production. Since local production of apples are increased, alley farming can overall be seen as more efficient than conventional farming.

Metabolism change

The additional raw oats produced is added to produce more oat bread. Raw oats become oat flour before it is taken as input into the oat bread manufacturing industry. Oat yield from mill is expected to be in the range of 68 to 72 percent as this is the percentage range of groat comprised inside oat hull (E. A. Decker et al., 2014). An average of 70 percent is taken as the oat yield from mill. Oat flour estimated is 1503 tonnes. Share of oats in oat bread is required for calculation of additional oat bread produced. It is expected to be in the range 20 to 30 percent (F. H. Webster, 2011). However, the ingredient list of some market manufactured premium bread (Bakels Sweden, 2022) mentions up to 67 percent use of oat flour. Hence an average of 50 percent oat share is taken from the range of 20 to 67 percent. Additional oat bread produced is 3006 tonnes per year. However, additional wheat is also required to produce additional bread. Since an average of 50 percent oat share is taken in oat bread production, the rest 50 percent is wheat flour. Hence additional wheat flour required is same as oat flour, which is 1503 tonnes per year. The metabolic changes are tabulated below which includes baseline for oat bread produced, new scenario where additional oat breads are added to existing production, change in the amount of oat bread produced and percentage change.

Table 4.2 Metabolism change from additional oats production

Indicator	NACE / Flow	CN4 involved	Baseline (tonnes)	New scenario (tonnes)	Change (tonnes)	% change	Process
DE	111- Growing of cereals and other	1004	2608	4755	2147	82.3	Additional oats produced locally
	1061 – Manufacture of Grain mill products	1001, 1107, 1101	-	-	-	-	Increased oat flour in first order production
	1071 – Manufacture of bread and others	1905	2266753	2269759	3006	0.1	Additional oat bread produced in second order production
Imports	Oats- International	1004	0	0	0	-	International imports of oats reduced
	Oats- National	1004	0	0	0	-	No national imports for oats
	Bread & other- International	1905	17177	14172	-3006	-17.5	Additionally produced oat bread reduces the international imports in CN1905
	Bread & other- National	1905	0	0	0	-	No national imports
	Wheat- International	1101	897	2400	1503	167.6	Increase in imports of wheat
	Wheat- National	1101	0	0	0	-	No national imports
Exports	Oats- International	1004	0	0	0	-	No international exports

Indicator	NACE / Flow	CN4 involved	Baseline (tonnes)	New scenario (tonnes)	Change (tonnes)	% change	Process
Exports	Oats- National	1004	995	995	0	-	No change in national exports
	Bread & other- International	1905	9063	9063	0	-	No change in international exports
	Bread & other- National	1905	0	0	0	-	No national exports
	Wheat- International	1101	152	152	0	-	No change in international exports
	Wheat- National	1101	0	0	0	-	No national exports

Note: Table values are rounded to the nearest whole number, while all calculations, including percentage changes, are based on unrounded values.

When additional agriculture land was allotted for alley farming, oat production increased by 2147 tonnes per year, which is around 82 percent from 2022 baseline. This increased the local oat production in Gothenburg. The extra oats is added to the making of bread, involving CN4 1905- Bread, pastry, cakes, biscuits and other and industry 1071- Manufacture of bread and others. This creates 3006 tonnes per year of additional oat bread. But this is only 0.1 percent additional oat bread produced because the extra oat bread is added to the bread manufacturing industry which manufactures not just oat bread but includes different varieties because the involved CN4 1905 consists of bread, crispbread, pizza, biscuits, gingerbread, waffles and so on. Oat bread produced become a small share of this and the metabolic change in industrial production of bread is very subtle. However, this is different for trade since the additional oat bread could be used to reduce the international imports within CN4 1905 bread products. International import is reduced by around 18 percent from a baseline of 17177 tonnes imported in 2022 to 14172 tonnes per year with alley farming. This results in the substitution of internationally imported oat bread products within CN4 1905.

At the same time, CN4 1001- Wheat and meslin amount also has to increase since oat bread production involves wheat, as it is added in similar quantity as oats. Gothenburg does not domestically extract wheat flour even though there is good amount of wheat produced. International import of wheat flour is 897 tonnes, while 152 tonnes are also internationally exported. To balance the trade flow, Gothenburg will have to either

domestically produce more wheat flour or internationally import additional requirements. It will require an additional 1503 tonnes which represents around 168 percent increase in international imports.

Table 4.3 Metabolism change from additional apple production

Indicators	**CN4 involved**	**Baseline (tonnes)**	**Scenario (tonnes)**	**Change (tonnes)**	**% change**	**Process**
DE	0808	0	134	134	-	Additional apples locally produced
International import	0808	7012	6879	134	-1.9	International imports of apples reduced
National import	0808	0	0	0	-	No national imports
International Export	0808	2	2	0	-	No change
National Export	0808	0	0	0	-	No national exports

Note: Table values are rounded to the nearest whole number, while all calculations, including percentage changes, are based on unrounded values.

The metabolism changes for apples produced in the alley field, is affected at CN4 0808- Apples. Domestic extraction for apples was zero in Gothenburg. Using the additional agriculture plots for alley farming will increase the local production of apples slightly by adding 134 tonnes per year. This will reduce the trade dependency to around 2 percent from international imports.

Action alley faming thus affects domestic extraction, second order production and trade flows of the food system. The additional alley farming land contributed to increased oats production of around 82 percent from baseline value. This increased local oat production in Gothenburg can support self-sufficiency and resilience. This additional oat produced supports the second order food production of oat bread manufacture but only corresponds to a small percent increase in industrial production. But in case of trade, there is around 18 percent reduction in the bread category due to the increased oat bread production. As a consequence, additional wheat is required for making of oat bread resulting in demand for imports or local production. Alley farming supports local production of oats and apples and can reduce some trade dependence. Although part of the land is used for apples, oat productivity remains at

99 percent of conventional farming. The additional oat-bread production reduces international imports of bread category by 3006 tonnes but requires an additional 1503 tonnes of imported wheat. Therefore, the strategy reduces external dependency without eliminating it, as part of the dependency shifts from bread to wheat. The baseline MFA shows domestic extraction and national exports of wheat, while model assumes additional wheat flour is supplied through imports. It can be inferred that part of the locally produced wheat can potentially be processed into flour and reduce flour imports. However, this would depend on the suitability of the wheat and the milling industry in Gothenburg, which is not assessed in the study. Alley farming has the potential to support a diversified and resilient food system for Gothenburg, with increased local production. In addition, it is a circular farming method that has wider benefits compared to the conventional monoculture farming. It is considered to be more productive because of the additional benefits from the combined trees. Soil health is also an important factor for farming in Gothenburg and alley farming can support this. In alley farming, tress improves soil conditions by supporting soil microbes, increasing organic matter and improving soil fertility (Dawson et al., 2013).

4.3.2 Diet change in public school meals

Baseline

Gothenburg public schools include compulsory schools, adapted compulsory school, upper secondary schools and adapted upper secondary school, represents students of age 6-19 years old. Number of pupils in compulsory schools and adapted compulsory were 47634 and 844 respectively (Årsrapport Grundskolenämnden, 2024), while for upper secondary schools and adapted upper secondary school were 10356 and 415 respectively (Årsrapport Utbildningsnämnden, 2022). An academic year in all types of public school consists of at least 178 school days (Skolverket, 2026). All the school menu showed a similar pattern with slight deviations on days serving vegetarian and non-vegetarian meals. There are at least three non-vegetarian meals served weekly with only two days left for vegetarian meals, while in some cases there were four non vegetarian meal days. Fish is served at least once every week. Hence, the ratio of meat to fish to plant based meals is currently 2:1:2.

The estimated amount was calculated by multiplying the number of school pupils by the number of school days, the number of meals served per day, and the portion size per meal. Swedish food agency recommends limiting the amount of cooked red meat and processed meat to 500g per week (Food Agency, 2023), while many other guidelines mention values less than this, with Nordic nutrition recommending 350g per week of cooked red meat (Nordic Nutrition 2023, n.d.) and 203g of poultry (EAT, 2019). Since all meat is modelled here, an upper estimate of 500g per week is assumed for all cooked meat. However, 500g of cooked red meat is equivalent to 700–750 g of raw meat (World Cancer Research Fund, 2018). Also, lunch represents 30 percent of daily nutrition (Colombo et al., 2019). A calculation was done to estimate the amount of uncooked meat that might be cooked per day at school alone, considering an assumption that students will have meat during weekends as well. The estimated amount of meat portion is 80g per day, for two days. The number of days should be represented by share of meat days, which is two out of five school days. From all the obtained values, the current scenario for meat consumption at school is 338988 kg/year. All calculation involved are presented in Appendix A.2.

Scenario

Nordic nutrition recommends replacing red and processed meat with alternatives such as pulses and fish can reduce risk and a combination of plant proteins, such as legumes and grains can provide a good distribution of essential amino acids (*Nordic Nutrition 2023*, n.d.) together making a good quality protein intake. Project Switch points out that they aim not only at increasing plant-based diets but also encourage sustainable seafood consumption in public schools as a replacement to high climate-impact meat. Fish is a food of high-quality protein with overall positive health benefits and lower environmental impact if sourced and produced sustainably (*Nordic Nutrition 2023*, n.d.), which is why many guidelines recommend the consumption of fish and seafood in schools. Hence, fish and seafood are not avoided in public school meals. The number of days fish served is kept constant for its overall benefits. The average number of fish serving is only one day per week, which will not be changed in this model. This makes the current ratio changed to 1:1:3, meaning one meat day is replaced by one more plant-

based meal day making it a total of three plant-based meal days. Cereals, grains, fruits and other vegetables included in the menu remains unchanged.

Estimated amount of meat consumption for the new menu is 169494 kg/year. This results in a reduction of 169494 kg/year of meat compared to the current value for meat consumption. From the MFA, the identified specific replacements for reduced meat are CN4 0708- Fresh leguminous vegetables, CN4 0713- Dry leguminous vegetables and CN41201- Soya bean. Out of which, good plant-based protein replacements chosen are Dry leguminous vegetables and Soya bean. As mentioned in section 3.2.2.2, for determining the percentage of distribution, weighted value calculation used the percentage of consumers and average intake. From the survey, percentage of consumers and average intake were derived, which was 14.4 percent and 64 g/day for legumes; and 3.8 percent and 89 g/day for soy. The distribution for legumes and soy were estimated to be 73 percent and 27 percent respectively. Replacement factor for legumes were derived to be 1.9, while for soy it was 1.6. Thus, the calculated amount of legumes needed for meat replacement is 237944 kg/year while the amount of soy needed for meat replacement is 73812 kg/year. See calculations in Appendix A.2.

Reduction of meat is distributed to CN4 0207 poultry meat, fresh, chilled or frozen, CN4 1601 sausages and similar meat products and CN4 1602 prepared or preserved meat products. The reduced meat quantity was redistributed as 60 percent to poultry, 10 percent to sausages and similar meat, and 30 percent to prepared or preserved meat. The amount of poultry meat reduced is 101696 kg per year, while sausages reduced to 16949 kg per year. Prepared or preserved meat products reduced to 50848 kg per year. See calculations in the Appendix A.2.

Metabolism change for meat and plant-based protein

The table below represents the quantified metabolism change from replacement. Replacing meat shows that there is very small decrease in the DMC, but the plant-based protein has very high increase. The percentage reductions in meat DMC are small, ranging from 0.3 percent to 0.9 percent. This might be because the modelling is done for public school meals alone in Gothenburg. The reduced meat was replaced with legumes and soybeans which showed around 19 percent to 412 percent increase. The huge difference is because the reduced meat was replaced with legumes and soybeans using protein-equivalent replacement factors and plant proteins needs much more amount than animal protein. In additional to that, the baseline for soybean is quiet low. Hence the change can be high.

The table below represents the effects of metabolism change from replacement. The modelling shows that the change mainly affects international imports. Here, replaced meat amounts were reduced from international import demand, but this replacement increased the dependency on imported plant-based protein. Diet change strategy can reduce meat demand in the MFA, but it does not reduce overall food material demand.

Table 4.4 Metabolism change from meat replacement

CN4	Indicators	Baseline (tonnes)	Scenario (tonnes)	Change (tonnes)	% Change	Process
0207-Poultry meat, fresh, chilled or frozen	DMC	11079	10977	-102	-0.9	Reduction in DMC
	International imports	6535	6433	-102	-1.6	Reduction in DMC
	National imports	6126	6126	0	-	
	International exports	66	66	0	-	
	National exports	0	0	0	-	
1601-Sausages and similar meat products	DMC	5948	5931	-17	-0.3	Reduction in DMC
	International imports	3534	3517	-17	-0.5	Reduction in DMC
	National imports	2746	2746	0	-	
	International exports	149	149	0	-	
	National exports	0	0	0	-	
1602-Prepared or preserved meat products	DMC	12899	12848	-51	-0.4	Reduction in DMC
	International imports	7117	7066	-51	-0.7	Reduction in DMC
	National imports	5290	5290	0	-	
	International exports	134	134	0	-	
	National exports	0	0	0	-	
0713-Dry legumes	DMC	1195	1433	238	19.9	Increase in DMC
	International imports	1273	1511	238	18.7	Increase in DMC
	National imports	0	0	0	-	
	International exports	17	17	0	-	
	National exports	0	0	0	-	
1201-Soya beans	DMC	18	92	74	411.9	Increase in DMC
	International imports	26	100	74	284.9	Increase in DMC

CN4	Indicators	Baseline (tonnes)	Scenario (tonnes)	Change (tonnes)	% Change	Process
	National imports	0	0	0	-	
	International exports	8	8	0	-	
	National exports	0	0	0	-	

Note: Table values are rounded to the nearest whole number, while all calculations, including percentage changes, are based on unrounded values.

Diet change strategy affects the DMC and trade flow. DMC of meat that could be reduced by the strategy is 170 tonnes per year resulting in an increase in plant-based protein DMC to 312 tonnes per year. However, the strategy does not significantly reduce meat DMC because it applies only to a small share of public schools in the city. Maximum replacement is seen in poultry which decreases by 0.9 percent from the baseline. Plant based proteins showed high increase in DMC particularly soybean which increases by around 412 percent compared to baseline. This is also a consequence from the strategy mainly because the reduced meat has to be replaced nutritionally. In replacing meat in public school project from OPTIMAT, food consumption did not significantly decrease. This is also seen here in Gothenburg. This action does not reduce the import dependency of Gothenburg. It shifts the demand from a high impact food category to a lower impact food category. The action was modelled for public schools that were directly under the municipality, while the action could be applied to other schools, elderly care and public meals served under municipality. As mentioned in section 2.3.2, Gothenburg city is already involved in promoting many such initiatives focusing on sustainable food culture. Redesigning public school menu can bring support the city initiatives bringing about effective changes in its food metabolism. Another important significance of the strategy is school pupil exposure to a sustainable culture, helping them create sustainable habits early in their lifestyle. This can positively support initiatives already working towards it.

4.3.3 Redistribution of retail surplus through centralised food bank system

Baseline

Food waste generated in Sweden is reported to be 9 kilograms per capita for 2022 (Johan Hultén & Martin Villner, 2024). Gothenburg population in the year 2022 was 596,841. Therefore, the total retail food waste generated in Gothenburg is estimated as 5371 tonnes. In a study conducted in ICA retail stores in Sweden, roughly 4 percent of retail food waste is donated much of it done through local initiatives and charities (Irmelin Gram-Hanssen, 2016). This percent of retail food waste along with the total retail food waste calculates the retail surplus reaching the non-centralised redistributions to be 214 tonnes. Since a loss of 40 percent is assumed in the system, only the rest 60 percent of the surplus is reaching people in need. This corresponds to 128 tonnes of redistributed surplus reaching human via non centralised redistributions in Gothenburg. Food waste generated at Gothenburg retail is estimated to be 5156

tonnes, while at non centralised redistribution is 85 tonnes. Total food waste generated by non-centralised redistribution system is 5242 tonnes in total.

Scenario

The scenario models redistribution of retail surplus through centralised food bank system in Gothenburg. Retail food waste generated in Sweden for 2020 is 10 kilograms per capita (Johan Hultén & Martin Villner, 2024). A percentage of 10.1 is the estimated retail surplus reaching at the studied non centralised redistribution. Since this value is assumed to be same for Gothenburg in the year 2022, Gothenburg retail surplus at redistribution is estimated to be 544 tonnes. As mentioned in methodology, there is further loss which takes place inside the redistribution system before it reaches to people. Based on data from (Sundin et al., 2022), food waste generated by organisations within the redistribution system accounted for 4.6 percent and 1.7 percent of the surplus food entering the system. Adapting this to the Gothenburg centralised redistribution, it was estimated that there is 6.3 percent of food loss occurring at the redistribution, meaning 93.7 percent of surplus redistributed is reaching human. Thus, total surplus that could actually be redistributed to human is estimated to be 509 tonnes per year. Food waste generated at Gothenburg retail is estimated to be 4827 tonnes, while at centralised redistribution is 34 tonnes. Total food waste generated by the centralised redistribution system is 4861 tonnes in total.

Metabolism change

It has been found that a centralised redistribution system in Gothenburg can increase redistribution up to 381 tonnes per year when compared to a non-centralised system. The substitution of this redistributed food reduces the dependency on imports. There was a total of 61 food products identified in the redistributed surplus. However, after excluding products of less share of total composition, there were a total of 37 specific food products. After mapping the food products with their corresponding CN4 codes, there were 27 products. These included products of dairy, vegetables, fruits, beverages and confectionaries.

The substitution of redistributed food in the international imports showed up to 10 percent changes in the new international imports. The most effected food imports were for banana which showed 10.4 percent of change corresponding to a reduction of 19 tonnes and grains which showed 7 percent of change in imports corresponding to a reduction of 15 tonnes. Milk and potatoes were found to reduce almost 5 percent of international imports. Other important reductions were found for yogurt, lettuce, carrots and beetroot with more than 1 percent of reduction in international imports.

Table 4.5 Effects of metabolism change

CN code	Redistributed food	Amount redistributed (tonnes)	Baseline International imports (tonnes)	Scenario International imports (tonnes)	Change (tonnes)	% Change
0401	Milk (0.5%)	19	433	414	-19	-4.4
0403	Yoghurt (3%)	15	923	908	-15	-1.7

CN code	Redistributed food	Amount redistributed (tonnes)	Baseline International imports (tonnes)	Scenario International imports (tonnes)	Change (tonnes)	% Change
0701	Potatoes	15	334	319	-15	-4.6
0702	Tomatoes	11	6008	5996	-11	-0.2
0703	Onion	4	1616	1612	-4	-0.2
0704	Cabbage; Broccoli	15	2206	2190	-15	-0.7
0705	Lettuce	15	1306	1291	-15	-1.2
0706	Carrots; Beetroot	8	346	338	-8	-2.2
0707	Cucumber	4	2661	2657	-4	-0.1
0709	Green & yellow pepper; Sweet peppers (red); Eggplant; Zucchini; Champignon	23	6626	6603	-23	-0.3
0803	Banana	19	183	164	-19	-10.4
0804	Avocado	4	3032	3028	-4	-0.1
0805	Citrus fruits	27	11651	11624	-27	-0.2
0806	Grapes	4	2429	2426	-4	-0.2
0808	Apple; Pear	19	7012	6993	-19	-0.3
0810	Strawberries	4	2182	2178	-4	-0.2
0901	Coffee	15	4538	4523	-15	-0.3
1104	Grains	15	216	200	-15	-7.1
1601	Charcuterie; mettwurst	8	3534	3526	-8	-0.2
1602	Chicken nuggets	8	7117	7109	-8	-0.1
1704	Candy	4	3133	3129	-4	-0.1
1806	Chocolate	4	1507	1503	-4	-0.3
1902	Pasta; Pasta salad (cheese/ham/chicken)	15	6062	6046	-15	-0.3
1905	Bread; Pastries; Sandwiches & wraps (cheese/chicken/shrimp)	46	17178	17132	-46	-0.3
2005	Kidney beans	4	10338	10334	-4	0.0
2009	Juice	4	3743	3740	-4	-0.1
2201	Mineral water	11	1514	1503	-11	-0.8

Note: Table values are rounded to the nearest whole number, while all calculations, including percentage changes, are based on unrounded values.

Retail surplus redistribution through a centralised food bank showed reduction in the internation imports of almost all products in the food bag by at least 0.1 percent.

Surplus retail capture could be increased by 329 tonnes per year corresponding to around 6 percent compared to non-centralised system. A large share could be redirected to people in need rather to waste treatments. The total loss from the redistribution system could be reduced to around 7 percent. This indicates that the centralised system is more effective in capturing retail surplus than non-centralised redistribution. Retail surplus capture rate at redistribution centres increased from 4 to 10.1 percent, representing a small change in the efficiency of system. However, a well organised centralised food bank system have the potential to increase the amount of surplus food captured from retail. For every 10 percent increase in capture rate, 537 tonnes additional food enters redistribution and when the capture rate reaches to full, it corresponds to 9 kilograms per capita of food reaching redistributions. Studies mention that reducing food waste can enhance food security (Irmelin Gram-Hanssen, 2016). Sweden is reported to have food insecurities in its 6 percent of population while also generating 1.3 Mt of food waste annually (Sundin et al., 2022). This strategy could support efforts to address food insecurity in Gothenburg by recirculating surplus food to people in need, thereby also reducing the food waste downstream.

4.4 Interpretation and Future work

All three presented actions are effective in bringing metabolism change in the Gothenburg's food value chain. Although some changes in the metabolism of food value chain shows relatively small values, their significance extends beyond the quantified results. Developing a diversified local production through agroforestry, a well-coordinated surplus redistribution system and long-term diet change programme among public sectors can establish an important foundation for strengthening the Gothenburg food value chain. These establishments can further support circular initiatives that the city is involved in and enable a gradual expansion of the actions over time and helps in reducing the dependence on imported food. The value of these actions lie not only in its short-term effects, but also in its potential to support a resilient, sustainable and resource efficient food system.

Retail surplus redistribution shows greater effectiveness in reducing material consumption in the food value chain as it make use of the food available in the system, reducing the need for that food to be imported. Alley farming is comparatively effective in greater reduction of material flow from imported food by shifting towards local production. Diet change plan is effective in substituting higher impact food in the material flow with lower impact food, that also alters the composition of consumption in the material flow.

The diet change action affects the consumption stage, alley farming effects both consumption and production stage, while food redistribution affects the downstream flow of waste along with its potential to impact international imports. Since all three actions has varying effects on the metabolism of the food value chain, a combined implementation will be affective rather than choosing one. A combined scenario of actions shows added effects on the food flow. Increased local production of oat bread in alley farming along with substituted bread through redistribution can together reduce the international imports of CN4 1905 bread and other category. This gives a combined import reduction in CN4 1905 of 3051 tonnes corresponding to 17.8 percent from 17.5 percent alone possible through alley farming. Similarly, increased

local production of apples combined with apples that could be substituted in international imports through redistribution shows a reduction of 153 tonnes from CN4 0808 corresponding to a reduction of 2.2 percent compared with the 1.9 percent possible through alley farming. Combining reduced meat demand from diet change with redistributed meat products could reduce international imports of CN1601 sausage and similar products by 25 tonnes corresponding to 0.7 percent compared with 0.5 percent from diet change alone. This was also same for CN1602 preserved and prepared meat, where additional chicken nuggets redistributed shows import reduction of 58 tonnes corresponding to 0.8 percent compared with 0.7 percent possible through diet change alone.

However, implementation for each action varies. Out of the three, alley farming and centralised redistribution might require high initial investment. Alley farming may require long-term maintenance, because nurturing crops and trees together require skilled labours. The Swedish alley farming projects mentions that the cost for establishment is high compared to monoculture (Anders Heimer, 2025).Retail surplus redistribution mainly requires legal agreements establishing control and quality assurance with the actors. Moreover, alley farming provides efficient land use as it accommodated different plant species on same land. An efficient centralised food bank requires well performed logistics with warehouses for collection, sorting, storage and transportation (Irmelin Gram-Hanssen, 2016). It is also mentioned in a study conducted in ten Norwegian cities, storage and transportation facilities in redistributions are underutilized. Therefore, a better coordination among actors within a centralised system can provide a clearer structure and support more effective implementation. Although redistribution requires land for storage and distribution facilities, it can reduce the demand for agricultural land by replacing food that would otherwise need to be produced. The implementation of diet change is comparatively easier than the other two action as it requires simple school meal redesign and planning and will not be costly. An important advantage is that the municipality can introduce changes within the existing school system through public procurement. Moreover, diet change do not demand land for its implementation and is an efficient action for reducing animal production related emissions.

4.5 Assumptions and Limitations

For the alley farming model, it was assumed that land currently used by small horse farms could be converted to cultivable land when their lease contracts expire. This assumption was based on the possibility identified by the municipality to take back the land at the expiry of the contracts. Only the estimated cultivable area was included in the model. Buildings, roads and other infrastructure that may occupy part of this land were not considered. Therefore, available area may have been slightly overestimated. Future work could improve the model by identifying the actual areas where crops and trees can be cultivated. However, the difference may be limited because most of the land is already used for agricultural purposes. The 25 percent pastureland within the municipality's 3000 hectares was not included, although parts of it may be suitable for cultivation. This land was excluded because it could also support other forms of agroforestry, such as agrosilvopasture or silvopasture, where crops and fruit trees are integrated with livestock. Possible conversion of this land was therefore left for future assessment.

For the diet change action, meat consumption in public schools was estimated using values from the literature rather than actual measured consumption. Actual consumption might differ and could affect the results. The model also did not assess students' acceptance of the dietary change, allergies, required changes in kitchen management or procurement costs. Assessing these factors would provide a more complete understanding of the strategy and its practical implementation.

The centralised redistribution strategy was also based on literature derived capture and loss rates rather than measured values from Gothenburg. Gothenburg's retail food waste was estimated using the Swedish average for the year. The difference between centralised and non-centralised capture rates was estimated using results from an existing redistribution centre that operates in a centralised manner. An actual centralised system in Gothenburg could potentially capture more retail surplus if supported by sufficient infrastructure. Food losses occurring within the redistribution system were included, but the potential to reduce these internal losses was not assessed. Although centralised redistribution showed lower internal losses, further reductions of losses could increase the amount of food reaching people and improve the overall efficiency of the system. The results of all three strategies are based on modelling assumptions and should therefore be interpreted within these limitations.

5 Conclusions

The study analysed the food system metabolism of Gothenburg using material flow analysis and evaluated the potential of selected circular food strategies. The MFA indicators established analysed the MFA by food products. The baseline assessment showed that Gothenburg is highly dependent on imports for food and only small amounts are produced locally in the city. The analysis also identified changes resulting in the MFA from the selected action.

Strategies were identified through a literature review and ECLECTIC project's list of actions and were developed based on the four pillars of the circularity. Strategies were selected by a co selection process with the Gothenburg municipality. Specific actions were formulated based on their relevance at the food chain and the city's focus. The selected strategies are alley farming supporting the production, diet change plan addressing the consumption and centralised redistribution of retail food surplus for waste reduction. The strategies together represent the circularity pillars of resilience, substitution, closing loop and lifetime extension.

The formulated action is modelled by defining a baseline condition, establishing the scenario and then quantifying the metabolism change anticipated. Alley farming increases local production of oats and apples while substituting imports of oat bread in small amounts. While implementation requires high initial investment and continued management, the strategy that brings diversification and resilience to the city by also supporting reduced dependence on external system. New public school meal redesign directly affects the consumption of the city by replacing some amount of meat by plant-based protein. Although this results in increased demand for legumes and soy products, it is an important strategy that will support the ongoing initiatives of the city to build sustainable eating choices. The implementation is rather easier than the other strategies through public procurements by the municipality. Centralised redistribution strategy shows an increased potential to the redistribute edible food waste reaching disposal along with reducing international imports of food products in food bag. It also brings coordination between actors which supports the effectiveness of the existing redistribution system. All the strategies have the potential to modify the food metabolism of Gothenburg but at different point of food supply chain. A combined effect of all three strategy will bring about an effective change in the food system.

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7 Appendix

Appendix A: Modelling calculations

A.1: Alley farming

Availability of Municipality owned Land for alley farming

Municipality owned agriculture land	3000	ha
Percentage of land dedicated to agriculture	75	%
Percentage of land dedicated to pastureland	25	%

Availability of municipal land from small-leased horse farms

Total horse farms leased by municipality	72	no
Convertible small horse farms	50	%
Convertible small horse farms	36	no
Size range of small horse farms	4 to 20	ha
Average size of small horse farms	12	ha
Total land availability	432	ha

Design consideration for alley farming plot

Height range of semi dwarf tree	12 to 20	feet
Assumed lowest height	4	m
Width of alley	10* height of tree	
Width of alley	40	m
Recommended tree spacing	2 to 4	m
Average width for fruit trees	3	m
Land lost to fruit trees	7	%
Available land for oats cultivation	402	ha
Available land for apples cultivation	30	ha

Food production

Yield for oats	5040	kg/ha
Yield for oats in alley farming	5342	kg/ha
Yield for apples	4431	kg/ha
Total oats production	2147	tonnes
Total apples production	134	tonnes

Oat bread production

Yield of oat from mill	70	%
Oat flour from mill	1502.83	tonnes
Share of oat flour in oat bread	20 to 60	%
Assumed share of oat flour in oat bread	50	%
Additional oat bread produced	oat flour / share in bread	

Additional oat bread produced	3005.66	tonnes
wheat flour in oat bread	1502.83	tonnes

A.2 Diet change in public school meals

Baseline

Number of students in Compulsory schools	47634	numbers
Number of students in Adapted Compulsory schools	844	numbers
Total number of students in Compulsory school	48478	numbers
Number of students in Upper secondary schools	10356	numbers
Number of students in Adapted Upper secondary schools	415	numbers
Total number of students in Upper secondary school	10771	numbers
Sum Total	59249	numbers

Number of school days	178	days
Share of meat days	0.4	days
Number of mealtimes	1	number

Meat Portion

Recommended meat	750	g/week
Recommended meat per day	107.14	g
% daily nutrition from lunch	0.3	
Recommended share of meat per lunch per day	32.14	g
For 5 school days	160.71	g
Meat served for 2 days should include	80.35	g
Meat served for 2 days should include	0.08	kg

Formula used for calculation of amount of meat:

$$Estimated\ amount = number\ of\ school\ pupil * number\ of\ school\ days * number\ of\ meal\ time * portion\ of\ food$$

Estimated meat	338988.92	kg/year

Scenario

Share of meat days	0.2	days
Estimated meat	169494.46	kg/year
Reduced meat	169494.46	kg/year

Table A.1 Added Plant based protein based on replacement rate

Food	Protein	average protein (g)	g replacement per 100 g meat	Replacement rate
Meat	20-30g / 100g	25	100	1
Legumes	10-16g / 100g	13	192.30	1.92
Soy based	15-16g / 100g	15.5	161.29	1.61

Table A.2 Redistribution into plant-based proteins

Legumes	% consumers	Average intake (g/day)	Weighted value	Share %
Legumes	14.4	64	921.6	73%
Soy products	3.8	89	338.2	27%
Total			1259.8	

Table A.3 Redistributed amount into plant-based proteins

CN4	label	% distribution	Amount	unit
0713	Dry legumes	0.73	237944.14	kg
1201	Soya beans	0.27	73812.10	kg

Table A.4 Reduction of Meat

CN4	label	% distribution	Amount	unit
0207	Poultry meat, fresh, chilled or frozen	0.6	101696.67	kg
1601	Sausages and similar meat products	0.1	16949.44	kg
1602	Prepared or preserved meat products	0.3	50848.33	kg

A.3 Retail surplus redistribution through centralised system

Gothenburg population	596841	number
Retail food waste in Sweden	9	kg per capita
Gothenburg retail food waste	5371.569	tonnes

Baseline

Gothenburg retail food waste	5371.569	tonnes
% surplus at redistribution	4	%
surplus at redistribution	214.863	tonnes
% surplus reaching human	60	%
surplus reaching human	128.918	tonnes

Loss

FW at retail	5156.706	tonnes
FW at redistribution	85.945	tonnes
Total loss by non-centralised redistribution	5242.651	tonnes

Scenario

Finding % surplus at redistribution (UCM)

Input at UCM	237	tonnes
Retail FW in Sweden	10	kg per capita
Uppsala population	233839	no.
Retail FW in Uppsala	2338390	kg
Retail FW in Uppsala	2338.390	tonnes
% surplus of retail at UCM	10.1	%
Gothenburg surplus at redistribution	544.418	tonnes

% surplus reaching human

FW at food bag + soup kitchen	11	tonnes
FW at soup kitchen	4	tonnes
Loss in the system	6.3	%
% surplus reaching human	93.7	%
surplus reaching human	509.961	tonnes

Loss

Gothenburg FW at retail	4827.151	tonnes
Gothenburg FW at redistribution	34.457	tonnes
Total loss by centralised redistribution	4861.608	tonnes

Table A.5 Percentage food share of specific food in food bag

CN code	Specific food redistributed	Food share (%)
1905	Bread	10
0805	Citrus fruits	7
0803	Banana	5
0401	Milk (0.5%)	5
1104	Grains	4
0701	Potatoes	4
0705	Lettuce	4
0808	Apple	4
0403	Yoghurt (3%)	4
0901	Coffee	4
1902	Pasta	3
0704	Cabbage	3
0702	Tomatoes	3
2201	Mineral water	3
0709	Green & yellow pepper	2
1601	Charcuterie; mettwurst	2
1602	Chicken nuggets	2
0709	Sweet peppers (red)	1
0706	Carrots	1
0704	Broccoli	1
0709	Eggplant	1
0703	Onion	1
0709	Zucchini	1
0709	Champignon	1
0707	Cucumber	1
0706	Beetroot	1
0806	Grapes	1
0810	Strawberries	1
0804	Avocado	1
0808	Pear	1
2005	Kidney beans	1
1905	Pastries	1
2009	Juice	1
1806	Chocolate	1
1704	Candy	1
1905	Sandwiches & wraps (cheese/chicken/shrimp)	1
1902	Pasta salad (cheese/ham/chicken)	1

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