Assessment of oyster mushroom production employing urban-based materials in Stockholm Stad

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Master's Thesis

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Abstract

This thesis investigates the opportunities and challenges regarding urban oyster mushroom production (*Pleurotus Ostreatus*) employing urban-based materials in Stockholm Stad as a growing medium. Additionally, the availability of the five most suitable substrates has been further explored with the indicator's availability in Stockholm Stad, and the Biological efficiency (BE%) for a suitable growing medium and the quantity of the substrates have been mapped out. In response to climate change and an uncertain future, cities need to be resilient to disasters and meet essential needs like water, food, and energy. Due to the COVID-19 pandemic, the Swedish government plans to increase self-sufficiency by developing the law of public procurement to prioritize buying locally produced goods. However, imported food is cheaper than Swedish goods, making it difficult for domestic products to compete. Moreover, a major part of Sweden's waste management consists of the combustion of various waste, which is being on a lower priority on the Waste hierarchy. Therefore, assessing the possible areas of use such as oyster mushroom cultivation could likely add further value to the residual waste streams investigated. Using Material Flow Analysis (MFA), interviews, and literature review, relevant data and information was collected to locate the five most suitable substrates: (1) wood waste from arborists and wood workers, (2) paper waste, (3) cardboard waste, (4) Spent Coffee Grounds (SCG) from five of the biggest chains coffee shops in Stockholm Stad, (5) garden waste collected from a collection company. The estimated availability of each residual waste stream has been mapped out with paper waste being 15 805 567 kg, 20 560 580 kg (cardboard), 64 166 500 kg wood waste, 3 939 664,2 kg garden waste, and 152 121,7 kg (SCG). The BE% is ranging from 18.61% for SCG, wood waste to 64.7%, garden waste to 95.3%, paper to 112.4%, and cardboard with a BE% of 117.5%. Moreover, the BE% will vary depending on the preparation of the substrate and the growing conditions of the mushrooms. The oyster mushroom's estimated kilo price is 245 SEK/kg, with a potential yearly value of the oyster mushroom is estimated to be approximately 128 333 000 SEK. This thesis highlights the potential of oyster mushroom cultivation potential where Stockholm Stad has the capacity to be locally self-sufficient when looking at the quantity of substrate available. Additionally, the results display the value of using residual waste streams as a resource in other ways than energy recovery.

Keywords

Industrial symbiosis, residual waste streams, Pleurotus ostreatus, Oyster mushroom cultivation, Circular economy

Sammanfattning

Detta examensarbete undersöker möjligheterna och utmaningarna när det gäller urban ostronsvampproduktion (Pleurotus ostreatus) med stadsbaserade material i Stockholm Stad som odlingsmedium. Dessutom har tillgången på de fem mest lämpliga substraten undersökts ytterligare med indikatorns tillgänglighet i Stockholm Stad och den biologiska effektiviteten (BE%) för ett lämpligt odlingsmedium och mängden av substraten har kartlagts. Som svar på klimatförändringar och osäker framtid är det viktigt för städer att vara motståndskraftiga mot katastrofer och tillgodose väsentliga behov som vatten, mat och energi. På grund av COVID-19 pandemin planerar den svenska regeringen att öka självförsörjningen genom att utveckla lagen om offentlig upphandling för att prioritera köp av lokalt producerade varor. Den importerade maten är billigare än svenska varor, vilket gör det svårt för inhemska produkter att konkurrera. En stor del av Sveriges avfallshantering består dessutom av förbränning av olika avfall, vilket är lägre prioriterat i Avfallshierarkin. Därför kan en bedömning av möjliga användningsområden, såsom ostronsvampodling, sannolikt tillföra ytterligare värde till de undersökta restavfallsströmmarna. Med hjälp av MFA, intervjuer och litteraturstudier samlades relevant data och information in för att lokalisera de fem mest lämpliga substraten: (1) träavfall från arborister och träarbetare, (2) pappersavfall, (3) kartongavfall, (4) SCG från fem av de största kafékedjorna i Stockholm Stad, (5) Trädgårdsavfall som hämtas från ett insamlingsföretag. Den uppskattade tillgängligheten för varje restavfallsström har kartlagts med pappersavfall på 15 805 567 kg, 20 560 580 kg (kartong), 64 166 500 kg träavfall, 3 939 664.2 kg trädgårdsavfall och 152 121.7 kg (SCG). BE% varierar från 18.6% för SCG, träavfall till 64.7%, trädgårdsavfall 95.3%, papper 112.4% och kartong med en BE% på 117.5%. Dessutom kommer BE procenttalet att variera beroende på preparationen av substraten och svampens odlingsförhållanden. Ostronsvampens estimerade kilopris är 245 SEK/kg, med ett potentiellt årligt värde på ostronsvampen uppskattas till cirka 128 333 000 SEK. Detta arbete belyser potentialen för ostronsvampsodlingspotential där Stockholm Stad har kapacitet att vara lokalt självförsörjande när man tittar på mängden tillgängligt substrat. Dessutom visar resultaten värdet av att använda restavfallsströmmar som en resurs på andra sätt än energiåtervinning.

Nyckelord

Industriell symbios, restavfallsströmmar, Pleurotus Ostreatus, Ostronskivlings odling, cirkulär ekonomi

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Stockholm, June 2023
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List of acronyms and abbreviations

BE%	Biological Efficiency in percent
CE	Circular Economy
IE	Industrial Economy
SCG	Spent Coffee Grounds
SMS	Spent Mushroom Substrate
SVOA	Stockholm Avfall och Vatten
UA	Urban Agriculture
MFA	Material Flow Analysis

1 Introduction

Agenda 2030 is an action plan by FN to reach prosperity for the people and the planet with transformational visions where the planet and people live in harmony, free of violence, fear, hunger, and inequalities, whilst working in a sustainable manner (UN, 2015). Food systems and security is one of the central aspects of the 2030 Agenda for more sustainable development. The goal is to extinguish hunger and poverty while maintaining a healthy socio-economic environment and minimizing the impacts of the planetary resources by enabling sustainable production and consumption (ibid.). However, these goals are far from being fulfilled as of today (WFP, 2022).

As the world's population continues to grow, so does the demand for food. By 2018, the global population had surpassed 7.6 billion and is expected to exceed 9 billion by 2050. This population growth will result in a significant increase in the demand for food, estimated to rise between 59-102%. (Pawlak & Kołodziejczak, 2020). According to United Nations data, this would require agriculture production to expand its productivity by about 75 %. In other words, food production must double by the year 2050 to meet the demand of the growing population (Prosekov & Ivanova, 2018). Due to the high-pressure agriculture has on the world's resources, improving the sector plays an important role in accomplishing food security and sustainability (Pawlak & Kołodziejczak, 2020).

The conventional production system of goods and services is linear as it starts from raw materials extraction, followed by the production and disposal phase (do Canto, 2021). On the other hand, circular material flow aims to find ways to convert something considered waste into a resource rather than disposing of it. This way, resources are reused, recycled, and recovered in a closed-loop system (ibid.).

Today's food system has grown to be longer and more complex, containing more stakeholders throughout the production line than before (FCRN, 2015). Agriculture is a sector that greatly impacts the planetary resources due to its resource intensiveness, pollution, and emissions (ibid.). Furthermore, the increasing complexity of the production chain diminishes the transparency of the process, causing challenges to assess and improve it. There are multiple reasons for obtaining transparency when it comes to food systems, such as the increase of the earth's population, the detection of illness caused by food, and the detection of inefficiencies (ibid.).

Agriculture is one of the biggest causes of greenhouse gas emissions (GHG) and biodiversity loss, accounting for approximately 30% of the total GHG emissions emitted today (Rockström & Klum, 2012). Agriculture is a significant user of land, accounting for 40% of the world's terrestrial surface (ibid.). Furthermore, irrigation, which is essential for agriculture, consumes a considerable number of freshwater resources, amounting to around 70% of the world's total (ibid.).

Additionally, agriculture causes water eutrophication due to nutrients like phosphorus and nitrogen leaking out. The substantial footprint of today's agriculture resulted from a modernization process that started in the 1950s. Entrenched with fossil fuels for vehicles, and excessive use of fertilizer and pesticides for food production, this modernization of agriculture through the Green Revolution was able to expand its productivity (ibid.).

Urban farming has emerged as a suggested alternative to traditional agriculture (Smit, Nasr, and Ratta, 2001). The increase of demand for local, sustainable, and safe produced goods have appeared recently where food can be grown and freshly harvested (ibid.). Increasing the circularity and decreasing the distance between farming and actual consumption could reduce food losses in the food production chain and become more resource efficient. The interest and investment in urban farming have increased where agribusinesses have invested in indoor controlled growing systems incorporated within cities such as Europe, Asia, the Middle East, and the US (Royse et al., 2017).

The expansion of indoor urban farming has mainly focused on the traditional vertical hydroponic agricultural systems where herbs and leafy greens are typically grown. In Sweden, the urban indoor farming sector is at an early-stage development with the capacity to diversify the crops and increase production (Ljungberg, 2020). Also, there is an interest in expanding to inter alia aquaponic structures and specialty mushroom plantations (Agritecture, 2021; Ljungberg, 2020). Sweden is highly dependent on importation of food, accounting for 50% of the food consumed (RISE, 2021). The capacity has decreased from 70% to 50% since the 1990s (ibid.). UA can assist Sweden with becoming more self-sufficient in their food production and decrease the dependency on imported food which consist of approximately 60% of all consumed foodstuff today (Skogindustrierna, 2020; Jordbruksverket, 2023).

Moreover, circular economy (CE) has been shown to be important when assessing current food systems' performance concerning sustainability (Dorr et al., 2021). The origin of circular economy is sourced from the multidisciplinary framework of Industrial Ecology (IE), which is the discipline centered around designing human-made systems to assimilate the natural ecosystem (ibid.). Circular economy is a framework to achieve circularity when handling limited resources in a closed system (ibid.). In a closed-loop system, resources are used efficiently, waste is minimized, and products are designed to be reused or recycled (Dorr et al., 2021). Adopting CE within agriculture can therefore close the loops minimizing resources being wasted, minimizing natural resource extraction, improving production systems, and enabling local food production (Abbate et al., 2023).

Edible mushrooms are appreciated for both their nutritional compositions and taste. They are a good source of proteins, polysaccharides, minerals, metabolites, and unsaturated fatty acids (Passari & Sánchez, 2020). Furthermore, mushrooms have been elected as the food of the year for four consecutive years, being recognized for their versatility and their properties. The interest in mushrooms has increased together with their consumption and importation, going from 193 million SEK to 297 million SEK in 10 years (2009-2019) (Ridder, 2022).

Specifically, mushroom farming is an interesting cultivation process to display the capability of industrial symbiosis (IS) and circular economy. Fungi are known to grow and to be cultivated on organic waste, generating edible mushrooms. The organic waste where the mushrooms are grown changes into a nutrient-rich soil as the waste decomposes (Dorr et al., 2021). Facilitating a symbiotic relationship between food cultivation and the waste management sector can lead to a more efficient use of resources. Sourcing nutrients from waste streams can be reintegrated into the food production process instead of being lost through landfill or incineration, thus keeping them within a productive loop (ibid.).

Mushrooms can grow on multiple industrial waste streams such as different types of straws such as wheat and rice, wheat brands, husks (Fungi Ally, n.d.), woodchips, logs, stumps, beer breweries residues, and spent coffee grounds (SCG). Coffee is an established part of Swedish culture. In 2020 alone, approximately 79.2 tons of roasted coffee was consumed, showing an immense potential for residual waste streams to be utilized (Ridder, 2022a). The consumption of mushrooms has increased in Sweden due to their many health benefits (SLU, 2021; Golak- Siwulska et al., 2018). Moreover, oyster mushrooms are known to be able to grow on most lignocellulosic containing substrates (Hikichi et al., 2017).

1.1 Problem statement

With the current climate change and the uncertain future, it is important for cities to be constructed to be resilient to disasters. Resilient cities are an important concept to urban planning, being defined as the city's ability to withstand and recover from strains while being able to meet the essential needs for a running city, such as water, foodstuff, and energy (Jordbruksverket, 2023).

Due to recent events of the COVID-19 pandemic, the government has plans to increase its degree of self-sufficiency. The Swedish government has announced in Motion 2020/21:2602 that they plan to develop the law of LOU (Lagen om offentlig upphandling), which governs public procurement. This means that procurers will always have the option to purchase locally produced goods from Sweden (Sveriges Riksdag, 2020). Additionally, imported food today is cheaper than Swedish locally produced goods causing Swedish products to have trouble competing with imported foodstuff (Eriksson, 2022).

A substantial section of imports comprises foodstuffs that Sweden does not produce, such as bananas, citrus, fruit, beans, and coffee soya (Jordbruksverket, 2023). However, the country also imports a substantial number of products that are directly competing with Swedish production. Examples of this are certain kinds of meat, vegetables, dairy products, and fruits (ibid.). During the last decade, Sweden imports an average of 70% more food and agricultural products than what the country exports (ibid.). Sweden's degree of self-sufficiency is approximately 50%, where there are three foodstuffs the country is entirely self-sufficient in, like carrots, sugar, and grains. Having experienced the COVID-19 pandemic, the government has decided to increase the self-sufficiency regarding foodstuff (Sveriges Riksdag 2020).

Today approximately 60% of the food consumed in Sweden is imported from abroad (Skogindustrierna, 2020; Jordbruksverket, 2023), where approximately 1181.6 kg of oyster mushroom is imported as a minimum (see Table 2 below).

Mushrooms became more popular during the 20th century when consumption was mainly canned champignon (Mannarp, 2014). However, fresh mushrooms were more obtainable as the assortments became broader and new mushrooms such as oyster mushrooms and shitake became more popular. The consumption of mushrooms, in general, is estimated to be 2-3 kg per person in Sweden (ibid.). Furthermore, According to Shaojun Xiong, a researcher in Umeå, approximately 20 000 tons of food mushrooms are imported annually (Skogindustrierna, 2020). Producing mushrooms locally would increase food security, and the residual waste can be used to create value as the spent mushroom substrate can be used for biofuel production and bioremediation. According to Svampoldarna, approximately 0.02 kg of oyster Mushroom is consumed per person a year (see Table 1 in section 2.3).

Pleurotus ostreatus is a mushroom enjoyed by many and is available in the majority of grocery stores in Sweden (Botaniska, 2021). Due to Pleurotus ostreatus being a typical saprophyte, living on decaying materials, the mushroom can grow on particularly any substrate containing cellulose, hemicellulose, and lignin (Thakur, 2020; Bernart, 2004). It is, therefore, possible to convert waste containing the prior listed organic compounds to highly nutritional mushrooms; read more about oyster mushrooms in section 2.3.

1.2 Aim & Objectives

The aim of this project is to assess the possibility for urban mushroom production employing urban-based materials produced in Stockholm as a growing media.

1. Investigate possible growing media and the needed flows for the mushroom production.
2. Map out the quantity of the most suitable growing media that are available and most suitable in Stockholm for mushroom farming.

1.3 Scope and limitations

Furthermore, the results on mushroom yields and biological efficiency are highly dependent on the cultivation method, substrate fractions, supplements, and treatment processes. However, even if different substrate possibilities are available, due to the time limit, it was not possible to cover them all. Therefore, a selection of substrates has been investigated where produce such as rice straw and other lignocellulosic wastes that are not produced in Sweden was covered in this report.

This master thesis has focused on five substrates: paper, cardboard, sawdust/wood chips, spent coffee grounds, and garden waste. The reason to focus on those five substrates is mainly because of their cultivation potential and availability in Stockholm Stad.

Moreover, this thesis has focused on assessing the production of the Pleurotus ostreatus species. There are numerous different species of oyster mushrooms; however, due to time limitations, it was not possible to include all.

This thesis consists of three different methods to collect data: interviews and semi-structured interviews, literature review, and a field study which will be described more comprehensively in Section 3.

1.3.1 Sample size and generalizability

Stockholm Stad has been the target of this report; hence, some of the results do not apply to other places. Due to the time and resource limitations, the study's sample size has been restricted, and the conclusion of this report can only be an estimation of a fraction of the available waste flow. This is described further in section 3 method.

To decrease the limitation, the samples for data collection were taken as spread out as possible within the geographical boundary to get a fair representation of the flows in Stockholm Stad. For paper and cardboard waste, five collection companies were contacted to estimate the quantity of their waste collection in Stockholm Stad; however, one of them was not able to answer. Moreover, 34 arborists and woodworkers and one company for the garden waste collection were contacted. Additionally, five coffee houses were investigated to map out available spent coffee grounds (SCG). This is described more in Section 3.

1.3.2 Geographical boundary: Stockholm Stad

Stockholm Stad is a municipality within Stockholm County. With about 984 700 residents, the municipality is rapidly growing (Stockholm Stad, 2022). This also implies an increased need to design a long-term waste management and a change of behavior in utilizing resources (ibid.). Stockholm City has continuously worked towards recycling and reusing within the city's operations. The municipality goals have been mainly focused on less resource use, better consumption, increased circularity of the city's resources and materials (ibid.).

The area consists of 13 urban districts: Bromma, Spånga-Tensta, Hässelby-Vällingby, Rinkeby-Kista, Skärholmen, Hägersten-Älvsjö, Kungsholmen, Enskede-Årsta-Vantör, Farsta, Skarpnäck, Södermalm, Östermalm and Norrmalm (Stockholm Stad, 2022). The boundaries can be viewed in figure below (Fig. 1). The urban districts consist of their city centers with residential areas that branch off from the areas to the most outer part of the city boundary (ibid.).

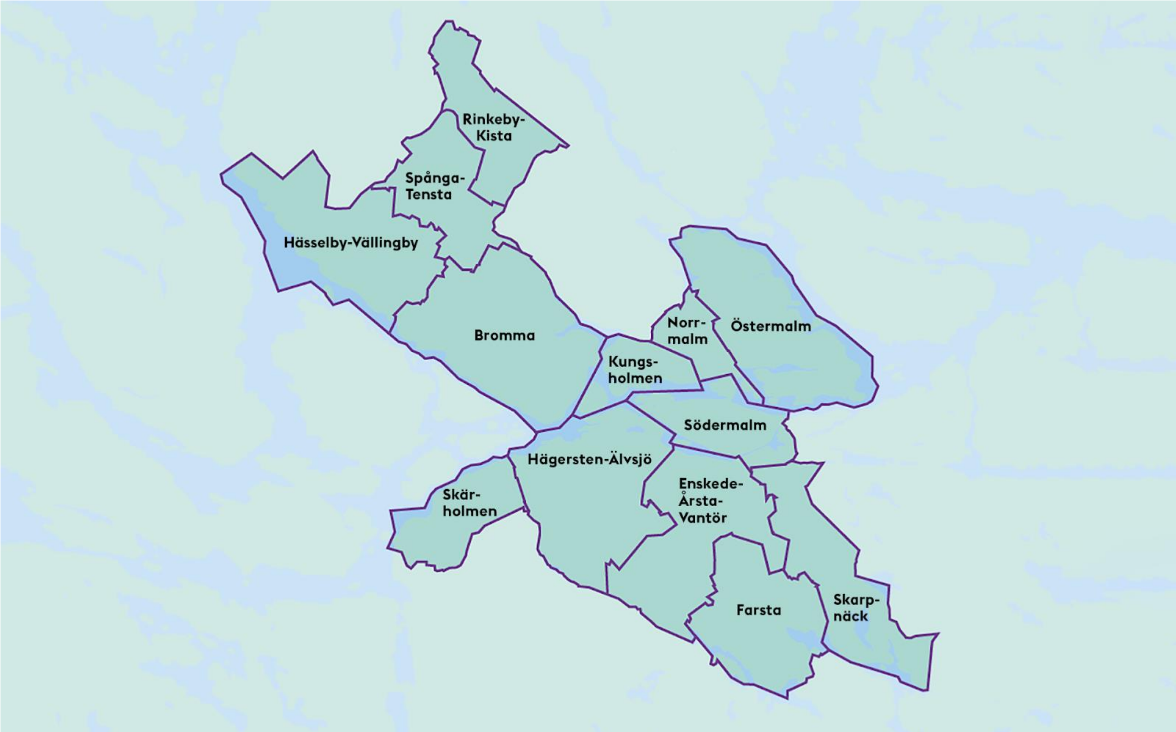

Figure 1. Geographical boundary of Stockholm Stad (Stockholm Stad, 2022)

The city aims to implement sustainable strategies within the city planning of the growing areas. Stockholm Stad is the most densely populated municipality in Sweden, where most of the inhabitants live in apartment blocks, and only a small percentage live in houses. The city's core is densely built and partly contains older and landmarked buildings. Within Stockholm Stad, there are a couple of Islands connected by bridges and ferries (Stockholm Stad, n.d.). The commercial and industrial life of the municipality is dominated by office operations, trading, and restaurants. There are no major industries, most of which fall under the service sector (ibid.).

The land usage within Stockholm is distributed between built-up and constructed land, agricultural land, open marshland, and other lands (Fig. 2) (ibid.).

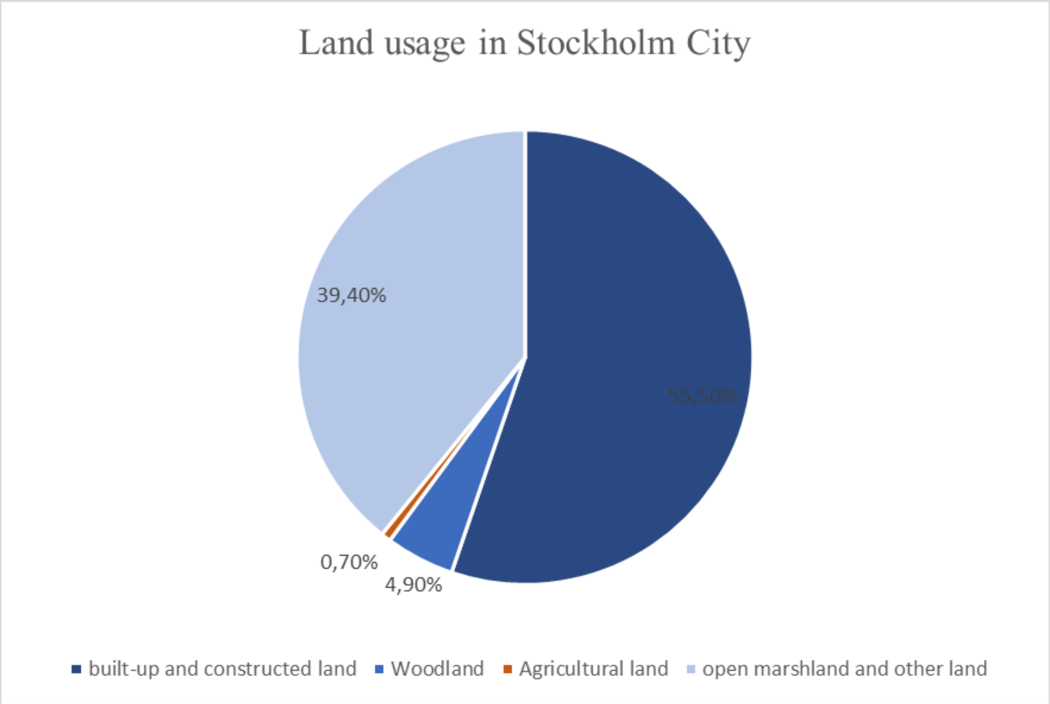

Figure 2. Land use (%) in Stockholm. Source: SCB (2022)

Stockholm Avfall och Vatten is going to take over all FTI stations (Förpackningsinsamlingen) where waste fractions such as Metal, paper, cardboard, and glass can be disposed of. Stockholm Stad has 250 Fti stations, also called recycling stations, and two recycling centers Vantör recycling center and Östberga recycling center.

1.4 Structure of Thesis

The thesis is structured into six distinct sections. Section 1 serves as the introduction, providing essential information on the research topic and highlighting its significance. This section presents the aim, objective, and scope of the study. Section 2 encompasses the literature review, which includes relevant information on oyster mushrooms and cultivation processes, as well as an introduction to sustainable development concepts pertinent to the topic.

In Section 3, the research method is detailed, including the research design, participant information, data collection procedures, and data analysis techniques employed in the study. Section 4 presents the key findings derived from the collected, analyzed, and interpreted data, addressing the aim and objective stated in Section 1. Section 5 delves into the discussion and interpretation of these key findings. Lastly, Section 6 provides a concise summary of the main findings and key takeaways from the study in the form of a conclusion.

2 Literature review

Section two presents the literature review on important concepts and background information relevant to the thesis, including the definition of sustainable development. Moreover, this section provides information regarding oyster mushrooms, their cultivation processes, habitats, and materials needed.

2.1 Sustainable development concepts

This section is presenting important sustainable development concepts relevant to this thesis. Sustainable development can be defined in multiple ways. One of the well-known definitions comes from "Our common future," published in 1978 by the World Commission on Environment and Development (WCED). The definition was enrolled in the Brundtland report on human development, and it is considered the first documented time the definition of Sustainable development was methodically presented (Ravago et al., 2015).

"Sustainable development is development that meets the needs of the present without compromising the ability of future generations to meet their needs" - Brundtland report

2.1.1 Industrial Symbiosis and Circular Economy

Industrial Symbiosis is a subdivision of Industrial Ecology (IE), a multidisciplinary framework that aims to achieve circularity and create an industrial system more similar to natural ecosystems (Graedel & Allenby, 2010). Industrial Symbiosis is a process where industries are connected to share waste streams or by-products so that the output of an industry becomes the input of another one. Industrial symbiosis can be regarded as a practical approach to Circular Economy (CE) (ibid.). CE focuses on reducing energy, waste, and environmental impacts by closing the material and energy loops by reusing and recycling (Dorr et al., 2021). Circular economy has shown to be an essential concept when assessing current food systems where the practice and policy have been prominent when looking at its considerable part in the European Green Deals Action plan (ibid.). Circular economy is a framework to achieve circularity when handling limited resources in a closed system (ibid.).

The conventional production system of goods and services is linear, going from extracting the raw materials, producing a product, and then disposing of it. Instead, Industrial symbiosis aims to utilize something considered a waste to find ways to convert it into a resource rather than dispose of it (Graedel & Allenby, 2010). This way, the material, nutrients, and energy flows are closed in a loop where fewer resources can be used, and materials are reused, recycled, and recovered (ibid.).

2.1.2 Urban metabolism

Urban metabolism (UM) is a framework used to assess energy flows, materials consumed, and waste elimination within a city (Sanches & Bento, 2020; European Commission, 2023).

To describe it further, UM describes the flows of resources and energy within an urban system. This includes the inputs of the materials, their usage, and the transformation surrounded by the system, with outputs being waste generation and emissions (Sanches & Bento, 2020). The framework emerged from the desire to understand and manage urban sustainability, acknowledging the city's dynamic and complex systems, which are closely connected to the natural systems that are both local and connected environmentally globally (ibid.).

Furthermore, UM includes evaluating the quality and quantity of numerous resources that flow in and out of the urban city, such as materials, water, and energy. Moreover, the processes, facilities, and systems flows are included (Sanches & Bento, 2020). Urban metabolism can be recognized as a way of accounting for the ecological footprint of urban systems (European Commission, 2023). This has been used to assess the sustainability of urban systems in terms of their resource consumption, waste generation, and greenhouse gas discharge. By analyzing the flows of resources and energy within the system, UM can assist with detecting opportunities for reducing excess material consumption and waste generation, promoting a circular economy. This adds to a unified and holistic point of view of the city's activities and resource productivity to increase efficiency, sustainability, and circularity (Sanches & Bento, 2020).

2.1.4 Urban Agriculture

With an increasing population migrating into urban areas, more than half of the population globally lives in urban spaces, and the reliance on the food supply from the rural hinterlands is reaching its boundaries of sustainability (Wadumestrige Dona et al., 2021). Historically, urban developers have separated the urban to be more focused on the purposes of a city and rural areas to be more centered around agriculture (ibid.). The separation was due to public health reasons, even though urban industries were likely to be more prone to pollution. Furthermore, urban developers prioritize land conversions that increase its value, such as converting the land into residential buildings or using it for commercial purposes (ibid.). Concerning climate change and increased urbanization, threats towards food security in urban areas are more apparent (ibid.).

Urban agriculture (UA) is related to manufacturing food, fiber, and other agricultural products within or on the fringes of cities (Chatterjee et al., 2020). UA can be executed using multiple farming techniques such as container gardening, vertical farms, and rooftop gardens. Moreover, soilless farming techniques like hydroponic and aquaponic can be utilized. Attention toward UA has increased due to sustainability challenges like food insecurity and difficult access to fresh and local healthy foodstuff in urban areas. Practicing UA can improve cities' resilience when unexpected incidents or catastrophes occur.
According to Audete et al. (2019), multiple studies have shown positive evidence of UA regarding food security, nutrition, and physical and mental health benefits (Audate et al., 2019).
Furthermore, it contributes to social capital, local and fresh foodstuff (O'Sullivan et al., 2019).
Moreover, the local food system promotes a reconnection of the food production system

between consumers and producers. The carbon footprint can be reduced due to less food loss throughout the production chain (Langemeyer et al., 2021), transport (O'Sullivan et al., 2019), and subsidizing the local economy (Audate et al., 2019).

2.2 Waste hierarchy

Waste hierarchy is a waste management framework that sets priorities to use resources in a more sustainable and efficient manner. The main design of the framework is to encourage the avoidance and reduction of waste. Furthermore, reusing and recycling are prioritized where waste disposal is less preferable (EPA, 2022). The waste hierarchy is often presented as an upside-down pyramid where the most preferable is on the top, working down on the priority list (Fig. 3) (ibid.).

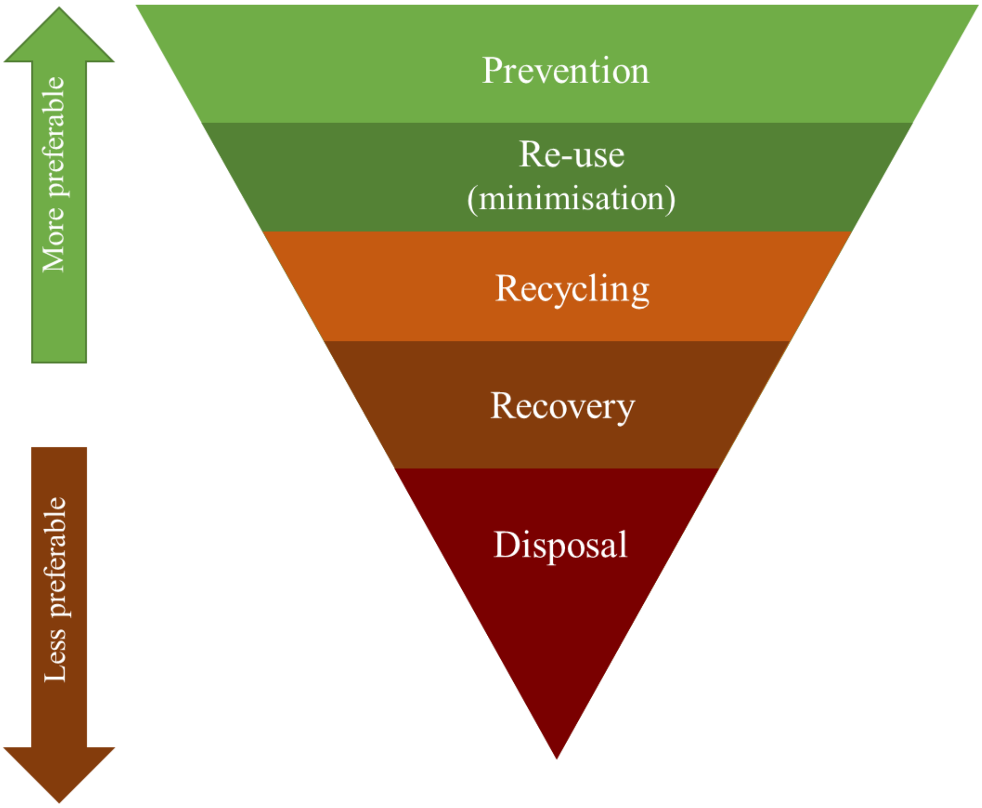

Figure 3. Waste hierarchy. Created with EPA (2022) as a source

Waste prevention: The highest priority is waste prevention, which is encouraged to minimize the amount of extracted raw materials, preventing excess production and consumption. When waste is inevitable, there is a desire to minimize waste by using materials more efficiently by reducing the number of packages or improving the production processes (EPA, 2022).

Re-Use & Recycling: When waste is generated, the next priority on the hierarchy is identifying ways to reuse it, such as repairing, donating, selling, refurbishing, or repurposing the materials for other usages. Waste materials that cannot be prevented, minimized, or reused could be recycled. In contrast, unwanted materials go through processing to become new materials that can become a resource for another purpose (EPA, 2022).

Energy recovery: When recycling is not suitable, there is a potential to recover the energy from the materials by converting the waste into a usable form like heat, fuel, or electricity. Energy recovery is usually a more desirable method as treatment than landfilling or incineration without energy recovery (Van Caneghem et al., 2019). Energy recovery with the help of a boiler and generator can recover heat and produce electricity when incinerating waste; furthermore, it can also minimize the volume of generated waste (Arabkoohsar & Sadi, 2021; Tait et al., 2019). It is also possible to produce biofuels with the help of anaerobic digestion of biowaste (Yang et al., 2020). However, energy recovery is relatively low on the priority list (Van Caneghem et al., 2019).

Disposal: The last step of the waste hierarchy is the disposal; some waste types, such as hazardous ones, cannot safely be recycled, which can include different types of asbestos or chemicals. The best way to manage it is by disposing of it (Van Caneghem et al., 2019; EPA, 2022).

2.3 Legislations

To become resource efficient, there is a need to cooperate with residents, companies, politicians, and public employees (Stockholm Stad, 2021 b). The reason for the contract is to make sure national, regional, and local planners are working towards the same goals. Stockholm Stad is one of the municipalities that have signed Klimatkontraktet, a contract between the city and the authorities to adapt to the development of climate-neutral cities more rapidly (ibid.). Klimatontrakt aims to develop cities to adapt Stockholm Stad to fit within Agenda 2030 goals while contributing to the recovery of Sweden's economy after the Covid-19 pandemic (ibid). The contract allows collaboration with the innovation program Viable Cities and Energimyndigheten, Vinnova, Tillväxtverket, Formas, and Trafikverket, which contribute to change (ibid.). Going from waste to resource iswas one of the main goals when the European Union Counsel 2018 decided to revise the waste legislation, that's called avfallspaketet (Naturvårdsverket, 2020). The goal is to minimize the volume of waste and increase product reuse, and recycling to implement better waste management. In 2020, the regulation of separate biological waste collection and textile waste was decided, and the new regulation of Avfallspaketet is going to be implemented before 2025 (ibid.). Numerous regulations were applied already in 2020; however, some regulations, such as the biological waste collection, will be implemented later (ibid).

According to the Waste Ordinance Avfallsförordningen (2020:614), the municipality shall provide a system to collect food waste for the households (Riksförvaltningen, 2020); this enters into force by 2024 (Stockholm Stad, 2023).

Furthermore, biological waste shall be sorted according to the following fractions:

1. Biologically compostable waste containing park and garden waste that can include parkslide or invasive species.
2. Other biologically compostable park and garden waste
3. Biologically compostable foodstuff and kitchen waste

In accordance with Regulation (EU) No. 1143/2014, bio-waste containing parkslide or invasive alien species that are listed on the Union list must undergo incineration or other treatment methods that effectively mitigate the potential for the spread of these species (Riksförvaltningen, 2020).

Furthermore, according to Avfallsförordningen (2020:614), the responsible for biowaste treatment shall always prioritize the treatment method following: (1) Material recycling and

(2) other treatments other than material recycling that results in equivalent or better effects on the environment (Riksförvaltningen, 2020). Moreover, according to the environmental code, 15th chapter. 11 § (SFS 1998:808), "Whoever handles waste must ensure that the handling does not damage or cause a risk of damage to human health or the environment." This means there is an obligation regarding the management of waste. In addition, specific actors are responsible for different management parts (ibid.).

Additionally, looking at the 15th chapter 20§ Environmental code, Stockholm Stad is responsible for a fraction of the waste that is listed in the paragraph reuse or disposal, which includes municipality waste, latrine, effluence fractions from buildings, and demolition waste that is not produced by a private business (Riksförvaltningen, 2020). Other waste fractions are the waste generators' responsibility, where the responsible must arrange transport and manage the waste in an environmentally correct manner (Stockholm Vatten och Avfall, 2021). Restaurants and other businesses serving more than 25 portions of food a day are required to collect their food. The goal is to reduce food waste by 25 % by 2025 compared to 2015 (ibid.).

Furthermore, in the summer of 2022, the Swedish parliament modified the legislation regarding producer responsibility for packaging. As a result, starting from January 1, 2024, municipalities will be entrusted with the task of collecting packages from households in proximity to their properties, operational areas, and easily accessible collection points.

2.3 Oyster Mushrooms

Oyster Mushrooms (Pleurotus spp.), also referred to as the tree oyster mushroom, white rot fungi, or abalone, are a typical saprophyte (a fungus, plant, or organism living if decaying or dead organic matter) (Bernart, 2004). Oyster mushrooms are a type of edible mushroom that belongs to the family Proteaceae. They are popular in culinary circles due to their delicate flavor, tender texture, and high nutritional value. However, oyster mushrooms are also of great interest to researchers due to their unique properties and potential applications in various fields. The oyster mushroom is globally one of the most popular and cultivated fungi species due to its high versatility and favorable properties both for their flavors, nutritional and pharmaceutical properties (Bernart, 2004).

One of the most remarkable properties of oyster mushrooms is their ability to produce bioactive compounds such as polysaccharides, terpenoids, and phenolic compounds (Golak-Siwulska et al., 2018). These compounds have been shown to have various biological activities, including antioxidant, anti-inflammatory, antimicrobial, and anticancer effects. As such, oyster mushrooms are considered a promising source of natural bioactive compounds that could be used to develop functional foods, nutraceuticals, and pharmaceuticals (Golak-Siwulska et al., 2018; Friedman, 2016).

In addition to their bioactive compounds, oyster mushrooms are also rich in nutrients such as protein, fiber, vitamins, and minerals (Golak-Siwulska et al., 2018). Furthermore, oyster mushrooms have been shown to have hypoglycemic and hypocholesterolemic effects, making them potentially beneficial for individuals with diabetes or high cholesterol levels (Friedman, 2016).

Spent mushroom substrate from oyster mushrooms are also of interest in the field of bioremediation, as they have been shown to be effective in degrading various environmental pollutants such as polycyclic aromatic hydrocarbons (PAHs) and heavy metals (Corral-Bobadilla, 2019). This makes them a potentially valuable tool for cleaning up contaminated soil and water (ibid.).

Table 1 below shows that 0.02 kg of oyster mushrooms are consumed per person in Stockholm Stad (Svampodlarna, n.d.), where the yearly consumption is approximately 19 tons of mushrooms. Moreover, Table 2 describes the estimation of 60% of the foodstuff consumed in Stockholm Stad being imported (Skogindustrierna, 2020; Jordbruksverket, 2023). Additionally, oyster mushrooms have significant health benefits and contain many nutrients (Golak-Siwulska et al., 2018; Friedman, 2016). See section 2.3 for more details.

Table 1. The estimated oyster mushroom consumption per person each year

Consumption [oyster mushroom/person/year kg]	Stockholm Stad residents [inhabitants]	Oyster mushroom consumption [kg/ year]
0.02	984 700	19 694

Table 2. Estimated imported foodstuff and mushrooms

Imported food	Imported mushrooms [kg]
60%	1 1816.4

According to Thi Hoa et al., 2015 the protein content of *Pleurotus ostreatus* is ranging between 19.52 – 29.70% dry weight. The moisture content of the mushroom was documented to be around 89.7 - 91.6 %. Moreover, the energy value of the *Pleurotus ostreatus* was mushrooms is estimated at 265.9 - 295 kcal per 100 g for dry weight (Table 3 below).

Table 3. Displays the protein percentage and calorific value of Pleurotus ostreatus

Pletrous Ostreatus		Mean Value	Potential value for 19 694 [kg/year]
Calorific value Kcal/100g	265.9 - 295	280.5	55 236 746.5
Protein percent %	19.52 – 29.7%	24.6	4 846.7

Pleurotus ostreatus shelf life is shorter as the mushrooms do not have a protective cuticle, resulting in high moisture content and respiratory rate (Castellanos-Reyes et al., 2021). The sensitivity of the mushrooms causes mechanical injuries such as enzymatic browning, microbial attack, weight loss, and loss of quality due to post harvest processes such as transportation (ibid.). The shelf life of Pleurotus ostreatus is about one to three days at room temperature of 20-25 °C and between five to seven days in cooling at a temperature of 4 °C (ibid.). Therefore, it is interesting to assess the possibility of urban mushroom production in Stockholm Stad employing urban-based materials produced in Stockholm as a growing medium. Moreover, it is estimated that the average price in Stockholm Stad supermarkets is 245 SEK/kg (see Appendix 11 for detailed information).

2.4 Different types of oyster mushrooms

There are multiple species belonging to the Pleurotus species, such as the grey oyster (*P. pulmonarius*), tree oyster (*Pleurotus ostreatus*), and Indian oyster (*P. sajor-caju*). As their morphology is similar, they vary (Wan Mahari, 2020). Furthermore, there is also the king oyster mushroom (*Pleurotus eryngii*) and the golden oyster mushroom (*Pleurotus citrinopileatus*).

Pleurotus pulmonarius, also known as the P. sajor-caju, has a light beige cap and a white stem. This nutritional food is appreciated by its taste, cultivated widely globally, and considered an inexpensive and good protein source. Similar to *Pleurotus ostreatus*, they are rich in antioxidants, antitumor, immunomodulatory and bioactive compounds (Radzi et al., 2021).

Pleurotus eryngii, also known as the king oyster mushroom. It has a rich, umami flavor and a firm flesh (Alfaro, 2022). P. eryngii contains bioactive compounds such as proteins, free amino acids, and polysaccharides. Moreover, they possess physiological functionalities such as antioxidants, antimicrobial, immune regulation, and hypoglycemic activities (Jun-Wen et al., 2022).

Pleurotus citrinopileatus, also known as the golden oyster mushroom, has a vibrant yellow cap and a thin, white stem. The mushroom has a distinct scent and slightly aromatic flavor (Mycoterra Farm, 2019). P. citrinopileatus contains bioactive compounds such as ergothioneine and polysaccharides, which have antioxidant, immunomodulatory, and antitumor activities (Golak-Siwulska et al., 2018).

Pleurotus cornucopiae, also known as the black oyster mushroom, grows typically on latifolia trees and has similar health benefits and nutritional value to other oyster mushroom species (Golak-Siwulska et al., 2018).

In nature, the fungi grow on waste materials, organic dead, or decomposed materials such as cottonwood, maple, or oak (ibid.). The role of these decomposers is to transform the dead organic matter by using their mycelia secrete, which works like a digestive enzyme system that dissolves the lignin cellulose into particles of nutrients that the fungi can digest, and thereby turn the organic matter back into soil (Wan Mahari, 2020).

Pleurotus ostreatus, also known as the pearl oyster mushroom, is one of the most widely cultivated oyster mushrooms. The mushrooms have a tender consistency and a mild taste which is sweet and woody (Mycoterra Farm, 2019). P. ostreatus is rich in protein, dietary fiber, and vitamins, and contains bioactive compounds such as β-glucans (Gallotti et al., 2020), which have been shown to have immunomodulatory, antioxidant, and antitumor activities (Nongthomban et al., 2021).

2.5 Oyster Mushroom Production Process

The development of oyster mushroom cultivation includes 3 primary steps: Isolating the mushroom from the fruiting bodies, organizing primary and secondary spawns on which the mushroom will grow on, and then being able to harvest the mushroom (Fig. 4, below). The central factors that affect the development of the mycelium are the substrate, temperature, nitrogen, and carbon sources, lignocellulosic substrate resources and grain sources (Hoa et al., 2015). Moreover, the fruiting culture is identified as the culture that has the capacity genetically to develop fruiting bodies in an appropriate growing circumstance. The chosen stock culture should be suitable in numerous terms such as yield, texture, taste, fruiting time, etc. (Cheung, 2008).

The fruiting culture grows into a mycelium on a medium that operates as the inoculum of the "germ or seed" for the mushroom cultivation substrate, also called the "mushroom spawn." The mushroom spawn is the inoculum that is utilized to establish mushroom mycelium to the substrate itself. When the yield is not adequate, it is often due to the spawn that was used being inadequate. However, the spawn substrate should also be considered since it can impact the spawn's growth speed and mycelium's development after the inoculation (Cheung, 2008).

The ideal growing substrate is sterile, free from microorganisms that can compete with the mushroom mycelium's growth. However, those conditions are usually too pricey and unfeasible on a larger scale. When preparing substrates for mushroom cultivations, it usually demands pre-treatments of various extents to stimulate the growth of the intended mushroom while eliminating other organisms. Moreover, the substrate must be rich in fundamental nutrients for the mushroom, without toxic substances that can impede the spawn's growth. Important factors for the substrate are moisture content, pH, ventilation, and temperature (Cheung, 2008). Adding supplements to the substrate is common to increase the nutrients (Carrasco et al., 2018). In some cases, gypsum is added to decrease the greasiness (Meigs Beyer, 2022).

A common way to sterilize the substrate is through pasteurization. During this process, a hot steam eliminates potential microorganisms that can compete with the spawn. The steaming room has a temperature of approximately 60 °C for 4 hours to remove other microorganisms. When the substrate has cooled down, the spawn is spread over the surface of the substrate, to be then pressed in properly to ensure proper contact; alternatively, the spawn is implanted 2-2,5 cm into the substrate before it is moved into a controlled environment to spawn (Cheung, 2008).

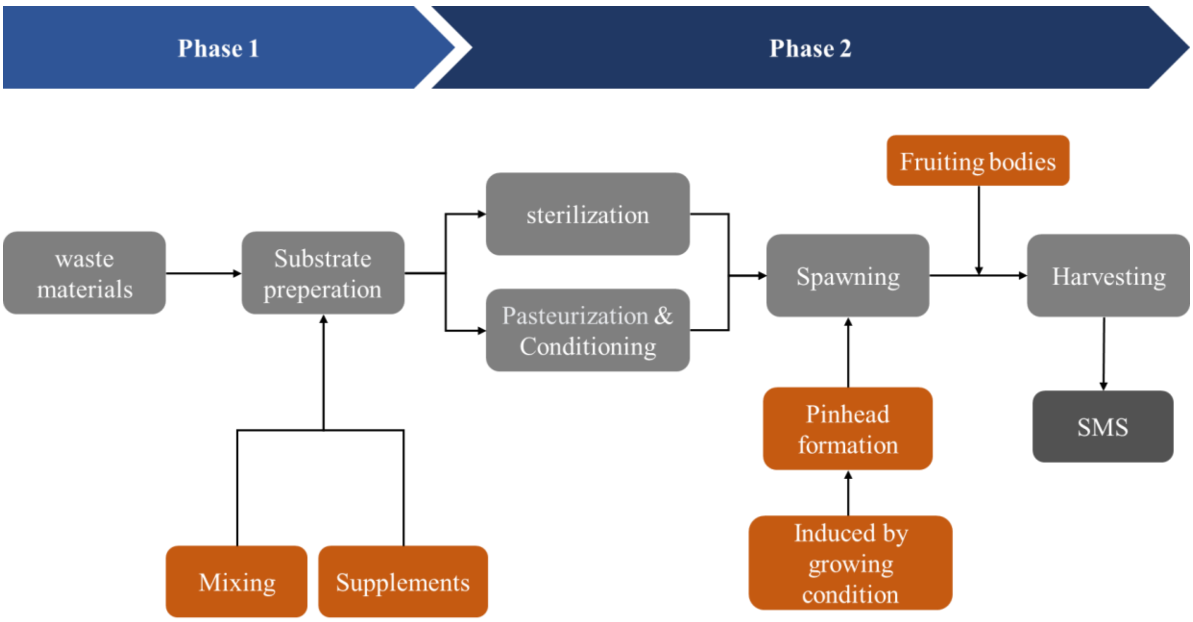

Figure 4. Oyster mushroom production process

2.5.1 Intrinsic factors

An optimal substrate requires a sufficient amount of nitrogen and carbohydrate contents to aid the growth of the mushroom (Wan Mahari et al., 2020). Compared to other species of mushrooms, oyster mushrooms can grow on numerous substrate materials; preferably substrates rich in lignocellulosic substrates. Therefore, the possibilities of using waste streams as a substrate to cultivate oyster mushrooms are good (ibid.). Substrates such as cotton waste, sawdust (Girmay et al., 2016; Das et al., 2020), paper waste (Mandeel et al., 2005; Girmay et al., 2016) are examples of urban residual wastes that mushrooms have successfully grown on (Wan Mahari et al., 2020; Ashrafi et al., 2014).

In contrast to other agricultural produce, mushrooms are heterotrophic systems requiring nutrients externally to maintain and grow (Taylor & Ellison, 2010). Supplements are added to the substrate for the mushroom to maintain a healthy metabolism and growth (Carrasco et al., 2018). The main macronutrients required are carbohydrates (C) and nitrogen (N) for energy and structure. To attain the highest yield in the least amount of time, a C/N ratio is essential (Wan Mahari, 2020; Taylor & Ellison, 2010). Additionally, trace elements, including Se, Fe, Cu, Zn, Mo, and Mn are essential for other various functions (Taylor & Ellison, 2010). According to Wan Mahari et al., 2020 the desired carbohydrate content should be approximately 40%, and the nitrogen content to be 1.84-2.1% (Wan Mahari, 2020).

The two main optimized preparations to produce substrates for cultivating mushrooms are pasteurization and fermentation (Vos et al., 2017; Pardo et al., 2017) and sterilization (Xie et al., 2017; Carrasco et al., 2018). The first preparation type includes composted resources through fermentation and pasteurization (Vos et al., 2017; Pardo et al., 2017) which is suitable for the cultivation of species such as *Pleurotus ostreatus* (Carrasco et al., 2018) and *Agaricus bisporus* (Pardo et al., 2017). The second method includes non-composite materials treated and sterilized in steam before inoculation (Xie et al., 2017; Carrasco et al., 2018). This method is standard in commercial cultivation of *Agrocybe aegerita* and *Lentinula edodes* (Carrasco et al., 2018).

Supplementation is considered a known method when cultivating mushrooms, where producers physically add nutritional components to the substrate mix during the compost period (Carrasco et al., 2018). There is a wide range of supplements accessible on the market consisting of soybean, organic sources of protein such as cereal bran, and vegetable meal which are commonly used for the cultivation of Pleurotus and Agaricus species (Carrasco et al., 2018). However, there are cost efficient alternatives using agricultural by-products being cereal brands and meals (ibid.). Chicken manure, urea, cottonseed, ammonium sulphate, defatted meals, grape pomace, wood chips, boll, wheat bran, soybean, oat husk, carrot pulp, rice bran and many more (ibid).

The pH of the substrate is an essential factor when it comes to a good cultivation of oyster mushrooms. Most mushrooms thrive in pH close to neutral or subtle bases. Lime (CaCO3) is an important component in regulating the pH in commercial production of mushrooms (Pathmashini et al., 2009; Wajid Khan, 2013). According to Wajid Khan et al. (2013) the Oyster mushroom (*Pleurotus ostreatus* & *Pleurotus sajor-caju*) thrives at a pH slightly on the basic nature where it gave the best yield when the pH was at 7.2 and 7.8 (Wajid Khan, 2013) and other sources report the optimum for the fruiting to be around 6.5-7 pH (Bellettini et al., 2019). Furthermore, sources are reporting that at a pH below 4-5, the mycelia stop growing (Wan Mahari, 2020). Additionally**, t**he substrate's moisture should range between 65-80% to ensure nutrients reach the fruiting bodies by the mycelium in a stable flow (Wan Mahari, 2020).

2.5.2 Extrinsic factors

Oyster mushrooms can grow in a broad range of temperatures; however, they thrive in temperatures between 20-30 °C (Nongthomban et al., 2021), with the optimal temperature for P. Ostreatus at 28 °C to obtain the maximum growth rate (Hoa et al., 2015). Moreover, there are different types of containers such as trays made of pottery and plastic, plastic bags made of polyester net and polyethylene bags. In a study conducted by Mandeel et al., (2005) comparing different container types, the polyethylene bags resulted in the highest biological efficiency compared to the other (Mandeel et al., 2005).

Humidity control is an important factor when it comes to mushroom cultivation; the desired humidity level is about 60-80% during the spawn phase, 80-85% during the mycelia stimulation, and lastly 10-35% for the development of fruiting (Bellettini, 2019), where spraying water on the growing mushrooms can be good to contain the moisture levels. However, it's important not to spray water on ready-to-harvest mushrooms since it can shorten the shelf time (Nongthomban et al., 2021). The humidity can be regulated by a humidifier and a fan (Mohammed et al., 2021)

Oyster mushrooms are not photosynthetic and do not require light for growth. However, some exposure to indirect light can help stimulate fruiting. Light can be provided through natural light or by using artificial lighting. According to Mohammed et al. (2023), the optimal light for oyster mushroom production is between 500 - 300 lux (Mohammed et al., 2023). Furthermore, as the mycelia begin to develop in the bed of substrate, the mycelia must have an adequate air circulation to prevent the build-up of carbon dioxide. Good ventilation and air change is therefore important during this stage. This can be achieved through natural ventilation or by using fans. If the carbon dioxide levels are high during this fruiting phase, the mushroom will grow thick and short, which is not desirable by the market (Wan Mahari et al., 2020).

When Mushrooms are cultivated in appropriate conditions the growth of mushrooms will appear in so-called “flushes” which refers to the rhythmic growth cycles of the mushroom. Oyster mushrooms can be harvested when they reach maturity before water spraying, which typically occurs around 28-35 days after inoculation (Wan Mahari et al., 2020). Moreover, remove the mushroom from the substrate by lightly twisting the body not to damage the other subsequent mushrooms to continue growing. However, additional nutrients might be needed for supplement (ibid.). Furthermore, with 1 ton of straw paddy as growing medium it is possible to produce about 500-700 kg of mushrooms (Nongthomban et al., 2021)

Overall, oyster mushroom farming requires careful attention to environmental and cultural factors to ensure optimal growth and yield (Golak-Siwulska et al., 2018). By providing the right conditions for substrate, spawn, temperature, humidity, light, ventilation, and harvesting, growers can produce high-quality oyster mushrooms for a variety of culinary, medicinal, and biotechnological applications (ibid.).

Table 4. A summary of the intrinsic and extrinsic factors for oyster mushroom cultivation

Intrinsic factors	
pH	6.7 – 7.8
Moisture content	65 - 80%
Nitrogen content	1.84 – 2.1 %
Carbon content	40%
Extrinsic factors	
Temperature	20 - 30 °C
Humidity	60-80% - Spawn phase, 80-85% - Mycelia stimulation, 10-35% - Fruiting
Light	500 - 300 lux

3 Method

In Section 3, the research method is detailed, including the research design, participant information, data collection procedures, and data analysis techniques employed in the study.

3.1 Research Design

The initial method of this project was a comprehensive background and information gathering about oyster mushroom production and its possible substrates by conducting a literature review. The literature review was used to analyze the growth phases, cultivation processes of oyster mushrooms to describe Stockholm city and its boundaries, and the food waste situation in Stockholm. Moreover, concepts relevant to this study such as industrial symbiosis, circular economy, urban metabolism, urban agriculture, planetary boundaries, and waste hierarchy were explained. The review used academic databases such as Research Gate, Google Scholar and Web of Science with the following keywords: oyster mushroom production, residual waste, mushroom cultivation on lignocellulosic wastes, oyster mushroom cultivation on by-products. Furthermore, the literature review served as a method for data collection to further conduct data analysis, investigating the statistics regarding the availability of the substrate in Stockholm City.

The methodology of this specific project is on the explorative side, where a mixed method approach was applied with data collected by the combination of literature-review literature review, interviews, and a field study. A Material Flow Analysis (MFA) was conducted to map out the metabolism of oyster mushroom cultivation. This is to gather information on what is required for the cultivation and the residual waste stream Stockholm City produces that can potentially be used. MFA is a quantitative method to assess the flow of resources and substances inside a specified system, such as a country, city, or a specified industrial sector (Graedel & Allenby, 2010). The method offers a comprehensive knowledge of both economic and physical processes concerning the production, utilization, and discarding of materials (ibid.). The method can be used for many purposes, where it analyzes the metabolism within the system and can assist with identifying inefficiencies (ibid.). There are typically three main stages in an MFA: (1) Data collection, (2) Calculation of material flows, and (3) interpretation and analysis (ibid.) (Fig. 5). The first steps include gathering the needed data, sources, characteristics, and destination of the materials to then be evaluated.

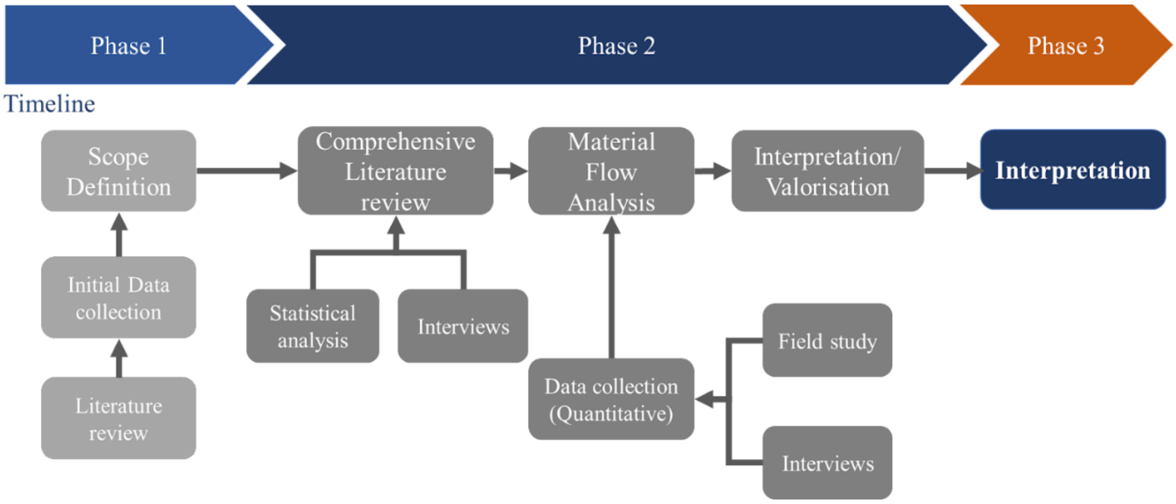

Figure 5. Overview of the projects timeline and its phases

3.2 Quantitative Data Collection

Initially, a literature review of quantitative numbers was collected while searching for possible substrates for oyster mushroom production. Most articles had biological efficiency (BE%); however, the article written by Oh et al., 2004 did not have it. To unify the results and make the numbers comparable, the BE% was calculated with the information from their article. Moreover, the project conducted structured and semi-structured interviews to collect data from various companies.

3.2.1 Calculation of biological efficiency (BE%)

The equation for calculating biological efficiency can be found in equation (1) (Mandeel et al., 2005). The yield was calculated to be yield/1000g substrate, since the experiments that were gathered used different amounts of substrate, and to increase the comparability the yield was calculated to be the same (See Appendix 2). To ensure the results are comparative, the BE% was used to measure the efficiencies of each substrate. However, some reports such as Oh et al., 2004 did not include it (see calculation in Appendix 1). The BE% was calculated for that specific source which was calculated according to the following equation:

$$BE\% = \frac{Total\ weight\ of\ fresh\ mushrooms}{Dry\ weight\ of\ substrate} \times 100 \qquad (1)$$

3.2.2 Interview of waste fractions: Garden and paper waste

Furthermore, to collect data, a collection of interviews was conducted. Initially, an interview was conducted with the administrative manager Mathias Dynesius at Stockholm Avfall och Vatten (SVOA), where Stockholm municipality waste collection system was discussed, and further plans and regulations were. Data regarding the collection system, waste fractions, and quantities was provided. The goal of the interview was mainly to collect data on available biological waste fractions in Stockholm Stad and to hear more about their operations. The interview was structured to be quantitative and qualitative. Half of the interview was spent on quantitative data, where information data regarding their waste fractions was provided, while the other half was an open discussion regarding their waste collection system and their future challenges since SVOA is taking over all FTI stations and have both collection and treatment responsibility for all packages in Stockholm Stad. The information gathered from the interview SVOA was used for paper and garden waste quantifications.

3.2.3 Sawdust and Wood Waste

To locate wood waste in Stockholm municipality, arborists and wood workers were contacted through email or phone call to be able to estimate the wood generation in their work activity. Moreover, fewer official interviews were conducted, and the majority of the information was collected by email conversation and interviews through phone calls. The collection of wood waste was managed by locating wood workers and arborists in Stockholm Stad, where 34 companies were contacted. The questions asked of each company were the following:

[Introduction to the thesis]

- How much wood waste do you generate each month or year?
- How do you treat the wood waste, and where does it go?
- Can you estimate the cost of the treatment process of the waste?

Fifty percent of the companies had answers to the questions above (17 out of 34 companies) to different degrees, and many had rough estimates of their waste generations rather than exact numbers. Furthermore, there were instances where the correspondent answered in $m3$ as many measures in container volumes and others in kg, where a conversion had to be made to unify the units. Therefore, for following equation was used to calculate all waste streams to be in kg.

$$\rho = \frac{m}{v} \qquad (2)$$

An assumption of medium heavy wood, with a density of 600 $kg/m3$, has been made (Skogskunskap, 2021). Moreover, due to a proportion of the correspondents answering wood waste in container volumes, there is also an assumption that it will be the amount said. Even though a percentage of the given volume is air. To acquire further information regarding the prior studies on oyster mushroom production on wood waste and its method, see Appendix 3.

3.2.4 Paper and cardboard

Furthermore, the waste fraction of paper and cardboard was additionally estimated by contacting five bigger waste collection companies in Stockholm Stad, where numbers were acquired by email conversation and phone calls. However, only four of the five collection companies could provide data for this thesis. The email and phone conversation contained the same questions asked of wood workers and arborists above. See Appendix 6 for more information regarding prior studies conducted and methods for oyster mushroom production on paper and cardboard waste.

3.2.5 SCG method calculations

Due to the limited information regarding available Spent coffee ground generation in Stockholm Stad, a field study was conducted where sample checks were made throughout cafes in the municipality. Samples were taken in Stockholm City, Södermalm, Fridhemsplan, Farsta and Kista. Five of the bigger cafe chains were selected to be of focus when looking at SCG generation. Moreover, when arriving at the cafe, a quick introduction to the project took place, followed by two questions:

- How much coffee waste do you generally generate each day?

- Is the SCG separated as food waste as for now?

Moreover, the number of cafes of each coffee chain within Stockholm Stad was calculated and located by investigating on Google Maps and their websites. One of the five coffee chains supplied exact numbers via email. However, a mean value of coffee consumption was calculated for the remaining four chains. The mean value for each day and cafe was calculated and summed up to a yearly SCG generation and was finally multiplied by the amount of coffee houses for each chain (see Appendix 9). Moreover, to read more about prior studies on SCG and the method used, see Appendix 4.

3.3 Calculation of possible mushroom production

Additionally, the estimation of freshly produced mushrooms was calculated by multiplying the BE% and substrate availability as shown in equation (3) (Mandeel et al., 2005):

$$\text{Total weight of fresh mushroom} = \text{BE\%} \times \text{Substrate availability} \quad (3)$$

Assuming that the substrate weight being the weight of the “collected” substrate (see Table 6). This substrate weight did not include the weight of water, limestone, and additional supplements. Moreover, the BE% was mainly gathered from prior studies on oyster mushrooms during the literature review phase. Moreover, the substrate availability highlights if the total collected residual waste stream residue was to be used for mushroom production.

3.4 Data Selection

The data selection consists of flows sourced from 44 different companies (Table 5). The data was sourced in multiple ways in Stockholm Stad such as interviews, semi-structured interviews (phone calls and e-mails) and a field study. For paper and cardboard waste, five collection companies were contacted to estimate the quantity of their waste collection in Stockholm Stad; however, one was unable to answer. Moreover, 34 arborists and wood workers and one company for the garden waste collection were contacted. The companies were located by initially deciding on what waste flows to be used and the specific industries, such as “woodworkers and arborists.” The reason for using these specific flows is due to the waste flow containing untreated wood. To locate the companies, Google Maps was used to investigate whether the company was within the geographical boundary.

Table 5. The sample selection of companies when assessing the available waste flows

Substrate	**Number of companies [nr]**
Paper aste and cardboard	5
Wood waste	34
Garden waste	1
Spent coffee grounds	5

Keep in mind that 1 company is in both paper waste flow and garden waste and therefore the total amount of companies assessed is 44.

The data selection of the coffee house field study was conducted to map out the available SCG and the chosen locations were planned to get quantitative data from the inner part of the municipality as well as the outer part of the municipality (Fig 6).

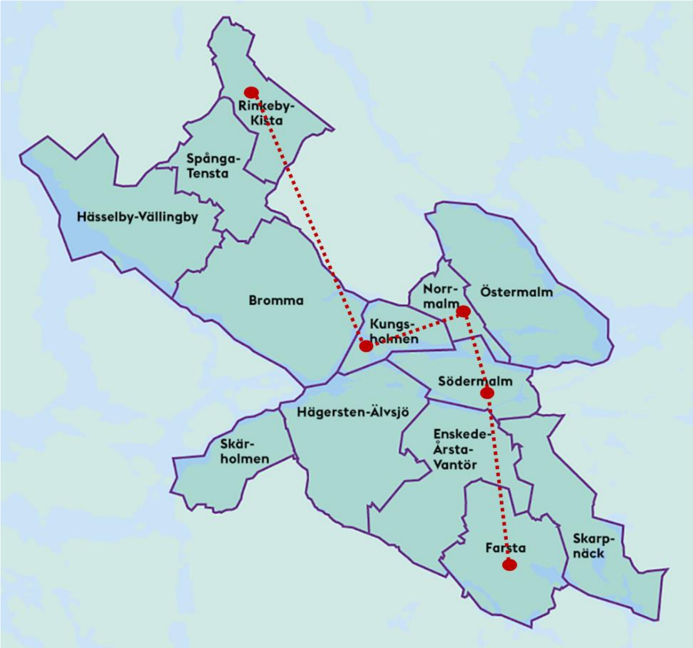

Figure 6 Route taken during the field study

3.5 Ethical Considerations

The study was conducted strictly to adhere to the ethical guidelines and principles to follow ethical guidelines and principles of the participants of the study. This is by safeguarding the privacy and confidentiality of the parties involved unless they explicitly did not mention it being alright for the company or organization to be mentioned in the report. In order to address concerns expressed by the companies involved, their identities and representatives have been kept anonymous throughout the study. Prior to data collection, informed consent was diligently obtained from all participants, and any identifying information has been meticulously excluded from the presentation of the research findings. An exception is made due to SVOA explicitly expressing being alright with sharing the information, and the required data can also be found publicly in their reports.

3.6 Limitations

Although this is an attempt to map out the waste flows of wood residues, it is estimated to only be a fraction of the actual waste. Furthermore, the fraction of garden waste is limited to one company being SVOA, which has a service to collect garden waste in Stockholm Stad households. Consider only looking into the municipalities garden waste collected by SVOA, where a big fraction of private individuals burns wood waste on their property or drive it to recycling centers themselves. Additionally, garden waste can also be considered to be collected by arborists as they are not only working on larger trees.

Moreover, the wood waste located is from two different professions in Stockholm Stad, where only 50% of the contacted replied with a quantitative number. This means that the estimated number is 50% of the waste stream at maximum for these two professions specifically. The sawdust and wood waste generation are heavily estimated, where many of the companies do not measure their generation. Moreover, there are probably numerous operations generating wood waste; however, due to the time limitations of this project, this thesis has only estimated untreated wood waste generated from arborists and wood waste generated in Stockholm Stad.

Additionally, when comparing the substrate, this thesis has mainly used BE% of the waste fractions with 100% of the substrate, without other supplements, to see the initial potential of the waste. This means that with the right supplement, more mushrooms can be produced to increase the productivity of the cultivation. The exception is Spent coffee grounds (SCG) due to no mushroom being able to spawn on 100% SCG substrate.

4 Results

The purpose of this study was to assess the possibility of urban mushroom production employing urban-based materials produced in Stockholm as a growing medium. The aim was to assess both the quantity and the most suitable residual waste to cultivate mushrooms. In the following section the result will be presented, and the aim and objectives will be answered.

4.1 Possible substrates

Oyster mushrooms are established to be a fungus with high productivity rates on numerous varieties of substrates, whereas some do not require any supplementations. Consequently, it is possible to cultivate oyster mushrooms on practically any agricultural residual waste regardless of supplements (Hikichi et al., 2017). There are multiple substrate possibilities, where there are various studies investigating substrate alternatives (ibid.). To see all the investigated substrates this thesis has investigated, see Appendix 2-7. This thesis has explicitly focused on the following five substrates: paper, cardboard, wood waste, garden waste, and SCG. The potential available waste residue for oyster mushroom production has been assessed (Table 6).

Table 6. Available residual waste streams in Stockholm Stad

Substrate type	Estimated substrate amount [kg/year]	BE%	Potential total weight of fresh mushrooms [kg/year]
Paper	15 805 567	112.4	17 765 457
Cardboard	20 560 580	117.5	24 158 681
Wood waste	64 166 500	64.7	41 509 308
Garden waste	3 939 664	95.3	3 754 499
SCG	152 121	18.6	2 830

The available residual streams and the potential amount of oyster mushroom produced calculated with equation (3). Note that the BE% of the substrate SCG only contains 10% SCG due to the BE% being very low or non-existent if the percentage was higher, see Appendix 2. The rest of the substrate BE% contains 100% of each substrate, excluding the pH treatment of limestone.

4.1.1 Wood Waste

Sawdust is a common lignocellulose that can be used as a growing medium for oyster mushrooms. The cultivation of mushrooms with sawdust from different types of woods as a substrate has been found to give high yields for Pleurotus ostreatus and is a medium widely used on a commercial scale. In general, different types of sawdust from softwoods are preferable to hardwood. Furthermore, it's common to mix sawdust with different types of substrates, such as wheat bran and other types of straw (Carrasco-Cabrera et al., 2019; A. Alsanad et al., 2021; Freitas et al., 2018; Gąsecka et al., 2020). In 2004, a study conducted by Shah et al. (2004) showed that sawdust alone as a substrate had a biological efficiency of 64.69 %. For more information regarding the method and prior study on oyster mushroom production on wood waste, see Appendix 3.

Wood waste generated by arborists and wood workers in Stockholm Stad was estimated to be around 64 166 500 tones as a minimum stream. See more about the data collection regarding wood waste in Appendix 8. Most of the wood is sent to different types of treatment depending on the organization cutting the wood; some sell their wood to energy recovery facilities, paper manufacturers, and sometimes it ends up in recycling centers.

Wood waste in different forms is generated in connection to work activities from arborists and wood workers; the treatment often includes the wood being brought to a facility where it is sorted and recycled by crushing it into wood chips. In accordance with space, some arborists attempt to dry the wood waste as thoroughly as possible. The main reason for this is due to one of the sources stating that the income of the solid wood to energy recovery facility was dependent on the energy that could be recovered from the waste. The income of wood waste was 240 SEK + moms/MW.

In the instances where the wood is sold to energy recovery facilities, the payment in some situations depends on the amount of energy it can source from the material. Therefore, green material such as leaves is not attractive to these companies, as it does not burn well; however, green materials have been shown to be a viable substrate for oyster Mushroom production (see Appendix 2).

4.1.2 Garden waste

Garden waste refers to organic materials generated from the maintenance and care of a garden or yard. It typically includes various types of plant material that are discarded or removed during routine gardening activities, such as pruning, trimming, mowing, weeding, and raking. Garden waste can come from various plant sources, including grass, leaves, branches, flowers, weeds, vines, and other plant debris (Law Insider, n.d.). According to Mandeel et al., the BE% of plant fibers is 95.3 % and leaves alone 21.5 %. See Appendix 6 to read more about the experiment on plant fibers (Mandeel et al., 2005).

The garden waste is a fraction collected by SVOA from both private households and the two recycling centers in Stockholm Stad, Vantörs and Östbergas recycling centers. Approximately 3 939 664 kg of garden waste is collected annually (see Table 6). The collected municipal garden waste in Stockholm Stad is used to produce biochar for cultivation and is used in plant beds, trees, and other plants. The biochar is used as a soil improvement medium to absorb and withhold water and nutrients for longer due to its porosity. Moreover, the biochar also acts as a Carbon sink (Stockholm Stad, 2022b).

4.1.3 Spent Coffee Grounds

SCG is produced in many ways throughout the production and consumption chain, for example, when coffee is getting brewed; moreover, 2 kg of spent coffee grounds are generated when producing 1 kilogram of instant coffee (Karlsson 2015). Approximately 50% of the coffee produced is consumed to make instant coffee. For every ton of unroasted coffee beans, 650 kg of spent coffee grounds are produced (ibid.).

Cultivating mushrooms from spent coffee grounds (SGCs) has been considered for numerous Pleurotus species using the waste stream generated by coffee producers. SCGs are constituted of high fractions of hemicellulose (39.1%), lignin (23%), and cellulose (12.4%) which can be a potential additional or alternative growing medium for the cultivation of the Pleurotus genus (Chai et al., 2021). The substrate has already been revealed to be a successful substrate of various oyster mushrooms (Carrasco-Cabrera et al., 2019; A. Alsanad et al., 2021; Freitas et al., 2018; Gąsecka et al., 2020). The biological efficiency was measured to be 13.8 in an experiment conducted by Chai et al., 2021 (See Appendix 2).

The biological efficiency of SCG is relatively low in comparison to the other substrates, with a BE% of 18.6 % (Table 6); this can be due to the toxicity levels of the substrate. Spent coffee grounds contain numerous chemical composites such as tannins, caffeine, and phenols that can be toxic to plants at great concentrations (Cervera-Mata et al., 2017). These compounds can adversely affect seed germination, root development, and overall growth of the plants (ibid.). Moreover, the pH levels of SCG are more acidic, ranging from pH 4.7 – 5.96 (Chrysargyris et al., 2020). Moreover, to read more about prior studies on SCG and the method used, see Appendix 4.

Spent coffee grounds were estimated from five of the biggest cafes in Stockholm Stad, which is called Chain 1 - 5 (see Appendix 9). Though many coffee shops throw their waste into the food waste fraction, there is still a big part of the organizations that does not separate it yet. The five coffee shops generated approximately 152 121 SCG yearly (Table 6). However, by 2024 all food waste is to be separated due to the Waste Ordinance Avfallsförordningen (Riksförvaltningen, 2020; Stockholm Stad, 2023). Spent coffee grounds are separated and treated as food waste today and are sent to biogas plants for fuel production. Additionally, 3 out of the 15 samples of the data collection did not sort their SCG to food waste, meaning it is sent to be combusted for energy recovery. The reason to not separate SCG as food waste being the infrastructure of the waste collection system yet was developed to be able to collect food waste.

4.1.4 Paper and cardboard

Furthermore, cultivation of oyster mushrooms (Pleurotus spp.) with paper and cardboard waste as substrates have displayed to be successful as well. In an experiment conducted by Mandeel et al. (2004) three variations of oyster mushrooms were cultivated on paper, plant fibers, sawdust, and cardboard waste. The BE% was recorded to be 117.5% with cardboard waste as a substrate and 112.4% for paper waste (Mandeel et al., 2005). Straw, sawdust, rice straw, spent beer grains, sugar bagasse, spent mushroom substrate and other lignocellulosic materials are substrates that oyster mushrooms can be cultivated on (ibid.).

Cardboard waste was the most efficient substrate to produce oyster mushrooms with an BE% of 117.5 followed by paper waste having a BE% of 112,4 (Table 6). Garden waste is third on the efficiency scale of the possible substrates being on an efficiency scale of 95%, followed by wood waste at 64%, and lastly SCG at 18.6%. See Appendix 6 for more information regarding prior studies conducted and methods for oyster mushroom production on paper and cardboard waste.

Paper and cardboard are treated in different ways depending on the facilities depending on the material type. Most of the collected paper and cardboard are recycled to become new products and packages. The material recycling is high for paper-based products (Avfall Sverige, 2022). The paper fiber can be recycled over 25 times; however, to keep it at a good quality and to manipulate the product's characteristics, the supply of new fibers is needed periodically. Sweden recycles approximately 78% of the packages and 90% of the other paper types. When the paper fiber has reached its limit on the recyclability, it can be used for biogas production (Alexandersson, 2022).

4.1.5 Limestone production

The manufacturing of limestone is dependent on the geology. The mining site location is dependent on the rock quality and structure, where the site needs to be economically feasible for operations (Svenska Kalkföreningen, 2022). There are no operations located in Stockholm, and the limestone is mainly sourced in Gotland and is then transported to a lime burning process (Buttle Kalk AB, n.d.) which occurs in Luleå, Boda, Sandarne, Köping, Rättvik, Storugns, and Oxelösund. Grinding and sieving limestone is occurring in nine locations, including Landskrona, Uddagården, Ignaberga, Glanshammar, Köping, Sala, Björka, Gåsgruvan och Kullsberg (Svenska Kalkföreningen, 2022).

4.2 Mushroom cultivation waste

Spent Mushroom Substrate (SMS) is profusely generated in mushroom farms after the harvesting period when cultivating mushrooms. According to Mohd Hanafi et al. (2018), approximately 5 kg of SMS is created for each kg of freshly produced mushrooms. SMS is one of the biggest challenges due to the amount of waste (Mohd Hanafi et al., 2018). The possible SMS generation regarding the amount consumed oyster mushrooms in Stockholm Stad would therefore be estimated to be 98 470 kg.

The waste can be used for multiple purposes, such as production of bioenergy, bioremediation, treating polluted wastewater (Mohd Hanafi et al., 2018), fertilizer, soil amendment, and a supplement for animal feedstock (Leong et al., 2022: Mohd Hanafi et al., 2018). Moreover, the substrate can be recycled to be used for the cultivation of new mushrooms as well (Leong et al., 2022).

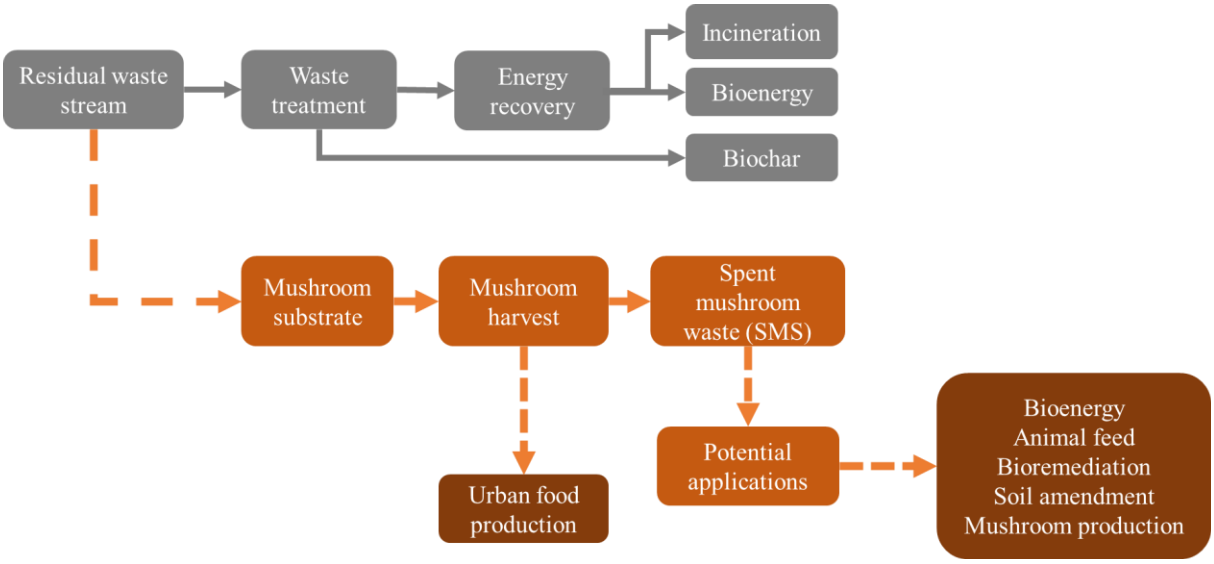

Figure 7. Flowchart of possible treatment routes (orange) compared to the current (gray)

Table 7. Quantity of required waste in relation to the available waste in Stockholm Stad calculated with the consumption of Oyster Mushroom consumption in the municipality. Calculations for this table are using equation 1, a more detailed presentation of the calculation is presented in Appendix 10.

Required substate	Required dry weight substrate [kg/year]	Needed fraction of the available waste [%]
Paper	17 521	0.099
Cardboard	16 760	0.069
Wood waste	30 443	0.073
Garden waste	20 665	0.550
SCG	10 582	37.38

5 Analysis

The results display a possibility to increase the UA within the city, where food production can increase, and the residual waste from oyster mushroom cultivation can be used additionally, increasing the circularity and industrial symbiosis within the city. This thesis investigated multiple substrate options and narrowed it down to the five most suitable substrates with the availability within the city and BE% as an indicator of suitability.

Moreover, paper, cardboard, and garden waste are waste residuals that are used to produce more paper products and biochar (for garden waste); these three waste streams should continue to be used for that purpose. However, eventually when the paper fiber strands are too small to produce more, it could be used as a substrate for oyster mushroom production. However, the collection the results show a possibility to increase the UA within the city by increasing food production and use of the residual waste from oyster mushroom cultivation thanks to circularity and industrial symbiosis within the city. This thesis investigated multiple substrate options and narrowed it down to the five most suitable substrates with the availability within the city and BE% as an indicator of suitability.

Moreover, paper, cardboard, and garden waste are waste residuals used to produce more paper products and biochar (for garden waste); these three waste streams should continue to be used for that purpose. Eventually, when the paper fiber strands are too small to produce more, they could be used as a substrate for oyster mushroom production. However, the collection processes for each substrate must be further investigated where the five waste streams would be collected separately; this would, for example, be to see the possibilities and challenges of collecting SCG separately, as most of it today is mainly thrown in together with food waste. Additionally, the cost and convenience related to managing these waste fractions can be of importance further to assess the practical possibility of the production process.

To assess the functionality of local oyster mushroom production on a larger scale, it is important to investigate the space requirements in Stockholm Stad. Mushroom cultivation requires somewhat small space; however, to produce on a larger scale to become self-sufficient within the city, an additional amount of space is needed. Moreover, the startup of an oyster mushroom farm on a larger scale requires a capital investment and is labor intensive as it needs a good amount of monitoring. From a social aspect, mushroom cultivation locally in Stockholm Stad would potentially lead to additional work opportunities, income, and overall welfare.

Looking at the current consumption within the municipality and oyster mushroom availability in most supermarkets, there is sufficient demand. Further analyzing the functionality of SCG, wood waste and paper (that no longer can be recycled) are waste streams with the potential to be used as substrates for mushroom cultivation. This is mainly due to garden waste being used to produce biochar. Moreover, the fraction of the residual waste stream needed to become sufficient in Stockholm Stad is small; most of the waste needed is less than a percentage of the available waste (Table 7). Moreover, an interesting point of view is that SCG mostly already contains water and might, therefore, not need additional water for the substrate's preparation.

Sensitivity of the results itself is the fact that the selection of the data collection, where the waste fraction from paper and cardboard from the three collection companies, might be unrestricted to the exact geographical boundaries of the study. Some collection companies had issues estimating Stockholm Stad alone as they operate in the entire county. When looking into companies collecting waste, there were five main companies, where three answered. That means that 40% of the data might be missing for the entire paper and cardboard picture.

Moreover, wood waste that was mapped out in this study is estimated to be approximately 50% of the total waste generation, as 17 out of 34 arborists and wood working companies were able to provide with data. Moreover, the garden waste fraction is garden waste fraction was only mapped out with one collection company, and it is expected that there is much more. Additionally, garden waste is also burned by private homeowners on their property (Stockholm Stad, 2022b), and it is assumed that a fraction of the garden waste is also collected by arborists, even though arborists mainly work with threes. The absence of data results in an uncertainty regarding the mapped flows, indicating that insufficient data leads to a lack of certainty.

Since the waste located within Stockholm Stad has the potential to be used as substrates to produce more mushrooms than needed, considering the assumptions that only 60% of the cardboard and paper waste were located (due to 4 out of 5 companies replying) and 50% of wood waste, where the potential for these waste flow residuals is likely (60% respective 50%) greater than the initial estimation in this thesis. Moreover, the sensitivity of this analysis is to be reliant on the BE% of prior studies, which can vary depending on the preparation of the substrates and the condition of the growing environment. However, there is a risk that there has been an overestimation from the interviews as well.

The kilo price of oyster mushrooms is estimated to be 245 SEK/kg, meaning that a production of 19 694 kg yearly would be approximately 128 333 000 SEK revenue annually if the goal is to produce the amount of Stockholm Stad estimated consumption. However, it is important to note that this is the price sold in store, which means that the cost to sell the mushroom is lower than 245 SEK/kg on average. The prices in store ranged from 197 – 326 SEK/kg. However, there is a need to map out the total costs of oyster mushroom cultivation in Sweden to further consider the profit of the cultivation.

5 Discussion

5.1 Possible growing media available in Stockholm Stad

When examining the availability of waste resources, it becomes apparent that there is a substantial amount of residual waste stream that can be effectively utilized to produce oyster mushroom substrate. Additionally, there is a diverse range of residual waste streams that are not only ample in quantity but are also perfectly suitable for oyster mushroom cultivation.

Using residual waste as substrates have been shown to be a viable way to produce oyster mushrooms; hence, five possible waste fractions available in Stockholm Stad have been investigated. By employing residual waste, urban agriculture in Stockholm could be expanded, boosting food production. As of today, Stockholm Stad consists of 0.7% of agricultural land (SCB, 2022). In addition, growing oyster mushrooms locally within the city limits could increase their shelf life by reducing transportation distances which also cause damage to the mushroom and food loss.

The author of this thesis drew upon the findings of Dorr et al. (2021), who conducted a life cycle assessment study on a circular mushroom farm. Both sources highlight the potential of circular economy principles to mitigate environmental impacts in modern food systems, particularly through closing material loops and maximizing resource utilization. The use of organic waste as substrate in mushroom farming is emphasized to generate valuable outputs such as food and soil amendment.

A noteworthy result from Dorr et al. (2021) is the similarity in climate change impacts between the conventional linear system and the circular system. Surprisingly, despite the farm's local nature, 31% of the climate change impacts were attributed to transportation. However, the implementation of circularity principles helped optimize environmental performance by minimizing material impacts through upcycling (Dorr et al., 2021).

In comparison, this thesis highlights the existence of multiple viable growing media that can promote circularity and generate valuable outputs. The results align with those of Dorr et al. (2021) in terms of the benefits and potential of circular food production systems.

Moreover, all five substrates investigated have been shown to be feasible for oyster mushroom production. As for today, garden waste has already been utilized to produce biochar for plant beds within the municipality because of the risk of containing invasive species that can harm the natural flora in Stockholm Stad (see section 2.3 Legislations). Due to this, garden waste may not be the most suitable one, although, the BE% of garden waste is the third most efficient substrate for producing oyster mushrooms (Table 6).

Additionally, the paper and cardboard fraction waste is currently recycled to produce new paper, an established process. However, when the paper fibers eventually become too short to be recycled into new paper, there is a possibility to use those fibers as a substrate to produce mushrooms. Today the non-recyclable paper fibers are sent to the combustion facilities for energy recycling. Additionally, previous studies on BE% of the various substrates, paper, and

cardboard showed the highest BE% of the five substrates investigated, with the BE% being 117.5 for cardboard and 112.4 for paper (Table 6).
Furthermore, the wood waste is mainly sent to sawmills to produce sawdust, where most of the wood waste is sold off for energy recycling in different combustion facilities or dumped in different dumpsites and recycling centers to be treated by an external company. Wood waste was ranked fourth (4 out of 5) when looking at BE% with 95.3% efficiency. Notably, the biological efficiency (BE%) percentage may vary based on the type of supplements added to the substrates. The BE% values mentioned above are calculated based on 100% of the substrates used. Additionally, to see variations of different supplements added, see Appendix 2 below.

Spent coffee grounds have the lowest BE% of the five substrates at 10%; this can be due to the chemical compounds that can be toxic to plants at higher concentrations. Moreover, the coffee grounds' pH ranges between pH 4.7 – 6.0, indicating the importance of including calcium carbonate to reach the optimal pH range of 6.7 – 7.8 required for oyster mushrooms. Additionally, 3 out of 15 coffee houses sampled did not sort their food as food waste, meaning a high percentage of SCG is being combusted for energy recovery.

The results in this study have mainly investigated the BE% of each substrate without any supplements (excluding SCG that could not generate any oyster mushroom without supplementation), when adding supplementation which can increase the BE%. A good example is the study by Ashrafi (2014) that investigate multiple oyster mushroom substrates where SMS had a BE% of 78 % and with the supplementation of sawdust (SD) and wheat bran (WB) increased to 84-108 % (Appendix 2) depending on the ratio between the two substrates. It might therefore be interesting to investigate using a combination of SMS, SD and WB (Ashrafi, 2014). Looking at appendix 2, the fraction of each component of the growing media is important when optimizing the substrate BE%. Additionally, in their study, Yoshida et al. (1993) found that the highest yield was obtained when the substrate was mixed with wheat bran, rice bran, and bean curd refuse at a 45% supplement level (Bhattacharjya, 2023; Ashrafi, 2014).

5.2 Available waste fractions and possibilities

Producing food with the help of residual waste generated in the municipality could increase the value of the municipality's resources and produce foodstuff consumable by the residents in Stockholm Stad (Fig 7). The estimated availability of paper waste is 15 805 567 kg, 20 560 580 kg (cardboard), 64 166 500 kg wood waste, 3 939 664 kg garden waste, and 152 121 kg (SCG). These waste fractions can generate oyster mushrooms well above the needed production for Stockholm Stads consumption (Table 6). However, it is important to note that there is a limitation to the waste fraction due to data collection limitations. Both SCG, wood waste, and paper waste (to some extent) are used for energy recovery and to use the flows to produce foodstuff before

Waste is treated in multiple ways, such as reusing, material recycling, energy recovery in retting and combustion, and landfilling. About 17 million tons of waste were recycled in other ways than material recycling in 2020. Approximately 8.9 million tons of waste were used for energy recovery in 2020 (Naturvårdsverket, 2020a). Moreover, 50% of the household waste is combusted for energy production. However, according to the waste hierarchy, energy recovery is a lower priority than prevention, minimization, reuse, and recycling. Using more residual waste streams for food production

It is estimated that 19 694 kg of oyster mushrooms are consumed per person every year, meaning that Stockholm Stad can technically become self-sufficient in oyster mushroom cultivation within the municipality. However, this claim does not hold when looking at cultivation possibilities in Stockholm. Today the urban city is only self-sufficient in three foodstuffs: carrots, sugar, and grains; still far from the goal of becoming more self-sustaining regarding food (Sveriges Riksdag, 2020).

Moreover, for each kg of freshly produced mushrooms, 5 kg of SMS are produced, which can be used in various applications such as bioremediation, soil amendment, more mushroom production, and bioenergy (see section 4.3 and Fig. 7). Looking at Stockholm municipalities consumption, approximately 98 470 kg of SMS would be produced in connection to the mushroom cultivation. Today's food system needs to be resilient and adaptable to climate change and population growth; in case of stressors, availability, quality, stability, and access are important factors of food security (Béné, 2020). Moreover, according to United Nations data, agriculture production needs to increase by 75% by 2050 due to population growth (Prosekov & Ivanova, 2018). Moreover, the conversion from waste into a highly nutritious, healthy, and protein-rich food makes mushrooms a good food source. Also, they can be grown at a fast pace and on basically anything due to being a saprophyte (Thakur, 2020; Bernart, 2004).

In a greater context, oyster mushroom is a foodstuff that can be produced locally and is a good source of food high with nutrients and could contribute to combat hunger since it grows on waste and can generate many mushrooms in a short period of time. Oyster mushrooms contain a protein source of 24%/100 g and a calorific value of 280 kcal/100 g (Thi Hoa et al., 2015). Moreover, producing oyster mushrooms more locally could decrease international transport between countries. If Stockholm Stad would produce 19 694 tons of oyster mushrooms a year, that would generate 55 236 746 calories and approximately 24% of the weight being protein which is approximately 4 846 g. As mentioned in section 1.1 problem statement, Pleurotus Ostreatus has a relatively short shelf life due to its lack of a protective cuticle, high moisture content, and respiratory rate. The mushrooms are sensitive and prone to mechanical injuries, enzymatic browning, microbial attack, weight loss, and quality loss during post-harvest processes like transportation (Castellanos-Reyes et al., 2021). Producing oyster mushrooms promote urban self-sufficiency within food production, decreases food loss during the production chain, and adds value to the waste generated in Stockholm Stad.

5.3 Limitations

The data collection does contain rough estimations collected from shorter semi-structured interviews where many wood worker and arborist companies were not aware of their exact number of waste generation. Furthermore, the data collected can be limited to different potential biases of answers being inaccurate due to recall biases or the phenomenon of answering the most desirable answers that are the most sociable and acceptable.

The limitation of the conducted field study concerns the mapping of SCG generation by the sample size, where the coffee generation has been estimated for only 5 coffee chains. It is important to note that coffee is consumed and sold in other places such as convenience stores, offices, and homes. This data only gives a rough estimation of these 5 chains within Stockholm Stad. Furthermore, visiting more coffee shops in the designated area would have enriched the data set, making the results more reliable. The number of coffee shops was higher in the inner part of Stockholm Stad; hence, the results can be considered a map of SCG mainly in the inner city of Stockholm Stad (Kungsholmen, Norrmalm, and Södermalm).

The limitations discussed above can impact the study's results in multiple ways. First, they can impact the study's internal validity, which refers to the extent to which the study accurately identifies causal relationships between variables. Moreover, the limitations in sample size, selection, and confounding variables can impact the internal validity of the study findings. Second, limitations can also impact the study's external validity, which refers to the generalizability of the findings to other populations or settings. In particular, this study is limited to Stockholm Stad, and most of the findings are mainly applicable to the set geographical boundary of this study. It is important to note that the waste fraction mapped out in this study is only a fraction of the available flow in Stockholm Stad.

6 Conclusions and Future work

6.1 Conclusions

This thesis emphasizes the prospect of effectively utilizing the residual waste stream beyond energy recovery, wherein the enterprises of Stockholm Stad have the opportunity to establish a viable food resource. Utilizing residual waste as a substrate for oyster mushroom cultivation offers a viable solution for increasing urban agriculture in Stockholm. This could boost local food production and promote circularity and industrial symbiosis within the city. The study investigated multiple growing media and set the focusing on the five most suitable possible waste fractions: paper, cardboard, SCG, garden waste, and wood waste, where garden waste is already being utilized for biochar production. Therefore, the most viable waste residues to be used would be SCG, wood waste, paper, and cardboard (that can no longer be recycled).

The estimated availability of each residual waste stream has been mapped out with paper waste being 15 805 567 kg, 20 560 580 kg (cardboard), 64 166 500 kg wood waste, 3 939 664.2 kg garden waste, and 152 121 kg (SCG). The BE% ranges from 18.61% for SCG, wood waste to 64.69%, garden waste to 95.3%, paper to 112.4%, and cardboard with a BE% of 117.5%. Moreover, the BE% will vary depending on the substrate's preparation and the mushrooms' growing conditions. Additionally, the mapped-out flows are 50% of the wood waste respectively 60% of the paper and cardboard waste. The oyster mushroom's estimated kilo price is 245 SEK/kg, with a potential yearly value of the annual value of the oyster mushroom estimated to be 128 333 000 SEK for 19 694 kg of mushrooms. However, the profitability of the oyster mushroom cultivation depends on the cost of the production associated with it, which has not been further assessed in this thesis.

The local production of oyster mushrooms could increase the shelf life of mushrooms by reducing transportation distances and associated food loss. The cultivation of oyster mushrooms locally could also potentially increase the overall welfare. Local production could be functional with sufficient demand for oyster mushrooms in the municipality. While mushroom cultivation requires relatively small space, scaling up production to achieve self-sufficiency within the city would require additional space, capital investment, and labor-intensive monitoring. Therefore, assessing the space requirements and startup costs is crucial in evaluating the feasibility of local oyster mushroom production on a larger scale.
In a larger context, oyster mushrooms are a nutritious food that can be cultivated on residual waste streams. Local production of oyster mushrooms can decrease the transports related to the importation of mushrooms and can also become a food source to combat hunger as it can give a yield every 3 weeks and contains good nutrients and proteins. There is a good potential for the waste residuals for an additional urban food production, whereas the by-product in the form of SMS can be used for various applications such as bioenergy, soil improvement, and bioremediation.

6.2 Limitations

The main limitations of this study are the time limitations that set the restrictions for the data collection and sample sizes. Moreover, this study is limited to oyster mushrooms, specifically Pleurotus Ostreatus, with Stockholm Stad as its geographical boundary. There are multiple waste residues where oyster mushrooms can grow; however, this study has focused on following five substrates: paper, cardboard, wood waste, garden waste, and SCG. Moreover, the study's data size is limiting the study's second objective, mapping out the current available residual waste streams suitable for substrates for oyster mushroom cultivation.

6.3 Future work

Building on the perceptions gained and acknowledging the limitations of this study, several recommendations for future research are proposed. These recommendations aim to further advance the field of study and address gaps in knowledge that were identified during this thesis.

- Conducting a larger-scale study on available resources in Stockholm Stad, including more comprehensive data to get a more representative number of the actual waste flows in Stockholm Stad.
- Conducting a study to investigate and compare the waste fractions conventional treatment process cost and the mushroom production cost.
- Mapping location possibilities for mushroom cultivation in Stockholm Stad.

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Appendix

Appendix 1: Calculation of BE%

$$BE\% = \frac{Total\ weight\ of\ fresh\ mushrooms}{Dry\ weight\ of\ substrate} \times 100$$

Assumptions: The source mentions a 4 kg substrate, with 70% moisture content (Oh et al., 2004). The author will thereby assume the substrate is wet. To remove the moisture the author will therefore remove the moisture from the substrate by multiplying the substrate with 0,3.

1: Weight of fresh mushroom for Cotton = 663 g

2: Weight of fresh mushroom for Cotton + non-fermented poplar + sawdust = 708 g

3: Weight of fresh mushroom for Cotton + fermented poplar + sawdust = 742 g

4: Weight of fresh mushroom for Cotton + fermented winter mushrooms = 702 g

Weight of dry substance = 4000

1:

$$BE\% = \frac{663}{4000 \times 0{,}3} \times 100 = 55{,}25\%$$

2:

$$BE\% = \frac{708}{4000 \times 0{,}3} \times 100 = 59\%$$

3:

$$BE\% = \frac{742}{4000 \times 0{,}3} \times 100 = 61{,}86\%$$

4:

$$BE\% = \frac{702}{4000 \times 0{,}3} \times 100 = 58{,}5\%$$

Multiplying with 0.3 to remove the moisture of the substrate. This assumption was made only for Oh et al., 2004, due to it being the only report not presenting it.

Appendix 2: All the investigated substrates

Substrate mix	Mushroom Species	Incubation time (weeks)	Flushes	Yield/1000g	BE (%)	Source
T1: SD+WS (50:50)	Pleurotus ostreatus	3.8	3	435.90	43,59	(Shah et al., 2004)
T2: SD+WS (75:25)	Pleurotus ostreatus	5	3	620.90	62,09	(Shah et al., 2004)
T3: SD	Pleurotus ostreatus	4	3	646.90	64,69	(Shah et al., 2004)
T4: WS+L (50:50)	Pleurotus ostreatus	4.81	3	447.20	57,85	(Shah et al., 2004)
T5: WS	Pleurotus ostreatus	3.8	3	578,5333333	44,72	(Shah et al., 2004)
T6: L	Pleurotus ostreatus	4.8	3	210,6	21,05	(Shah et al., 2004)
SMS	Pleurotus ostreatus	≈3 (20–25 days)	4-5	282	78,4	(Ashrafi, 2014)
SMS+SD (70:30)	Pleurotus ostreatus	≈3 (20–25 days)	4-5	302	84,2	(Ashrafi, 2014)
SMS+SD (60:40)	Pleurotus ostreatus	≈3 (20–25 days)	4-5	308	85,5	(Ashrafi, 2014)

SMS+SD (50:50)	Pleurotus ostreatus	≈3 (20–25 days)	4-5	372	103,6	(Ashrafi, 2014)
SMS+SD (40:60)	Pleurotus ostreatus	≈3 (20–25 days)	4-5	378	105,1	(Ashrafi, 2014)
SMS+SD (20:80)	Pleurotus ostreatus	≈3 (20–25 days)	4-5	334	92,8	(Ashrafi, 2014)
SD+WB (65:35)	Pleurotus ostreatus	≈3 (20–25 days)	4-5	340	94,8	(Ashrafi, 2014)
SMS+SD+WB (20:60:20)	Pleurotus ostreatus	≈3 (20–25 days)	4-5	386	107,5	(Ashrafi, 2014)
SMS+SD+WB (30:50:20)	Pleurotus ostreatus	≈3 (20–25 days)	4-5	356	99	(Ashrafi, 2014)
SMS+SD+WB (40:40:20)	Pleurotus ostreatus	≈3 (20–25 days)	4-5	352	98,1	(Ashrafi, 2014)
SMS+SD+WB (50:30:20)	Pleurotus ostreatus	≈3 (20–25 days)	4-5	324	90,2	(Ashrafi, 2014)
SMS+SD+WB (60:20:20)	Pleurotus ostreatus	≈3 (20–25 days)	4-5	308	85,3	(Ashrafi, 2014)
C	Oyster mushroom, not species specific	-	-	165,75	55,25	(Oh et al., 2004)
C+NFP SD (84:57)	Oyster mushroom, not species specific	-	-	177	59	(Oh et al., 2004)
C+FP SD	Oyster mushroom, not species	-	-	185,5	61,83	(Oh et al., 2004)

	specific					
C+FWM	Oyster mushroom, not species specific	-	-	175,5	58,5	(Oh et al., 2004)
Paper	Oyster mushroom, not species specific	2	5	1148,367953	112,4±8,680	(Mandeel et al., 2005)
Cardboard	Oyster mushroom, not species specific	2	6	1172,106825	117,5±7,485	(Mandeel et al., 2005)
Plant Fiber	Oyster mushroom, not species specific	3	4	952,5222552	95,3±8,365	(Mandeel et al., 2005)
SD	Oyster mushroom, not species specific	4	2	298,8130564	59,6±10,930	(Mandeel et al., 2005)
SD+RB+CAOC3 (89:10:1)	P. pulmonarius	3,028571429	-	159,3	15,93± 1,25	(Chai et al.,, 2021)
SD+SCG+RB+CAOC3 (79:10:10:1)	P. pulmonarius	3,4	-	186,1	18,61± 1,17	(Chai et al.,, 2021)
SD+SCG+RB+CAOC3 (69:20:10:1)	P. pulmonarius	5,114285714	-	110,5	11,05± 2,11	(Chai et al.,, 2021)

SD+SCG+RB+CAOC3 (59:30:10:1)	P. pulmonarius	-	-	-	-	(Chai et al.,, 2021)
SD+SCG+RB+CAOC3 (49:40:10:1)	P. pulmonarius	-	-	-	-	(Chai et al.,, 2021)
SCG+RB+CAOC3 (89:10:1)	P. pulmonarius	-	-	-	-	(Chai et al.,, 2021)
SD+RB+CAOC3 (89:10:1)	P. floridanus	3,114285714	-	180,5	18,05± 1,01	(Chai et al.,, 2021)
SD+SCG+RB+CAOC3 (79:10:10:1)	P. floridanus	3,514285714	-	137,9	13,79± 1,31	(Chai et al.,, 2021)
SD+SCG+RB+CAOC3 (69:20:10:1)	P. floridanus	4,028571429	-	88,9	8,89± 0,98	(Chai et al.,, 2021)
SD+SCG+RB+CAOC3 (59:30:10:1)	P. floridanus	-	-	-	-	(Chai et al.,, 2021)
SD+SCG+RB+CAOC3 (49:40:10:1)	P. floridanus	-	-	-	-	(Chai et al.,, 2021)

SCG+RB+ CAOC3 (89:10:1)	P. floridanus	-	-	-	-	(Chai et al.,, 2021)

SD=Sawdust, WS=Wheat Straw, L=Leaves, SCG=Spent Coffee Grounds, SMS=Spent Mushroom Substrate, WB=Wheat Bran, C = Cotton, NFP SD=Non-fermented Poplar Sawdust, FP SD = Fermented Poplar Sawdust, FWM = Fermented by-product of winter mushrooms, RB = Rice Bran, CACO3 = Calcium Carbonate. Although all of the substrate mixes are treated with some kind of calcium to regulate the substrate mix pH.

Appendix 3: Information regarding prior studies on Mushroom cultivation on wood waste

Sawdust is a common ligno cellulose that can be used as a growing medium for oyster mushrooms. The cultivation of mushrooms with sawdust from different types of woods as a substrate has been found to give high yields for Pleurotus Ostreatus and is a medium widely used on a commercial scale. In general different types of sawdust from softwoods are preferable to hardwood. Furthermore, it's common to mix sawdust with different types of substrates such as wheat bran and different types of straw (INSERT massa källor).

There are also varieties of substrates that are mixed with sawdust such as wheat straw and leaves. In a study written by Shah et al., (2004) they tried five different varieties of sawdust, wheat straw, and leaves combinations (Shah et al., 2004).

SD + WS (50:50), SD+L (75:25)

SD (100), WS (100)

WS+L (50:50), W (100)

(Shah et al., 2004)

The sawdust can be prepared in numerous ways, a common way is to dry the substance before it is mixed with chalk or limestone to then mix it in water to obtain the optimal moisture content of 65-75 %. Moreover, 5 % lime (Pathmashini et al., 2009; Shah et al., 2004) is mixed into the substrate in relation to the dry mass weight. The substrate was left to ferment for five days covered up by a polyethylene sheet before they were packed in bags of 1000 g each (Shah et al., 2004).

The packed bags were autoclaved (Shah et al., 2004), which is a machine that utilizes steam and pressure to eliminate bacteria, and microorganisms that can be harmful to the cultivation (STERIS, 2022). The treatment was under 15-20 lb pressure at the temperature of 121 °C. After the substrates cooled down, the inoculation was initiated (Shah et al., 2004). The substrates were cultivated at a temperature of 25 °C during the spawning and 17 °C during the fruiting phase, which was controlled by electric heaters. The humidity was controlled with water spraying twice a day while the ventilation was regulated by fans (ibid.).

The yield of the oyster mushrooms was highest for the 100 % sawdust substrate with a yield of 646.90 g of oyster mushrooms after 3 flushes (Shah et al., 2004). Moreover, the composition of sawdust and leaves yielded 620.90 g of oyster mushrooms (ibid.). The substrate mix composed of wheat straw and leaves produced 447.20 g of mushroom while sawdust and wheat straw produced 435.90 g (ibid.). The 100 % wheat straw produced 433.90 g, and the substrate producing the least amount of oyster mushroom was the 100% leaves with a yield of 210.60 g after 3 flushes which can be viewed in the table below (ibid.).

Table 9: Information regarding the wood waste

Substrate mix	**Mushroom Species**	**Incubation time (weeks)**	**flushes**	**Yield/1000g**	**BE (%)**	**Source**
T1: SD+WS (50:50)	Pleurotus ostreatus	3.8	3	435.90	43,59	(Shah et al., 2004)
T2: SD+WS (75:25)	Pleurotus ostreatus	5	3	620.90	62,09	(Shah et al., 2004)
T3: SD	Pleurotus ostreatus	4	3	646.90	64,69	(Shah et al., 2004)
T4: WS+L (50:50)	Pleurotus ostreatus	4.81	3	447.20	57,85	(Shah et al., 2004)
T5: WS	Pleurotus ostreatus	3.8	3	578,5333333	44,72	(Shah et al., 2004)
T6: L	Pleurotus ostreatu	4.8	3	210,6	21,05	(Shah et al., 2004)

	s					

BE = Biological efficiency, SD = Sawdust, WS= Wheat straw, L=Leaves,

Appendix 4: Information regarding prior studies on Mushroom cultivation on SCG

Coffee today is one of the most important products in the world market, second after oil-based products such as different types of fuels. In some nations, the export of coffee consists of 50 % of their income when it comes to exportation goods (ICO, 2015a). The biggest coffee exporters of coffee globally in 2014 were Brazil with 2720 tons, Vietnam with 1650 tons, and Colombia with 750 tons. The total production of coffee in 2014 was 8.5 million tons 2014 and the biggest importers were US and Europe (ICO, 2015c).

Spent coffee grounds are produced in many ways throughout the production and consumption chain, for example; when coffee is getting brewed, moreover 2 kilos of spent coffee grounds are generated when producing 1 kilogram of instant coffee. Approximately 50 % of the coffee produced is spent to produce instant coffee. For every ton of unroasted coffee beans, 650 kilos of spent coffee grounds are produced (Karlsson, 2015).

Cultivating mushrooms from spent coffee grounds (SGCs) has been considered for numerous Pleurotus species using the waste stream generated by coffee producers. SCGs are constituted of high fractions of hemicellulose (39.10%), lignin (23%), and cellulose (12.40%) which can be a potential additional or alternative growing medium for the cultivation of the Pleurotus genus (Chai et al., 2021). The substrate has already been revealed to be a successful substrate for some of the mushroom races such as P. ostreatus (Carrasco-Cabrera et al., 2019; A. Alsanad et al., 2021), P. citrinopiletaus (Freitas et al., 2018), P. eryngii (Gąsecka et al., 2020).

Table 10: Information regarding the SCG

Substrate mix	Mushroom Species	Incubation time (weeks)	flushes	Yield/1000g	BE (%)	Source
SD+RB+CAOC3 (89:10:1)	P. pulmonarius	3,028571429	-	159,3	15,93± 1,25	(Chai et al.,, 2021)

SD+SCG+RB+CAOC3 (79:10:10:1)	P. pulmonarius	3,4	-	186,1	18,61±1,17	(Chai et al.,, 2021)
SD+SCG+RB+CAOC3 (69:20:10:1)	P. pulmonarius	5,114285714	-	110,5	11,05±2,11	(Chai et al.,, 2021)
SD+SCG+RB+CAOC3 (59:30:10:1)	P. pulmonarius	-	-	-	-	(Chai et al.,, 2021)
SD+SCG+RB+CAOC3 (49:40:10:1)	P. pulmonarius	-	-	-	-	(Chai et al.,, 2021)
SCG+RB+CAOC3 (89:10:1)	P. pulmonarius	-	-	-	-	(Chai et al.,, 2021)
SD+RB+CAOC3 (89:10:1)	P. floridanus	3,114285714	-	180,5	18,05±1,01	(Chai et al.,, 2021)
SD+SCG+RB+CAOC3 (79:10:10:1)	P. floridanus	3,514285714	-	137,9	13,79±1,31	(Chai et al.,, 2021)
SD+SCG+RB+CAOC3 (69:20:10:1)	P. floridanus	4,028571429	-	88,9	8,89±0,98	(Chai et al.,, 2021)

SD+SCG+RB+CAOC3 (59:30:10:1)	P. floridanus	-	-	-	-	(Chai et al.,, 2021)
SD+SCG+RB+CAOC3 (49:40:10:1)	P. floridanus	-	-	-	-	(Chai et al.,, 2021)
SCG+RB+CAOC3 (89:10:1)	P. floridanus	-	-	-	-	(Chai et al.,, 2021)

Appendix 5: Information regarding a prior study on Mushroom cultivation on SMS

The benefits and increased popularity of mushrooms leaves residuals in the form of spent mushroom substrates (SMS) which have been discovered to be useful in many fields. SMS has shown to be promising as a biofertilizer where it is both cheap and resource efficient, SMS can also be used as a high protein and nutritious animal feed substitute. Furthermore, SMS can be used for biofuel, as a bioremediation agent, and as a substrate to produce more mushrooms (Leong et al., 2022).

Experiments using SMS to cultivate oyster mushrooms were conducted in 2014 where two oyster mushroom species were conducted together SMS, sawdust, and wheat bran in different fractions (see Table 11) (Ashrafi, 2014). The gathered SMS from P. ostreatus was shredded mechanically into a grainy structure, to the left to air dry on a concrete floor for 3-4 days to obtain 45% moisture content (ibid.). Each batch included 500 g of substance which was placed in polypropylene heat-resisting bags which were autoclaved and then inoculated with the two oyster mushroom species after cooling (ibid.). The inoculation took place at a temperature between 32-25 °C for approximately 20-25 days before the bags were filled with mycelia. The bags were placed in a conditioned room where about 4-5 harvest cycles were accomplished throughout the growing period (ibid.).

Table 11: Collective information regarding SMS summarized

Substrate mix	Mushroom Species	Incubation time	flushes	Yield/1000g	BE (%)	Source

		(weeks)				
SMS	Pleurotus ostreatus	≈3 (20–25 days)	4-5	282	78,4	(Ashrafi, 2014)
SMS+SD (70:30)	Pleurotus ostreatus	≈3 (20–25 days)	4-5	302	84,2	(Ashrafi, 2014)
SMS+SD (60:40)	Pleurotus ostreatus	≈3 (20–25 days)	4-5	308	85,5	(Ashrafi, 2014)
SMS+SD (50:50)	Pleurotus ostreatus	≈3 (20–25 days)	4-5	372	103,6	(Ashrafi, 2014)
SMS+SD (40:60)	Pleurotus ostreatus	≈3 (20–25 days)	4-5	378	105,1	(Ashrafi, 2014)
SMS+SD (20:80)	Pleurotus ostreatus	≈3 (20–25 days)	4-5	334	92,8	(Ashrafi, 2014)
SD+WB (65:35)	Pleurotus ostreatus	≈3 (20–25 days)	4-5	340	94,8	(Ashrafi, 2014)
SMS+SD+WB (20:60:20)	Pleurotus ostreatus	≈3 (20–25 days)	4-5	386	107,5	(Ashrafi, 2014)
SMS+SD+WB (30:50:20)	Pleurotus ostreatus	≈3 (20–25 days)	4-5	356	99	(Ashrafi, 2014)
SMS+SD+WB (40:40:20)	Pleurotus ostreatus	≈3 (20–25 days)	4-5	352	98,1	(Ashrafi, 2014)
SMS+SD+WB (50:30:20)	Pleurotus ostreatus	≈3 (20–25 days)	4-5	324	90,2	(Ashrafi, 2014)
SMS+SD+WB (60:20:20)	Pleurotus ostreatus	≈3 (20–25 days)	4-5	308	85,3	(Ashrafi, 2014)

The mean biological efficiency in the conducted study was 96.06% where the highest yield being on a BE% of 107,5% (Table 11) (Ashrafi, 2014). As this study presents, SMS can be utilized as a growing medium for mushroom production, and supplements from sawdust or wheat bran can in this case produce greater yields. For P. ostreatus the most efficient percentage of supplements was 50% or 60% sawdust or having 40%, 50% or 60% sawdust with wheat bran gave the highest yield which can be seen in Table 11. Using SMS alone is not optimal and could not generate a sufficient amount of yield due to the nutrient depletion from prior use (ibid).

Appendix 6: Information regarding prior studies on Mushroom cultivation on cardboard, paper, plant fibers, and sawdust

The cultivation of oyster mushrooms (Pleurotus spp.) on various lignocellulosic wastes has been displayed to be successful on paper and cardboard waste as well. In an experiment conducted by Mandeel et al., (2004) three variations of oyster mushrooms were cultivated on paper, plant fibers, sawdust, and cardboard waste. One of the variations was P. ostreatus, which was cultivated in polyethylene bags with 1 kg wet substrate (ibid.). The cardboard and paper waste were shredded by an office shredding machine, and plant fibers were chopped by hand at a length of about 3-5 cm (Mandeel et al., 2005). The air-dried substrates weighed 337 g and were soaked overnight in 60 tap water at 60 C. The substrate was submerged in distilled water overnight to then be rinsed repeatedly three times (ibid). Calcium carbonate (CaCO3) and Calcium sulfate (CaSO4) (2% w/w) was added to the mixture with dry oats (5%) to maintain a healthy pH (ibid.). The moisture content of the substrate was measured to be 65% and the mixture is sterilized by the autoclave at 15 psi and 121 °C for 1h. Each batch was inoculated without any light source in a ventilated room at the temperature of 20 ± 2 °C, with a relative humidity of >90% for 20 days to make sure all substrate was completely colonized (ibid.).

Table 12: Collective information regarding paper, cardboard, plant fibers, and sawdust.

Substrate mix	Mushroom Species	Incubation time (weeks)	flushes	Yield/1000g	BE (%)	Source
Paper	Pleurotus ostreatus	2	5	1148,367953	112,4±8,680	(Mandeel et al., 2005)
Cardboard	Pleurotus ostreatus	2	6	1172,106825	117,5±7,485	(Mandeel et al., 2005)
Plant Fiber	Pleurotus ostreatus	3	4	952,5222552	95,3±8,365	(Mandeel et al., 2005)

SD	Pleurotus ostreatus	4	2	298,8130564	59,6±10,930	(Mandeel et al., 2005)

Appendix 7: Information regarding a prior study on Mushroom cultivation on cotton waste

Cotton is a fiber that is widely used in textiles and clothing, the fiber is soft and delicate and grows in the form of a protective case or a ball. Cotton is considered to be one of the most prominent organic crop fibers (Khan et al., 2020). In an article written by Oh et al., (2004), a study was conducted to grow oyster mushrooms on fermented cotton waste together with poplar sawdust, and by-products of winter mushrooms. The main purpose of fermentation was to provide the nutrients needed to grow the mushroom. The substrate preparation took place via an outdoor fermentation where the mixture of 84 % of shredded cotton and 16 % of Fermented by-products of winter mushrooms, Fermented poplar sawdust, and non-fermented poplar sawdust (Oh et al., 2004).

The substrates were separated into four different plots where there were 100% cotton, a mix of 84% cotton and 16 % non-fermented poplar sawdust, a mix of 84% cotton waste and 16 % fermented poplar sawdust and a mix of 84% cotton and 16 % by-products of winter mushrooms (Oh et al., 2004). The substrate was placed in containers with the dimensions of (40 cm × 40 cm × 12 cm) containing 4 kg substrate. The substrate then went into a pasteurization process where the substrate was exposed to a temperature of 62 °C for 12 h, the temperature was preserved at 52-55 °C the following 5 days to condition the substrate (ibid.).

Table 13: Collective information regarding Cotton, fermented by-products of winter mushrooms, fermented poplar sawdust, and non-fermented poplar sawdust.

Substrate mix	Mushroom Species	Incubation time (weeks)	flushes	Yield/1000g	BE (%)	Source
C	Oyster mushroom, not species specific	-	-	165,75	55,25	(Oh et al., 2004)
C+NFP SD (84:57)	Oyster mushroom, not	-	-	177	59	(Oh et al., 2004)

	species specific					
C+FP SD	Oyster mushroom , not species specific	-	-	185,5	61,83	(Oh et al., 2004)
C+FWM	Oyster mushroom , not species specific	-	-	175,5	58,5	(Oh et al., 2004)

C = Cotton, NFP SD= non-fermented poplar sawdust, FWM = Fermented byproduct of winter mushrooms

The outcome of the mushroom cultivation of the substrate showed the highest yield for waste cotton and fermented sawdust with 4 kg substrate. There was not much difference between the tree substrate mixes where the 100 % cotton substrate produced the least number of mushrooms see Table 13 (Oh et al., 2004).

Appendix 8: Wood waste data collection

Table 14: Displays the estimations of the quantity of generated wood waste for arborists.

Arborist	Areas	Estimations
A1	Bagarmossen	30 m3/month
A2	Bromma	30-50 m3/day
A3	Hägersten	-

A4	Skärmarbrink	750 m3/year compact volume
A5	Älvsjö	-
A6	Sofo	-
A7	Nacka	-
A8	Hornstull	30 m3/week No more than 10 m3 sawdust a week, maybe 500 m3/year
A9	Hagsätra	-
A10	Älvsjö	500 kg/day
A11	Enskede	40-50 m3/mån in high season (aug-oct), 20-30 m3/monthly in lowseason
A12	Årsta	-
A13	Vasastan	30x100 m3/year
A14	Södermalm	50 000 tonnes/year
A15	Vasastan	-

A16	Vasastan	-

Table 15: Displays the estimations of the quantity of generated wood waste for woodworkers.

Wood workers	Areas	Estimations
W1	Hornstull	500 kg/month
W2	Norrmalm	-
W3	Södermalm	240-340 m3/month
W4	Södermalm	-
W5	-	-
W6	Mosebacke	6 m3/month
W7	Liljeholmen	-
W8	Vasastan	4 m3/month
W9	Östermalm	100 kg/month
W10	Sofo	-
W11	Gamla stan	20-30 kg/month
W12	Bromma	300 kg/week
W13	Vasastan	-
W14	vantör	-

W15	Farsta	300kg/week
W16	Södermalm	4-5 m3/month
W17	Högalid	-

Appendix 9: Sample collection of Coffee houses from four of the five different coffee house chains

Table 16: Sample collection of Coffee houses from four of the five different coffee house chains.

Coffee house chains	Location	Approximate location	SCG dry kg/day	SCG medel dag kg/day	Comment
Chain 1	Stockholm city	Drottninggatan (Sergels torg)	1,2*4–6 (4.8-7.2)	6	Is sorted as food waste
Chain 2	Stockholm City	Drottninggatan (Sergels torg)	7	7	Is sorted as food waste
Chain 3	Stockholm City	Drottninggatan	1,05	1,05	Do not sort as food waste
Chain 1	Stockholm City	Drottninggatan (liten)	0,583333333	0,58	Is sorted as food waste
Chain 1	Stockholm City	Drottninggatan (nära city)	6,6	6,6	Is sorted as food waste
Convenient store	Stockholm City	Gamla stan	0,20–0,56	0,38	Do not sort as food waste (not included

					in total)
Chain 3	Södermalm		1,6333333 33	1,63	Is sorted as food waste
Chain 2	Södermalm	Nära slussen t-bana (och i typ en galleria ish)	9	9	Is sorted as food waste
Chain 1	Södermalm		3	3	Do not sort as food waste
Chain 1	Farsta	Galleria	4,8-6	5,4	-
Chain 1	Farsta	Galleria	5	5	-
Chain 5	Farsta	Galleria	04-jan	2,5	Is sorted as food waste
Chain 1	Kista	Enda cafét vi hittade i kista galleria	12	12	Is sorted as food waste
Chain 1	Fridhemspla n		6,6	6,6	-
Chain 5	Fridhemspla n		3	3	Is sorted as food waste

Table 17: Displays the mean value of SCG generated in general each day.

Coffee house chains	Mean value/SCG kg/day	Comment
Chain 1	5,6475	With Extreme values
Chain 1	5,433333333	Without Extreme values
Chain 2	8	

Chain 5	2,75
Chain 3	1,34

Table 18: Displayed the fifth coffee house chain production each day and year.

Chain 4 (Buy in 2022)	**Espresso-bean**	**Filtered coffee**	**Comment**
Bag size	661*6 st á 1 kg	861*48 st á 125 g	-
Consumption/ year	3966	5166	kg/year
Consumption/day	10,86575342	14,15342466	kg/day
Consumption/day/coffee house	1,358219178	1,769178082	kg/day/coffee grounds
Total:	3,12739726		There are 7 coffee houses in Stockholm Stad

Table 19: Amount of Coffee houses within Stockholm Stad and the generated SCG.

Focus Coffee house's	**Amount of stores**	**Size of the chain**	**Mean generated dry SCG/day**	**Generated dry SCG/year**	**Assumption**
Chain 1	48	Large	5,6475	9 894 4,2	That all coffee beans and coffee powder becomes SCG
Chain 2	8	Small	8	23 360	
Chain 3	20	Medium	1,34	9782	
Chain 4	7	Small	3,12739726	7990,5	
Chain 5	12	Small	2,75	12 045	
Total:				15 212 1,7	

Table 20: display an example of how the quantity of coffee chains in Stockholm Stad is mapped for Coffee chain one looked like.

Chain 1	**Amount of coffee houses**
Kista	1
Rinkeby	0
Spånga	0
Tensta	0
Hässelby	0
Vällingby	1
Bromma	1
Skärholmen	1
Hägersten	0
Liljeholmen	1
Stora Essingen	0
Kungsholmen	4
Norrmalm	26
Östermalm	3
Norra Djurgården	0
Djurgården	0
Gamla Stan	2
Södermalm	3
Enskede/Årsta/vantör	2
Älvsjö	1
Högdalen	1
Farsta	1
Skarpnäck	0

Total amount:	48

Appendix 10: Calculation of needed fraction of the waste

$$BE\% = \frac{Total\ weight\ of\ fresh\ mushrooms}{Dry\ weight\ of\ substrate} \times 100$$

$$Dry\ weight\ of\ substrate = \frac{Total\ weight\ of\ fresh\ mushrooms\ \times\ 100}{BE\%}$$

Fresh mushroom produced = [19 694 kg/year]

Assumption: The number “Fresh mushroom produced” was acquired from the estimated amount of mushroom consumed in Stockholm Stad each year.

$$Needed\ fraction\ of\ the\ available\ waste\ [\%] = \frac{Required\ dry\ weight\ substrate\ [kg/year]}{Available\ substrate\ [kg/year]} \times 100$$

Appendix 11: Price estimation of oyster mushrooms in Stockholm Stad

Grocery store price	Oyster Mushroom price kr/kg
M1	179
M2	299,67
M3	326,33
M4	149,75
M5	199,5
M6	197,5
M7	246,33
M8	312,67
M9	233
M10	259,67

M11	253
M12	286,33
Mean value	245,229167

Calculated with the following equation:

$$Mean\ value\ = \frac{\mathrm{M1} + \mathrm{M2} + \dots\dots\dots + \mathrm{Mn}}{Mn}$$