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Product-service systems for office furniture

- An analysis of GHG emissions of PSS scenarios within a suggested model framework

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Abstract

The furniture industry has high potential for improving with large amounts of waste and low product recovery rates (Tveit et al., 2021). In circular economy literature, product-service system (PSS) models have been proposed as a possible solution to incentivise reuse and prolonged product lifetimes (Tukker, 2004). However, few studies have assessed and evaluated the environmental impacts of PSSs for furniture. Therefore, this study's goal was firstly to assess and provide an overview of PSS models for furniture on the B2B and B2G market in Norway. Secondly, it aimed to preform an environmental analysis of global warming potential (GWP) of office PSS scenarios, which were rooted in data collected through a case study of an office relocation process in Oslo. A generic model based on the LCA method was developed. Two baseline scenarios and four reuse scenarios implementing PSSs were constructed and analysed.

Ten PSS offers for furniture were identified on the Norwegian B2B and B2G market. The environmental analysis showed an emissions reduction potential of 65% between the worst baseline scenario and the best reuse scenario. The lowest emissions total was achieved through internal reuse with added repairs, a high office utility rate, and by utilising reused furniture of age ten to fulfil the remaining furniture need. Scenarios with a flexible office rental solution reduced energy related emissions by 36% compared to the baseline scenario with a fixed office size. For a declining number of employees, flexible rental solutions where both furniture and office space can be reduced according to number of employees gave the lowest emissions totals for scenarios with furniture age ten as input. Energy efficiency and space reduction measurements were identified as highly relevant to minimize the environmental impact of offices. This suggests flexible office rental solutions that facilitate a long service life for furniture can be a highly relevant PSS offer for companies to consider.

Sammendrag

Møbelindustrien har et stort forbedringspotensial med store mengder avfall og lav produktgjenvinningsgrad (Tveit et al., 2021). I litteraturen om sirkulær økonomi har modeller for produkttjenestesystemer (product-service systems, PSS) blitt foreslått som en mulig løsning for å stimulere til gjenbruk og forlenget produktlevetid (Tukker, 2004). Imidlertid har få studier vurdert og evaluert miljøpåvirkningene av PSS-modeller for møbler. Målet for denne studien var derfor for det første å gi en oversikt over PSS-modeller for møbler på B2B- og B2G-markedet i Norge. For det andre hadde den som mål å utføre en miljøanalyse av globalt oppvarmingspotensial (GWP) av PSS-scenarier, som var forankret i data samlet inn gjennom en casestudie av flytteprosessen for et kontor i Oslo. En generisk modell basert på LCA-metoden ble utviklet. To grunnscenarier og fire gjenbruksscenarier med implementering av PSS-tilbud ble konstruert og analysert.

Ti PSS-tilbud for møbler ble identifisert på det norske B2B- og B2G-markedet. Miljøanalysen viste et utslippsreduksjonspotensial på 65 % mellom det verste referansescenarioet og det beste gjenbruksscenarioet. Det laveste utslippet ble oppnådd gjennom intern gjenbruk av møbler med ekstra reparasjoner, høy kontorbruksrate og ved å supplere med brukte, ti år gamle møbler for å dekke det gjenværende møbelbehovet. Scenarier med en fleksibel kontorleieløsning reduserte energirelaterte utslipp med 36 % sammenlignet med referansebanen med en fast kontorstørrelse. For et synkende antall ansatte ga fleksible leieløsninger, hvor både møbler og kontorlokaler kan reduseres etter antall ansatte, de laveste utslippssummene for scenarier med møbelalder ti som input. Tiltak for reduksjon av energi- og plassbruk ble identifisert som svært relevante for å minimere miljøpåvirkningen fra kontorlokaler. Dette tyder på at fleksible kontorleieløsninger som legger til rette for lang levetid for møbler kan være et høyst aktuelt PSS-tilbud for bedrifter å vurdere.

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Abbreviations

B2B – Business-to-business

B2C – Business-to-consumer

B2G – Business-to-government

BSN – Søndre Nordstrand borough (Bydel Søndre Nordstrand)

CE – Circular Economy

CO2eq – CO2 equivalents

GHG – Greenhouse gases

GWP – Global warming potential

LCA – Life cycle assessment

REV – Residual environmental value

1. Introduction

The global consumption of resources happens at a faster and faster rate. We consume far more resources than is environmentally sustainable. The annual extraction of materials has grown with an average rate of 2.6% per year from 1970 to 2017 with a material demand per capita of 12.2 tons in 2017 (IRP, 2019). In 2021, the annual material extraction had passed 100 billion tonnes (Circle Economy, 2021). The severity of the unsustainable use of resources is starkly demonstrated by The Global Footprint Network. Each year, they calculate Earth Overshoot Day, the theoretical day where we have used up Earth's renewable ecological resources and services. In 2021, Earth Overshoot Day fell on July 29th. After that date, we started liquidating the stock of natural resources and generating waste, adding to the carbon dioxide emissions already in the atmosphere, and depleting resources for generations to come (Earth Overshoot Day, 2021).

The furniture industry has been identified as having a high potential for improvements with large amounts of waste and low product recovery rates (Tveit et al., 2021). The European Environmental Bureau (EEB) estimates that 10 million tonnes of furniture are discarded each year by businesses and private consumers in the EU (Forrest et al., 2017). Reuse activity in the furniture sector is characterized as low and unstructured (Forrest et al., 2017). According to statistics from the European Federation of Furniture Manufacturers (UEA), between 80% and 90% of furniture waste in the municipal solid waste steam is incinerated or sent to landfill, meaning only around 10% of furniture are recycled (Forrest et al., 2017).

There are no official numbers for reuse or recycling of furniture in Norway. The popular Norwegian TV show Sløsesjokket (The Waste Shock) by the Norwegian Broadcasting Corporation (NRK) investigated furniture waste in Norway. They assumed that 140,000 tonnes of office furniture is thrown away every year, amounting to approximately 200 moving trucks every day (NRK, 2021). This take-make-waste approach of furniture consumption is increasingly being challenged.

The Circular Economy (CE) concept maps out ways of keeping resources in use with as high quality as possible for as long as possible before going to waste (Ellen MacArthur Foundation, 2014). In CE literature, there is a branch of business models that have gained attention in the last decades, called product- services systems (PSS) (Tukker, 2015). PSSs focus on providing a bundle of products and services that function together in order to fulfil the customer's need, not necessarily through selling a product, but through providing a service or a result (Tukker, 2004).

For furniture, the PSS concept could potentially give a greater incentive for reuse and prolonged lifetime of furniture if the customer procures the access to the functions of furniture instead of the ownership of it. For the business-to-business (B2B) and business-to-government (B2G) markets, this is an enticing idea, as furniture procurements can be seen as a supporting function, providing a good work environment for the office employees to execute their work tasks.

However, real world examples of PSS solutions that are environmentally, economically and socially sustainable are few and far between (Costa et al., 2015). For furniture there is little academic literature on what offers exist that could be classified as PSS and how sustainable these solutions are in practice. Besch (2005) provides a thorough introduction and description of a PSS scenario for office furniture. Their scenario is used in interviews to assess barriers and opportunities for PSS on the European market. Additionally, Costa et al. (2015) use life cycle assessment (LCA) and service design tools to inform the PSS design in a pilot project for an office furniture manufacturer. The lack of quantitative research on the environmental effects of PSSs in general and for furniture in particular provides space for speculations as to the environmental advantages of PSSs for furniture. Therefore, the aim of this research was to contribute to the subject by analysing the environmental impact of possible PSS scenarios for office furniture. To do so, an assessment of what PSS models for furniture exists on the Norwegian market was done as a necessary first step. Furthermore, 2 baseline scenarios and 4 PSS scenarios were constructed for an office space setting. The offices of Søndre Nordstrand borough's administration (BSN) situated in Oslo were used as a case study. Data collected about the office space and inventory needs served as a frame for environmental analysis. The environmental analysis was based on the life cycle assessment (LCA) method with global warming potential (GWP) as the chosen impact category to be analysed.

1.1. Objectives and research questions

It is unclear whether PSS models for furniture offer substantial environmental benefit. Furthermore, practical examples of PSS models for furniture are lacking. Therefore, the study objectives are:

1. To assess and give an overview of PSS models for furniture on the B2B and B2G market in Norway
2. To construct a model framework and relevant PSS scenarios as a basis for analyses of GHG-emissions of a PSS system of office furniture
3. To compare GHG-emissions from relevant PSS models against conventional furniture procurement situations
4. To discuss how different factors and preconditions of the PSS scenarios influence on the GHG-emissions of the systems

Research questions:

RQ1: What PSS models for furniture are in use on the Norwegian B2B and B2G market today?

RQ2: How can a generic model be developed to analyse GHG emissions related to PSS of office furniture in a systems perspective?

RQ3: How can the generic PSS model be further developed into a set of sub models to analyse and compare GHG emissions from a number of PSS scenarios?

RQ4: What are the differences between the developed PSS scenarios with regard to GHG-emissions and what factors contribute most to differences between the scenarios?

2. Background

In the following, information that is important for the context of the study is presented. Firstly, the Circular Economy (CE) concept will be presented. Secondly, a brief introduction to the furniture market in Norway and environmental aspects of furniture will be introduced. Thirdly, the product-service systems (PSS) concept is explained. Lastly, themes such as Life Cycle Assessment (LCA), Environmental Product Declarations (EPDs) and allocation of greenhouse gas (GHG) emissions are introduced in section 2.4 Assessment of environmental impacts from products and services.

2.1. Circular economy

Today's linear economy is based on a system where natural resources are inefficiently used and production processes contain a high amount of non-renewable resources. The take-make-waste model of the linear economy, as shown in Figure 1 entails that many products are used only once before being treated as waste. It relies on a high amount of non-renewable resources which are not recycled back to become new products. The circular economy (CE) concept has been promoted as an alternative solution. CE aims at decoupling economic growth from resource use through continuous circulation of products, materials and resources (Ellen MacArthur Foundation, 2014; Murray et al., 2017). The concept has rapidly gained a lot of attention and enthusiasm, with hundreds of scientific articles being produced with numerous different definitions. Kirchherr et al. (2017) analysed 114 definitions of CE.

They summarize CE with the following definition:

> *"A circular economy describes an economic system that is based on business models which replace the 'end-of-life' concept with reducing, alternatively reusing, recycling and recovering materials in production/distribution and consumption processes, thus operating at the micro level (products, companies, consumers), meso level (eco-industrial*

parks) and macro level (city, region, nation and beyond), with the aim to accomplish sustainable development, which implies creating environmental quality, economic prosperity and social equity, to the benefit of current and future generations. It is enabled by novel business models and responsible consumers." (Kirchherr et al., 2017, p. 229)

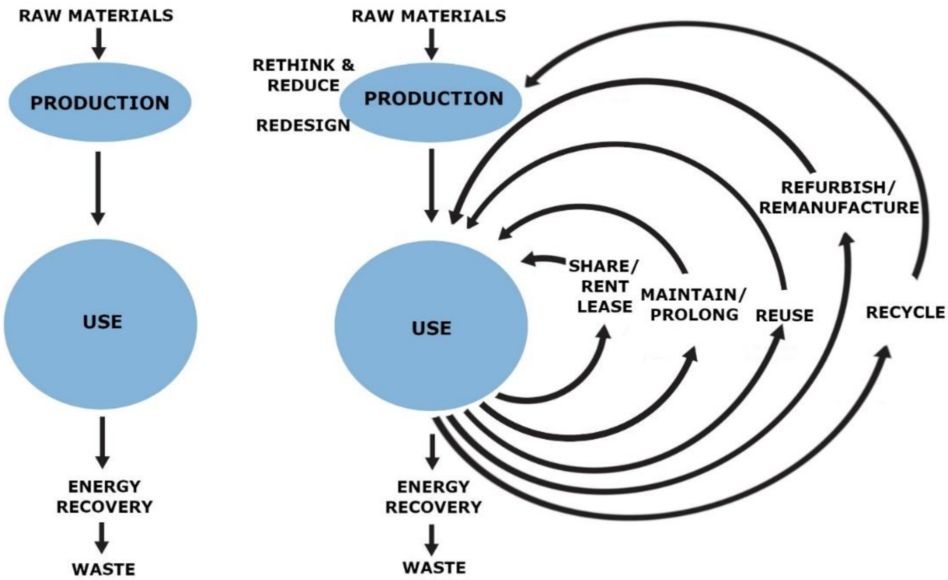

Figure 1: Linear and circular economy, based on (Ellen MacArthur Foundation, 2022; PBL, 2022).

The main CE principles proposed in literature are visualized in Figure 1. Rethink and reduce refers to rethinking the need for a new product in the first place. It also involves rethinking business models and production processes in order to use less material, water and energy. Redesign entail designing products that are durable and fit for reuse, repair, and recycling. Sharing might not be appropriate for all products but is considered an environmentally friendly option as the production of one product can fulfil the need for several people. This way, resources are saved by avoiding excess raw material extraction and emissions from production. *Renting or leasing* is considered a good environmental choice as it creates a stronger incentive for producers to prolong the lifetime of their products. If the ownership stays with the producer, they have direct benefits of prolonging the usage of the products so they can rent it out for longer periods. Maintain and prolong entails efforts at prolonging the usable life of the product. Proper maintenance will protect most products from unnecessary wear and tear. Reuse keeps products in use in its original form by a change of hands or location. This can for example be reuse of packaging by businesses, or second-hand purchase of clothing. Reuse both keeps an item from becoming waste when is still has usable years left in it, and displaces the need for a new product to be made. Refurbish refers to actions done to restore products to a good working order. Examples can be to replace parts, update specifications or improve or restore the aesthetics of the product. Remanufacture requires more extensive changes and fixes than reuse. Remanufacturing is done when products cannot enter the market again in their current state, but the main components and materials can be worked into a new product. It entails making an as-new product by re-engineering the original product or components. Recycling is the final loop of the diagram. The goal of the circular economy is to keep recycling processes as the last considered step after all the previous options has been considered. This means only products that are beyond repair or not suitable for the previous steps should go to material recycling. Recycling entails changing the product back into materials that can go into the production of new products. When recycling, the value of the materials in the product are retained, but the investments of time and energy of making the product itself, are lost. Some products and components can be deemed unfit for recycling all together because of their use of complex material mixes or the high expense of disassembling or extracting the different materials (Besch, 2005; Ellen MacArthur Foundation, 2022; PBL, 2022; Simon, 2019).

Designing products that are fit for the different cycles and for the end step of recycling, is an important first step to avoid materials going to energy recovery or waste treatment. If materials cannot be recycled, energy recovery is to be considered. This means burning the waste so that electricity or district heating can be produced from the energy still embedded in the discarded products. Lastly, if it is not possible to burn the product, for example due to high toxicity risks or the materials not being flammable, a safe final disposal in landfill is the least favoured option (PBL, 2022; Simon, 2019).

2.1.1. Circular economy and politics

The European Union have a high priority in accelerating the implementation CE principles in the member countries. The European Green Deal is a set of policy initiatives by the European Commission. The overarching goal is to make the European Union climate neutral by 2050. The deal was approved by the EU members in 2020, and affects Norway through EU regulations and directives that must be implemented in national law through The European Economic Area (EEA) Agreement (Norway.no, 2022; Regjeringen.no, 2021).

The European Union's Action Plan for a Circular Economy promotes reuse and repair services as a way of creating new businesses with important contributors to the circular economy (European Union, 2015). Through the Horizon Europe funding programme, the development of new business and consumption models can apply for funding (European Commission, 2022b).

A central legislation for production companies is the proposed Ecodesign for Sustainable Products Regulation which was published in March 2022. The press release by The European Commission says:

> *"The proposal builds on the existing Ecodesign Directive, which currently only covers energy-related products. (…) The framework will allow for the setting of a wide range of requirements, including on*
>
> - *product durability, reusability, upgradability and reparability*
> - *presence of substances that inhibit circularity*
> - *energy and resource efficiency*
> - *recycled content*
> - *remanufacturing and recycling*
> - *carbon and environmental footprints*
> - *information requirements, including a Digital Product Passport"*
>
> (European Commission, 2022a).

Furniture is one of ten product categories identified by the commission as suitable for the mentioned requirements, due to having high environmental impacts and potential for improvement. This could mean implementation of stricter rules for furniture produced within Norway and the EU within the coming years.

The stronger focus on circular economy principles such as reuse and repairs have also become evident in Norwegian politics. A National Strategy for a Circular Economy has been developed in order to promote circular economy principles nationally (Regjeringa.no, 2021). On a local scale, Oslo municipality is leading on in the work with a Strategy for Sustainable and Reduced Consumption (Framtidens forbruk – strategi for bærekraftig og redusert forbruk, 2019–2030) (Byrådssak 249/19). The role of reuse and repairs of products are emphasised in both strategies. Public procurements are highlighted as an important driver towards supporting business models for reuse and repairs.

2.2. Furniture

The furniture industry encompasses companies and activities that are involved in the design, manufacture, distribution, and sale of free-standing or built-in furniture units. Furniture is made to support human activities connected to storage, seating, lying, working or eating. Thus, furniture includes shelves, chairs, sofas, desks, tables, beds etc., but excludes building products (walls, flooring, panels etc.), carpets or loose fabrics, sanitary equipment, office supplies, electronics or other products that do not fill the beforementioned functions of furniture (Parker et al., 2015). Furniture can be divided into furniture for personal use and furniture for business use. This article is limited to the business use of furniture in commercial companies and the public sector.

The Norwegian market for furniture and interior sales was estimated to be 48,1 billion NOK in 2020 (Rekdal, 2021). There is no official register of furniture producers or resellers in Norway, but it is estimated that about 60% of the furniture industry operates on the private market and 40% on the contract market for businesses and public procurements (E Braathen 2022, personal correspondence, 3 March). Both an increase in price and turnover has occurred within the last ten years, with the furniture retail sector having an increase of 3,1% in yearly sales since 2010 (Rekdal, 2021).

All products come with an environmental impact caused by the sum of resources used in their life cycle stages. 80-90% of the total environmental impact of furniture comes from the extraction of raw materials and the manufacturing stage (Cordella & Hidalgo, 2016; DFØ, 2022). Literature suggests two main strategies for reducing the environmental impact of furniture. The first strategy is to design furniture that is more suitable for material recycling, thus minimizing the extraction of new materials (Besch, 2005; Cordella & Hidalgo, 2016). The second strategy is to decrease furniture consumption by prolonging the lifetime of the product. According to the CE principles, reducing the amount of furniture purchased by prolonging the lifetime of furniture is considered the prioritized strategy, although producing furniture with lower emissions by both designing furniture for reuse and utilising reduced materials are important additional strategies. It is a simple fact that if a furniture item is kept in use for 15 years instead of 5, it has kept its embedded emissions in use for three times as long. By doing so, it has possibly avoided emissions from the production of new furniture that would have been made to replace it. In this way, prolonging the user phase of products is considered a good environmental strategy (Besch, 2005).

How long furniture can or will be in use, is influenced but its functional and technical lifetime. The functional lifetime of furniture is influenced by the user's preferences in regard to aesthetics, fashion trends and changes in needs (Besch, 2005). A good example can be the change from mainly working on paper to working on computers. This has reduced the need of large desks and storage spaces associated with paper filing. These factors can make it highly varying how long the furniture will be in use before it is disposed of. Furniture's technical lifetime is related to intensity of use and how long the furniture is designed to last. The limits of the technical lifetime of furniture is set by decisions made in the design phase of the furniture and in the choice of materials (Parker et al., 2015).
Table 1 show the life expectancy stated in different studies on furniture, what type of furniture has been considered and a short explanation of the information source. It can be difficult to determine whether it is the technical or functional lifetime that has been described. Often these differences are

not made clear. Table 1 shows that most literary sources find the expected lifetime of furniture to be 15 years. This estimate will be used in the further analysis.

Table 1: Life expectancy for different furniture types found in literature.

Literary source description	Life expectancy [years]	Furniture type
Besch (2005), interviews of office furniture customers	12	Average of office furniture
EPD-Norge (2018b), estimated service life	15	Indoor seating, tables and storage
EPDs by Flokk (EPD-Norge, 2022c), reference service life	5 or 15	Upholstered office chairs
Hoxha & Jusselme (2017), literature review.	20	Working desks, metal cabinets.
	15	Working chairs, meeting tables, meeting chairs and cabinets
Parker et al. (2015), own estimates.	5-10	Chairs
	15	Working desks

2.3. Product-service systems (PSS)

"PSS is a business model focused toward the provision of a marketable set of products and services, designed to be economically, socially and environmentally sustainable, with the final aim of fulfilling customer's needs" (Annarelli et al., 2016, p. 1017). PSS incentivises producers to prolong the lifetime of products. Producers and retailers get revenue from the service provided rather than the product itself. Tukker (2004) arranges PSS into three main categories with a total of eight subcategories as shown in Figure 2. The three main categories product-oriented, use-oriented, and result-oriented services align themselves on an axis from the value creation mainly being in the tangible product, to the more intangible value creation being in the provided service.

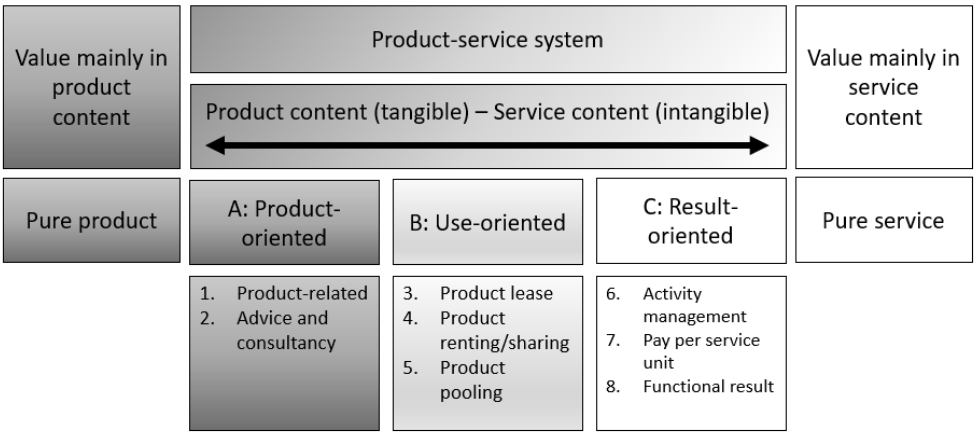

Figure 2: Main subcategories of PSSs based on Tukker (2004).

The first main category, product-oriented services, is closest to the usual product sales-oriented business models, but some extra services are added. The subcategory product-related service consists of added services to the user phase of the product. For furniture, services such as a maintenance contracts or take-back schemes fall under this category. The Advice and consultancy-subcategory consists of giving advice on the most effective use of the product. This can for instance be management advice for the organization using the product, or logistics advice relating to the product if it is part of a production or logistics function.

The second main category, use-oriented services, focuses on the user experience rather than the product itself. The product ownership generally stays with the service provider, who is oftentimes responsible for maintenance, repairs and other needed services related to the product. The products can sometimes be shared by different users. The main subcategories of use-oriented services are leasing, renting and product pooling. Under a leasing contract, the lessee pays for the user rights of the product while the product ownership and maintenance responsibility stays with the provider. When the leasing contract period ends, the lessee can oftentimes choose between buying the ownership rights of the product or have the product removed when the leasing period is over.

Product renting is similar to leasing, but while under a leasing contract, the lessee has unlimited and individual access to the product, the product can be sequentially used by different users in a renting scheme. The renting periods are often shorter and with a more flexible contract than that for leasing contracts. Lastly, product pooling refers to business models like renting or leasing, but where the business model opens for simultaneous use of a product.

Result-oriented services is the third and last main category. With this business model, the client and provider agree upon a result that is to be met by the provider, regardless of what product is needed to meet this result. The three subcategories, activity management/outsourcing, pay per service unit and functional results, differ in the way the results of the service are paid for or measured. With activity management, a company activity is outsourced to a third party where the quality and completion of the provided service is measured by performance indicators. Widespread examples of PSSs falling under this category are catering or office cleaning services. Pay per service unit is another commonly used PSS model. Here, the customer buys the output of the product rather than the product itself. It can for example be to pay per printed page on an office printer. Another example is how Schiphol Airport in The Netherlands pays for light as a service. The light components and fittings are owned by the companies Philips and Cofely, who take full responsibility for the complete life cycle of the products used at the airport (European Union, 2022).

The functional results services can be seen as including the most intangible of the PSS models. Tukker (2004) describes this category as containing services with abstract result-oriented models, where the results can be provided by "all means necessary". Examples can be companies offering an agreed upon reduction in electricity needs rather than selling insulation. The common factor is that these services often do not rely on only one product in order of achieving the agreed upon results.

2.4. Assessment of environmental impacts from products and services

Environmental assessments are key to understanding what impacts our choices can have on the environment. Taking a life cycle perspective makes it possible to identify improvement areas where the contribution of environmental burdens are largest in a product's life cycle. It can also help avoid making decisions that shift environmental burdens from one life cycle stage to another rather than reducing it. The life cycle assessment (LCA) method provides a basis for comparing environmental performance of different products or processes. In the following sections, the LCA method will be described, as well as Environmental Product Declarations (EPDs) which summarise product information based on the LCA method. Lastly, the subject of emissions allocation through multiple user phases will be addressed.

2.4.1. Life cycle assessment (LCA)

A well-established method of environmental assessment of products and services is the life cycle assessment (LCA) method. The life cycle metaphor is borrowed from biology, indicating that not only the environmental impacts from the manufacturing of a product or system has been evaluated, but all of its life cycle (Hauschild et al., 2018, p.10). This will mean looking at every stage from material consumption through manufacturing, into the user stage and eventually the processes involved in treating the discarded product as waste.

By characterizing and quantifying all material flows related to a product's life cycle, the LCA provides a method to collect information about associated environmental burdens of the product system in question. The method is standardized through the International Organization for Standardization (ISO), specifically the ISO 14040 and 14044 standards (Curran, 2015, p. 13). ISO 14040 describes the framework and underlying principles, while ISO 14044 includes requirements and guidelines on how to preform LCAs (ISO, 2022a; ISO, 2022b). The ISO standardisation of LCA provides a harmonised framework and methodology, making it possible to compare results and use the same standardised method across different products and services.

Important prerequisites for the assesment are how the functional unit and system boundaries are defined. The functional unit is "a quantifiable description of the service provided by the product system" (Curran, 2015, p. 24). It acts as a reference point for which all input and output flows to the system must refer to. An example is the production of one unit product, such as one specific office chair model, provided and maintained for over an estimated service life. The system boundary describes what processes are included and excluded from the analysis. There are four main categories of system boundaries: gate-to-gate, cradle-to-gate, cradle-to-grave and cradle-to-cradle. Gate-to-gate studies draw the system boundary around a specific process or operation, for example a factory. In cradle-to-gate studies, the system boundary starts with raw material extraction and ends when the product is ready to leave the factory gate. Cradle-to-grave study boundaries start with the production of raw materials and include all the stages of the product's lifetime through its use phase and until end-of-life management processes such as material recycling or waste disposal. Cradle-to-cradle studies include all phases from raw material production til end-of-life treatment, as well as any reuse or recycling processes that might occur (Curran, 2015). The system boundaries set the limits to which processes environmental information must be gathered about.

The goal of LCA is often to compare or inform about the environmental impact of specific products or production choices (Hauschild et al., 2018, p. 68). Many environmental impacts can be assessed in LCAs, such as global warming potential, stratospheric ozone depletion, acidification, eutrophication, photochemical ozone formation or ecotoxicity. Global warming potential is the category in which Greenhouse (GHG) gasses, which contribute to climate change, are summarised. GHGs are for example CO_2, CH_4, N_2O and fluorinated gases. These gasses accumulate in the atmosphere and have been identified as leading to global temperatures rising over time (Curran, 2015; IPCC, 2018; United Nations, 2022). Each GHG contributes differently to global warming. For example, one kilo of CH_4 has been found to contribute 25 times more to global warming than one kilo CO_2 in a hundred-year perspective. To give one summarised number for all the substances' contribution to global warming, their effects are measured up against the effects of CO_2 and converted into CO_2 equivalents (CO2eq). Meaning, 1 kg CH_4 plus 1 kg CO_2 equals 26 kg CO2eq (Curran, 2015, pp. 145-146).

GWP is the main attention of many research articles and studies based on the LCAs method. Showcasing how different products, life cycle stages and services contribute to global warming is seen as an important tool for global warming reduction measures. This study will also only consider the GWP impact category, but acknowledges that it is merely one out of many environmental impacts of importance.

2.4.2. Environmental product declarations (EPDs)

EPDs are standardized environmental information about components, products or services based on LCAs that follow the ISO 14040-14044 standard. The specific standard for EPDs is found in ISO standard 14025 Environmental Labels and Declarations Type III (EPD-Norge, 2021b). For each category of products or services, Product Category Rules (PCRs) are made, which determine what should be included in the specific product's EPD (Fet et al., 2009). When making a furniture EPD, all requirements outlined in NPCR Part A for Construction products and services (Version 2.0) and NPCR 026 Part B for Furniture (Version 2.0) must be followed (EPD-Norge, 2018b).

EPD-Norge is the Norwegian operator of the Norwegian EPD-program. They are responsible for verification, registration and publication of Norwegian EPDs (EPD-Norge, 2022b). There are 223 furniture items registered at EPD-Norge. 142 registered EPDs for seating furniture, 54 tables and tabletops. Cabinets and shelves have 19 registered items (EPD-Norge, 2022a).

The life cycle stages are arranged in modules throughout the PCR and EPD system, making it easy to compare furniture of the same category. The different modules are shown schematically in Figure 3. Module A1 to A3 represents the production stage with raw material supply, transport, and manufacturing of the product. Module A4-5 is the construction process, which for furniture would be additional transport after manufacturing and installation at location if needed. Module B1-7 is the user phase, which includes maintenance and repairs of the product. Module C1-4 contains the end-of-life stage of the product with emissions generated from transport, waste processing and disposal. The last module that can be included is for the benefits of reuse, recovery, and recycling potential of the product, Module D. Here the substitution effects from keeping materials in the loop are accounted for, giving a negative contribution on emissions. This can be the positive effects of substituting virgin raw materials by recycling material from the product, or it can be the positive contribution of the energy recovery process when electricity or heat is made (LCA.no, 2021). Module

D is however described as an information module, meaning these effects cannot be credited to the product and is held outside of the system boundary.

	Product stage			Construction/ Installation stage		Use stage							End of life stage				Benefits and loads beyond system boundary
	Raw material supply	Transport	Manufacturing	Transport	Assembly	Use	Maintenance	Repair	Replacement	Refurbishment	Operational energy use	Operational water use	De-construction demolition	Transport	Waste processing	Disposal	Reuse- Recovery- Recycling- potential
	A1	A2	A3	A4	A5	B1	B2	B3	B4	B5	B6	B7	C1	C2	C3	C4	D
Type 1	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	O
Type 2	X	X	X	X	O	O	O	O	O	O	O	O	O	O	O	O	O

Figure 3: The life cycle modules (A1 to D) with corresponding life cycle stages that can be included in EPDs type 1 and 2 for furniture. X means the stages are included; O means the stage is optional. Own figure based on EPD-Norge (2018b; 2021a).

For furniture, two different types of EPDs can be made, depending on what life cycle stages are included. They give different amounts of information about the declared item. Type 1 EPDs declare the whole life cycle of the product, from cradle to grave, where modules A1 to C4 are mandatory, while module D is optional. Type 2 EPDs are a cradle-to-gate EPD with module A1 to A4 being mandatory, while A5 to D is optional (EPD-Norge, 2018b).

There are no environmental performance requirements that must be met in order to be given an EPD (Fet et al., 2009), it is merely a presentation of selected environmental impact categories. Seven impact categories are included in EPDs: Global warming potential (GWP), depletion potential of the stratospheric ozone layer (ODP), formation potential of tropospheric photochemical oxidants (POCP), acidification potential of land and water (AP), eutrophication potential (EP), abiotic depletion potential for non-fossil resources (ADPM) and abiotic depletion potential for fossil resources (ADPE) (EPD-Norge, 2018b). GWP, summarising the effects of GHG emissions in kg CO2 equivalents is the focus of this study. EPDs provide an important source of information of the GHG emissions associated with furniture production.

2.4.3. Allocation of GHG emissions through multiple user phases

Allocation is also referred to as partitioning. It is a term used for methods that lay down rules on how total flows of inputs and outputs are portioned out over the different products associated with the shared input and output flows (Matthews et al., 2014, p. 164). Products and services have a measureable amount of GHG emissions attached to their production, use and eventual waste treatment or recycling potential. When these totals are found through an LCA, or presented in an

EPD, it is a measure of what emissions can be expected from the product during parts of its lifetime or its full lifetime. When reuse or recycling of materials happen, the question of how the different emissions should be portioned out may arise. For example, if a chair is sold second-hand, should the first user be given all of the GHG emission "burdens" of the lifetime of the product up until then, or should the second owner also be given some of these burdens? If materials from obsolete products are recycled in an open market, should the resources used to recycle the material be attributed to the lifetime of the now discareded product, or onto new products that are made by the recycled material? These questions pose practical issues as to where the system boundary of one product ends and the other begins, and can lead to emissions being counted twice (double-counting), or left out.

The only scientifically unambigous solution is to expand the system boundary to include all the associated processes of both the first use of material and the use of the recycled material (Hauschild et al., 2018, p. 90). In practice however, this is often not possible, as we oftentimes do not know where the recycled material ends up. The same problem happens with reuse of products or parts of products, where you cannot know in advance, when making the product, how its lifespan will turn out. An allocation rule must therefore be established to portion out the emissions and avoid double-counting when reuse happens. It is common practice to see product reuse as a quasi-recycling process, lending allocation practices from recycling (Baxter & Callewaert, in press). Literature provides several different methods on how to allocate emissions in environmental assessments. Ekvall et al. (2020) has identified 12 main allocation methods for recycling. Three methods that are frequently used for both open-loop recycling and reuse are cut-off methods, 50/50 methods and allocation at the point of substitution.

Cut-off methods assign all the environmental burdens of the processes involved in the life cycle of the product to that particular product. The challenge becomes where to set the boundary between life cycles when recycling of materials is part of the process. The boundary can for example be set at the point where the material has its lowest value, which is typically before it is collected for waste treatment. This means that the recycling processes are included in the next product which uses the recycled material. Burdens from final waste treatment is assigned to the last product.

The 50/50 methods split the burdens of the virgin material production and the end-of-life treatment equally between the first and last user of the product (Ekvall et al., 2020). Other environmental burdens are split equally between the product system that supplies the recycled material and the product system that receives the recycled material. This means that if there are more than two user phases or recycling processes, the systems in between will only be allocated half of the recycling burdens and none of the burdens from virgin material extraction or final disposal.

Allocation at the point of substitution (APOS) apply allocation factors to the recycling processes and activities that generates waste and allocates these impacts between the product that generated the waste and the material that is recycled from it. This allocation between product and recycled material is typically based on the difference in value between the product and the recycled material (Ekvall et al., 2020).

Another approach used to model the impacts of recycling is the substitution method or avoided burden method, which is described as "subtracting the avoided emissions from additional functions" (Curran, 2015, p. 68). This means all the burdens from processes associated with making the product are assigned to the product, and credit is given for the services or materials that comes from co-products or recycling. For example, a product is assigned the emissions from waste treatment and recycling processes. Credit is given for the avoided emissions from using the recycled material instead of extracting new virgin materials. In the same way, avoided emissions from energy recovery from the product is also credited the product if it displaces a more polluting energy source.

Most of the abovementioned methods implies that you must know how many phases of reuse is to be expected of a product to allocate emissions properly. This can be highly speculative in real life. The different methods give high or low incentives for reuse, for example if the first user is assigned all burdens associated with the production of the product, this can be seen as giving a low incentive to the first user to consider reuse, as they have already "paid" for the environmental costs.

Baxter & Callewaert (in press) suggests using the concept of residual environmental value (REV) to distribute the environmental impact of a product through multiple reuse phases. The method follows the same principle of depreciation of assets that is well-established in economic accounting. REV is calculated from the indirect environmental costs that is embedded in the product as a function of its age. REV starts at one at age zero and falls to zero during the full life span of the product. The indirect factors giving the rate of depreciation is such as the product's age, condition, and timelessness of design, and will be different for different products and markets.

Extrinsic factors such as the general state of the market, effects of marketing and brand associations, price and regulatory conditions, for example from public procurement criteria, can also influence the probability of reuse for the given product (Baxter & Callewaert, in press). The normalised REV function can take on several different shapes, depending on the identified depreciation rate. It can for example be a linear function, where the product lose value at the same rate for every given year, or it can decline at an accelerating pace, where the value is reduced with a percentage every year. Figure 4 shows examples of two normalized REV functions for a product with a potential lifespan of 20 years. For the solid line showing the linear function, the product emissions are divided equally between every year until age ten, thereafter each coming year the product is in use are not accounted for any emissions. The dashed line shows an accelerated depreciation where the product loses 20% of its value each year until reaching its full lifespan.

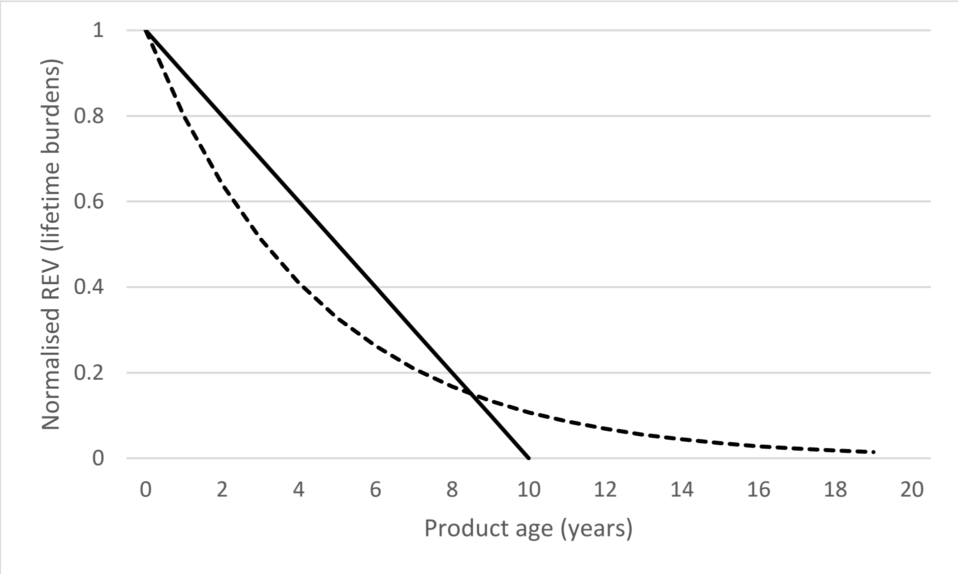

Figure 4: Examples of possible normalised REV functions if a product's lifespan is set to 20 years. The solid line shows a linear depreciation function over 10 years. The dashed line shows an accelerated depreciation function where the product loses 20% of its value each year. Figure based on Baxter & Callewaert (in press).

The normalised REV function is used to allocate the GHG emissions total from the product's lifetime to each year of its expected life. The benefit of this method is that it leaves no doubt about what environmental costs each actor should be given; it is the portion of total emissions associated with the period the actor is holding it. It also excludes a debated assumption that a reused product replaces a new product at a 1:1 ratio. The 1:1 assumption does not take into consideration that the new offset product also had a potential second life that should also be accounted for. The REV function avoids this problem by focusing on the function of the product rather than the product itself. Baxter & Callewaert emphasise this trait by stating that "reuse is actually concerning the full replacement of a partial life cycle and not the partial replacement of a full life cycle; the two are quite different" (Baxter & Callewaert, in press, p. 2).

3. Research method and materials

This study used mixed methods, including a start-up phase, data collection phase, data analysis phase, and a writing phase. These phases were iterative, rather than linear, allowing for saturation with the material. Both qualitative and quantitative research methods were used in this study. Quantitative methods involve measuring and counting. Qualitative research methods focus on gaining understanding or insights into a specific phenomenon or context (De Vaus, 2001, p. 10). The office space of Søndre Nordstrand borough (BSN) was used as a case study. The research design is presented in Figure 5. It shows how qualitative and quantitative methods were used to answer the research questions.

The start-up phase consisted of narrowing the scope of the thesis, research planning, meeting with the thesis supervisor, a literature review, and correspondence with members from the furniture industry and relevant actors in the case study (see section 3.4). Throughout the data collection phase, lists of relevant information were provided by employees at BSN and data was additionally collected via semi-structured interviews. Information on GHG emissions from furniture was gathered from furniture EPDs for the environmental analysis. The data analysis phase was two-fold and consisted of model and scenario building, an environmental analysis of GHG emissions and coding and analysis of interviews. Excel was the main tool used in the data analysis phase. Finally, the writing phase of this thesis was completed.

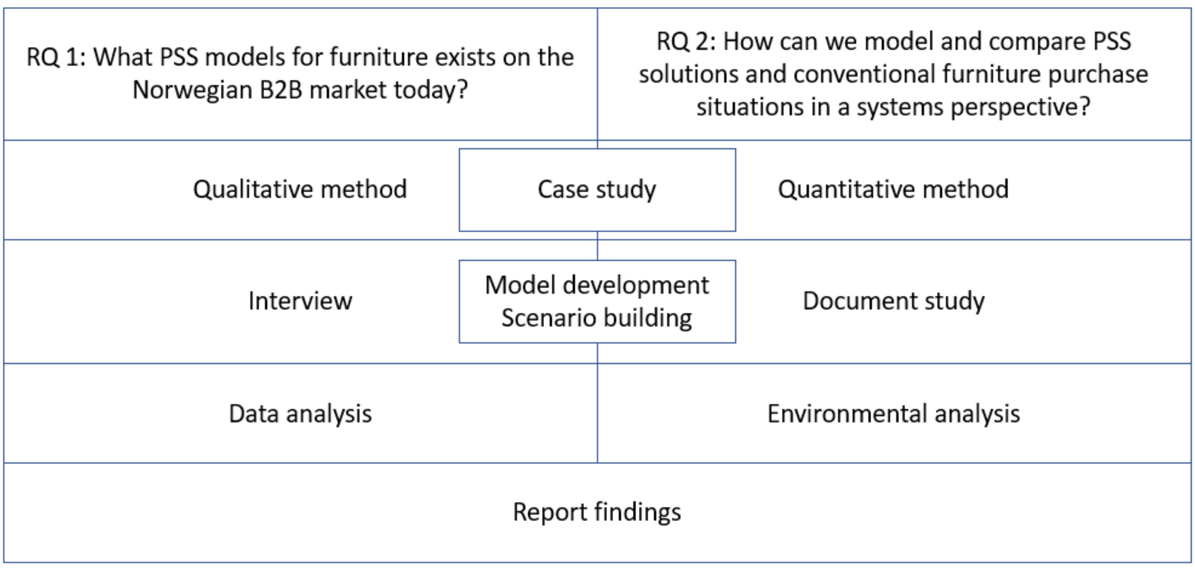

Figure 5: Visualisation of the research design for the study in relation to research questions (RQ). Visualisation based on Reppe (2021).

3.1. Start-up phase

The theme of PSS models and sustainability was brought to attention by the ongoing project on Producer Ownership Models tendered by the Nordic Council of Ministers (NCM). It is a collaborative project between research institutions in Denmark, Norway, Iceland, Sweden and Finland. The overall objective of the project is to demonstrate whether, when and how models of producer ownership can be both economically successful and environmentally beneficial in a Nordic context. PSS models for furniture were identified as an interesting topic in conversations with the thesis supervisor.

After narrowing the scope, a broad preliminary literature search was carried out to collect background information and become familiar with the subject. Google Scholar and Oria were used to search for terms such as "Product service system sustainability", "PSS furniture", "PSS sustainability", "PSS inventory", "PSS LCA", and "PSS office". This process led to Tukker's (2004)work on classifications of PSS models, which was chosen as a framework to structure identified PSS models for furniture.

Becoming better informed regarding the Norwegian furniture industry entailed a general search for Norwegian companies having offers that could be categorised as PSS. Offers were first identified through a Google search with Norwegian keywords for "furniture lease" (møbel leasing), "furniture rental" (møbelleie), "furniture reuse service" (service tilbud gjenbruk møbel/ brukte møbler) etc. Secondly, preliminary conversations were held with representatives for furniture companies, retailers and organisations involved in the furniture industry or with stakeholder interests. Approximately 50 companies were contacted by e-mail during the start-up process. Twenty-two informal phone calls and meetings, both physical and digital, were conducted in in order to make contacts within the furniture industry and gather information on providers and their activities in the furniture industry. In this process, contact with the Norwegian Institute for Sustainability Research (NORSUS), the Norwegian research organisation affiliated with the NCM project, and the Development and Competence Agency of Oslo municipality (UKE) was established. Designindustrien, the industry association for Norwegian design, brand and finished goods industries, including furniture, was also contacted and they suggested furniture producers to contact. This helped narrow the scope to PSS models for furniture in the business-to-business (B2B) and business-to-government (B2G) market, with a strong focus on possible environmental benefits.

A case study approach was chosen to frame and contextualize how PSS models for furniture could be environmentally beneficial. In conversations with the thesis supervisor and representatives from UKE, possible cases were evaluated. Søndre Nordstrand borough in Oslo municipality (Bydel Søndre

Nordstrand, BSN), was selected as a suitable case study and a starting point for an environmental analysis of PSS models (see section 3.4).

3.2. Data collection phase

The operations manager at BSN provided relevant information about the case such as furniture registrations and inventory lists, employee information, office space facilities, etc. Table 2 shows what types of information were provided and in what format. The information had to be sorted and adapted to the needs of this study. This information is presented in detail in section 3.4.

Table 2: List of information provided about the case organisation BSN.

Type of information	Format
Inventory registered in previous office buildings	Loopfront database, Excel files
Inventory lists for new furniture needs	Excel file
Lists matching furniture needs with reusable furniture	Excel file
Areal plans with furniture registrations (reuse and new) for the new office building	PDF files
Receipts for new furniture purchases	PDF files
Information about employees	Meeting and mail correspondance

The inventory lists, furniture information and employee information gave the basis for the quantitative environmental analysis. New furniture procurements had been made, but there was no available information about the GHG emissions attached to each furniture piece. Therefore, Environmental Product Declarations (EPDs) were used to find averages for the GHG emissions that are connected to each furniture group's lifetime.

EPD information from EPD Norge was used to set average GHG emissions. Eight main furniture groups were defined based on the registered furniture at BSN and a previous analysis of EPD information of furniture by Lauvland (2021). Table 3 shows the average GHG emissions for the analysed furniture product groups divided into the main life cycle stages, cradle-to-gate, end-of-life treatment and substitution effects. EPD averages collected by Lauvland (2021) were used for cradle-to-gate emissions when this had been gathered for similar furniture types, shown with a star in Table 3. For the lacking furniture product groups, EPDs for products within each furniture type were gathered, and the averages of these were used for the cradle-to-gate emissions. In the same way, emissions connected to end-of-life treatment and substitution effects were gathered. Detailed information about the EPD data used for each furniture category and life cycle stage is found in Appendix 1: GHG calculations from EPD information.

Table 3: GHG emissions in kg CO2eq for different life cycle stages for the analysed furniture product groups.

Furniture product	Cradle-to-gate	End-of-life treatment	Substitution effect	Cradle-to-grave Emission totals
Office chair*	68.1	16.7	-12.3	72.5
Working desk non-adjustable*	64.0	6.4	-4.8	65.6
Working desks adjustable	81.1	6.4	-4.8	82.7
Meeting chair, mixed material	16.3	4.8	-3.5	17.6
Meeting chair, wood**	9.7	5.6	-4.9	10.4
Meeting tables (2-4p)*	31.7	3.8	-3.5	32.1
Meeting table (6-12p)*	195.5	12.5	-2.8	205.1
Cabinets and shelves*	52.7	26.3	-3.7	75.3

* Estimates of cradle-to-gate emissions from Lauvland (2021).
** Average values for the models Duun and Modus stacking chairs by Helland Møbler AS (EPD-Norge, 2019a; EPD-Norge, 2019b) has been used as a best fit.

Eight semi-structured interviews were conducted with nine interviewees to collect data for research question 1. The interviewees were sorted into two main groups (Table 4). Group 1 consisted of interviewees from companies that provide PSS solutions for furniture. The participants of group 1 were identified through the initial literature search and meetings done in the start-up phase. A total of 15 people were asked to participate. Group 2 consisted of interviewees selected for their role in the case study or for their relation to public procurements and environmental criteria in the public sector. Group 2 were selected through the thesis advisor's guidance and the operational manager at BSN. BSN experienced turnover in staff between the time of the relocation process and the start of this research project. Both employees who had participated in the procurement process of new furniture had quit. This resulted in only the operation manager participating in interviews. The final number of 9 participants was also limited by time constraints.

Table 4: List of interviewees with work affiliation and job title.

Group	Interviewee letter	Affiliation
1	A	Furniture producer, manager
1	B	Furniture producer, founder
1	C	Furniture producer, manager
1	D	Furniture retailer, manager
1	E	External service provider for furniture, manager
2	F	Case study, manager
2	G	Public procurement, manager
2	H	Public procurement, advisor
2	I	Public procurement, advisor

One interview guide was made for each group (see Appendix 2: Interview guides). The interviewees were asked about their knowledge of PSS offers for furniture based on Tukker's general classification of PSS models.

All participant's signed a consent form stating the university's ethical clearance policy and the purpose of the project. The interviews were held digitally and recorded via Microsoft Teams. The interviews lasted from 40 to 65 minutes. The recordings of the conversations were stored in NMBU OneDrive behind password protection. The interviews were transcribed manually from the recordings.

3.3. Data analysis phase

The data analysis phase was two-fold. First, identified PSS solutions from literature were supplemented with in-depth information and practical examples given by interviewees. Second, a model framework and six scenarios (two baseline scenarios and four reuse scenarios) were developed to analyse possible environmental benefits of PSS solutions.

The transcribed interviews were coded and analysed based on an inductive thematic approach. In thematic coding, themes and sub-themes are identified after a thorough reading of the transcripts (Bryman, 2012). Common themes were identified and used to support the results of the thesis.

A model framework was developed to define and structure the environmental analysis. A systems perspective approach was used, based on LCA methodology of tracking inputs and outputs through a defined system. The system boundaries of the analysis were based on the case study's office building and is limited to the office areas designated to working desks and meeting rooms. The developed model is presented and described in section 4.2 Development.

Using the model framework, two baseline scenarios of furniture purchase situations, deemed to represent conventional purchasing, and four possible PSS scenarios were constructed. A total of 26 different scenario variations were constructed and analysed. The visualisations of the model and scenarios were drawn in draw.io. GHG emissions in kg CO_2-eq were calculated for each scenario using Excel.

3.4. Case Study and Quantitative Data Preparation

Søndre Nordstrand borough in Oslo municipality (Bydel Søndre Nordstrand, BSN), was used as a case study and a starting point for the environmental analysis of this study. The administration of BSN moved 300 employees from five different locations into a new town hall, situated at Holmlia Senter in the south of Oslo. In the process, the office workers went from mainly having cell offices, to a new work environment with open plan offices adopting an activity-based office layout. This means that employees are not assigned to a particular workstation but choose where to work based on what kind of work environment they need. This requires designated quiet sones, group work areas and different kinds of meeting rooms (Arundell et al., 2018).

It was a wish to move and reuse as much of the old furniture as possible in this process. A digital platform by the company, Loopfront, was used to register the existing furniture in the buildings (Loopfront, 2022). Over six months, BSN employees mapped existing furniture and defined new interior needs with the help of interior designers. Staff at BSN compared the lists of registered furniture to the furniture needs in the new office building to determine which furniture to relocate. The moving process was finished in February of 2022.

The case has two main features making it particularly interesting for analysis. First, the co-location process could be highly relatable to other municipalities and businesses going through merging and relocation processes. Second, the registration of furniture in the old office buildings could provide a basis for analysing the reuse potential in a specific office building. Since the process was already executed, the data could give insight on what furniture was thought preferable to directly reuse by BSN. The case could then be used as a basis to explore how PSS solutions can create different scenarios for reuse.

3.4.1. Inventory lists

The furniture registrations for each building were exported from Loopfront's online platform into excel files to group and sort the different furniture registrations. A total of 777 furniture pieces were registered as left in the old buildings. The analysis is limited to the eight furniture categories: office chairs, working desks (non-adjustable and adjustable), meeting chairs (mixed materials and wood), meeting tables (small and large) and cabinets and shelves. Registrations of other objects such as mirrors, paintings and lamps, as well as sofas, room dividers and kitchen utilities were excluded from the selection. This left a total of 731 items for further analysis.

The inventory lists compiled by BSN were not fully updated. Furniture registrations for some office areas both in the old buildings and the new building were lacking. In the old buildings, some areas were not registered due to strict privacy policies, for example in the former child welfare service offices. The operations manager at BSN assumed a similar office building in size and number of employees had the same kind of furniture inventory. Therefore, this registration was duplicated for the child welfare service offices.

In the new building, furniture in social zones such as lounge areas or sitting groups were not registered at the time of the data gathering. Therefore, the inventory list used in this study is limited to the office spaces and furniture used for areas designated for working desks and meeting rooms.

The lists of furniture from the old buildings were combined with the list of reused furniture in the new building to make up the old furniture total. Table 5 show the totals of furniture items grouped by furniture type.

Table 5: Grouping of furniture items registered in the previous office buildings.

Furniture type	No. Of items
Office chairs	166
Working desks, non-adjustable	68
Working desks, adjustable height	98
Meeting chairs, mixed	325
Meeting chairs, wood	208
Meeting tables, 2-4 seats	160
Meeting tables, 6-12 seats (=/>120x200cm)	6
Cabinets and shelves	493
Total	**1524**

Meeting chairs is the largest furniture category of 35% when the categories wood-based meeting chairs and meeting chairs of mixed material are combined. Cabinets and shelves make up the second largest furniture group with 32%. Very few large meeting tables were available, only 6 tables with measurements from 120X200cm or above were registered. The age of the furniture is not registered by BSN. The manager at BSN assumed the furniture to be anywhere between five and 20 years old. To calculate the remaining emissions based on the residual environmental value (see section 2.4.3), the average age of 7.5 has been chosen for all furniture categories.

3.4.2. Reuse of furniture

A list was compiled of furniture that had been moved from the old buildings and registered in the areal plan of the new buildings. Table 6 shows the total amount of reused furniture sorted by furniture type. This made up the share of reused furniture in the reuse scenarios.

Table 6: List of furniture from the old buildings that were reused in the new office building

Furniture type	No. of reused items
Office chairs	105
Working desks, non-adjustable	42
Working desks, adjustable height	71
Meeting chairs, mixed	220
Meeting chairs, wood	0
Meeting tables, 2-4 seats	24
Meeting tables, 6-12 seats (=/>120x200cm)	2
Cabinets and shelves	65
Total	**529**

Based on expert opinions from interviews, it was assumed that 30% of the old furniture could be reused if repairs were added. This estimate was matched with the furniture needs in the new building and used in a reuse optimalisation scenario in the environmental analysis (See Appendix 3: Calculations of reuse potential for calculations).

3.4.3. Space and furniture need per employee

Number of employees and how much they use the office space are important factors that influence both furniture needs and needed office space size and utilities. The case study's number of employees and their work habits set the basis for the analysis. Two main groups of employees were identified, employees primarily working in the office building and employees mostly working off-site, for example in cleaning services or mobile healthcare services. These two groups have different office use frequency and corresponding intensity of furniture use. This influence the overall utility rate of the office, meaning to which extent the office is utilized as a percentage of maximum capacity. Therefore, each group was designated a use factor as shown in Table 7. The first group called Full time office workers were assigned the use factor 0.9, meaning it is assumed they spend 90% of their workdays in the analysed work areas. The second group, Drop-in employees, are employees mainly working off-site. They are assumed to use the office space 20% of the time, corresponding to a use factor of 0.2. This results in a 100% utility rate for the office if scaling the office space and furniture needs to correspond to 228 employees using the office space 100% of the time during core workday hours.

Table 7: Groupings of employees and assigned use factor used in the analysis deducted from the case study at BSN.

Employee group	No. of employees	Use factor	Use of office space
Full-time office workers	240	0.9	216
Drop-in employees	60	0.2	12
Totals	**300**		**228**

However, monitoring of office use often shows that office workers use their workplaces far less than 90%. The American multinational engineering firm AECOM surveyed workspace usage from 500 offices in 27 countries. Their observations revealed that on average, 40% of workplaces are empty during core work hours. There are some variations across different sectors and geographies, but the occupancy levels are generally low for all sectors (Whitehead & Gillen, 2021). In a similar study, the Norwegian research centre SINTEF found that working desks were empty 60% of the time, while the rest of the workday is spent elsewhere (Blakstad & Hatling, 2007). This corresponds to use factors of 0.6 and 0.4. A slightly higher use factor than the measured workplace activity requires ensures that there are workstations for everyone, also at busy days. A realistic but space efficient measure would therefore be to adjust the use factor of the full-time office workers from 90% to 70%. In practice, this meant instead of offering workplaces for 228 employees to share at any given time during core working hours, both furniture needs, and use of space were reduced to fit the needs of 180 employees, as shown in Table 8. This change would make it possible to reduce the office space designated to working desks and meeting rooms.

Table 8: Heightened use efficiency by changing the use factor for full time employees from 0.9 to 0.7

Employee group	No. of employees	Use factor	Use of office space
Full-time office workers	240	0.7	168
Drop-in employees	60	0.2	12
Totals	**300**		**180**

Since it is office space furniture that is the focus of this study, it is logical to limit the analysis to the areas in which this furniture is situated. The total office space of BSN is 3365 m2, while 2144 m2 is designated for working desks and meeting rooms. This means 64% of the total office area is analysed in this study, which is 7.1 m2 per 300 employee, or 9.4 m2 if dividing by the user factor total of 228 found above.

Table 9 shows the amount of furniture that is found when dividing the furniture totals from BSN's inventory list by the total number of employees and the user factor total of 228. The numbers show that BSN already scaled the amount of office inventory down to match their employees not all being in the office at the same time. For example they did not designate one office chair and desk to each and every office worker.

Table 9: Furniture totals and averages per employee at BSN.

Furniture type	Furniture totals	items/300 employee	items/use factor of 228
Office chairs	235	0.78	1.03
Desks non-adjustable	42	0.14	0.18
Desks adjustable	193	0.64	0.85
Meeting tables (2-4p)	31	0.10	0.14
Meeting tables (6-12p)	25	0.08	0.11
Meeting chairs	293	0.98	1.29
Cabinets and shelves	94	0.31	0.41
Total	**913**	**3.04**	**4.00**

3.4.4. Allocation of GHG emissions

The GHG emissions from furniture consumption needed to be allocated between several user phases in the analysis. The allocation method proposed by Baxter & Callewaert (in press) of allocating emissions based on the Residual Environmental Value (REV) of furniture was selected as a way of portioning the emissions related to the cradle-to-gate emissions of furniture (see section 2.4.3). To use this method, a REV function for furniture must be established, based on the monetary value of furniture. This was done by collecting data from Finn.no, the largest online marketplace for second-hand products in Norway.

A total of 130 product adds were examined, and 73 products were able to be given a specific age, either from information in the product description or by asking the seller. The selling price for the same products was collected from online price lists. If the exact product model was no longer for sale, a similar model from the same company was used as a replacement. The initial best fit for price fall being a function of age was y = -0.0085x2 + 0.1067x + 0.342 with R^2 = 0.3246. There were only three data points for ages over six years. The three data points had great varieties in price fall, making them unreliable in setting a trend line for older furniture. Therefore, they were excluded from the selection. Two more outliers were excluded where the values deviated abnormally from the rest. In total, five outliers were excluded.

Excel was used to find the best-fitting regression line with the highest coefficient of determination, R^2. Figure 6 shows the collected data and the trendline for the best-fitting function f(x) = 0.0669x + 0.3657 where x is the furniture age. The R-squared value is an expression of how much variation is in the collected data around the ideal curve given by the model. In this case, R^2 = 0.4047, meaning the model explains 40% of the variability of the dependent variable around its mean. This indicated that factors other than the age of the furniture also influenced the price fall.

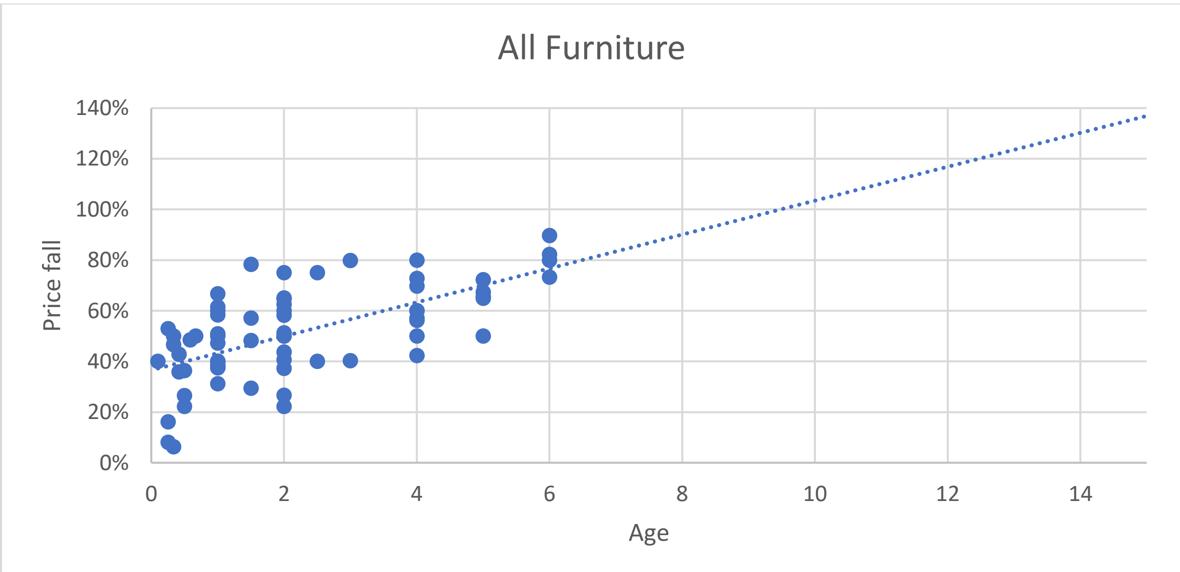

Figure 6: The price fall of furniture data from Finn.no as a function of the furniture's age.

The linear function was then used to allocate the cradle-to-gate emissions. The function shows a sharp decrease in value of furniture just by changing hands, where the price falls with 37% between year zero and one. After this, the price falls with the same amount per unit time until year 10, when all the emissions has been accounted for. Table 10 shows the percentage of the emissions total that was given to each year of a furniture's expected lifetime.

Table 10: The percentage of the emissions allocated to specific years in the furniture's lifetime.

Furniture age (years)	Emissions (% of total)	Remaining burden (% of total)
0-1	37%	63%
1-2	7%	56%
2-3	7%	49%
3-4	7%	42%
4-5	7%	35%
5-6	7%	28%
6-7	7%	21%
7-8	7%	14%
8-9	7%	7%
9-10	7%	0%
10-11	0%	0%
11-12	0%	0%
12-13	0%	0%
13-14	0%	0%
14-15	0%	0%

Finally, the cradle-to-gate emissions are not the only emissions related to the life cycle of furniture. Emissions from repairs and final disposal once the owner decides to discard it, must also be accounted for. The emissions from repairs are allocated to the first year of use after the repair has been done. The emissions from waste treatment, including the substitution effects, are allocated to the year when the furniture is discarded.

3.4.5. Repair and service needs

Repair and service needs for furniture can vary greatly. For this to be included in an environmental analysis, emissions associated with different types of repairs and frequency of repairs must be determined. Literature reviews have not resulted in quantitative data on the emissions associated with repairs, nor an estimate for the frequency in which such repairs must be added. Therefore, general assumptions have been made by asking for estimates from several actors in the furniture industry, combined with data from Norwegian EPDs.

Details from EPDs by the furniture companies Flokk and NCP made it possible to isolate CO_2 emissions associated with the production of armrests, headrests, and upholstery of office chairs (EPD-Norge, 2018a; EPD-Norge, 2019c; EPD-Norge, 2019d). Table 11 presents the specific and average emissions for the production of these furniture parts. It was found that the emissions from a full replacement of upholstery can account for as much as 38% of the emissions from producing a chair, while only changing the fabric for the back pad can be as low as 5% of the furniture's emissions. The average emissions from fabric and upholstery are found to be 19% of the total emissions of the furniture item. Changing an armrest is equivalent to around 6% of the chair's emissions, while changing the headrest accounts for approximately 12%. Associated emissions of other parts suitable for repairs, such as gas lifts, castors, foot bases etc. was not possible to isolate through literature or EPDs. Due to the lack of more specific data on this matter, averages are used in further analysis.

Table 11: Emissions in kg CO2eq associated with the production of different furniture parts (EPD-Norge, 2018a; EPD-Norge, 2019c; EPD-Norge, 2019d).

Furniture part	Producer	kg CO2eq/part	kg CO2eq total for chair	% of total from furniture part
Armrest	Flokk	5.5	79.8	6.9
Armrest	Flokk	5.5	79.8	6.8
Armrest	Flokk	5.1	79.8	6.4
Armrest	NCP	2	14.3	14.0
Armrest	Flokk	9.5	87.4	10.8
Armrest average		**5.5**	**68.2**	**9.0**
Headrest	Flokk	9.5	79.8	11.9
Headrest	Flokk	10.3	79.8	12.9
Headrest average		**9.9**	**79.8**	**12.4**
Full upholstery	NCP	11	29	37.9
Fabric back pad	NCP	1	19	5.3
Fabric seat pad	NCP	3	21	14.3
Upholstery average		**5**	**23**	**19.2**
Average all furniture parts		**6.2**	**57.0**	**12.7**

The variety of possible repairs and remanufacturing needs that can occur for different types of furniture, combined with the highly individual need for repairs due to differences in habits of use, makes an argument for the overall need of repairs to be highly case and user specific. Historic data of service needs from similar offices could give estimates for the analysis. However, it was not possible to obtain such data. Therefore, several professionals in the furniture industry who work with furniture repairs and/or reuse of furniture were asked for their assumptions about the need for repairs of main furniture groups (G Enger-Ullbråten 2022, personal communication, 6 April; SJ Moen 2022, personal communication, 15 May; LE Sikkeland 2022, personal communication, 25 May; I Skogheim 2022, personal communication, 2 June). The overall opinion was that the furniture's service life could be more than doubled by professionally executed repairs. In the further analysis, the life expectancy of furniture with repairs will therefore be 22.5 years. Based on the EPD information gathered in Table 11, an overall average of emissions was set for each furniture type as summarised in Table 12. Emissions from repairs of upholstered chairs was set to be 13% of the production of the furniture item. It was assumed that 15% of upholstered furniture will need repairs when supplied through external reuse, regardless of age (G Enger-Ullbråten 2022, personal communication, 6 April; SJ Moen 2022, personal communication, 15 May; E Sagen 2022, personal communication, 20 May; LE Sikkeland 2022, personal communication, 25 May). It was assumed that 30% of working desks need to change desktops when supplied through external reuse, regardless of age. This corresponds to approximately 26% of the desk's emissions, given through EPD information. It was assumed that meeting tables and storage units will have a lower need for repairs than working desks, thus it was assumed that 15% will need repairs when supplied through external reuse, regardless of age. It was also assumed smaller fixes and changes of parts will be needed, therefore the same emissions for repairs were used as for chairs, i.e., 13% of the furniture's total emissions. Tightening of screws and gentle cleaning is thought to be needed, but these maintenance services are assumed to be done internally and have neglectable CO_2 emissions.

Table 12: Summary of assumptions regarding repair needs and emissions associated with average repairs for the analysed furniture product types.

Furniture product	**Estimated repair need [% of total no. of furniture]**	**Added emissions from repairs [% of cradle-to-gate emissions]**
Office chairs	15%	13%
Working desks non-adjustable	30%	26%
Working desks adjustable	30%	26%
Meeting chair, mixed material	15%	13%
Meeting chair, wood	15%	13%
Meeting tables (2-4p)	15%	13%
Meeting table (6-12p)	15%	13%
Cabinets and shelves	15%	13%

3.4.6. Emissions from energy use

The case study building is a new shopping mall and office building from 2021. Because of the covid-19 outbreak, the office space of BSN cannot be assumed to have had a year of normal energy use. For this reason, general numbers for the average energy use in office buildings has been used. Average energy use in office buildings newer than 2009 is found to be 156.4 kWh/m2/yr (Enova, 2021). This energy use might be higher than what the BSN offices will require, it being a new building with high energy efficiency standards (Eiendomswatch, 2021; Enova, 2019).

75% electricity and 25% district heating is the most commonly used energy mix in office buildings (Enova, 2016). The emissions from Norwegian electricity is set to be 0.017 kgCO2eq as given by NVE (2019). Average emissions from district heating is calculated to 0.011 kg CO2eq/kWh based on information by the district heating supplier Fortum (Fortum, 2021). This gives a weighted total of

0.016 kg CO2eq/kWh, presented in Table 13. With basis in 156.4 kWh/m2 as yearly energy use this equals 2.42 kg CO2eq/m2 per year from the energy use of an average office building.

Table 13: Calculations of emissions in kg CO2eq/kWh for the typical energy mix used in Norwegian office buildings.

	Weighting	kg CO2eq/kWh
Electricity	0.75	0.017
District heating	0.25	0.011
Energy mix total		**0.016**

3.5. Reliability and validity

Reliability is related to whether the study design will deliver the same results if the study is repeated (De Vaus, 2001, pp. 28-30). In interviews, poorly phrased questions can result in the interviewees answering the same question differently at different occasions. The interview guides are included in the appendix so that another study can be repeated using the same questions.
The quantitative analysis of GHG emissions have been conducted following stated allocation rules with values added throughout the text and in the appendix. This provides a basis for replicability and comparison to other similar studies.

The validity of the study is linked to its research design and to what extent it is possible to draw unambiguous conclusions from the results and generalize from the case itself to other similar cases (De Vaus, 2001, pp. 28-30). The low number of interviewees reduce the validity of the study. The interviews were used to verify, and supplement identified PSS offers. The interviewees are not thought representative for all PSS providers in Norway. There might exist PSS offers for furniture that this study has not been able to identify. The case study of BSN is central to the research design. The case is thought to be representative for similar relocation processes of this size, especially in the public sector. It is uncertain if the results of the study can be generalized to other countries. There might be conditions in the case study or the furniture market that are endemic to Norway.

4. Results

Identified PSSs for furniture on the Norwegian B2B and B2G market will be presented. Next, the developed model framework and method for assessment of PSS will be described, after which two baseline scenarios and four reuse scenarios implementing different PSS solutions will be presented. Finally, the results of the environmental analysis of GWP for the scenarios will be presented and analysed.

4.1. PSS models on the Norwegian B2B market

The classification system by Tukker (2004) described in section 2.3 was used as a basis for a systematic study of PSS models identified for furniture in the Norwegian B2B and B2G market. Data from interviews with multiple furniture company representatives, the case study, and public procurements were used to confirm and supplement initial findings from literature. Figure 7 shows an overview of the identified PSS offers in this study. In the following sections, the identified PSS offers will be described following the structure of Tukker's classification system.

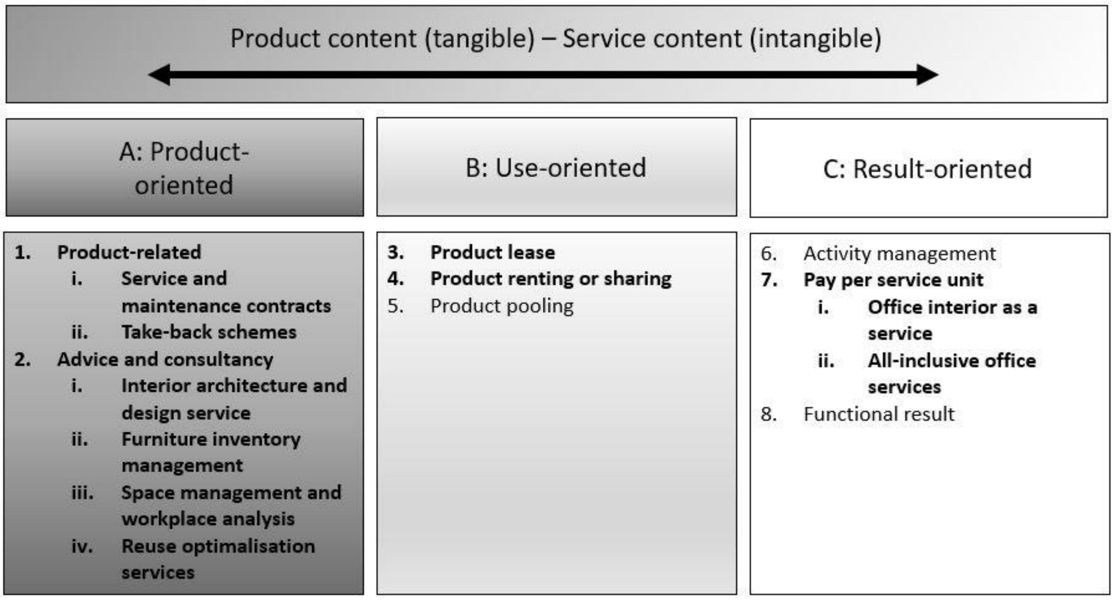

Figure 7: Tukker's (2004).classification of PSS with identified offers for furniture in bold letters.

4.1.1. Product-oriented PSSs

Product-oriented PSSs are divided into two main sub-categories: product-related services and advice and consultancy services (Tukker, 2004). First, product related services are provided together with a furniture purchase. Two product-related services were identified, including service and maintenance contracts (category 1i) and take-back schemes (category 1ii). Second, advice and consultancy services include services attached to furniture purchases and services offered by external providers. This is a broad category with many different types of offers. It was therefore seen as advantageous to further divide these offers into specific focus areas.

The four main sub-categories of advice and consultancy services identified are as follows: 1) Interior architecture and design services (category 2i), which recommend an overall plan for a company's inventory; 2) Furniture inventory mapping (category 2ii), which focuses on giving an overview of the company's existing furniture stock; 3) Space management and workplace analysis (category 2iii), which optimize the office space as a whole; and 4) Reuse optimalisation services (category 2iv), which combine furniture inventory mapping with advice on optimizing the reuse of existing furniture. The following sub-chapters describe the identified offers in more detail.

Service- and maintenance contracts

Service and maintenance contracts (category 1i) are on-site services included in furniture purchases or added in addition to furniture purchases. This includes minor fixes, deep cleaning of upholstered textiles, or surface treatments such as oiling. The offer is often a yearly service or a customized offer. More extensive repairs or refurbishments involve specialized knowledge and must be done off-site. The service is offered both by furniture producers such as Slettvoll and Martela and by retailers such as Holmris FormFunk and Lindbak. It is promoted as a way for the customer to prolong the furniture's lifetime (Lindbak, 2021).

Take-back schemes

Different take-back services (category 1ii) on the market can be executed in different ways. Two main distinctions between take-back schemes have been identified. On one hand, several of the interviewed furniture companies offer to remove unwanted and obsolete furniture when new furniture is delivered. If the contract includes a total order of furniture as part of a relocation or renovation process, the contract often involves a "cleaning out" of the office space in question. In this case, the distinction between furniture originally from the service provider or from another provider is not made. On the other hand, in new purchasing contracts, the contract can state that the furniture provider only takes back their own furniture, if the furniture becomes obsolete.

What happens to the obsolete furniture is determined on a case-by-case basis. The interviewed representatives from companies offering this service consider selling the used furniture either though their own channels or collaborating companies. For example, the retailer Holmris Form/Funk is part of a donation network where obsolete but useable furniture can be donated (Form/Funk, 2022). Collaborations with companies that specialise in selling used office furniture, such as Movement and MøbelMeglerne were mentioned by representatives from several companies.

Providers may also offer a discount on new furniture if a customer returns old furniture from the same company (IKEA, 2022; Ope, 2021). In both cases, the returned furniture can either be resold as second-hand furniture, be dismantled for spare parts, or be recycled for material recycling or energy production.

Interior architecture and design services

Interviewed representatives from both the supply and the demand side saw the conceptualization and advice from interior architects and interior designers as important additional services to furniture purchases, especially for larger interior projects. Interior architecture and interior design are terms, often intertwined, for the aesthetic design of indoor space. However, interior architecture often refers to a building's structural aspects, while interior design involves planning, equipping, and furnishing already existing interior spaces (White, 2009). Both furniture producers with direct sales, resellers, and external service providers offer interior architect and design services. The interior architect or designer may set requirements for the interior purchases that can affect whether other PSS solutions are considered good options for the project or whether reuse of furniture is favourable.

Furniture inventory management

The majority of the interviewed PSS suppliers had offers falling under furniture inventory management (category 2ii), which entails fully mapping a company's inventory. It requires an inventory management system where all information about furniture location, producer, age, and state of the piece are added and updated. QR-codes or radio-frequency identification (RFID) tags are added to the furniture, allowing the user to scan a particular piece and anchor information about the piece to the physical object and the inventory management system. An added feature described by several interviewees is to link the inventory management software to a service and maintenance contract, so that repairs and faults on furniture can be easily executed. Keeping a large furniture park organized can be handled through this system (Lindbak, 2021; Martela, 2021a).

A closely related offer uses digital platforms for furniture inventory mapping, where the goal is to offer the customer a tool to optimise reuse of furniture and connect with possible buyers and sellers. One example of such a platform is provided by the company Loopfront. Loopfront started out as a reuse platform for building materials but has further developed into a system that is similar to an inventory management system. Each user has an online account where materials and inventory are added to a database with pictures and descriptions. The user decides how detailed the information will be. The platform can function collaboratively where used materials and furniture are made available for other platform users, or it can function as a private internal inventory management system. It also provides features such as making reports on financial saving, CO_2, and waste based on the user's gathered information or averages from Loopfront's database (Loopfront, 2021).

Space management and workplace analysis

Space management (category 2iii) is broader than furniture inventory management, as it involves managing and optimizing a company's physical space, not only the inventory (Guofeng et al., 2020). In this paper, workplace analysis is used as a broad term for the services offered by the interviewed companies to gather information about the actual use and needs at their customer's office space. The services can involve using sensors to record how frequently different working areas are used. For example, infrared sensors can be placed under chairs or tables in meeting rooms, social zones, or at work desks to record how often and for how long they are used. It can also involve surveying the company's employees about their experiences using the current facilities and inventory. The goal of the analysis is to ensure good decisions about new furniture purchases and possible inventory rearrangements that will optimize the work environment.

Several companies provide furniture mapping and workplace analysis in combination with advice and execution of repairs and reuse of the customer's furniture. These PSS solutions are categorised as reuse optimalisation services, as described in the following sub-chapter.

Reuse optimalisation services

Reuse optimalisation services (category 2iv) assess the customer's existing interior, give advice on what furniture pieces to repair and/or refurbish, and execute the agreed upon services. The goal for the customer is to have both an economic and environmental gain by delaying the need for new furniture investments. This service can be offered by furniture manufacturers and retailers when combined with a contract on new furniture procurements. External consultancy firms that specialize in reuse or remanufacturing of furniture also offer this service, as well as interior architects when they plan the interior on behalf of the customer. The offers falling under this category are often combined with other PSS offers and will vary depending on the service provider's business model. Identified suppliers of these kinds of offers are Re:Inventar, GoGood, Martela, Lindbak, Holmris FormFunk, Kinnarps and Input Interior. For example, Re:Inventar and their collaborators work case-by-case to give consultancy and complete inventory solutions that focus on reuse, repairs, and refurbishments. They use a digital platform that, not unlike Loopfront's system, matches furniture with production information and environmental information, so that this information can follow the furniture through its user phase (LE Sikkeland 2022, personal communication, 8 February).

4.1.2. Use-oriented PSSs

Tukker (2004) characterized use-oriented PSSs as solutions where the product ownership stays with the service provider while the customer pays for the product’s use within the contract period. Through literature and interviews, furniture leasing and furniture rental were identified as use-oriented PSS models for furniture.

Furniture leasing

Furniture leasing lets the lessee preserve their liquidity by breaking the expenses related to the furniture into smaller regular instalments (Ikano Bank, 2021; NorEngros, 2021). While leasing contracts and types differ, two end goals were identified throughout this study. First, customers may intend to buy the product at the end of the lease period. This typically involves a leasing bank who have ownership rights over the products. By the end of a leasing period, the lessee normally has three options. The first option is to purchase the furniture for a set amount, often equal to one- or two-month's instalment of the leasing contract. The second option is to continue the tenancy at a greatly reduced rent. The third option is to terminate the contract and deliver the furniture back to the leasing company (Finfo, 2021). If the end goal of the leasing is for the lessee to gain full ownership of the furniture by the end of the leasing period, it can be argued not to be a use-oriented PSS model, but rather a product-oriented financing scheme.

While conversations with leasing banks and furniture providers offering leasing implied that buying out is by far the most common (MS Bentzon 2022, personal communication, 12 April; G Enger-Ullbråten 2022, personal communication, 6 April; E Hallquist 2022, personal communication, 11 April; AGS Melleby 2022, personal communication, 11 April), there are also leases where the goal is to have user access to the product without gaining ownership of it. The lessor most often provides additional services or offers that follow the product, and the lessee returns the product to the lessor after the agreed upon lease term. The contracts are typically shorter than the expected lifetime of the product. For example, the company Slettvoll actively promotes taking furniture back at the end of leasing contracts. However, Slettvoll does not lease typical office furniture, but instead started leasing high-end furniture in the B2B. The offer is new as of May 2021 and no takebacks have happened yet (KF Gati 2022, personal communication, 23 March).

Furniture Rental

With furniture rental, the customer does not have unlimited access to the furniture, and the furniture can be used by other customers at other times (Tukker, 2004). Companies offering furniture rental set a monthly price for the use of the furniture, with a contract outlining the length of the rental period and how the furniture must be returned (G Enger-Ullbråten 2022, personal communication, 24 January; E Sagen 2022, personal communication, 28 January). Rental of office furniture is a more common option for clients who need flexible solutions for short periods of time. Companies specializing only in furniture rental for office spaces have not been identified, but several companies offer furniture rental as part of a larger service package, more in line with result-oriented PSS models. The identified offers of larger furniture inventory subscriptions are described under 4.1.3 result-oriented PSSs.

4.1.3. Result-oriented PSSs

Results-oriented PSSs for furniture shift the focus from the product itself to the furniture’s function (Besch, 2005; Tukker, 2004). The focus falls more towards workspace functionality and highlights that furniture essentially supports a good working environment. All the identified result-oriented PSS solutions fall under Tukker's pay per service unit-category, where the price is set per person or as a total sum per month. The difference between the identified offers is connected to the scale in which the services are provided. Therefore, the offers are divided between office interior as a service and all-inclusive office services.

Office inventory as a service

Office inventory as a service entails paying for the results of a functioning office interior rather than the furniture pieces themselves. The office interior is provided as a flexible furniture subscription that can be tailored to fit the customer. Four offers of this kind have been identified, by the companies Martela, Re:Inventar, GoGood and Lindbak (Martelas WaaS, Lindbak's "Smidig kontor", GoGood's Good Work).

The office furniture is provided as a pay-per-unit service, or a monthly subscription fee, based on the provided furniture inventory list. The furniture company Martela, for example, shows the subscription costs as a monthly fee per employee based on dividing the inventory list total onto the number of employees. If the customer wants to subtract or add furniture or services to the list, the monthly fee is reduced or increased, respectively. At the start of the contract period, the customers' needs are mapped through a consultation. This is often combined with a workplace survey or a monitoring of the existing office space use. Based on the initial gathered data, the supplier suggests a suitable workplace design (GoGood, 2020; Lindbak, 2022; Martela, 2021b).

The customer's existing inventory can be integrated into the PSS offer. This involves furniture inventory mapping and consultancy on what furniture should be kept, what can be repaired, and what should go to material recycling. The service provider then executes the suggested measurements that the customer wishes to implement. The supplementary furniture can be all new furniture, reused furniture, or a mix, depending on the service provider's offer and available furniture pool. For example, Martela's Workplace as a service-subscription has primarily new furniture in the subscription, but they can take used furniture into the subscription if their customers wish (I Bucher 2022, personal communication, 15 June). Alternatively, GoGood's Good work-subscription has reused furniture as the basis of their furniture stock, but new furniture is added if needed to fulfil the customer's needs (GoGood, 2021).

All-inclusive office services

All-inclusive offices are here defined as all-in-one solutions for office spaces where IT, furniture, reception employees, and other administrative tasks are managed by the facility management company instead of the tenants. In the last few years, numerous such offers have been launched on the Norwegian market under names such as office hotels, flex office, coworking spaces, flexible workplaces, and serviced offices (Lundgaard, 2022).

The concepts and variations in these offers are many, but flexibility and short leases are key features for all. The offers vary from renting one desk to whole floors for company customers with over 100 employees (Wework, 2022). The customer can quickly scale up or down the number of office spaces they rent. Both individuals and companies have access to meeting rooms, social zones, and common areas. At the smallest scale, one person can pay a monthly fee for a dedicated desk or use available desks on a first-come, first-served basis, referred to as hot-desking. Larger companies, wanting whole sections of the building to themselves, are offered more customizable solutions regarding office space design and inventory choices. International Workplace Group (IWG) is the world's largest provider of flexible workplaces with eight million customers worldwide. They are present in four Norwegian cities with the chains Spaces and Regus. Other major actors are Evolve, Mesh and WeWork. Large Norwegian real estate companies such as Thon, Aspelin Ramm and Høegh are also investing in the concept (Lundgaard, 2022).

The concept incentivizes the service provider to think of furniture as part of a functioning package and to choose furniture with a long service life. Interviews indicated that all-inclusive office providers outsourcing, or leasing, furniture is practiced. In such a case, the inventory is provided from a furniture company as a service to the all-inclusive office company, providing flexible inventory solutions for their tenants. Moreover, the tenant only has one service provider to correspond with for their office space and supporting functions (Lundgaard, 2022).

4.2. Development of a systems model for analysing PSS solutions for furniture in a life cycle perspective

A suitable model framework for assessing PSS solutions for an office building was not available. Therefore, a goal of this study was to develop such a framework. The suggested framework is based on the LCA method, setting a boundary as to what inputs and outputs must be included in an analysis of the defined system.

A specific office space in m2 with a given number of employees is the focus point of the model. A time aspect has been included, divided into three periods: P1, P2, and P3 of five years each, setting the total analysed period to 15 years. This corresponds to setting a functional unit equal to *Office space for X number of employees for XX years with necessary area and furniture solutions.* This made it possible to compare different alternatives that all fulfil the same functional unit. The time period and number of employees can be aligned with the defined needs of the study. The functional unit itself will be changed in the assessments, due to changes in need of workspace per employee between different scenarios.

The office space is represented by a three-dimensional box, B_N, in the models (Figure 8). The number of employees who use the office space in the given time periods P1-P3 influence the needed area of office space and the number of furniture items required in each period. The arrows in the diagram represent the mass flows of furniture units in and out of the office space B_N. The model can therefore be used to assess units, tons, or economic value of furniture in and out of the system. The furniture can come from three main sources: externally supplied new furniture, externally supplied reused furniture, or internally reused furniture. The three furniture supply options are each represented by their own colour. New furniture will always come in from an external source. Internal furniture reuse indicates that the furniture has been used in the same organisation and is therefore supplied through an internal market. Externally reused furniture indicates that the furniture had a previous user phase outside of the organisation. For both internally and externally reused furniture, it is expected that the furniture passes through service steps where repair needs are evaluated and executed before the furniture enters B_N. For all three furniture supply options, an exchange of furniture in and out of the studied system can happen throughout all periods and at any given time, shown by the arrows in and out at the top of the model. The arrows going out from the bottom of the model represent furniture going to waste treatment. This happens when the furniture has reached its life expectancy and is too damaged to be considered for repairs. It can also happen before the furniture has reached its expected age, for example if the owner decides to send furniture to waste treatment instead of finding a new owner.

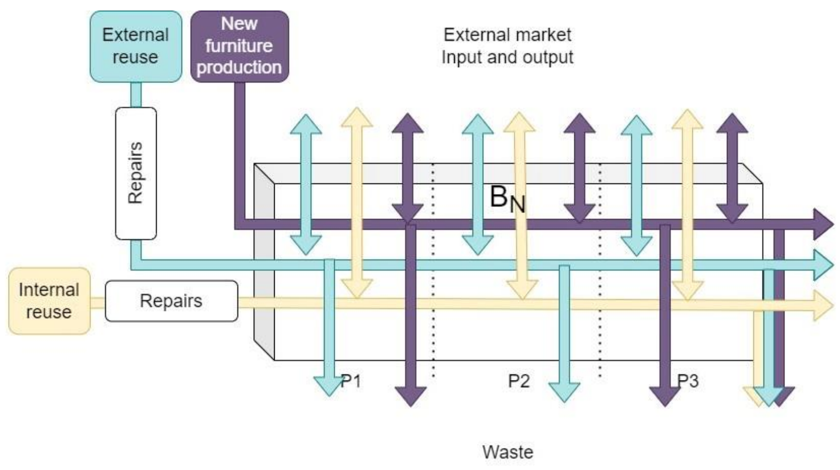

Figure 8: Visualisation of the office space as the box B_N, with furniture consumption represented by the arrows.

In a system where reuse occurs, B_N is connected to other organisations, represented by B_{N-1} and B_{N+1} (Figure 9). The flow of internally reused furniture from B_{N-1} to B_N can represent furniture reuse from a previous location if the organisation has moved to a new building. Acquiring furniture through external reuse means the furniture is bought, rented, or leased through a source outside of the business in question, in the open market.

If a piece of furniture is no longer wanted by B_N, the furniture can either be discarded as waste, be reused internally in the organisation, or be reused by external organisations. The need for repairs can vary greatly from one situation to the other, but information about repair history or previously exchanged parts can be incorporated into the model. The repairs and remanufacturing services can be added as a process step that prepares the furniture for reuse at B_N. Reuse or remanufacturing processes done throughout period 1-3 to prolong the user phase of the furniture are not included in the model. At the end of the 15-year period, the furniture at B_N either goes to waste treatment or goes to a new user phase represented by B_{N+1}.

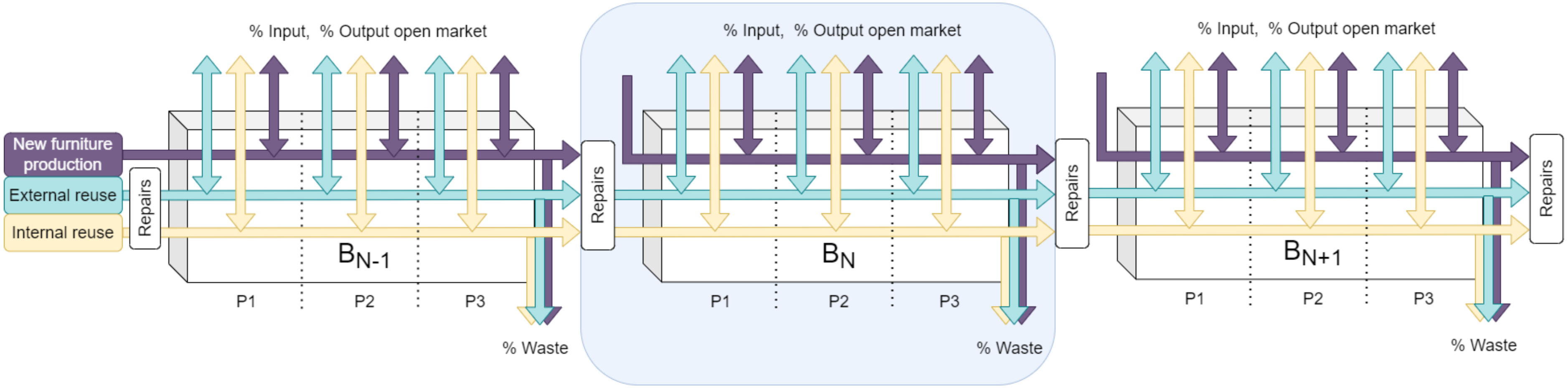

Figure 9: Visualization of how the organisation B_N can be connected to other organisations B_{N-1} and B_{N+1} in a chain of reuse.

4.3. Modelling of alternative PSS scenarios with different sets of preconditions

A total of six scenarios were constructed to compare PSS solutions within the model framework. The scenario's starting point is the establishment of a new office organisation, by moving from an earlier location or by renovation of an old office building. Two baseline scenarios (BS1 and BS2) have been developed that simulate conventional furniture purchase behaviour. Four reuse scenarios (RS1-RS4) that implement different PSS solutions for furniture have also been developed. These reuse scenarios facilitate furniture reuse to various degrees. All reuse scenarios use data from the case study as a starting point to build on. The analysed scenarios are as follows.

BS1:	**"The Stable office"** is the first baseline scenario. It simulates the organisation buying all new furniture for their new office building and keeping it for the 15-year period.
BS2	**"The Fashionable office"** is the second baseline scenario. All furniture is purchased new and exchanged every five years to renew the look of the office.
RS1:	**"The Static reuse scenario"** simulates the use of a furniture inventory management system so that furniture from the old buildings is reused. The remaining furniture needs are fulfilled by furniture purchase or leasing.
RS2:	**"The Efficient reuse scenario"** builds on the static reuse scenario (RS1) but adds a space management services to customize and reduce the space needed before moving to a new office building. The remaining furniture is rented as a subscription service for office furniture.
RS3:	**"The Flexible reuse scenario"** builds on the efficient reuse scenario (RS2), and a reuse optimalisation service is added so that more furniture is internally reused. The remaining furniture, as well as the office space, are provided through an all-inclusive office service.
RS4:	**"The All-inclusive office scenario"** simulates the organisation not reusing any furniture, but rather moving into an established and fully equipped all-inclusive office.

To compare the different scenarios in an environmental analysis, system prerequisites and a number of assumptions has been made. It is assumed that furniture supplied externally from new furniture purchases or from internal reuse has a life expectancy of 15 years. Repaired furniture has a life expectancy of 22.5 years. All furniture is kept until reaching its life expectancy, unless otherwise stated. All furniture goes to waste treatment when reaching its life expectancy. Furniture that has not reached its expected lifetime by the end of P3 is assumed to be reused. A full list of assumptions can be found in Appendix 4: System prerequisites.

The elements that change between the scenarios are: 1) the age of the furniture that enters the system; 2) the time at which furniture goes to waste treatment, based on life expectancy assumptions; 3) the use factor of the full-time office workers; and 4) whether it is possible to reduce the size of the office space within the 15-year period.

4.3.1. Modelling changes in number of employees

Both a fixed number of employees and a changing number of employees can be analysed using the model. This challenges the traditional definition of the functional unit in the LCA method, influencing the need of employees to use less space. Two overarching employee situations have been used as a basis of analysis including a fixed number of employees and a declining number of employees. For a fixed number of employees, the office provides working space and furniture for 300 employees during the 15-year period. For a declining number of employees, the office provides working space and furniture for 300 employees in period 1, which decreases by 20% for period 2, and decreases again by 20% for period 3. The analysis of a declining number of employees can also simulate a higher number of employees working from other locations, such as home office or satellite offices. The declining number of employees simulates the need for change and flexibility that arises in businesses that experience downsizing and changes.

The selected scenarios were chosen to construct realistic reuse scenarios that could happen in the context of the case study. The age of the furniture is highly relevant for the environmental analysis using the REV allocation method as described in sections 2.4.3 and 3.4.4. Therefore, the age of the furniture is visualized in the model for each scenario (see Figure 10-14).

4.3.2. BS1: The Stable office scenario

The first baseline scenario simulates a situation where furniture is purchased as a lasting inventory investment. All furniture supplied is 100% new, while all furniture from previous locations go to waste treatment. The purchased furniture is kept for 15 years before going to waste treatment. The amount of furniture and use of space is constant and does not change if number of employees change.

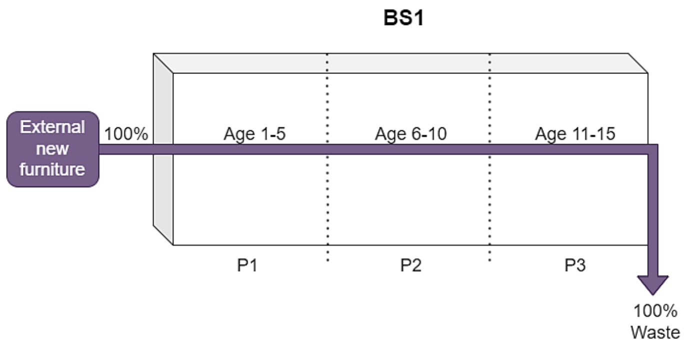

Figure 10: Visualization of BS1: The Stable office scenario.

4.3.3. BS2: The Fashionable office scenario

The second baseline scenario simulates furniture being purchased and changed at a high pace. All furniture supplied is 100% new, while all furniture from previous locations go to waste treatment. The purchased furniture is kept for five years before being thought obsolete. Two alternatives for obsolete furniture are analysed, giving two different sub-scenarios (BS1a-b):

a) All furniture goes to waste treatment
b) All furniture goes to reuse

The amount of furniture that goes into the system changes if number of employees change. The use of office space is constant and does not change if number of employees changes.

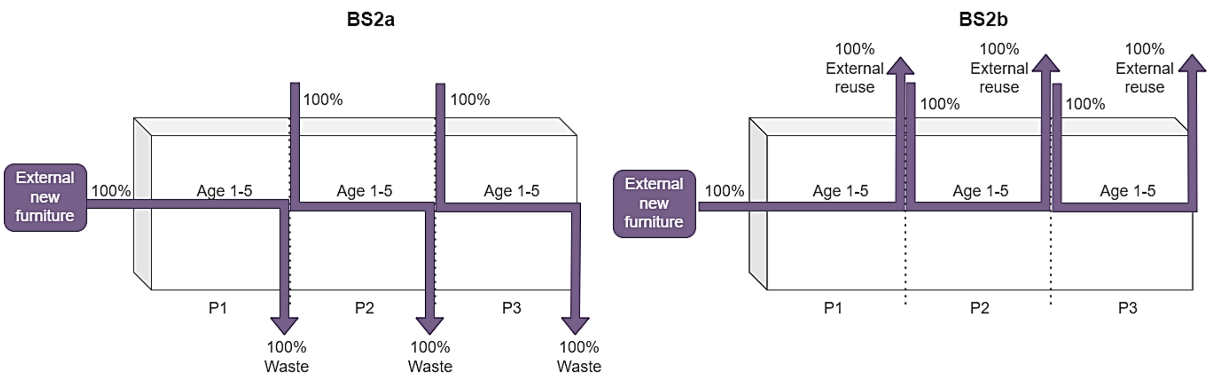

Figure 11: Visualization of BS2: The Fashionable office scenario.

4.3.4. RS1: The Static reuse scenario

Furniture that is not internally reused is bought or leased with a financial leasing option. The furniture supply options give three different sub-scenarios (RS1a-c):

a) 58% internal reuse of furniture, 42% new furniture production
b) 58% internal reuse of furniture, 42% external furniture reuse, age five
c) 58% internal reuse of furniture, 42% external furniture reuse, age ten

The use of space is constant and does not change with number of employees. When furniture reaches life expectancy, it goes to waste treatment and is replaced by furniture of the same age as the initial external furniture.

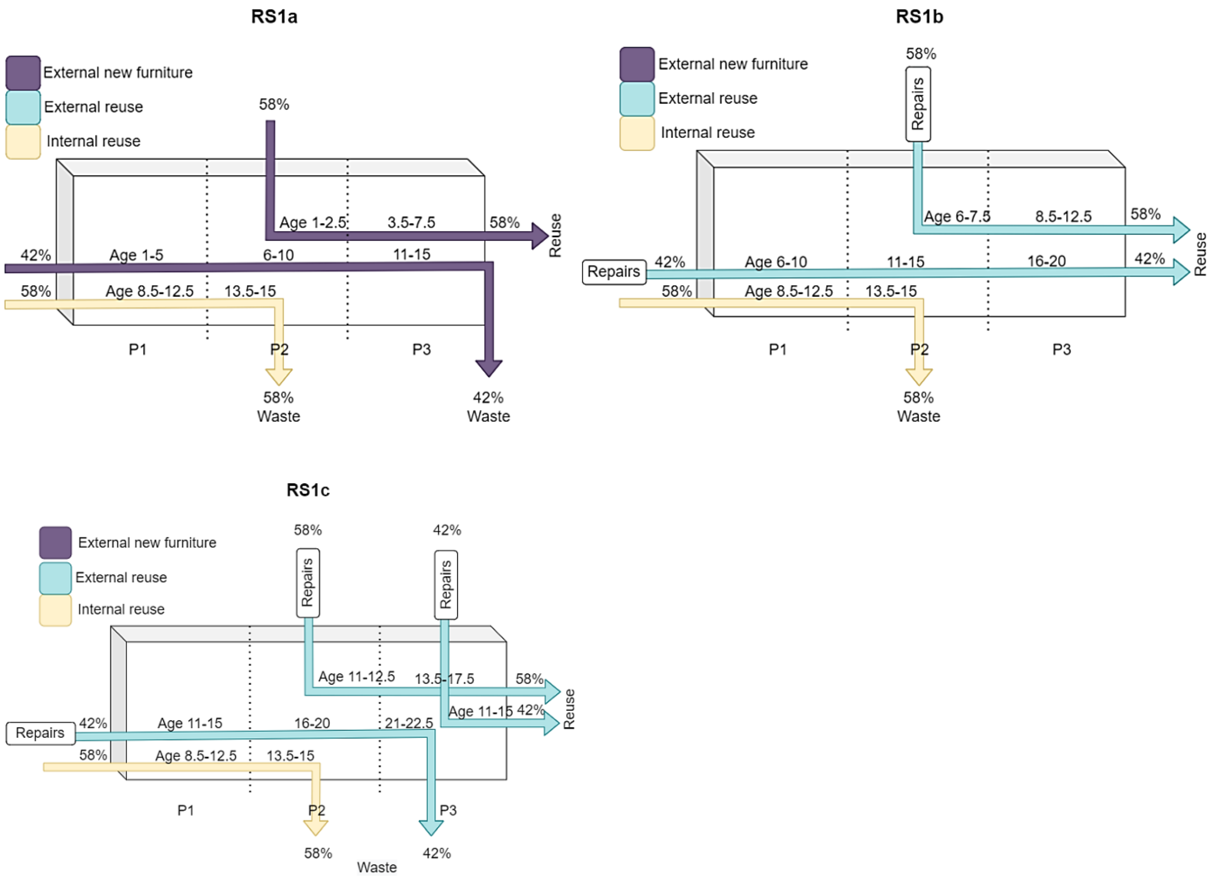

Figure 12: Visualization of RS1: The Static reuse scenario.

4.3.5. RS2: The Efficient reuse scenario

The furniture that is not internally reused is rented as a flexible furniture subscription. The use of space is optimized to correspond to the employees' actual use of the office space. In this case, it is found that full time office workers are only in the office 70% of the time. This adjusts the use factor from 0.9 to 0.7. The overall need for furniture and office space is therefore reduced. Internally reused furniture therefore stands for a higher share of the total furniture need compared to the previous scenarios. The furniture supply options are the same as in the static reuse scenario, but with a higher percentage of reused furniture due to the efficiency changes. Furniture supply options are (RS2a-c):

a) 73% internal reuse of furniture, 27% new furniture production
b) 73% internal reuse of furniture, 27% external reuse of furniture, age five

c) 73% internal reuse of furniture, 27% external reuse of furniture, age ten

The use of space is constant and does not change if number of employees changes.

4.3.6. RS3: The Flexible reuse scenario

The furniture that is not internally reused is rented as a flexible furniture subscription. The use of space is optimized, meaning the use factor for full time office workers is adjusted from 0.9 to 0.7. The overall need for furniture and office space is therefore reduced. Repairs are added to internally available furniture, enhancing the reuse rate. The amount of reused furniture goes up from 73% to 82%. Internally reused furniture therefore stands for a higher share of the total furniture need compared to the previous scenarios. Furniture supply options (RS3a-b):

a) 82% internal reuse of furniture, 18% external reuse of furniture, age five

b) 82% internal reuse of furniture, 18% external reuse of furniture, age ten

The amount of furniture changes if number of employees changes. The use of space is optimized and changes if number of employees changes.

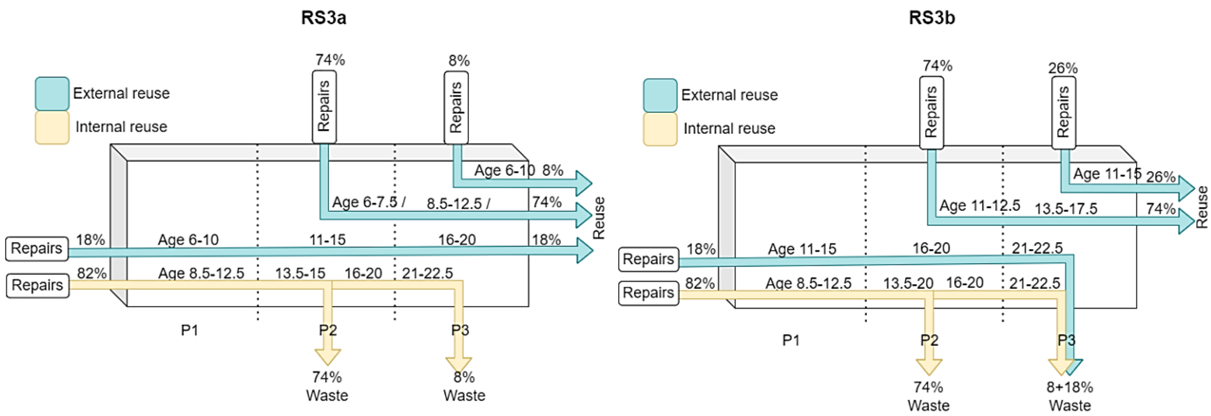

Figure 13: Visualization of RS3: The Flexible reuse scenario.

4.3.7. RS4: The All-inclusive office scenario

All furniture is included in the rent of the office space and is assumed to be reused from previous tenants or the service provider's own furniture pool. The use of space is optimized, meaning the use factor for full time office workers is adjusted from 0.9 to 0.7. The overall need of furniture and office space is therefore reduced. Furniture supply options are (RS4a-b):

a) 100% external reuse of furniture, age five

b) 100% external reuse of furniture, age ten

The needed amount of furniture and corresponding need of office space changes if number of employees changes.

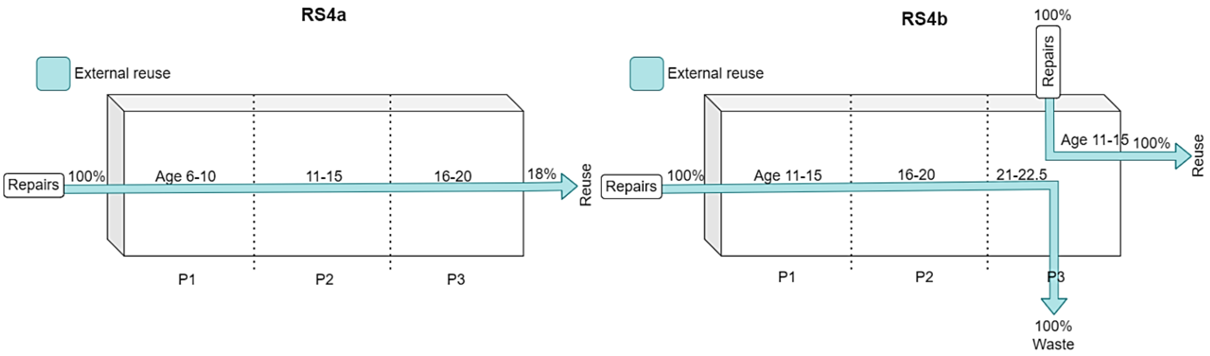

Figure 14: Visualization of RS4: The All-inclusive reuse scenario.

4.4. Assessment of GHG-emissions from the different scenarios

The model and scenarios presented in section 4.2 and **Feil! Fant ikke referansekilden.** were used together with the furniture inventory data from the case study to perform assessments of GHG emissions of the scenario alternatives. Only the impact category GWP measured in kg CO2eq have been analysed.

For a fixed number of 300 employees over a 15-year period, the results of the analysed scenarios are shown in Figure 15. The diagram shows the amount of GHG emissions from seven main categories:

- Emissions from the waste treatment of old furniture from the previous office locations
- Cradle-to-gate emissions from new furniture production
- Cradle-to-gate emissions from internally reused furniture
- Cradle-to-gate emissions from externally reused furniture
- Emissions from the waste treatment of the acquired furniture
- Emissions from repairs
- Emissions from the energy use in the analysed office space

The two most stable factors across the scenarios are emissions from energy use in the analysed office space and emissions from waste treatment of the furniture from the previous office buildings. The emissions associated with furniture consumption vary more. The differences between alternatives (a, b, and c, or in some cases, only a and b) are the furniture's age entering the system. These three factors will be presented in depth in the following section.

All GHG emission totals associated with the main processes can be found in Appendix 5: GHG emission totals for analysed scenarios. The scenario with the highest GHG emissions total is the Fashionable office scenario (BS2a) with 264.2 tonnes CO2eq. The Flexible reuse scenario with input furniture age ten (RS3b) has the lowest emissions total of 93.5 tonnes CO2eq. There is a 65%

decrease in emissions between these two scenarios. The high emissions in BS2a are a result of replacing all furniture three times within the 15-year period and not reusing any furniture. This puts the burdens of the furniture's lifecycle onto the analysed period.

Emission totals for the Stable office scenario (BS1) simulates buying all furniture new and keeping it for the full life expectancy, which results in an emission total of 156.0 tonnes CO2eq. The Static reuse scenario (RS1a) shows the scenario of reusing furniture from the old buildings while buying all the other furniture new. This reduces the emissions by 4% compared to the Stable office (BS1), down to 149.4 tonnes CO2eq. If the external furniture input is of age five when entering the system, the emissions of the Static reuse scenario (RS1b) are reduced to 128.2 tonnes CO2eq. This is an 18% reduction compared to the Stable office scenario. A total reduction of 25% down to 117.2 tonnes CO2eq can be achieved compared to the Stable office scenario (BS1) if the externally supplied furniture is of age ten (RS1c).

For the Efficient reuse scenario (RS2a), the emissions from energy use and furniture are reduced by 21% from that of the Static reuse scenario (RS1a). This is due to the office size and furniture need being reduced by applying office space efficiency measures and adjusting use factor for full-time office workers from 0.9 to 0.7.

The Flexible reuse scenario with furniture input age ten (RS3b) achieves the best total of all the scenarios with 93.5 tonnes CO2eq. This is due to a combination of three factors, including reduced energy use by office space optimalisation, optimising and delaying waste treatment of internally reused furniture by adding repairs, and choosing externally reused furniture of age ten with no residual cradle-to-gate emissions attached to them. The All-inclusive office scenario (RS4), where all furniture from old buildings goes to waste treatment comes in as second best with 102.8 tonnes CO2eq when using input furniture of age ten (RS4b). This is due to the slightly higher emissions from new furniture entering the system when no furniture from the old buildings is utilised.

The difference between the Flexible reuse scenario (RS3) and the All-inclusive office scenario (RS4) shows the benefits of internal reuse with added repairs to furniture the organisation already possesses, compared to throwing away all old furniture and relocating to an all-inclusive office. When both scenarios have input furniture of age five, the difference is less than 1% (106.2 tonnes CO2eq for RS3a and 106.3 tonnes CO2eq for RS4a). If the input is furniture of age ten, the Flexible reuse scenario (RS3b) has 3% lower emissions than the All-inclusive office scenario (RS4b) with 93.6 tonnes CO2eq compared to 102.8 tonnes CO2eq, respectively.

The Flexible office scenario (RS3) has a higher amount of internally reused furniture than the Efficient reuse scenario (RS2) by adding repairs to furniture that fits the needs of the new building. This reduces emissions by 0. 1% and 3%, if comparing scenarios using externally supplied furniture of the same age (RS2b compared to RS3a with furniture of age five; RS2c compared to RS3b with furniture of age ten). The low reduction is due to the fixed amount of emissions for old furniture in both scenarios, no matter if repairs are added or not. The remaining emissions from the old furniture cannot be avoided, they can only be portioned out differently over time. By adding repairs, a portion of the internally reused furniture can last longer, which delays adding other furniture related emissions. However, all internally reused furniture reaches its life expectancy and goes to waste treatment within the 15-year period, which is set by the prerequisites of the analysis.

The All-inclusive office scenarios (RS4) have quite similar emission totals to the Efficient reuse scenario (RS2). The furniture supply options using input furniture of age five have the same emission total of 106.3 tonnes CO2eq respectively (RS2b and RS4a). Since the same furniture mix is used in all scenarios, with the same embedded emissions, the scenarios become equal if furniture with the same age is used in the same amounts, which is the case for the abovementioned scenarios. When the externally supplied furniture is age ten, the Efficient reuse scenario RS2c gives 6% less emissions than the All-inclusive office scenario RS4b (96.3 tonnes CO2eq and 102.8 tonnes CO2eq respectively). The difference in emissions comes from the slight reduction in repair related emissions in the Efficient reuse scenario (RS2c), since the total amount of externally reused furniture, which have added emissions from repairs, is reduced due to the internal furniture reuse.

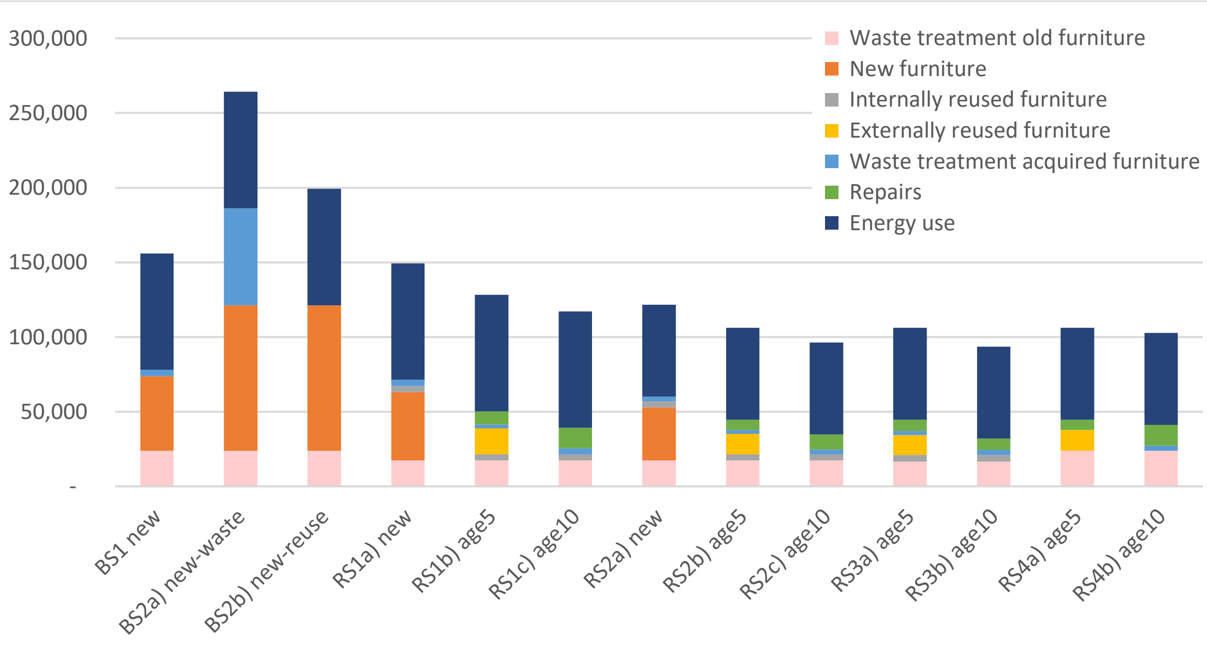

Figure 15: Scenario comparison of GHG emission totals in kg CO2eq for a fixed number of 300 employees.

Figure 16 shows the accumulative GHG emissions per office worker over the analysed 15-year period. Only the baseline scenarios (BS1 and BS2) and scenario alternatives with the lowest emission totals have been included. The Fashionable office scenario with the waste treatment alternative (BS2a) has the highest total of 881 kg CO2eq per employee. The Flexible reuse scenario with furniture of age ten as input (RS3b) has the best total, with 312 kg CO2eg per employee. The Efficient reuse scenario with furniture of age ten as input (RS2c) is a close second with 321 kg CO2eq per employee. Emissions do not start at zero for any scenario, because the emissions from the waste treatment of old furniture are accounted for in year one. Emissions from energy use add a steady, yearly increase of emissions to all the scenarios. The emissions in year one lie higher for the baseline scenarios (BS1 and BS2), because these are the only scenario alternatives taking in new furniture to cover the employees' furniture needs. The changes in the curve of The Fashionable office scenario with waste treatment (BS2a) show the rapid emission increases from year five, when all furniture is replaced, similar to an office renewal situation. This adds emissions both from end-of-life treatment and the residual value of the furniture. At the same time, new furniture is purchased. This gives another rapid emission increase since the first year of the furniture's lifetime will add 37% of the furniture's cradle-to-gate emissions to this first year of use. This replacement of furniture happens again in year 10 and year 15, giving two more rapid increase in accumulated emissions. In comparison, the Fashionable office scenario (BS2b) shows the same circumstances but without the emissions from waste treatment, since the furniture goes to reuse. This reduces the emissions per office worker by 24.6% over the 15-year period, from 881 kg CO2eq to 664 kg CO2eq.

The curves shown for the best reuse scenario alternatives have lower emissions from furniture use by taking in furniture which has "paid down" their cradle-to-gate emissions over the previous 10 years of their lifetime. In the All-inclusive office scenario (RS4b), for example, changing the furniture inventory which has become 22.5 years old accounts for the increase in emissions between year 13 and 14. This adds emissions both from waste treatment of the old furniture and from furniture repairs associated with the reused furniture (age ten) that is replacing it. This is also the case for the other reuse scenario alternatives with furniture of age ten as input (RS1c, RS2c and RS3c) which need two exchanges of furniture during the 15-year period: the first when internally reused furniture goes to waste treatment, the second when the initially externally reused furniture purchased in year 0 reaches 22.5 years and must be replaced.

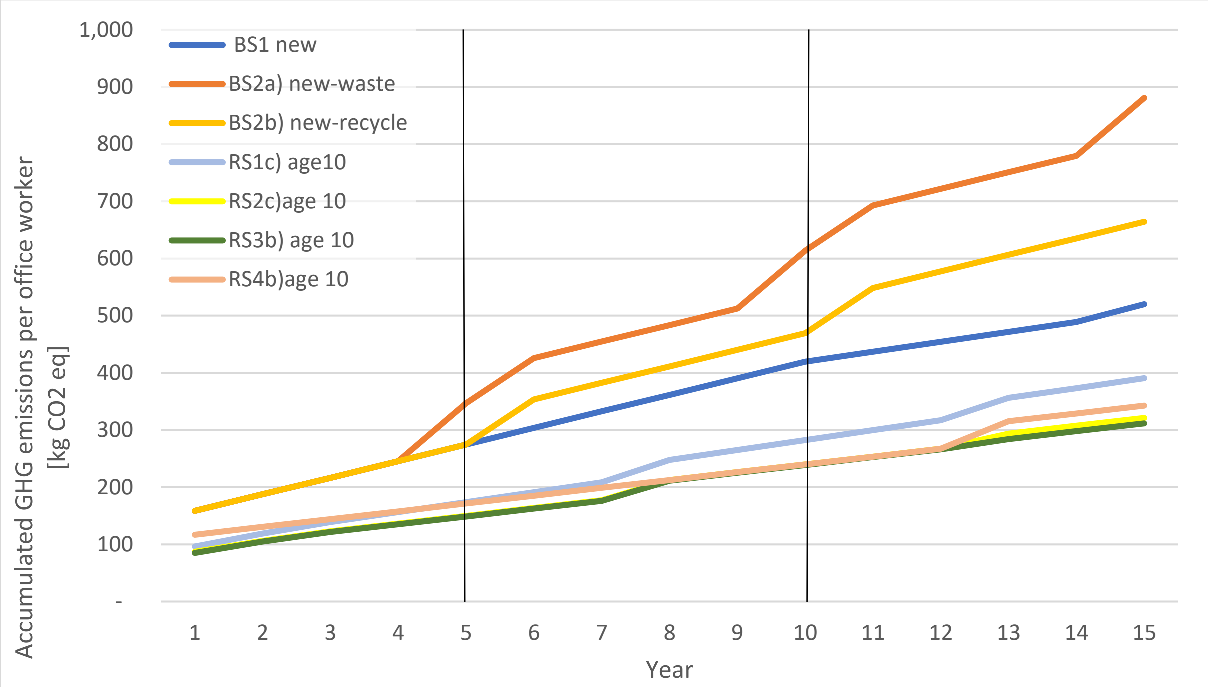

Figure 16: Accumulative GHG emissions totals per office worker for a fixed number of 300 employees over the analysed 15-year period.

4.4.1. Waste treatment from previous office buildings

Emissions from waste treatment include both emissions from waste treatment processes and emission reduction potential from substitution effects if furniture is disposed of before age ten (see section 2.4.2 on substitution effects and section 3.4.4 for allocation rules). The furniture in the old buildings that is not relocated to the new buildings is sent to waste treatment. When all 1524 furniture items from the old buildings is discarded, this adds 23.9 tons CO2eq to the emission totals. This is the case in the Baseline scenarios (BS1 and BS2) and the All-inclusive office scenario (RS4). In the Static reuse scenario (RS1) and the Efficient reuse scenario (RS2), 529 furniture items are directly reused without doing any repairs. Thus, the emissions from waste treatment of the old furniture are reduced by 28% to around 17.4 tons CO2eq. In the Flexible reuse scenario (RS3), reuse of the old furniture is increased to a total of 828 furniture items by adding repairs to some of the furniture as described in section 3.4.5. This reduces emissions from waste treatment by an additional 4% compared to RS1 and RS2, which gives a total of 16.6 tons CO2eq emissions from the waste treatment. In this case, the total emission reduction potential has been found to be 31% by direct reuse and a slight increase of furniture repairs compared to not reusing any furniture from the old buildings.

4.4.2. Energy use

Emissions from energy use are a major contributing factor to the total emissions in all scenarios. Utilisation of office space is the same for the Baseline scenarios (BS1 and BS2) and the Static reuse scenario (RS1) using 2144 m2 of office space which results in almost 78 tonnes CO2eq from energy use. In the Efficient reuse scenario (RS2), the Flexible reuse scenario (RS3) and the All-inclusive office scenario (RS4), the office space is reduced to 1693 m2, giving 62 tonnes CO2eq, a decrease of 21%. This is due to the use factor for full time office workers being set to 0.9 in BS1, BS2 and RS1, while it is adjusted to 0.7 in RS2-RS4. This is equivalent to saying that instead of scaling the inventory needs to meet the needs of 90% of the office workers to be at work at the same time, it is scaled to fit 70% of the office workers being at the office simultaneously.

An overall reduction in number of employees has also been analysed. A 20% reduction in number of employees was introduced in period 2, and again in period 3. This reduction in employee number did not affect the office space size in the baseline scenarios (BS1 and BS2), the Static reuse scenario (RS1) and the Efficient reuse scenario (RS2), which do not have flexible office space rentals. This means the total GHG emissions from energy use stays the same when number of employees is decreasing. However, for the Flexible reuse scenario (RS3) and the All-inclusive office scenario (RS4), the size of the office space can be scaled up or down as part of a flexible office space rental. This means that the size of the office space can be reduced by 20% each period to fit the reduced need of space and inventory, resulting in a total reduction in energy related emissions of 36% compared to the non-flexible office solutions. This results in 50 tonnes CO2eq from energy use for the Flexible reuse scenario (RS3) and the All-inclusive office scenario (RS4). The differences in use factor, office size, and GHG emissions are summarized in Table 14.

Table 14: The total emissions from energy use in the office space given the precondition of the analysed scenarios.

Office space utilisation for full time office workers	Used in scenario	Office space starting point [m^2]	GHG emissions total [tonnes CO2eq]
Use factor 0.9	BS1, BS2, RS1	2144	78
Use factor 0.7	RS2	1693	62
Use factor 0.7 plus 20% periodic office size reduction	RS3, RS4	1693	50

The energy use per employee per year is presented in Table 15. Higher emissions are attributed to each employee if the office size is not scaled to fit number of employees. This is the case for the baseline scenarios and the Static reuse scenarios (BS1, BS2 and RS1). The lowest amount of emissions from energy use per office worker achieved in the analysis is 13.7 kg CO2eq per year. This is achieved in the Efficient reuse scenario, the Flexible reuse scenario, and the All-inclusive office scenario (RS2, RS3 and RS4) for a fixed number of 300 employees, due to adjusting the use factor of full-time office workers from 0.9 to 0.7. For a declining number of employees, the low emissions number per employee per year is achieved in the Flexible reuse scenario (RS3) and the All-inclusive office scenario (RS4). This is made possible by the flexible office rental solution, in which the office space size can be reduced to match the declining number of employees. The highest emissions per employee of 27 kg CO2eq per year occurs in period 3 of the baseline scenarios (BS1 and BS2) as well as the Static reuse scenario (RS1), when the number of employees has declined but the office size stays the same.

Table 15: Energy use per office worker per year [kg CO2eq] for each scenario with distinctions made between time periods.

Fixed number of employees	**Period 1 (years 1-5)**	**Period 2 (years 6-10)**	**Period 3 (years 11-15)**
BS1, BS2, RS1	17.3	17.3	17.3
RS2, RS3, RS4	13.7	13.7	13.7
Declining number of employees			
BS1, BS2, RS1	17.3	21.7	27.1
RS2	13.7	17.1	21.4
RS3, RS4	13.7	13.7	13.7

The accumulative energy related emissions for a declining number of employees is presented in Figure 17. For the baseline scenarios and the Static reuse scenario (BS1, BS2, and RS1) the energy use per employee increases for each period as the number of employees has been reduced, but not the size of the office space. This means the average employee is held accountable for more emissions each year, a total of 330 kg CO2eq by year 15. For the Efficient reuse scenario (RS2), where the office space is reduced by 21% from that of the previously mentioned scenarios, these emissions are reduced to 261 kgCO2eq. The best result is achieved by the flexible office solutions in the Flexible reuse scenario and the All-inclusive office scenario (RS3 and RS4) with a total of 205 kg CO2eq over the 15-year period. This shows a possible emissions reduction of 38% if opting for an office rental solution that can facilitate a reduction in office space size to fit the declining number of employees.

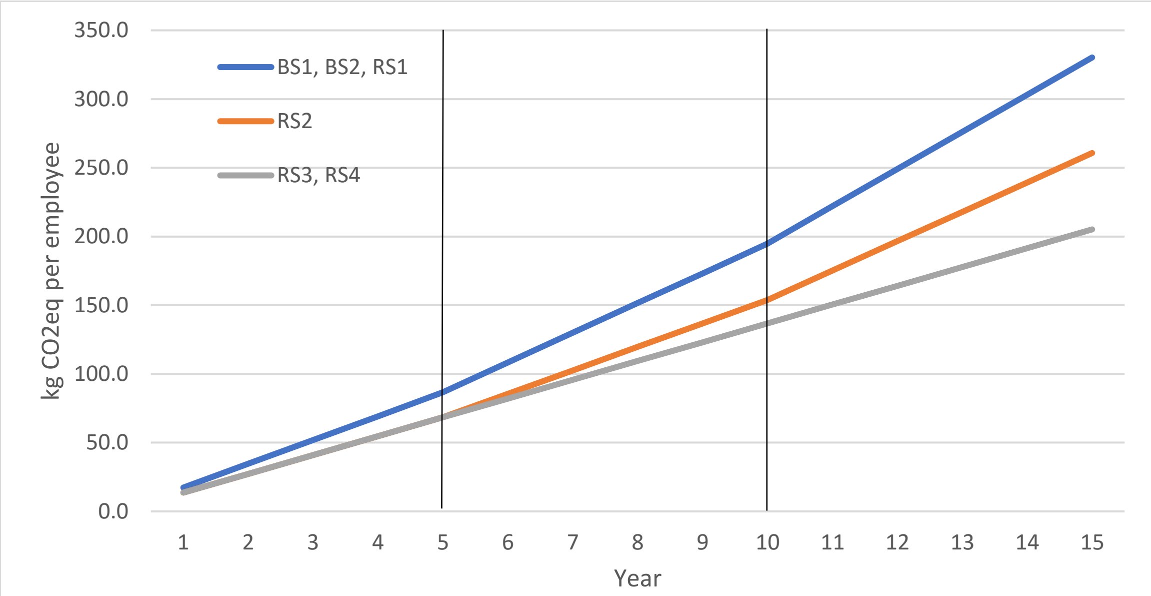

Figure 17: Aggregated energy use per employee in kg CO2eq over a 15-year period when the number of employees is declining by 20% for period 2 (year 6-10) and again for period 3 (year 11-15).

4.4.3. Emissions from furniture consumption

In the analysed scenario alternatives, the furniture entering the system is either new (age zero), five years old or ten years old. Figure 18 shows GHG emissions totals from furniture consumption by 300 employees over the analysed 15-year period when emissions from energy use and waste treatment of old furniture are excluded. The Stable office scenario (BS1) shows that furniture is bought for 300 employees in the start and kept throughout the whole period. This gives emissions related to furniture consumption of 54 tonnes CO2eq. The Fashionable office scenario (BS2a) represents a "worst case scenario" where new furniture is bought and discarded every five years, where all furniture goes to waste treatment, resulting in emissions accounting for 132 tonnes CO2eq. This is almost 2.5 times higher than the Stable office scenario (BS1). The emissions embedded in the furniture makes this furniture consumption behaviour the most environmentally burdensome, even if all furniture goes to reuse as in BS2b. If the furniture is reused, the emissions are reduced by 40%, to 79 tonnes CO2eq. This is still a higher emission total from furniture consumption than for the reuse scenarios, which span from 44.5 tonnes CO2eq in the Static reuse scenario with all new furniture as input (RS1a) to the lowest emissions from furniture in the Flexible reuse scenario with input furniture of age ten (RS3b) with 14.3 tonnes CO2eq. The scenarios using furniture that is more than 10 years old score best in all scenario alternatives.

Interestingly, the furniture related emissions are the same for the Stable office scenario (BS1) and the Static reuse scenario with all new furniture as input (RS1a). Both have a total of 54.1 tonnes CO2eq. The explanation is that both scenarios use new furniture (age zero) as input. Since the internally reused furniture must be replaced within the 15-year period, and new furniture of the same amount and with the same embedded emissions is the input, this gives RS1a the result of not avoiding any emissions compared to BS1. The emissions are rather delayed in time. However, if externally reused furniture had been chosen as replacement when the internally reused furniture reaches its life expectancy, then the emissions could have been reduced. If furniture of age five was chosen as replacement, it would give an emission reduction of 13%, down to 47.0 tonnes CO2eq. Choosing furniture of age ten as replacement would give a 29% reduction with 38.7 tonnes CO2eq.

The reductions in emissions between the alternatives a, b, and c for the Static reuse scenario (RS1) show the effects of opting for reused furniture. Furniture related emissions are reduced by 39% if all the externally provided furniture is reused furniture of age five as in RS1b, instead of new furniture as in RS1a. In RS1c, the emissions from externally provided furniture of age ten when entering the system reduce the emissions by 60% compared to all furniture being new, from 54.1 tonnes CO2eq in RS1a to 21.9 tonnes CO2eq in RS1c.

For the Efficient reuse scenarios RS2a-c, the reduction in furniture needs due to more effective use of furniture reduce the furniture related emissions by approximately 20% compared to the less effective furniture utilisation of RS1a-c. The two scenario alternatives with the lowest furniture emissions both use externally reused input furniture of age ten. The Flexible reuse scenario RS3b has 15.3 tonnes CO2eq from furniture consumption while the All-inclusive office scenario RS4b has 17.3 Tonnes CO2eq. This is due to all furniture from the old buildings going to waste treatment in the All-inclusive office scenario (RS4). This means more furniture must be acquired than in the Flexible reuse scenario (RS3), resulting in more emissions from repairs and waste treatment within the 15-year period, even though furniture of age ten has no embedded cradle-to-gate emissions left to be accounted for.

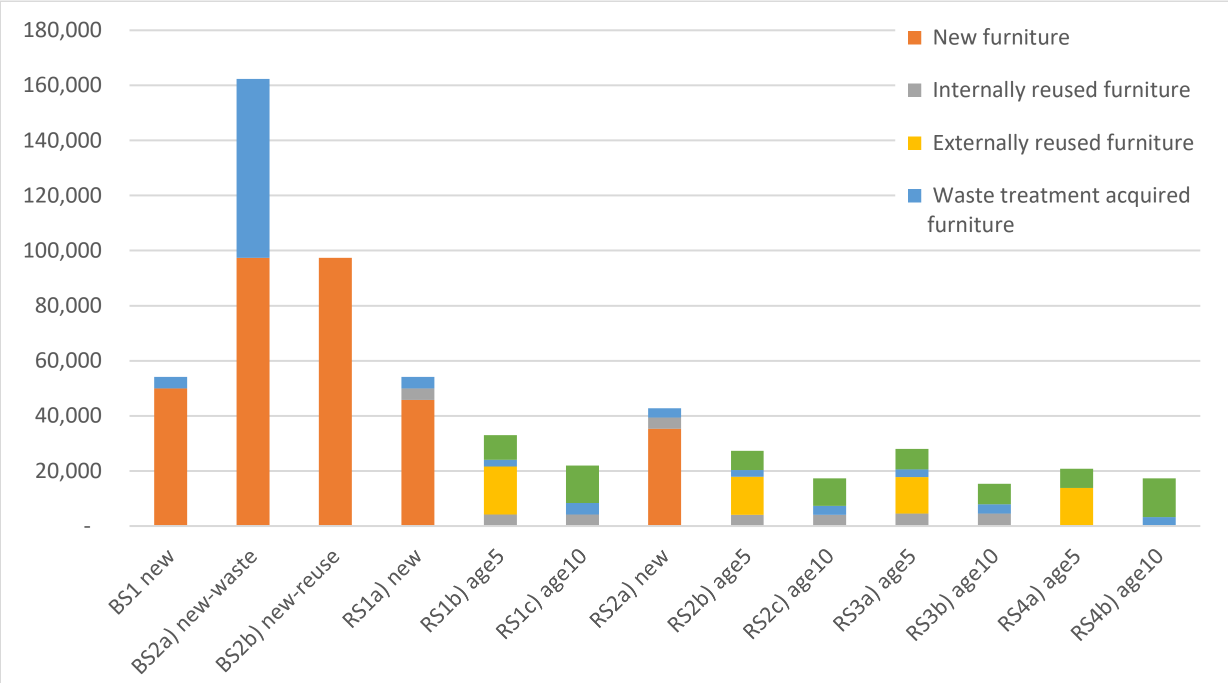

Figure 18: Scenario comparison of GHG emission from furniture consumption in kg CO2eq for a fixed number of 300 employees. Emissions from energy use and waste treatment from old buildings has been excluded.

Figure 19 shows the emissions associated with one employee's furniture use distributed over time. It shows the difference of the employee's furniture needs being covered by all new furniture (the blue line), all furniture of age one (orange line), all furniture of age five (grey line) or of furniture age ten (yellow line). New furniture of age zero has all embedded cradle-to-gate-emissions left to be allocated over the next ten years, as shown by the blue line starting at 81 kg CO2eq in year one. At year ten, the line levels out when all the emissions have been accounted for, before the waste treatment adds emissions in year 15. If furniture is bought when it is one years old, shown by the orange line, the emissions allocated to the first year of use are avoided, giving the lower emissions total of 54 kg CO2eq, even though repairs are included in year one. The flattening of the curve is due to the furniture reaching age ten after being in the system for nine years, and all the embedded environmental burdens have been accounted for. The same pattern repeats itself for furniture that is five years old when entering the system, but then the cradle-to-gate emissions are accounted for earlier, after being in the system for five years. For furniture that is ten years old when purchased, all embedded cradle-to-gate emissions have been accounted for in previous years, and only the emissions from repairs are added in year one. However, there is a need to exchange the furniture when reaching its life expectancy of 22.5 years in year 13, in the middle of period 3. Combined with the repairs of the furniture that replace it, this gives the spike in the diagram at year 13, before levelling out when no more emissions are associated with the furniture use.

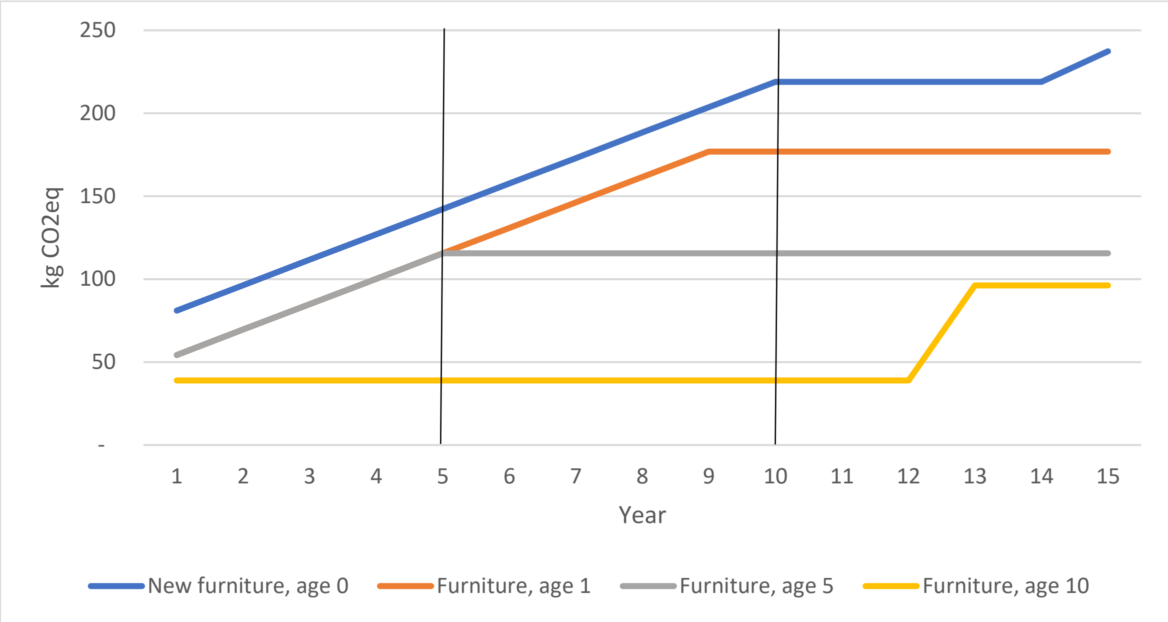

Figure 19: The accumulative GHG emissions associated with one employees' furniture use during a 15-year time period.

The same totals for furniture-related emissions per employee are shown with distinctions between their associated processes (Table 16). The three main processes the emissions are associated with are cradle-to-gate, repairs, and waste treatment. If an employees' furniture needs are fulfilled by all new furniture or one-year-old furniture, most of the associated emissions will come from the cradle-to-gate processes. 92% of the emissions associated with an all-new furniture purchase will be from the cradle-to-gate process, while the rest is from the waste treatment. One year old furniture has 25% less emissions associated with the 15-years of use compared to purchasing all new furniture. This is due to the allocation method placing 37% of the cradle-to-gate emissions on the first-year user of the furniture, so that even if repairs are added to the one-year-old furniture, the total emissions from this furniture mix is still lower. Both one year old furniture and five-year-old furniture is thought to last through the whole 15-year period of the analysis, due to repairs prolonging their life expectancy to 22.5 years instead of 15 years. Still with repairs added, the lower emissions left from the cradle-to-gate processes give a 51% GHG emissions reduction between five-year-old furniture and all new furniture. For ten-year-old furniture, the emissions come from the repair needs and the emissions from waste treatment, since the first furniture inventory has to be replaced by similar furniture when life expectancy is reached within the 15-year period. This still gives the lowest emissions total of 96 kg CO2eq per employee, which is 59% lower than for all new furniture.

Table 16: GHG emissions in kg CO2eq associated with the furniture need of one employee over a 15-year period. The different columns show the total emissions related to all furniture being either of age zero, age one, age five or age ten when entering the system.

Process description	New furniture, age 0	Furniture, age 1	Furniture, age 5	Furniture, age 10
Cradle-to-gate emissions	219	138	77	0
Repairs		39	39	78
Waste treatment	18	0	0	18
Total	**237**	**177**	**116**	**96**

For a declining number of employees, the All-inclusive office scenario with input furniture of age ten (RS4b) becomes the slightly better alternative with 13.6 tonnes CO2eq for emissions related to furniture consumption. The Flexible reuse scenario, also with input furniture of age ten (RS3b), following close behind with 14.3 tonnes CO2eq. However, this is not enough to make up for the added emissions the All-inclusive office scenario (RS4) has from not reusing any furniture from the old buildings. This difference gives RS3b a slightly better total, as shown in Figure 20. The best Flexible reuse alternative (RS3b) has total emissions of 81.0 tonnes CO2eq compared to 87.6 tonnes CO2eq for the best All-inclusive office alternative (RS4b). GHG emission totals for all the scenarios with declining number of employees can be found in Appendix 5: GHG emission totals for analysed scenarios.

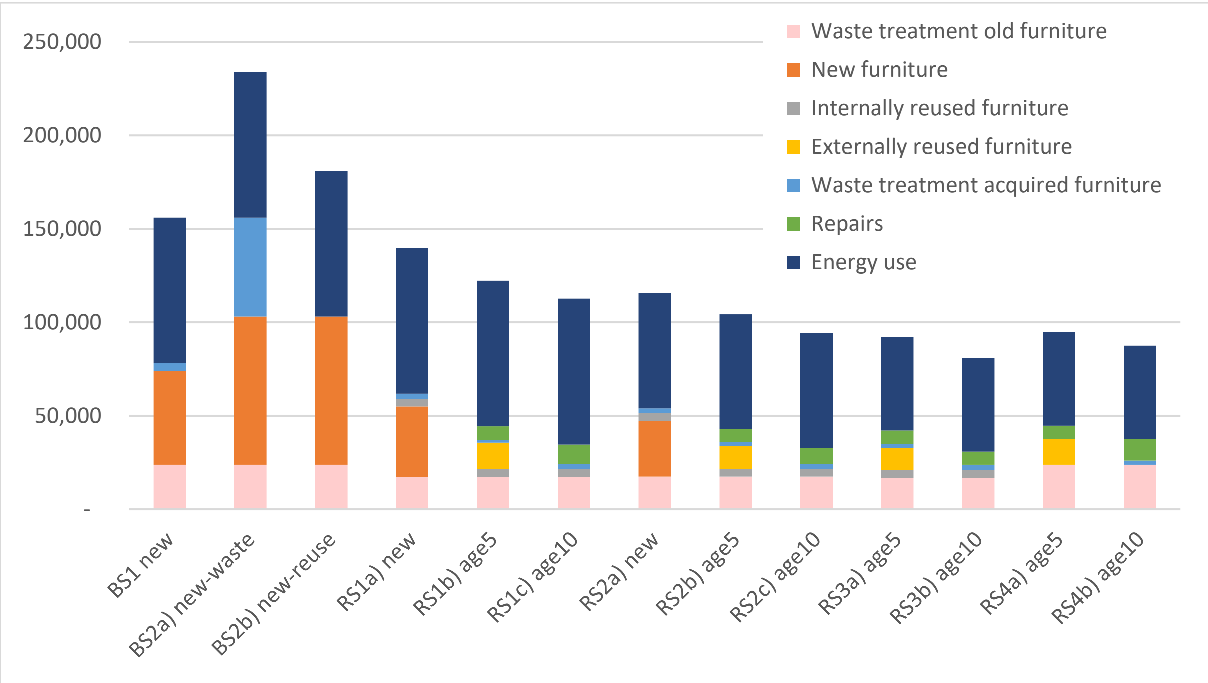

Figure 20: Scenario comparison of GHG emission in kg CO2eq for a declining number of employees. Emissions from energy use and waste treatment from old buildings has been excluded.

5. Discussion

PSS solutions for furniture can promote circular economy principles by economically incentivising service providers to offer services rather than products. This can promote repair and reuse of furniture as the service provider collects revenue for keeping furniture in use for as long as possible (Besch, 2005; Tukker, 2015). The role of repairing and reusing products is emphasised locally in Oslo municipality, nationally through the National Strategy for a Circular Economy, and through the European Union's Green Deal and proposed supplements of the Ecodesign directive. A study conducted by SINTEF suggests an added focus on quality and service offers in the furniture industry can create 1,300-2,500 new jobs in 2030 with a potential of 1,000-1,800 million NOK in added revenue (Nørstebø et al., 2020). This is due to an assumed shift towards buying fewer products and more services, thus shifting value creation from production outside of Norway to local service providers, in turn increasing job creation locally (Nørstebø et al., 2020). This suggests opportunities for added revenue by offering PSS solutions, which may also gain a stronger focus both in public procurements and national policies in the future. The results suggest many PSSs offers for furniture are quite new on the Norwegian market, which suggests a slow influence of national and international policies that have not yet resulted in a drastic increase in demand.

Examining the main categories from Tukker's classification system, this study set out to identify PSS solutions on offer in the Norwegian market. Information from interviews was used to verify and supplement the identified PSS offers and to provide an impression of how common and in demand the services are in the B2B and B2G market. Highlights from this study’s results section are further discussed below.

5.1. PSS models on the Norwegian market

The identified PSS models include six product-oriented offers, two use-oriented offers, and two result-oriented offers. These models range from services that compliment conventional furniture purchases to alternatives for product ownership. The scale in which the services apply vary from one product to all-inclusive solutions for a complete office inventory with supporting functions.

The identified product-oriented PSSs have potential for prolonging the lifetime of furniture and stimulate increased reuse through service and maintenance contracts and advice and consultancy services. While a total of six offers were identified under product-oriented PSSs, most fell under the advice and consultancy sub-category. One explanation can be that it is an easy way to add value to the already established product offer. In many markets, products become quite similar when the general quality of products are high and their performance has been optimized. Product differentiation then becomes limited, and businesses look for other ways to add value to their products aside from competing purely on price (Tukker, 2015). This is surely the case for the office furniture market too, where the essential features of furniture within the same furniture type are not highly different from another. Thus, PSSs provide opportunities for product differentiation and added value to the customer on a market where the product is not easy to differentiate just by the product itself.

The two product-related PSS offers identified include service and maintenance contracts and take-back schemes. Several representatives from furniture companies highlighted maintenance services as an important additional service to prolong the lifetime of furniture. The general impression is that these services are not frequently offered or used, but it is a growing market. The interviewed representatives agreed less on whether take-back schemes were economically feasible to implement. The opinions seemed divided between the furniture companies being product-oriented and companies who also had result-oriented PSS offers. The reasons given were the need for a completely different business model and a reversed logistics system with added transport and storage capacity.

Finally, repair services were categorised as "reuse optimalisation services" and placed under the "advice and consultancy" subcategory of product-oriented PSSs. However, it should be discussed whether offers of refurbishment and repairs can be classified as product-oriented PSS offers. Repair and refurbishment services are undoubtably furniture related service offers, but it was not identified that these kinds of offers were added to a furniture purchase per se. Rather this was offered as a free-standing service to customers who desire repairs for furniture they already possess. Therefore, the service is not necessarily provided by the company selling the furniture in the first place.

Two use-oriented PSS offers were identified, including furniture lease and furniture rental. The terms rent and lease are often mixed in the Norwegian furniture industry. This is evident both on company websites, interviews, and conversations with company representatives. The results showed that financial leasing, provided through leasing banks, often has an end goal for the customer to acquire the furniture after the end of the leasing contract. This makes an argument for financial leasing not to be classified as a use-oriented PSS, but rather a product-oriented financing scheme. This is supported by the feedback from company representatives in the interviews, stating that when a bank takes over the furniture ownership, an incentive for the customer relationship to be centred around the financial transaction is created. A very low percentage of financially leased furniture seems to be returned to the furniture provider for resell or donation.

Furthermore, no PSS offers categorized as furniture pooling were identified. Tukker (2004) defines pooling as simultaneous use of the product. Simultaneous use does not seem to be compatible with the use of office furniture. However, interviewees mentioned different organisations, both in the public sector and private market, renting storage facilities to operate as an internal furniture pool. This can facilitate exchange of furniture between departments and establish an internal market for furniture reuse.

Not many result-oriented PSS offers for furniture were found, as this is fairly new in Norway. However, a distinction was made between the scale or context in which result-oriented offers are given. Both office interior as a service and all-inclusive office services were categorised under Tukker's pay-per service unit-category, due to the price of the identified offers being set per m2 or per office worker. The offers could also fall under Tukker's activity management category since the offers entails outsourcing furniture or the whole office function as a service. Tukker also described a third result-oriented category not identified in this study named functional result, where the service provider agrees with the client on a result that must be achieved by the service (Tukker, 2004). The functional result category could also apply to all-inclusive office services if the offer is defined by the results, for example by meeting a pre-defined goal. The chosen category, for the few identified offers in Norway, must therefore be seen as a matter of interpretation.

Result-oriented offers have the benefit of the customer not having ownership of the furniture and therefore all maintenance and supporting functions are operated by the service provider. By purchasing furniture as a service, or the whole office as a service, the organisation can focus less on the operational aspects of running an office and more on their core-activities (Tukker, 2004). Most interviewees were aware of all-inclusive offices but did not have much knowledge regarding these services. The first all-inclusive office solution in Norway were co-working spaces, with Mesh opening as the first one opening in 2012 (Lundgaard, 2022). Since then, there has been a rapid increase in all-inclusive offices in Norway, but no research has been found on the environmental effects of this business model regarding consumption of resources. Several all-inclusive office providers were contacted during preliminary data gathering, but no companies were able to attend interviews. Therefore, more research is needed on this subject.

5.2. Model framework and PSS scenarios

A model framework and possible PSS scenarios were developed to perform an environmental analysis of the GHG emissions associated with the furniture and office space needs of the case study. The case study was used as a basis for the analysis, but the analysed period goes beyond what has happened with the case study in real life. In this way, the analysis can be seen as an exploration of the effects of possible purchase decisions, should an organisation wish to adopt different PSS solutions in the future. The process of model and scenario development was done in parallel, so that contradictions between the two could be addressed throughout the process. The case study suggested a natural system boundary to be made by the office furniture which could be identified through the inventory lists. However, a wider system boundary including all of BSN's office, not just space designated to desk work and meetings, would give a better overview of the environmental impact of the whole organisation.

The defined scenarios describe theoretical situations that can differ greatly from real-life cases of PSS solutions. No case studies of the environmental impacts of PSS solutions from furniture were identified through literature, which suggests a knowledge gap for these offers. The scenarios were therefore constructed based on information from representatives from relevant companies and descriptions from websites, later verified to some extent through interviews.

In the environmental analysis, the scenarios with the highest amounts of new furniture entering the system have the highest emission totals. All simulated reuse scenarios are better than the baseline scenarios where no furniture from the old buildings are reused and all furniture is bought new. The results of the environmental analysis of global warming potential (GWP) shows that the largest emissions are related to a high exchange rate of new furniture and emissions from energy use in the office building.

5.3. New work conditions and external requirements to organisations

The physical work environment has gone through drastic changes within the last decades, with internationalisation, digitalisation, and new demands for companies to be dynamic and flexible both towards internal employee needs and external demands of both productivity and resource efficiency (Martela, 2022). Dynamic companies with a wish for flexibility should consider all-inclusive office services where furniture is included. The results suggest this as a possible environmentally friendly offer if the furniture is reused and maintained to have a long service life after age ten. The office space must be used efficiently and should be scaled to fit number of employees.

The analysis of the changes to the scenarios when the organisation has a declining number of employees could simulate the effects of optimizing space and furniture over a 15-year period. Workplace analyses typically show that designated desks are empty 40-60% of core working hours (Blakstad & Hatling, 2007; Whitehead & Gillen, 2021). This suggests a high number of organisations can reduce their office size. Flexible office rental solutions allow the office space to be adaptable and dynamic rather than static.

The possibility to scale office spaces up or down is an attractive feature to businesses with uncertain future needs. The COVID-19 outbreak showed that rapid changes in workplace habits and needs can come unexpectedly. This suggests flexibility can become a highly valued function in the future office interior market. However, it can be debated whether these flexibility features could stimulate a higher exchange rate of furniture in the Flexible reuse scenario (RS3) and the All-inclusive office scenario (RS4) than is included in the analysis. The challenge will be for the adaptable qualities to be utilised sustainably, both economically, socially, and environmentally. If the adaptability provided by result-oriented PSSs means rapidly increasing changes in furniture, without ensuring multiple user phases, the result in terms of GHG emissions could be more similar to the Fashionable office scenario (BS2) than the All-inclusive office scenario (RS4). A lack of knowledge about the exchange rate of furniture in PSS models in general makes assumptions about possible higher exchange rates difficult to include in the model. Case studies or questionnaires to different PSS customers could shed light on these matters in further analyses.

5.4. GHG accounting

The results of the environmental analysis of GWP showed that furniture related emissions made up 61% of total emissions if furniture was kept for short use periods before going to waste treatment. The emissions from furniture consumption were drastically reduced if the PSS solution used furniture of age ten, due to all cradle-to-gate emissions being allocated to previous years in the furniture's lifetime. The waste treatment of furniture that was not internally reused in the relocation process added a substantial amount of emissions both from the waste treatment processes and the residual cradle-to-gate emissions. Added repairs extend the lifetime of furniture which were favourable by delaying emissions from new furniture procurements.

The highest emission totals in analysed scenarios were related to high exchange rates of new furniture and emissions from energy use in the office building. Throwing away everything old to start anew in a space efficient office with all reused furniture such as in the All-inclusive office scenario (RS4) did not make the best result for either a fixed number of employees or a declining number of employees. However, the emissions were only 3-8% higher than for the Flexible reuse Scenario (RS3) when furniture was reused from the old office buildings. This is due to the emissions associated with the furniture from old buildings essentially being a fixed total that cannot be avoided, only delayed in time by postponing new furniture purchases. The influence of these emissions became evident when repairs were added to internally reused furniture, so that more furniture is reused. This reduced emissions with 0.1-3% (See RS2b compared to RS3a and RS2c to RS3b). The overall change in furniture need in the case study by moving from cell offices to an open office solution gave a lower percentage of reuse for furniture groups such as large office desks, storage units and small tables, being thought superfluous in the new office layout. Adding refurbishments could possibly decrease the waste from these furniture categories. However, time constraints and the need for expert opinions on the possibilities of refurbishments limited a further analysis in this regard.

Moreover, the GHG emissions totals from energy use were reduced by 36% (28 tonnes CO2eq) between scenarios which have the same office size throughout the period, and offices that can reduce the office space to fit a declining number of employees. This suggests a great emission reduction potential by reducing the size of the office. The energy mix and energy consumption in the scenarios was based on average energy use for office buildings in Norway. The case study building is from 2021, and it is assumed the building will have lower emissions from energy use in real life. Due to the lack of historic data on energy use in the building it was decided to use averages, but once a full year of energy consumption has been recorded, this data can be added to the analysis as a prediction of energy use for the 15-year period. The suggested model can also be used to evaluate different energy reduction measures that can be undertaken during a 15-year period. Office space reductions can for example be compared to other energy efficiency measures such as installing solar panels or heat pumps.

Figure 19 (page 57) presents the accumulative GHG emissions associated with one employees' furniture use during the analysed 15-year period, showing the effects of all furniture being of the same age group when entering the analysed system. This shows a possible 59% reduction in emissions between choosing all furniture age ten compared to all new furniture. This result can indicate that if a start-up company is considering moving into a new office, it should either try procuring used furniture of age ten or older or enter an all-inclusive office that utilises old furniture that is made to last.

The results are also influenced by the same furniture mix being used across all scenarios. The embedded cradle-to-gate emissions of the furniture was the same. This limits the reduction potential for furniture related emissions during the analysed period. If new furniture with lower cradle-to-grave emissions were selected when procuring new furniture, the emission totals could be reduced.

5.5. Life span of furniture

Both customers and PSS providers should strive to incorporate used furniture of high quality that can be used beyond the age of ten and that can withstand multiple user phases. The expected lifetime of furniture was set to 15 years for furniture that has not gone through repairs and 22.5 years for furniture which has gone through a quality check where needed maintenance and repairs are added. The true life-expectancy depends greatly on the exact furniture model, its materials and design, as well as utility rate and treatment by the user. How long the life expectancy is prolonged by repairs is highly speculative and only based on expert opinions. These opinions also varied slightly from informant to informant. Further research on the link between repairs, maintenance and prolonged lifetime of furniture would be highly beneficial and make it possible to change these parameters to find the optimal solutions to balance environmental benefits as well as economic aspects.

The need for repairs is assumed to be the same for all scenarios. This is due to lack of data on repair needs in different lease or rental situations compared to conventional furniture purchases. In the business to consumer (B2C) market, it is assumed that wear and tear might be more frequent for rented products than for bought products, as the customer feel less obliged to treat the product carefully (Tukker, 2015). It is unknown whether this applies to the B2B and B2G market, as the owner of the furniture is the company, while the users are the employees, who will not have ownership of the furniture either way. Therefore, it is not assumed that furniture would last shorter due to different treatment in the different scenarios. However, there might be a higher degree of wear and tear associated with dismantling and moving furniture more frequently in rental situations.

5.6. Preconditions in the LCA methodology

The choice of changing the utility rate in some scenarios and not others, as well as changing the number of employees during the analysed period, challenges the typical LCA method. The functional unit in traditional LCAs is usually linked to a set amount of furniture with a fixed utility rate used by a fixed number of employees. The argument for adding these features is to model a realistic scenario in many office buildings. One office with an optimized amount of space (m2) and furniture items can serve the same function for the same number of employees as another office that is more spacious with several furniture items and a lower utility rate.

A study of different ownership models for textiles by Levänen et al. (2021) exemplifies the issue. The study compares the GWP impacts of one pair of jeans in a purchase situation compared to a rental scenario where multiple users lend the same pair of jeans. Their rental scenario is meant to follow the logic of collaborative consumption, where "environmental benefits are assumed to follow from increasing the utility rate of a product" (Levänen et al., 2021, p. 3). However, in their analysis, the utility rate of the product is the same, the jeans are used 200 times in both scenarios with no time aspect included. This makes the rental scenario the worst option, due to a higher number of transport and cleaning processes for the jeans to be used 200 times. However, a situation closer to a real-life scenario would be a rental situation for clothes of high value that are seldomly used by one owner, such as formal evening wear. The increased utility rate of the product being frequently used if rented out to numerous users can potentially avoid the production and sale of multiple dresses within the analysed period.

The model framework suggested in this study follow the latter principle, by including different utility rates, while the time period is equal in all scenarios. When the use factor is adjusted in the scenarios from 0.9 to 0.7, several employees share the same amount of space and furniture, which will result in a higher utility rate. The effects of the higher utility rate when it comes to wear and tear of furniture has not been analysed further. A further development of the model would be to add these effects. More knowledge is needed about how the higher utility rate will influence the expected lifetime and repair needs of different furniture types.

The chosen allocation method greatly influenced the furniture related emissions of the scenarios. Choosing a different allocation method such as the 50-50 method or the cut-off method would change the emission totals and lower the differences between the scenario alternatives. For example, the 50-50 method divides the cradle-to-gate and waste treatment emissions equally between the first and last user of the product, while the cut-off method assigns the virgin material use to the first user, and the waste disposal to the last user. The emissions associated with transport, maintenance, and possible recycling in between the first and last user phase are also portioned out differently.

The allocation method suggested in this study allocated the cradle-to-gate emissions based on the formulated REV function as described in section 3.4.4. Further, the emissions associated with repairs are placed on the user phase in which the repairs are intended to facilitate. The emissions from end-of-life treatment and substitution effects are counted at the end of the furniture's lifetime. This method is thought to avoid double counting of emissions, except for possible double counting of the substitution effects. These emissions can be counted both as benefits of material reuse and energy recovery in this analysis, and as benefits of avoided emissions in new products.

When furniture of age ten is added to the inventory lists, no emissions from the cradle-to-gate stages of the furniture production are added. These emissions have been accounted for in previous years of the furniture's lifetime. This is due to the REV function going to zero when the furniture reach age ten, meaning its monetary value is thought to be zero after this point. Keeping furniture after age ten shows the benefits of extending the use period of furniture beyond its economic value. This benefit is not accentuated in the 50-50 or cut-of method, where the emphasis is placed on number of user phases and not on the age of the product. This means a change in allocation method would make the results the same for scenario alternatives using furniture of age five and age ten as input if the furniture lasted through the whole 15-year period. This would give a lower incentive to keep older furniture in use longer.

An associated issue with the proposed REV-function is the fixed emissions allocation of 7% of the cradle-to-gate emissions total for year two until year ten. This implies it is the same environmental benefit to having a two-year old furniture item and a nine-year old furniture item. This issue is addressed by Baxter & Callewaert (in press), suggesting a diminishing balance form where the product loses a percentage of its value each year would be a better fit. However, the gathered data for this analysis of second-hand furniture prices suggested a linear function as the best fit. Moreover, the low R^2 value for the gathered data on price of furniture being a function of its age suggests that there are other factors influencing the price of office furniture. Other factors identified by Baxter and Callewaert (in press) are the general condition of the furniture and the attractiveness of the design in terms of timelessness or trendiness. An attempt to add the general condition of the furniture was made based on the pictures in Finn.no advertisements. However, it was not possible to make satisfying distinctions between degrees of wear and tear based on the photos alone, resulting in some uncertainty in the regression model. Furthermore, the REV function is based on sales data from Finn.no, a marketplace mainly used for private sales of furniture, meaning it is a consumer-to-consumer (C2C) platform. This assumes that the C2C market has the same price sensitivity as the B2B and B2G office furniture markets. It also assumes that different types of office furniture follow the same price function. These aspects and assumptions should be further analysed to set more accurate REV functions, preferably with different functions established for different furniture types.

The highlighted issues and effects of the chosen allocation method in environmental analysis where reuse happens advocates for the necessity of establishing shared standards for allocation methods for reuse. Since no consensus has yet been established, the proposed allocation method is a viable addition to possible methods. Due to time constraints, a further analysis of the effects of changing the allocation method have not been executed but should be addressed in a further environmental analysis.

Finally, the environmental analysis was based on EPD information which provide GHG emissions associated with different life cycle stages for furniture products. It was not possible to obtain environmental information about the exact furniture pieces either in the old office buildings or purchased for the new office space. Therefore, average emissions from EPDs were used. The analysis is, however, based on few data sources. For example, out of 64 investigated EPDs for chairs, only half had emissions from end-of-life treatment and substitution effects. For cabinets and shelves, only two EPDs with emissions from waste processing were identified, neither of which had emissions from the modules C3 (Disposal) and D (reuse-recovery-recycling potential). This lack of information weakens the validity of the results since the emission input is based on few secondary data sources. The issue can be avoided with access to larger datasets of GHG emissions from furniture. This would give a more robust average suitable for generalization.

5.7. Factors not addressed

Some relevant factors have not been addressed in the analyses. Transport emissions are only included in the cradle-to-gate emissions gathered from EPDs. No other transport emissions are included in the analysis. It is highly likely that transport emissions would differ greatly between the scenarios and be dependent on the location of the service provider in relation to the analysed office building.

The potential impacts of procuring poorly designed furniture have not been included in the analysis. Furniture that are worn quickly or are difficult to repair will have a shorter life expectancy than 15 years and must be replaced by new furniture. A wide array of consumption behaviours could also influence the practical reuse potential of the scenarios. For example, to what extent aesthetic qualities such as timelessness or trendiness is emphasized, or what is regarded as the acceptable level of marks and scratches on furniture in a PSS service. Throwing away furniture that could have been repaired or reused is strongly linked to the assumed monetary depreciation rate of the furniture and the cost of these services compared to buying new furniture. It also requires a willingness to spend time and resources by the customer to gather and evaluate different PSS offers, which might not be prioritized compared to the straight forwardness of buying everything new. The availability and flexibility of PSS solutions, paired with possible time savings by outsourcing inventory or office related services to a professional service provider, are advantage that might outweigh the possible added costs of such services. An economic analysis of different PSS offers would give insights into how economically sustainable these different scenarios are.

6. Conclusion

Product-service system (PSS) is not a term that is widely used in the furniture industry in Norway. However, this research showed many companies have offers that can be classified as such. In total, ten different offers were identified. Six offers were identified as product-oriented offers, where two offers were identified as product-related and six offers were identified as advice and consultancy offers. Two use-oriented PSS offers were identified: furniture rental and furniture lease. Lastly, two offers were identified as result-oriented PSSs: office interior as a service and all-inclusive office services.

A model framework and scenarios utilising PSS solutions were constructed based on case study data to compare the environmental impact of different PSS implementations. An allocation method based on the residual environmental value (REV) approach proposed by Baxter & Callewaert (in press) was used to allocate emissions from furniture production over the furniture's' lifetime. The lowest GHG emissions total was achieved in the Flexible reuse scenario (RS3b), which combined reuse optimalisation measures, a higher office utility rate, and utilised reused furniture of age ten to fulfil the remaining furniture need. Emissions from energy use contributed to 30-69% of the emissions totals, which suggested energy efficiency and space reduction measurements were highly relevant to minimize the environmental impact of offices. The scenarios with a flexible office rental solution reduced energy related emissions by 36% compared to the baseline scenario with a fixed office size. For a declining number of employees, flexible rental solutions where both furniture and office space can be reduced in accordance with number of employees gave the lowest emissions totals for scenarios with furniture age ten as input.

The model and scenario development give new insights to how different PSS solutions can be analysed in a systems perspective. The chosen allocation method is a novel attempt at allocating emissions through multiple user phases, an issue yet to be standardized in established LCA methodology. The suggested allocation method emphasises the value of reuse beyond the monetary value of furniture.

The environmental analysis showed the benefits of internal and external reuse of furniture. Efficient use of office space was identified as an important factor that can add unnecessary emissions from energy use and excess furniture consumption. Result-oriented PSS offers where office space and furniture can be rented or leased as a flexible and scalable service have a potential of low emissions if utilising furniture of age ten with a long life expectancy.

The analysis was a theoretical testing and exploration of what PSS can look like if implemented in an office organisation. CE literature advocates for result-oriented PSSs in particular as a promising business model that promotes prolonged service lives for furniture that both the customer and PSS provider benefit from. However, PSS is a concept and a business model, which does not necessarily have environmental benefits. The scenarios presented are not exclusive situations only PSS offers can achieve. Any organisation has the potential to achieve the same amount of furniture reuse and can implement space reduction measures that would accomplish similar results. A crucial point for decision makers should be to critically evaluate whether the office and inventory needs will be handled most efficiently by internal personnel or external service providers. The results suggests that PSS solutions will give low environmental impacts if they promote an efficient use of office space, efficient reuse and long lifetimes for furniture. For organisations experiencing uncertainties about office needs, number of employees and corresponding furniture needs, opting for a flexible result-oriented PSS should be considered as an option to attain a good work environment with a low environmental impact.

Appendix

Appendix 1: GHG calculations from EPD information

GWP contribution totals [kg CO2 eqv] for the end-of life stages for the main furniture types

Furniture product	No. of EPDs	C2: Waste processing Low	C2: Avrage	C2: High	C3: Disposal Low	C3: Avrage	C3: High	D: reuse-recovery-recycling potential Low	D: Avrage	D: High
Office chairs	10	22.7	16.5	6.4	0.1	0.17	0.0	-17.9	-12.3	-7.1
Working desks	5	1.6	2.2	2.8	1.9	4.2	5.7	-7.8	-4.8	-1.0
Meeting chair, mixed	14	1.9	4.7	10.2	0.7	0.2	0.0	-2.3	-3.5	-5.3
Meeting tables small	6	0.4	1.7	2.5	1.2	2.1	2.9	-4.8	-3.5	-2.0
Meeting tables large	4	4.7E-06	3.2	9.1	0.0	9.3	20.3	-11.3	-2.8	0.0
Cabinets and shelves*	2	20.2	21.2	22.1	N/A	N/A	N/A	N/A	N/A	N/A

* For missing values N/A, averages for the categories of mainly wood based furniture (Working desks, meeting tables) has been used.

GWP contributions [kg CO2 eqv] for Office chairs

No	Furniture type	Company	End-of-life treatment (Module C2 and C3)	Substitution effect (Module D)
1	Office chair RH New Logic	Flokk	22.8	-17.9
2	Office chair HÅG Tribute 9031	Flokk	29.0	-16.9
3	Office chair upholstered	Flokk	22.6	-16.1
4	Office chair R-20 Pro Office Chair	NCP	13.5	-11.8
5	Office chair BMA Axia®	Flokk	16.2	-11.5
6	Office chair upholstered	Flokk	15.0	-10.8
7	Office chair HÅG Futu	Flokk	15.6	-10.8
8	Office chair upholstered	Flokk	14.2	-10.2
9	Office chair	NCP	11.9	-9.5
10	Office/meeting chair	Flokk	6.6	-7.1
Average			**16.7**	**-12.3**

GWP contributions [kg CO2 eqv] for Meeting chair, mixed materials

No	Furniture type	Company	Cradle-to-gate (Module A1-3)	End-of-life treatment (Module C2+C3)	Substitution effect (Module D)
1	Chair stackable	Fora Form	9.2	2.6	-2.3
2	Chair Public seating	NCP	10.3	4.6	-3.5
3	Public seating chair	NCP	10.3	4.6	-3.5
4	Chair Stackable	Helland Møbler	11	2.9	-2.8
5	Favn seating chair	NCP	12.3	0.9	-1.1
6	Meeting chair stackable	NCP	13.6	4.5	-3.3
7	Meeting chair	Flokk	16.3	5.5	-4.6
8	Public M seating chair	NCP	17.2	4.6	-3.8
9	Favn M seating chair	NCP	17.3	1.2	-2
10	Chair stackable	NCP	18	3.7	-2.9
11	Meeting chair stackable	NCP	19.6	4.6	-4
12	Meeting chair stackable	NCP	22.2	7.7	-4.7

13	Meeting chair	Fora Form	22.7	10.1	-5.2
14	Meeting chair	Fora Form	27.7	10.2	-5.3
Average			**16.3**	**4.8**	**-3.5**

GWP contributions [kg CO2 eqv] for Module A1-3 (Cradle-to-gate) for Working desks with height adjustable legsystem

Furniture product	No. Of EPDs	Low [kg CO2 eq]	Average [kg CO2 eq]	High [kg CO2 eq]
Height adjustable electric legsystems	5	41.1	59.6	68.8
Table tops	5	16.4	21.5	29.4
Total	10	57.5	81.1	98.2

GWP contributions [kg CO2 eqv] for Working desks

Averages used for both non-adjustable and height adjustable due to lack of Modules included in EPDs for the latter furniture group.

No	Furniture type	Company	End-of-life treatment (Module C2 and C3)	Substitution effect (Module D)
1	Desk 1800x800 Foldable	Svenheim Møbelindustri	7.4	-5.2
2	Desk 1800 x 800	Fora Form	5.8	-5.2
3	Desk 1200 x 800	Fora Form	4.5	-4.8
4	Legs + Table top 1800x900	Svenheim Møbelindustri	7	-7.8
5	Legs + table top 1600x801	Svenheim Møbelindustri	7.3	-1
	Average		**6.4**	**-4.8**

GWP contributions [kg CO2 eqv] for small meeting tables

No	Furniture type	Company	End-of-life treatment (Module C2 and C3)	Substitution effect (Module D)
1	Round table 750x750	Fora Form	4.1	-3.3
2	Clip table 1200 x 450	Fora Form	3.7	-4.8
3	Clip table 800 x 800	Fora Form	3.7	-3.6
4	Round wood table Ø70	Helland Møbler	4.4	-2
5	Small table R-80	NCP	4.4	-4.6
6	Factor Lite table (Ø800)	Svenheim Møbelindustri	2.7	-2.6
	Average		**3.8**	**-3.5**

GWP contributions [kg CO2 eqv] for large meeting tables

No	Furniture type	Company	End-of-life treatment (Module C2 and C3)	Substitution effect (Module D)
1	Large meeting table 3000x1200	Fora Form	25.8	-11.3
2	Large conference table 2000x1200	JSC Svenheim	21.0	0.0
3	Large conference table 4000x1200	JSC Svenheim	3.0	0.0
4	Large conference table 6000x1200	JSC Svenheim	0.0	0.0
	Average		**12.5**	**-2.8**

GWP contributions [kg CO2 eqv] for cabinets and shelves, wood material

No	Furniture type	Company	C2 Waste processing	C3 Disposal	D reuse-recovery-recycling potential
1	Cabinet, shelves & drawers	JSC Svenheim	22.1	Not declared	Not declared
2	Cabinet, pullout dawers	JSC Svenheim	20.2	Not declared	Not declared
	Average		**21.2**		

Appendix 2: Interview guides

<u>Background information for discussion</u>

<u>Illustration of circular value chains:</u>

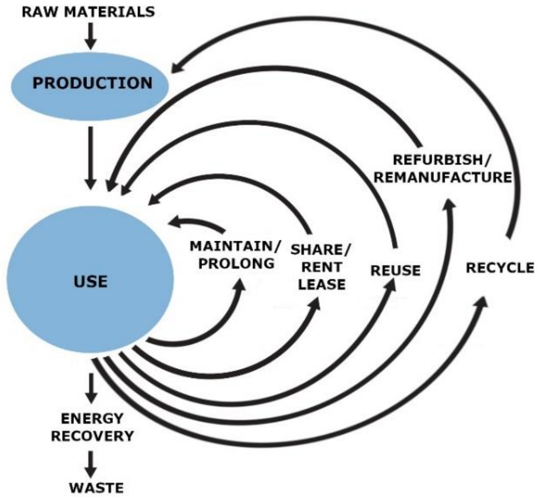

Figure based on (Ellen MacArthur Foundation, 2022; PBL, 2022)

<u>Definition of PSS:</u>

"PSS is a business model focused toward the provision of a marketable set of products and services, designed to be economically, socially and environmentally sustainable, with the final aim of fulfilling customer's needs" (Annarelli et al., 2016, p. 1017).

<u>Identified PSS offers classified according to Tucker's model (2004):</u>

Product content (tangible) – Service content (intangible)

A: Product-oriented	B: Use-oriented	C: Result-oriented
1. Product-related i. Maintenance contract ii. Take-back schemes 2. Advice and consultancy i. Furniture inventory management ii. Reuse optimalisation services iii. Interior design services?	3. Furniture rental 4. Furniture leasing	6. Interior-oriented i. Office interior as a service 7. Office space-oriented i. Coworking spaces ii. All-inclusive offices

Figure based on Tukker (2004)

Interview guide group 1

Representatives from companies that offer PSS solutions for furniture.
The questions are adapted to the informant's role in the company.

Introduction	• Interviewer: Introduces the background information on circular value chains and PSS. • Interviewee: introduces themself and the company
Drivers: Sustainability and company reputation	1. In relation to the figure with circular value chains: How are the different forms of circular value chains emphasized at [company]? What is the focus?
General driver/Motivation for PSS	2. In relation to the table with identified PSS offers: What PSS solutions does [company] offer? - When was it introduced? 3. What was the motivation behind offering the PSS solution(s)? (eg increased sustainability, more efficient use of resources, brand building, new market segment, innovation etc).
Demand and market	4. How is the demand for your PSS offer(s) today? (high, low, increasing) - Why do you think that is? 5. Who is the typical PSS customer? 6. What do you consider to be the most advantageous for the customers by choosing this / these PSS solution(s)? (flexibility, sustainability, economy, save time) 7. What have been the biggest challenges you have faced in marketing / selling PSS solutions?
Supply chain and collaborations	8. Have you entered into new collaborations or changed the business model to introduce PSS offers? - Can you describe the value chain with the various partners for their PSS offer? 9. Are there any challenges / bottlenecks in the value chain that you feel must be solved for the offer to work optimally? - What does it take for the offer to work even better? 10. (eg technical solutions, tracking systems) 11. Have you encountered any technical challenges in implementing the PSS solution? - If yes: how have they been resolved?
Environmental impact	12. What environmental impacts do you reduce by offering a service rather than a product? - How do you document environmental impact today? 13. How can the PSS offer be even more environmentally friendly?
Economic opportunities and barriers	14. What factors must be present to make PSS competitive in relation to conventional product purchases?
Public procurements	15. Is there demand from public procurement for their PSS service? a. If so, to what extent? b. If not, why do you think that is the case? 16. Are there barriers that are specific to public procurement in relation to PSS services? a. If so, how can they be minimized?

	17. Do you have examples of public tenders from recent years that have requested or had an opening to lease / rent furniture instead of buying? 18. What procurement criteria for furniture do you think would promote good resource use and sustainability in general?
Additional barriers	19. Are you facing any other barriers, which haven't been mentioned? - Which? - How are you tackling these? - Can you foresee any future barriers?
Last remarks	20. What do you think are the most important criteria for choosing interior solutions that stimulate sustainable use of resources? 21. Other topics related to PSS and furniture consumption that you find important that we have not talked about?

Interview guide group 2

Representatives linked to the case study (BSN) or public procurement.
The questions will be adapted to the informant's position and connection to the case study.

Introduction	• Interviewer: Introduces the background information on circular value chains and PSS. • Interviewee: introduces themself and the company
Drivers: sustainability focus in general	1. In relation to the figure with circular value chains: How does [business] work to facilitate the promotion of circular value chains and sustainable consumption for furniture? 2. Has the EU's new policy to promote more circular and sustainable products and services affected public procurement?
Opportunities and barriers for PSS in public procurement in general	3. In relation to the table with identified PSS offers: Which of the PSS services for furniture are you familiar with that are used in public enterprises / Oslo municipality today? 4. Are there any other PSS services you think are relevant for public enterprises / Oslo Municipality to request? - If so: why do not you think they have been used? - If no, what makes it irrelevant? 5. In which situations / for which public bodies do you think it would have been advantageous to choose PSS over conventional product purchases? (eg departments that work a lot project-based / with hired personnel in periods, need for flexibility, small / large departments) 6. Are there legal aspects of the public procurement process that make it difficult to procure rental / leasing / furnishing services rather than product purchases? - If so, how can they be minimized so that the "best solution" wins? 7. Which procurement criteria would be advantageous for use- and result-oriented PSS? 8. Do you have examples of public tenders from recent years that have requested or had an opening to lease / rent furniture instead of buying?
Specifically for municipal level / BSN	9. What premises have already been set for furniture purchases for municipal departments with regard to the regulations of public procurement? 10. Who is responsible for the design and evaluation of tenders in the municipalities?
Environmental impact	11. To what extent and how do you think that buying a service rather than a new product can promote sustainability and a circular economy? 12. What procurement criteria for furniture do you think promotes good resource use and sustainability?
Economic opportunities and barriers	13. Are there any financial barriers that make it more difficult to choose a rental / leasing / subscription solution for furniture rather than product purchases? (eg. in the public procurement system, operating budget versus investment budget) 14. How is the environment weighed against the economy in the procurement processes for furniture?
Last remarks	15. Other topics related to PSS and furniture consumption that you find important that we have not talked about?

Appendix 3: Calculations of reuse potential

Furniture type	Total no. of items in old buildings	Reused no. of ite	Items left, potential reuse	Needed items from order list	Needed items for Scenario with 0.7 use factor	repaired (estimated that 30% can be used)
Office chairs	166	105	61	130	81	18
Working desks non-adjustable	68	42	26	0	0	8
Working desks adjustable	98	71	27	122	73	8
Meeting chairs, mixed	325	220	105	73	11	32
Meeting chairs, wood	208	0	208	0	0	62
Meeting tables (2-4p)	160	24	136	7	0	41
Meeting tables (6-12p)	6	2	4	23	11	1
Cabinets and shelves	493	65	428	29	9	128
Total	**1524**	**529**	**995**	**384**	**185**	**299**

Appendix 4: System prerequisites

A) All furniture is set to have a general life expectancy of 15 years without repairs.
B) It is assumed that furniture provided through external reuse has gone through repair services specified under section 3.4.5 Repair and service needs.
C) Internally reused furniture is assumed not to go through repairs unless otherwise stated.
D) Furniture supplied through external reuse is assumed to last half a lifetime longer on average due to the added repair service, making the new expected lifetime 22.5 years.
E) When the furniture reaches its final life expectancy, it is assumed to end up as waste and go to waste treatment. This adds the emission averages from module D found in EPDS of the furniture group.
F) Emissions from transport that is part of the Cradle-to-gate information from EPDs (information module A1-A3, transport of raw materials to manufacturing) are included in the analysis. They were included in order to use comparable data from different sources. Otherwise, no transport emissions are included in the analysis, such as transport from manufacturer to retailer, or transport related to picking up or delivering repair services.
G) Emissions related to the user phase of furniture are not included due to lack of data for this module in EPDs. Electricity use for height-adjustable electric tables for example, or emissions connected to cleaning or vacuuming of furniture items are therefore not included.
H) Only work areas and furniture for office work is included in the analysis, meaning designated office spaces and meeting rooms identified by the floor plan. This excludes space and furniture used for functions such as reception areas, and other areas used for social or service functions.
I) Energy use is included for the studied work areas as described in section 3.4.6 Emissions from energy use.
J) Emissions for construction and maintenance of the building are excluded.
K) The most important furniture groups regarding environmental impacts are included based on available data.
L) The number of employees is set to 300 as a basis but can vary as explained in section 4.3.1. It is also a varying factor how many employees are working in the office on a daily basis., how many are in meetings or business trips etc.
M) Home office use is not included with regard to furniture needs, energy etc, which underestimates the total output of the analyses.
N) Emissions from moving services are excluded.
O) For scenarios where the amount of furniture can be customized to the number of employees due to a rental/subscription, it is assumed that all furniture is reused by being relocated to be used elsewhere or put into storage by the service provider. This means the furniture is not considered for waste disposal unless it has reached its expected technical age.
P) For scenarios with furniture purchase, it is assumed that when the number of office workers decline, it is assumed that the newest furniture is regarded as more desirable to keep while the oldest furniture is put up for reuse. In leasing/rental options however, it is assumed that the newest furniture will have the highest value to the renting company, and therefore also the highest renting price. Therefore, the newly supplied furniture is reduced firstly, while internally reused furniture is taken away as last option.

Appendix 5: GHG emission totals for analysed scenarios

Emission totals in kg CO2eq for scenarios with a stable number of employees

Scenario	Waste treatment old furniture	New furniture	Internally reused furniture	Externally reused furniture	Waste treatment acquired furniture	Repairs	Energy use	Total
BS1	23,911	49,932	-	-	4,187	-	77,962	**155,993**
BS2a)	23,911	97,367	-	-	64,990	-	77,962	**264,231**
BS2b)	23,911	97,367	-	-	-	-	77,962	**199,240**
RS1a)	17,316	45,775	4,156	-	4,187	-	77,962	**149,397**
RS1b)	17,316	-	4,156	17,476	2,439	8,875	77,962	**128,225**
RS1c)	17,316	-	4,156	-	4,187	13,565	77,962	**117,187**
RS2a)	17,429	35,362	4,057	-	3,306	-	61,549	**121,704**
RS2b)	17,429	-	4,057	13,797	2,425	7,007	61,549	**106,264**
RS2c)	17,429	-	4,057	-	3,306	9,975	61,549	**96,316**
RS3a)	16,606	-	4,551	13,235	2,754	7,459	61,549	**106,154**
RS3b)	16,606	-	4,551	-	3,296	7,459	61,549	**93,461**
RS4a)	23,911	-	-	13,797	-	7,007	61,549	**106,264**
RS4b)	23,911	-	-	-	3,306	14,013	61,549	**102,780**

Emission totals in kg CO2eq for scenarios with a declining number of employees.

Scenario	Waste treatment old furniture	New furniture	Internally reused furniture	Externally reused furniture	Waste treatment acquired furniture	Repairs	Energy use	Total
BS1	23,911	49,932	-	-	4,187	-	77,962	**155,993**
BS2a)	23,911	79,191	-	-	52,859	-	77,962	**233,924**
BS2b)	23,911	79,191	-	-	-	-	77,962	**181,065**
RS1a)	17,316	37,664	4,156	-	2,691	-	77,962	**139,790**
RS1b)	17,316	-	4,156	14,111	1,631	7,176	77,962	**122,352**
RS1c)	17,316	-	4,156	-	2,691	10,481	77,962	**112,607**
RS2a)	17,544	29,795	4,057	-	2,634	-	61,549	**112,607**
RS2b)	17,544	-	4,057	12,232	2,239	6,766	61,549	**104,387**
RS2c)	17,544	-	4,057	-	2,634	8,544	61,549	**94,328**
RS3a)	16,606	-	4,551	11,499	2,344	7,129	50,060	**92,189**
RS3b)	16,606	-	4,551	-	2,635	7,129	50,060	**80,981**
RS4a)	23,911	-	-	13,797	-	7,007	50,060	**94,775**
RS4b)	23,911	-	-	-	2,116	11,491	50,060	**87,578**

Accumulated emissions per office worker in kg CO2eq for scenarios with a fixed number of employees.

	Year	BS1 new	BS2a) new-waste	BS2b) new-reuse	RS1a) new	RS1b) age 5	RS1c) age 10	RS2a) new	RS2b) age 5	RS2c) age 10	RS3a) age 5	RS3b) age 10	RS4a) age 5	RS4b) age 10
Period 1	1	159	159	159	113	102	96	97	91	87	88	85	126	117
	2	188	188	188	142	131	119	120	114	106	111	105	149	130
	3	217	217	217	168	158	139	140	134	123	131	121	172	144
	4	246	246	246	191	181	157	158	151	136	148	135	195	158
	5	275	347	275	215	204	174	175	169	150	164	149	217	171
Period 2	6	303	426	353	238	222	191	193	183	164	178	162	231	185
	7	332	455	382	262	239	208	210	196	177	192	176	245	199
	8	361	484	411	308	281	248	250	234	212	230	211	258	212
	9	390	513	440	349	304	265	284	253	226	249	225	272	226
	10	419	614	469	378	327	283	307	272	240	268	239	286	240
Period 3	11	437	693	548	401	350	300	326	291	254	287	252	300	254
	12	454	722	577	424	373	317	345	310	267	306	266	313	267
	13	471	751	606	446	393	356	365	327	294	325	284	327	315
	14	489	780	635	469	410	373	384	341	307	340	298	341	329
	15	520	881	664	498	427	391	406	354	321	354	312	354	343

Accumulated emissions per office in kg CO2eq worker for scenarios with a declining number of employees.

	Year	BS1 new	BS2a) new-waste	BS2b) new-reuse	RS1a) new	RS1b) age 5	RS1c) age 10	RS2a) new	RS2b) age 5	RS2c) age 10	RS3a) age 5	RS3b) age 10	RS4a) age 5	RS4b) age 10
Period 1	1	159	159	159	113	102	96	98	91	87	88	85	126	117
	2	188	188	188	142	131	119	120	114	107	111	105	149	130
	3	217	217	217	168	158	139	141	134	123	131	121	172	144
	4	246	246	246	191	181	157	158	152	137	148	135	195	158
	5	275	347	275	215	204	174	176	169	150	164	149	217	171
Period 2	6	311	430	358	244	226	195	195	186	167	178	162	231	185
	7	347	463	391	273	248	217	215	203	184	192	176	245	199
	8	383	497	424	320	289	256	261	249	227	232	214	258	212
	9	419	530	458	362	314	278	301	272	244	252	227	272	226
	10	456	635	491	396	340	299	328	296	261	272	241	286	240
Period 3	11	483	724	580	428	372	326	355	323	282	291	255	300	254
	12	510	763	618	460	405	353	382	350	304	310	268	313	267
	13	537	801	657	492	434	403	409	374	336	331	288	327	315
	14	564	840	696	524	461	430	436	395	358	346	301	341	329
	15	613	951	735	562	488	457	465	417	379	361	315	354	343

Number of employees, use factor specifications and GHG emissions from energy use in modelled scenarios with a declining number of employees

Scenario BS1, BS2, RS1

	Number of employees	**Factor use of space**	**Office use estimate**
Drop-in employees	60	0.2	12
Full time office workers	240	0.9	216
Totals	**300**		**228**

	Period 1	**Period 2**	**period 3**
Number of employees	300	240	192
Use factor total	228	182	146
BS1, BS2, RS1:			
Use of space [m2]	2,144	2,144	2,144
Emissions from energy use [kg CO2eq]	25,987	25,987	25,987

Scenario RS2, RS3, RS4

	Number of employees	**Factor use of space**	**Office use estimate**
Drop-in employees	60	0.2	12
Full time office workers	240	0.7	168
Totals	**300**		**180**

	Period 1	**Period 2**	**period 3**
Number of employees	300	240	192
Use factor total	180	144	115
RS2:			
Use of space [m2]	1,693	1,693	1,693
Total emissions from energy use [kg CO2eq]	20,516	20,516	20,516
RS3, RS4:			
Use of space [m2]	1,693	1,354	1,083
Total emissions from energy use [kg CO2eq]	20,516	16,413	13,130

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