The cost of comfort: waking up to furniture waste

Researching material use in European household furniture using dynamic stock analysis

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Executive summary

This study is a first attempt to address some of the more significant gaps in the available data on (European) furniture. Furthermore, this study takes a dynamic stock analysis approach to look into material stock- and flow dynamics of European household furniture and project them over time. A total of 11 material categories in 14 furniture product categories are assessed. Using principles of dynamic stock analysis and IMAGE data on population and residential floorspace per capita: a Python model has been developed to assess required furniture- and material stocks, the required primary material used in furniture production and the total amount of recycled- and landfilled material per year, and to project the results overtime.

To further inform the model, a material database is developed, containing material- and lifetime information on 14 furniture product categories and a survey (n=108) on household furniture has been conducted to derive furniture intensities per unit residential surface.

To project the development of material stocks- and flows in European household furniture over time, two scenarios are defined: the business-as-usual or the 'baseline' scenario and a second scenario called 'the reduced waste scenario' in which reuse and recycle fractions are gradually increased over time.

Following business-as-usual patterns in the baseline scenario, the total material stock for furniture is projected to increase with roughly 97 Mt (or 20%) to 584 Mt, towards 2050. The total amount of landfilled- and recycled waste material from household furniture is estimated to be 36 Mt and 4 Mt respectively in 2050. The total amount of required primary material is estimated to increase to 38.5 Mt in total in 2050.

In the reduced waste scenario, the total amount of landfilled material is estimated to decrease to 15 Mt in 2050, where the amount of recycled material is estimated to increase to 15 Mt. Also the amount of required primary material is estimated to decrease to less than 18 Mt in 2050. The results from the reduced waste scenario show that a gradual increase from the reuse fraction from 2021 onwards (from 6% to 35% with a 1% step per year) and a gradual increase from the recycle fraction from 2021 onwards (from 10% to 50% with a 2% step per year), would be enough to reduce the need for primary material by half towards 2050.

Based on these results, it is the author's conviction that furniture should be given a separate waste status, similar to that of cars as set out in the end-of-life vehicle directive (European Commission, 2000): materials inside furniture should be labelled and furniture manufacturers should develop dismantling guidelines for their products to ease repair, remanufacturing and recycling. Targets should be set on the country level for the recycling of waste furniture and for the use of recycled (furniture) material in primary production.

… Let's wake up to furniture waste.

1 Literature review

According to the International Resource Panel (IRP), global consumption of primary resources has increased rapidly since 1970 due to rising populations and rising level of affluence. This development comes at environmental cost as 90 percent of biodiversity loss and water stress are caused by resource extraction and processing, on top of major contributions to global greenhouse gas emissions. The IRP concludes that, unless the global community is able to reduce its resource consumption related impacts, it will be very hard to achieve the goals set out in the Paris agreement and the sustainable development goals (Oberle et al., 2019).

One major industry is furniture: according to a report by the European Environmental Bureau (EEB), the European furniture industry accounts for roughly a quarter (28%) of the World's total furniture production, with a market value estimated at 84 billion euros, employing 1 million workers (Forrest, Hilton, Ballinger, Whittaker, & Arditi, 2017).

Up to 90% of environmental impacts of furniture are related to material use (Donatello, Moons, & Wolf, 2017): European yearly consumption of furniture is estimated at a total worth of 68 billion euros, amounting to roughly 10.5 million tonnes in furniture, 82% of which is for home use (Forrest et al., 2017). As a size comparison: 15.5 million new cars were registered in Europe in 2019, with an average weight of 1415 kg (ICCT, 2020). This amounts to a yearly European material consumption for cars of 22 million tonnes. Compared to the European car industry, where there are specific governmental incentives and targets for collection, dismantling, recycling, and use of recycled material in primary production as described by the European directive for end-of-life vehicles (European Commission, 2000), furniture falls under the municipal solid waste category which is far less regulated.

According to the EEB, taken over the whole of Europe, there is little reverse logistic available for furniture: most European furniture waste is destined for landfill and incinerated after it reaches its end-of-life, only 10% is recycled. Hardly any furniture is remanufactured, accounting for less than 0.1% of the total industry value. Moreover, there is little demand from end markets for recycled materials and given the low cost of primary production there is no incentive to invest in scaling up of repair- and refurbishment efforts, or improved methods of recycling (Forrest et al., 2017). This means that huge amounts of material from furniture goes to waste every year.

One way to manage natural resources more sustainably is by making use of Circular Economy (CE) practices, which are aimed at preventing waste and reducing the use of virgin materials (Blok & Roemers, 2017). Building on the Paris agreement, the European Union has adopted CE as a key principle in its sustainable strategy (European Commission, 2019). Given size and resource intensity, any comprehensive CE strategy attempting to increase circularity and reduce virgin material consumption should involve the furniture sector, but in order to define an informed CE based strategy, it is of great importance to have an understanding of in-use product- and material stocks and product lifecycle dynamics. Currently, very little of such information is available for (European household) furniture. This study will therefore look into the material side of European (household) furniture.

A body of literature already exists, in which methods of dynamic material stock- and flow analysis are combined with data from integrated assessment models to estimate various major in-use product- and material stocks and project them over time. As this study takes a similar approach to its subject, this chapter contains a review of studies that successfully apply this method (section 1.1), before reviewing some available literature on furniture specifically (section 1.2).

1.1. IMAGE & dynamic stock assessment

Issues of climate change and its relation to human activity are inherently comprehensive. Integrated assessment models are used to describe and model these functional relationships and to understand their long term development (Stehfest, van Vuuren, Kram, & Bouwman, 2014). There are various IAM frameworks available, such as AIM/CGE2.0, GCAM4.2, REMIND1.6, MESSAGE V.4 and IMAGE 3.0 (Pauliuk, Arvesen, Stadler, & Hertwich, 2017). The focus of this study is on IMAGE 3.0.

According to the IMAGE 3.0 model description, IMAGE is an integrated assessment model, developed by the PBL Netherlands Environmental Assessment Agency. IMAGE provides macro-scenario descriptions of future global development, the 'Shared Socioeconomic Pathways' (SSP's), with assumptions on key driving forces such as population, economy, policies and technology. Based on these assumptions, projected datasets on direct and indirect drivers such as population, GDP, and residential floorspace are provided for each of these pathways for 26 world regions. These datasets can be used for scenario analysis (Stehfest et al., 2014).

Dynamic material stock- or flow analysis is a method to model, project and assess material stocks (Muller, Hilty, Widmer, Schluep, & Faulstich, 2014). Muller et al., describe some important distinctions, first of which is the distinction between 'retrospective' and 'prospective' analysis: the first uses real life data to determine historic and in-use stocks and flows, where the latter is meant to project future stock- and flow development. A second important distinction is between 'endogenous' and 'exogenous' model variables, in which 'endogenous' variables are based on other variables within the model environment, and 'exogenous' variables are based on (real life) input data, outside of the model environment (Muller et al., 2014).

Muller et al., also distinguish between top-down and bottom-up methods to quantify material stocks: top-down methods calculate an in-use stock from a (known) stock (S[0]) and adding the mass-difference in inflow and outflow over time, where a bottom-up method defines a 'driver' such as products (e.g. per furniture item), applications (e.g. furniture per square meter or room), or end-use sectors (e.g. furniture per capita or household), and characterises this with a material intensity (Muller et al., 2014). The stock can then be calculated using function (i):

$$S[n] = \sum_{i=1}^{I} * P_i[n] * c_i\,[n] \qquad \text{(Muller et al., 2014)} \qquad \text{(i)}$$

Where S[n] is the in-use stock, $P_i[n]$ the subject- product and $c_i[n]$ is the material characterisation (Muller et al., 2014).

According to Muller et al., as outflows are generally unknown, these are calculated from the inflow using a lifetime distribution which is based on the subject-product lifetimes as a mean. Examples of such lifetime distributions are the Weibull, Winfrey beta, delta, log-normal and normal distributions (Muller et al., 2014).

According to the IMAGE 3.0 model description, IMAGE is used primarily to model the relation between human activity and use of energy, land, water and other natural resources. It is also used to model various environmental side-effects related to these activities, using indicators such as emissions, climatic change and fossil- or forests stock depletion (Stehfest et al., 2014).

In a first attempt to integrate methods of dynamic material flow analysis with global integrated assessment- and energy models, demand growth of metals is modelled for electricity generation technologies, cars, and electronic appliances (Deetman, Pauliuk, van Vuuren, van der Voet, & Tukker, 2018): an in-use stock for cars is estimated from IMAGE data on person kilometres driven by passenger car annually, and the in-use stock for energy generation technologies is derived based on IMAGE data on newly installed power generation capacity. Data on the appliances per household is directly available through IMAGE. The authors use a survival function based on a Weibull product lifetime distribution to determine how much of an initial stock-inflow[0] still survives in year[i], which are called 'age cohorts'. The total number of surviving products[i] can then be determined by summing all surviving stock from the different age cohorts[i]. Inflow or 'sales' in year [i] can then be calculated from the difference in estimated stock and the total number of surviving products. All outcomes are then characterised with metal intensities. To this end, the authors have gathered data from various sources on the metal contents and lifetimes of different types of cars, appliances and power generation technologies and structured the available data in a material database. IMAGE SSP scenarios are used as a starting point to compare different demand scenarios (Deetman et al., 2018).

In a similar study by Marinova et al., the IMAGE framework is used to model material demand scenarios for residential buildings (Marinova, Deetman, van der Voet, & Daioglou, 2020): the study makes use of IMAGE data on population and useful floor area as model drivers. Together with national statistics which includes information on home-ownership, this is used to determine a total floorspace per building-type, which has been characterised with material intensities to determine in-use material stocks. For the material intensities, a material database for six materials in four building types has been developed (Marinova et al., 2020). The study by (Marinova et al., 2020) makes use of a similar methodology as (Müller, 2006), who is the first to use a combination of population and floorspace as model drivers to forecast concrete stocks in Dutch dwellings and (Daioglou, van Ruijven, & van Vuuren, 2012), who are the first to use IMAGE data on population and floorspace, together with heating intensities and heating degree days to calculate space heating demand in developing countries.

In a companion paper, building on these efforts, multiple commercial building types are added to the stock model, previously developed by (Marinova et al., 2020), and more attention is put to the characteristics of the inflow and outflow of the stock for both residential and commercial buildings (Deetman et al., 2020): the authors model the material stock in commercial buildings by estimating service sector floorspace per capita averages (m^2/capita) and multiplying this by the population to get a total building stock in service sector floorspace. This is characterised with material intensities from a building material- database developed by (Heeren & Fishman, 2019), which is supplemented with data gathered by the authors (Deetman et al., 2020).

The authors then make use of a dynamic stock model previously developed by (Pauliuk & Heeren, 2019) to determine global yearly inflow (as building construction) and outflow (as building demolition). In this model, outflow is determined based on a Weibull probability density function and the inflow can be calculated as the difference between projected stocks in addition to the replacement of natural stock-outflow (Deetman et al., 2020).

Despite efforts to study in-use material stocks in building structures, no such research has been conducted on material stocks in the interior, furnishings part of buildings: a search on common libraries such as Elsevier library, TU Delft University library, Leiden University Library and Google scholar, shows that studies on furniture product- and material stocks are virtually non-existent. Also there is inferior coverage of (structured) data on furniture consumption and disposal, and general furniture product characteristics such as material composition, lifetime, etc. There are some studies available describing the characteristics of consumer behaviour towards purchasing furniture, these are reviewed together with some general information on furniture in the next section (section 1.2).

1.2. Literature on furniture

The furniture industry is characterised as labour- and resource intensive, dominated by a combination of local craft-based firms and some large-scale producers (Renda et al., 2014). Globally, the industry is dominated by a top 10 producing countries, that together cover 79% of total production, with China (40%), the USA (14%) and Germany (5%) as the biggest contributors (Renda et al., 2014). As already mentioned in the previous section (section 1), the European furniture industry accounts for roughly a quarter of total production (Forrest et al., 2017). The furniture production in Europe satisfies most of its own consumption need with roughly 85% (Renda et al., 2014). The EU excels in the production of high-end furniture: with almost 66% of all the high end furniture sold globally, originating from the European region (European Commission, 2021). Apart from some general statistics on yearly European furniture consumption as already discussed in the previous section (section 1), little information is available on the consumption of individual household furniture products. The European production- and trade statistics database PRODCOM, primarily uses big aggregate categories, with only specific data for swivel chair- and mattress products.

According to the EEB, a trend can be distinguished in the global furniture sector, in which producers increasingly use lower quality materials (MDF, plastic, chipboard) instead of more durable solid wood and metals. Moreover, possibilities of disassembly, reconfiguration and repair are taken less into account in the design. This leads to an overall weaker product, which makes furniture less suitable for reuse and decreases options for repair and refurbishment. Taken over the whole of Europe, there is a weak demand for second-hand furniture, which is related to the relative small price difference compared to new products and poor consumer information on the availability and the sustainable effects of second hand furniture (Forrest et al., 2017).

1.2.1. Literature on furniture consumption

According to a study by the centre for industrial studies (Csil), which includes a survey on furniture consumption (n=5072 respondents), shows that price is not the main driving element behind consumer choice when it comes to purchasing (first hand) furniture products. A more important driver of furniture consumption is the design, which should fit the consumers taste (Renda et al., 2014).

This suggestion is supported by a different study on consumer behaviour, which also finds that furniture consumers want ‘personally tailored’ products, but also conclude that the pricing of furniture remains a key factor in the consumer buying behaviour of furniture, even in groups that are strongly motivated by environment- and health reasons (Bednárik & Pakaine Kovats, 2010).

Although there is no hard data on the consumption of second hand furniture, some information is available on the characteristics of second hand furniture consumers: one study looked into the attitude of consumers to alternative models of consumption, specifically focused on furniture and home products (Gullstrand Edbring, Lehner, & Mont, 2016): the authors conducted a survey among IKEA consumers, age 20-35 (n = 1159 respondents) on their attitude toward buying options, alternative to new-buy. Only respondents that indicated to have bought second-hand furniture in the past were asked about their motivations for buying second-hand. The results show that 47% of the people who buy second hand furniture do this for economic reasons. This share is significantly higher than the alternative motivations of environmental reasons (14%), a desire to be unique (25%) or other (14%). This suggests that level of income is the main driver in second hand furniture buying behaviour (Gullstrand Edbring et al., 2016).

A study on the difference in carbon footprint between slum areas and non-slum areas in Pakistan, for which a survey was conducted on household consumption of different income groups, also looked into the buying behaviour of these groups regarding furniture (and electrical items). The results of this survey suggest that high income groups rarely buy used or second hand items, whereas lower income groups primarily buy second hand items (Adnan, Safeer, & Rashid, 2018).

According to Gullstrand Edbring et al., there is a significant difference in attitude towards ‘soft’ (e.g. mattresses) and ‘hard’ (e.g. tables and chairs) materials where it comes to buying second-hand furniture, where 63% of respondents were positive toward buying second-hand hard material products and 67% of respondents reacted negatively to second-hand soft material products. This is mainly with regard to furniture products containing textiles and upholstery, and is related to concerns for hygiene and pests. Factors relating to this are “the frequency of use, perceived degree of intimacy in their use, and social and emotional values associated with the product” (Gullstrand Edbring et al., 2016, p. 13). The study also suggests that ‘beds’ are considered a similarly unhygienic furniture product by consumers of second-hand furniture. Another interesting observation is the different way of consumption between younger age groups (20-24 years) and older age groups (25-35 years), where younger consumers often replace furniture due to the availability of new products and older consumers only replace furniture after product failure (Gullstrand Edbring et al., 2016).

A different study looks into consumer attitudes towards buying refurbished products, including some furniture products (Mugge, Safari, & Balkenende, 2017). The authors suggest that consumers take the visibility of refurbished (furniture) products into account in their buying behaviour, but that signs of use in furniture can actually increase the attractiveness of a product as it is perceived as 'vintage'. Furthermore, the authors conclude that hygienic concerns exist for buyers of refurbished products, reducing the attractiveness of the product, e.g. for products that come in contact with the skin (Mugge et al., 2017). This conclusion is similar to the findings of Gullstrand Edbring et al., who show that consumers respond negatively to second hand furniture products made from soft materials, also in relation to hygienic concerns (Gullstrand Edbring et al., 2016).

1.3. Research gap

Given previous research efforts on material stock development in buildings, that is: the material used in the outer, structural part of buildings; here is an interesting opportunity to look into the indoor use of materials in the form of furniture, using similar methods of dynamic stock- and flow analysis in combination with IMAGE data as is used in previous studies (Deetman et al., 2020; Deetman et al., 2018; Marinova et al., 2020). Also, there is a major lack of data on first and second hand furniture possession, and the material composition and lifetimes of various furniture products. This research gap can be addressed by gathering all available furniture product-data and structuring this in a material database in a similar way as is used in previous studies (Deetman et al., 2018; Marinova et al., 2020) and by defining methods to research furniture possession. This study will look into all of these, thus adding to the already existing body of literature on dynamic stock analysis, integrated assessment models and furniture.

1.4. Study objectives

The goal of this study is to provide a first assessment of the size, dynamics and development of product- and material stocks for European household furniture. Given the conclusions from the literature review, its objective is to contribute to the body of knowledge on major material stocks, urban mining, circular economy, dynamic stock- and flow modelling and furniture (consumption).

The intended study outcomes are a material database for a selection of furniture products, a (Python) model to project material development in European household furniture over time, a review of the estimated material stock in European household furniture and a review of its projected development. In addition, the study aims to identify opportunities for further research.

1.5. Research questions

This study must thus be understood in two parts: an inventory, in which the current European material stock in household furniture is estimated. In the second part, future stock development will be projected in a scenario analysis. To this end, two research questions are defined which are further divided into sub-questions:

1. What are the major material stocks and flows related to European household furniture?
    1.1 What types of furniture can be distinguished and how should they be categorised?
    1.2 What are the material contents of these furniture categories?
    1.3 What are the lifetimes of these furniture categories?
    1.4 How much furniture is in stock in European households?
    1.5 What furniture flows can be distinguished?
2. How will material stocks and flows in European household furniture develop in the future?
    2.1 How can scenarios be used to forecast future development of European material consumption for household furniture?

1.6. Scientific relevance

(Household) furniture is an underexplored subject of research. Hardly any data is available on furniture products, consumption and stocks. This study fills this gap with first efforts to gather and structure relevant data on furniture that can be used for various study purposes. Furthermore, it adds to the existing body of literature on dynamic stock analysis, by adding the subject of furniture. It also provides a starting point for future research efforts on the subject of furniture stocks- and flows.

1.7. Societal relevance

European governments face a very large and complex issue with their endeavours to make their economies circular. Without information on major material stocks and stock dynamics, government officials would fly blind in their attempts of defining circular economy policy. The outcomes of this study can be used to inform policymakers and allows for scenario analyses to help decide on approaches to make the market for household furniture more circular. Furniture is a product category that is particularly well suited for circular economy efforts, as emissions are mainly related to resource consumption and production, with hardly any emissions in the use-phase of the product (Donatello et al., 2017). Relative to other product categories such as electronics and cars, there is lower risk of (technological) obsolescence of furniture products regarding reuse or refurbishment and often environmental performance is comparable to that of newer products.

2 Methodology

Building upon methodology already applied in previous research, this study takes the form of a bottom-up dynamic material stock assessment as described by (Muller et al., 2014), adapted to furniture, and making use of IMAGE data files in a similar way as (Deetman et al., 2020; Deetman et al., 2018; Marinova et al., 2020).

The model developed in this study, from here-on called the 'study model', builds on previous modelling efforts, from here on referred to as the 'base model', which is further described in section 2.1 (Base Model) and Appendix C. The study model has a soft link with the IMAGE framework, which means that the model is connected through the exchange of data files (Stehfest et al., 2014). Two IMAGE datasets are used: floor area per capita and population data, both specified by urban or rural region and per income group or 'quintile'. These IMAGE datasets are largely based on published data, and are projected for future years according to the IMAGE SSP2 scenario (Stehfest et al., 2014). The SSP2 scenario is the 'Middle of the Road' scenario in which future development follows historic patterns (Riahi et al., 2017). Gaps in the data have been filled using linear interpolation.

The study model consists of multiple parts. No historic data on inflows and stocks of furniture are available. However, IMAGE population and floorspace-per capita data are based on published data and thus partly historic (Stehfest et al., 2014). A combination of retrospective and prospective bottom-up material stock analysis is used as described by (Muller et al., 2014), to estimate historic and current furniture stocks in the first part of the model. Following methodology as is used in previous studies (Deetman et al., 2020; Marinova et al., 2020), the main model driver for product ownership in this study is 'residential floorspace' which has been characterised with furniture [units]- and material [kg] intensities for a selection of furniture products.

The IMAGE datasets are used together with furniture- intensities per square meter and material- intensities per unit furniture, to estimate in-use furniture- and material stocks, from here on referred to as 'required stocks', which are further projected over time, for all 26 IMAGE regions. Note: as the available data on furniture- and material intensities is only considered valid for European countries, this study only considers the results from that region.

In the second part of the model, the current and projected required stock in units, together with data on product lifetimes and the reuse of furniture, are used in a dynamic-stock model (DSM) function, to assess the contribution of first and second hand furniture to the total required stock, to model furniture demand (first and second hand furniture inflow) and the outflow of first and second hand furniture, all in units. It is assumed that all the outflow of second hand furniture is discarded, without entering a third or fourth hand market. Note: as the required stock is determined for all 26 IMAGE regions, so are the outcomes of the DSM function. Only the results from the European regions are considered.

In the third part of the model, the results from the DSM function are used, together with material intensities per unit furniture, to determine the total amount of landfilled (and incinerated) material, the total amount of recycled material and the required primary material, for Europe specifically, all in Mt.

Based on estimations of the EEB, which shows that very little waste furniture is remanufactured (Forrest et al., 2017), no flow is included in the model for remanufacturing. The endogenous input data from the European region in the third part of the model is an aggregate of the DSM function results for the IMAGE regions of ‘Central Europe’ and ‘Western Europe’.

This chapter provides calculation flowcharts for each part of the model, together with a description of the methods used. Following the distinction by Muller et al., exogenous input data is described individually (Muller et al., 2014). Not all required data was readily available through IMAGE or through the (scientific) literature. To fill the gaps in the data, a company inquiry and a survey on household furniture possession were conducted. Also, data was collected on material intensities and lifetimes per product category and combined in a Furniture Material Database, similar to methodologies used in previous studies (Deetman et al., 2018; Marinova et al., 2020). The methods used for gathering this data are described in section 2.7. The next section (section 2.1) provides a description of the base model, before the description of the study model which start with an overview of the study model scope (section 2.2).

2.1. Base model

The study model makes use of some previous modelling efforts by a student from the university of Utrecht (von Köckritz, 2020), referred to as the ‘base model’. The original source code of the base model is made available in the supplementary material (SM2). In its base form, the ultimate outcome of the model is a total weight in kg per furniture product for all IMAGE defined regions. The base model makes use of a selection of datasets: some provided by IMAGE (e.g. urban and rural population, floorspace per capita, poverty gap, Gini coefficients), some provided by the researcher, which for a large part consists of dummy data (furniture intensities per square meter, material intensities per unit furniture, lifetimes, etc.). Not all of the elements of the base model have been preserved in the study model. The study model uses some of the same datasets, which are IMAGE floorspace per capita- and population data. The study model also uses the code- structure laid out in the base model for the calculation of the required stock, with floorspace as the main model driver characterised with furniture- and material intensities.

Furthermore, the ‘historic stock tail function’ of the base model has been used to linearly interpolate ‘historic’ stock data, back to 1900 (which is assumed as the first model year to prevent an initial inflow pulse in the model start year (1971). A similar function of the base model called the ‘interpolate data function’ is used in the study model to linearly interpolate IMAGE data for all the model years (1900-2100).

Also, the study model makes use of a similar concept for the weight factor (W_q) as is used in the base model, although the calculation and coded application of the weight factor is different: in the base model, the weight factor is calculated as the mean per price quintile relative to the mean weight of the third price quintile. In the study model the weight factor is calculated as the weight per price quintile, relative to the mean weight of all products. Furthermore, in the study model the weight factor is product dependent for some product categories, where the base model only makes use of a general weight factor. In both cases, the weight factor calculations are based on the same data, which is gathered by (von Köckritz, 2020). The calculation of the weight factor is included in Appendix B. Also, a description of the base model is included in Appendix C.

2.2. Study Model Scope

Subject

This study only focuses on household furniture, excluding furniture meant for commercial purposes, because IMAGE only provides data on residential floorspace. This is the majority, as it is estimated that household furniture comprises of 82% of total furniture consumption (Forrest et al., 2017). Furthermore, this study only considers non-fixed furniture, excluding built-in furniture (e.g. bathroom furniture, toilet), as these types of furniture are assumed to have a faster turnaround, making them more interesting for CE policy. Also, outside of calculations related to IMAGE population- and residential floorspace data, no further distinction is made between urban and rural regions, as other available data is not specified to region type. The distinction between urban and rural regions is therefore only used in the calculation of the total floorspace. All furniture stocks and flows are characterised by income group or 'quintile'. Quintiles are equally represented by a 20% share of the total population (Stehfest et al., 2014).

Spatial

Based on the available data, this study only focuses on the European region, which is an aggregate of the IMAGE regions of 'Central Europe' and 'Western Europe', including the United Kingdom (IMAGE, 2018). All model results are presented for the Europe region only.

Temporal

The model start is the year 1900 and projections go up to the year 2100, with a focus on the period 1971 to 2050. Current in-use stock is in the year 2021. Most data before 1971 is interpolated. Assuming the year 1900 as the first model year means that (some) antique furniture is excluded. This means that the model somewhat overestimates furniture demand (required stock), as some of the furniture demand will actually be already fulfilled by antique furniture.

Furniture categories

The groups of furniture according to their functionality, as described by Smardzewski, are used as a starting point for the selection of furniture used in the study model (Smardzewski, 2015): Smardzewski distinguishes 36 furniture product categories, grouped by function, respectively: sitting and lounging, reclining, working and eating meals, learning, storage, multifunctional furniture, complementary furniture (Smardzewski, 2015). These 36 product categories have been reduced to 16 categories, in some cases by merging multiple categories into one aggregate category, e.g. (library) bookcase, wardrobe, dresser and buffet into 'big closet' and shelf, chest of drawers, buffet into 'small closet', and in some instances omitting furniture categories that are assumed relatively exceptional in modern homes, e.g. davenport, drafting table, dressing table. Some product types often found in literature have been added to the product categories such as tv cabinet (small closet category), coffee table (side table category), and mattresses as a separate product category. This yields the furniture categories of table 1. By lack of material composition data, the corner sofa- and single bed categories have been excluded from the material database and the model results. The categories are included in the survey on household furniture.

Product Category	Notes
Armchair	
Barstool	
Big closet	Aggregate category: (library) bookcase, wardrobe, dresser
Chair	
Container	
Corner sofa	By lack of data, this category is excluded from the material database and the model results.
Desk	
Dining table	
Double bed	
Mattress	
Office chair	
Side table	Aggregate category: pupil's table, drafting table, side table, nightstand, coffee table
Single bed	By lack of data, this category is excluded from the material database and the model results.
Small closet	Aggregate category: shelf, chest of drawers, tv cabinet, buffet
Sofa	Aggregate category: couch, folding sofa, sofa
Stool	Aggregate category: tabouret, stool

Table 1: Overview of the model furniture categories based on the groups of furniture according to their functionality by (Smardzewski, 2015). Some product types have been added by the researcher (e.g. coffee tables and tv cabinets, mattresses). Some categories are aggregate categories, meaning that they consist of products that are relatively similar, but can nevertheless vary quite significantly in shape and size.

2.3. Required stock per product category

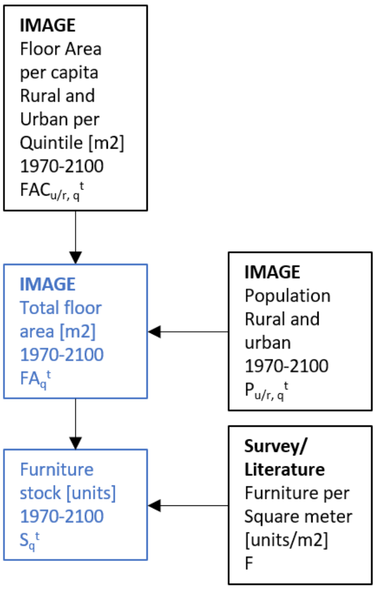


Figure 1: Calculation flowchart of required stock [units] per product category. Black boxes carry input data, blue boxes contain primary calculations.

The calculation flowchart of the required stock per product category [units] is depicted in figure 1. Black boxes show the model input data, with the data source shown in bold font. Blue boxes carry the primary model calculations. IMAGE provides Residential Floor Area per capita ($FAC_{u/r,q}^t$), which is specified to urban and rural regions (u/r), scaled to income level (q) and projected over time (t).

Multiplied with IMAGE Population data ($P_{u/r,q}^t$), this yields the floorspace per urban/ rural region and quintile ($FA_{u/r,q}^t$). Note: the Floorspace is then aggregated per quintile, taking out the urban/ rural specification, which yields the total Floorspace per quintile (FA_q^t).

The total floorspace can be characterised in a similar way as described by (Muller et al., 2014) and used by (Marinova et al., 2020), with an amount of furniture per square meter (F), which yields the total furniture stock in units per year (S_q^t), according to function 1:

$$S_q^t = FAC_{u/r,q}^t * P_{u/r,q}^t * F \qquad (1)$$

2.3.1. Furniture per square meter (F)

For data on furniture per square meter (F), both a company inquiry and a household survey on furniture possession have been conducted. More information on the company inquiry is included in section 2.7.1. More information on the survey methodology is included in section 2.7.2. Furniture intensities are ultimately derived from the survey on household furniture and are included in the results chapter of the survey in section 3.2.1.

2.4. Required stock per material category

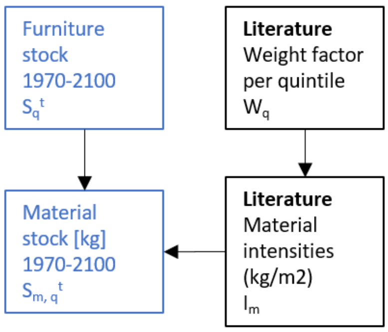


Figure 2: Calculation flowchart of required stock [kg] per material category. Black boxes carry input data, blue boxes contain primary calculations.

The calculation of the required stock per material category [Mt] is shown in figure 2. Given the required furniture stock in units per year ($S_{u/r,q}^t$), this is characterised with material intensities (I_m) per unit furniture, which are weighted per quintile (W_q). This yields the total material stock per year in Mt ($S_{m,q}^t$), according to function 2:

$$S_{m,q}^t = S_q^t * (I_m * W_q) \qquad (2)$$

2.4.1. Weight factor (W_q)

Based on preliminary product research, it is assumed that more expensive furniture is generally made from heavier materials and that high income groups can afford more expensive furniture products. The material intensities per unit product are therefore multiplied with a weight factor, scaled to income (W_q). More information on the weight factor calculation is included in appendix B.

2.4.2. Material intensities (I_m)

For the data on Material intensities (I_m) a database has been made containing material information on fourteen furniture product categories. More information on the material database methodology is included in section 2.7.3. Material intensities used in the model are included in the results chapter of the material database by mass percentage (section 3.3.3) and in Appendix E and F. The product categories and corresponding material intensities from the material database are assumed to be applicable for the whole of the European region.

2.5. DSM function: first and second hand stocks and flows

At the heart of the model is a Dynamic Stock Model function developed by Deetman (2021), with contributions by the author. The function uses a (re)combination of cohort-based dynamic stock- and flow modelling, which is largely based on modelling methods previously used in a study by (Deetman et al., 2020), and which are originally developed by (Pauliuk & Heeren, 2019): based on the required furniture stock, product lifetimes and a dynamic reuse fraction, the model calculates the stock first hand, stock second hand and the first and second hand inflow (furniture purchases) and outflow (furniture disposal). The DSM function is primarily stock driven as calculations are based on the endogenous required stock input as described in the previous section (section 2.3). However, second hand stocks are flow driven as they are based on (a reuse fraction of) the outflow of furniture from the first hand stock. The calculations shown in this chapter are repeated per product category. The calculation flowcharts of the DSM function are included in figures 3 and 4.

Using the average product lifetimes per product category from the material database and a standard deviation based on a fixed fraction of the product lifetime, the DSM function uses a survival function based on a folded normal distribution to determine how much of the inflow of a furniture product in a certain point in time (t[0]) which is called the 'age cohort', still survives in the stock every subsequent year (t[i]), using the same calculation principles as (Deetman et al., 2018). The same lifetime distribution and standard deviation fraction is used for all product categories and for both first and second hand furniture.

The total number of surviving first hand furniture products ($SP1_q^t$) and second hand furniture products ($SP2_q^t$) in a certain year[i] can be calculated in a similar way as (Deetman et al., 2018), by taking the sum of all surviving products per age cohort in that year[i].

In the first model year (=1900), the required stock[0] equals the first hand stock $S1_q^t[0]$, without an outflow of first hand furniture ($O1_q^t[0] = 0$), inflow of second hand furniture ($I2_q^t[0] = 0$) or second hand stock ($S2_q^t[0] = 0$), according to figure 3.

After the first year, the first hand outflow ($O1_q^t[i]$) can be determined by calculating the difference in the first hand stock [i] and the first hand stock of the previous year [i-1] per age cohort and summing all the age cohort stock differences.

The second hand inflow can then be determined based on the outflow of furniture from the first hand furniture stock, using a dynamic reuse fraction (RF^t), according to function 3:

$$I2_q^t[i] = O1_q^t[i] * RF^t \quad (3)$$

The second hand stock ($S2_q^t$ [i]) can be calculated as the sum of the inflow into the second hand stock ($I2_q^t$ [i]) and all of the surviving stock from previous second hand inflows or 'age cohorts' ($SP2_q^t$ [i]), according to function 4:

$$S2_q^t[i] = I2_q^t[i] + SP2_q^t[i] \quad (4)$$

Based on the required stock (S_q^t [i]), the second hand stock ($S2_q^t$ [i]) and the surviving first hand stock of the previous years ($SP1_q^t$ [i]) the inflow of furniture into the first hand stock ($I1_q^t$ [i]) can be determined, according to function 5:

$$I1_q^t[i] = S_q^t[i] - S2_q^t[i] - SP1_q^t[i] \quad (5)$$

The first hand stock ($S1_q^t$ [i]) can be determined as the sum of the inflow into the first hand stock ($I1_q^t$ [i]) and all of the surviving stock from previous first hand inflows ($SP1_q^t$ [i]), according to function 6:

$$S1_q^t[i] = I1_q^t[i] + SP1_q^t[i] \quad (6)$$

The second hand outflow ($O2_q^t$ [i]) can be determined in a similar way as the first hand outflow, by calculating the difference in the second hand stock [i] and the second hand stock of the previous year [i-1] per age cohort and summing all the age cohort stock differences. It is assumed that all of the outflow from the second hand stock ends up as waste. All of the DSM function calculations are shown in the calculation flowcharts of figures 3 and 4.

2.5.1. DSM function negative inflow correction

Due to a decrease in required stock (e.g. caused by a declining population), the required furniture stock can become lower relative to the realised stock of the previous year, resulting in a surplus in furniture. This surplus in furniture appears in the DSM function results in the form of negative inflow. This event is observed at least once in the model results (1990, Central Europe). This negative inflow has been corrected by adding a 'negative inflow correction' to the model, which is based on the DSM model developed by (Pauliuk & Heeren, 2019). For this negative inflow correction it is assumed that all surplus furniture will be immediately discarded in the year where the surplus appears. The first hand stock is used to subtract the surplus and correct the mass balance, assuming no surplus furniture is subtracted from the second hand stock.

The negative inflow correction does a number of things: First, the negative inflow correction sets the negative inflow to zero, as no primary inflow of furniture is required due to the declining stock. The value of the negative inflow (read: surplus furniture) is then subtracted from the age cohorts of the first hand stock based on their relative contribution to the total first hand stock. The value of the surplus in furniture is added to the first hand stock outflow to correct the mass balance, in addition to the natural outflow, using the same relative distribution per age cohort. Lastly, as this stock correction in turn can lead to negative stock values, especially in old age cohorts, these are set to a '0'-value.

The assumptions for the negative inflow correction of the model have some implications for the model results: in reality, a (sudden) surplus of furniture will not be discarded so quickly and will often be put in storage, surviving alongside the in-use required furniture stock. This stored furniture can be used later, when the demand for furniture increases, thus reducing the need for primary furniture. This also means that estimations for furniture- and material stocks might be a little low, excluding furniture in storage.

2.5.2. Product lifetimes (L)

Data on product lifetimes are derived from the material database. More information on the material database methodology is included in section 2.7.3. The product lifetimes from the material database are assumed to be applicable for the whole of the European region. The product lifetimes used in the model are included in Appendix E.

2.5.3. Reuse fraction (RF^t)

The fraction of the first hand furniture outflow that is reused is based on data from the furniture reuse network in the UK, which shows that roughly 6% of the total furniture waste in weight is delivered as reuse by its members (Forrest et al., 2017). As there is no information available on furniture reuse from other countries in the European region, this reuse fraction is used as a substitute for the whole of the European region.

2.5.4. Relative reuse fraction (RRF^t)

The relative reuse fraction is based on the results from a household survey. The relative reuse factor (RRF^t) is used to weigh the general reuse factor of the model (RF^t), which is based on literature, per product category, which is assumed to yield a more realistic reuse dynamic. The relative reuse fractions used in the model, as well as a more in-depth description, are included in section 3.2.4. More information on the survey methodology can be found in 2.7.2. Although the results from the survey are predominantly based on data from the Netherlands, the relative reuse fraction based on these results is used as a substitute for the whole of the European region.

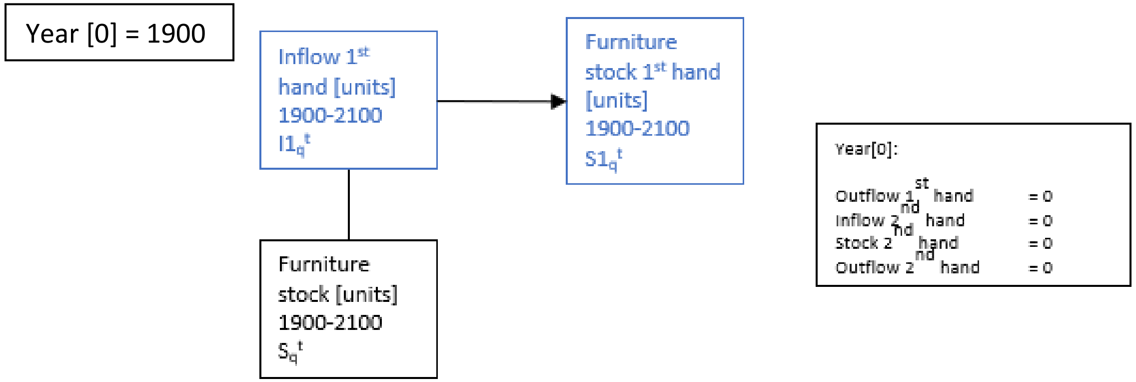


Figure 3: Calculation flowchart of DSM function in first modelled year[0], which is the year 1900 in the model. The 1st hand furniture stock equals the required stock. There is no outflow of first hand furniture, 2nd hand stock or 2nd hand outflow. Black boxes carry input data, blue boxes contain primary calculations.

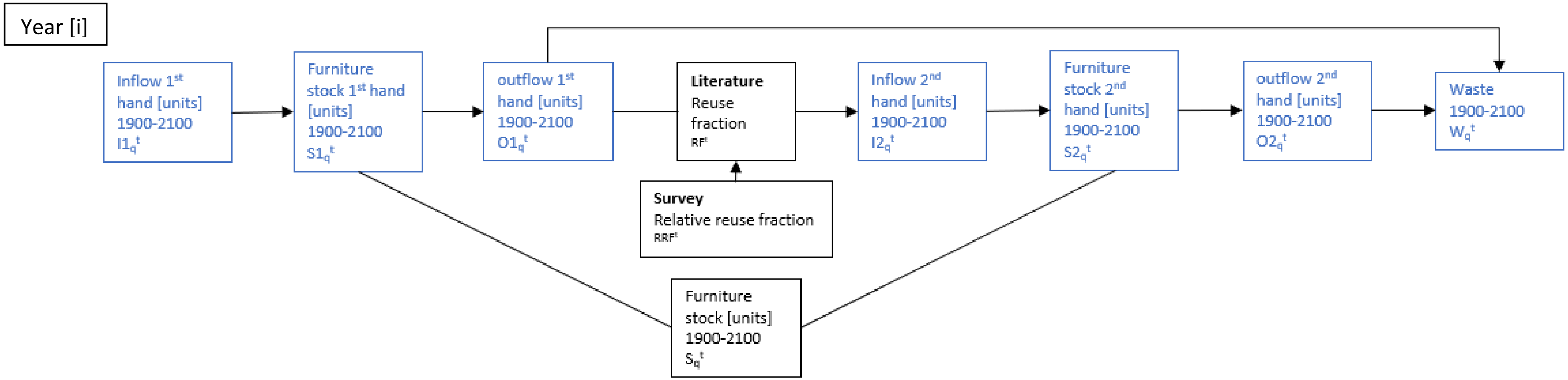


Figure 4: Calculation flowchart of DSM function per year and product category iteration. The 1st hand inflow can be determined based on the required stock, the surviving 1st hand stock from previous age cohorts and the 2nd hand stock. The 1st hand stock [i] consists of the 1st hand inflow [i] and the surviving stock of the previous age cohorts. 1st hand outflow is determined based on the outflow of the stock per age cohort from stock 1st hand [i] and the previous year stock 1st hand [i-1]. The 2nd hand stock can be determined based on the outflow from the 1st hand stock and a re-use fraction per product category. Similarly to the 1st hand outflow, the 2nd hand outflow can be determined based on the difference in stock between stock 2nd hand [i] and stock 2nd hand [i-1] per age cohort. All of the outflow from the 2nd hand stock is assumed to end up as waste. Also the share of the 1st hand outflow that is not reused ends up as waste. The DSM function returns: inflow 1st hand, stock 1st hand, outflow 1st hand, inflow 2nd hand, stock 2nd hand, outflow 2nd hand. Black boxes carry input data, blue boxes contain primary calculations.

2.6. Calculation recycled and landfilled material and required primary material

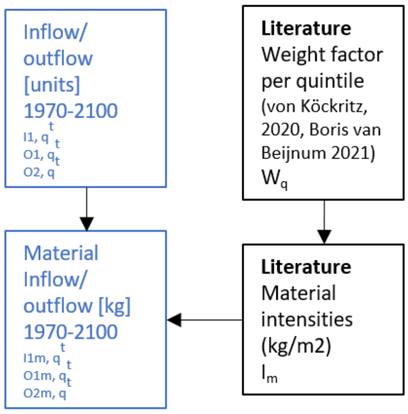


Figure 5: Calculation flowchart of in-and outflow per material category. Black boxes carry input data, blue boxes contain primary calculations.

In the same way as the calculation of the required stock per material category (see section 2.4), the in-and outflow per material category can be calculated by using the in-and outflow results in units from the DSM function as endogenous input, and characterising these with the material intensities per unit product, which are weighted with the weight factor per quintile. The calculation flowchart of the in-and outflow per material category is shown in figure 5.

The outflow first hand ($O1_{m,q}^{t}$) together with the reuse fraction (RF^{t}), the relative reuse fraction per furniture category (RRF^{t}) and outflow second hand ($O2_{m,q}^{t}$) can then be used to calculated the total waste.

Using the dynamic recycle fraction (MRF^{t}), the amount of material that is being recycled (RM_{q}^{t}) and landfilled (LM_{q}^{t}) per year can be calculated.

The required primary material can be calculated by subtracting the recycled material from the first hand inflow ($I1_{m,q}^{t}$ - RM_{q}^{t}).

A 'recycling function' has been defined to calculate the amount of recycled- and landfilled material. A calculation flowchart of the recycling function is included in figure 6. For dataframes containing the second hand outflow ($O2_{m,q}^{t}$), the function takes two inputs: the flow dataframe and a dataframe containing the dynamic recycle fraction (MRF^{t}).

For the first hand outflow ($O1_{m,q}^{t}$), the same dataframe containing the dynamic reuse fraction (RF^{t}) as is used in the DSM function, which should already be characterised with the relative reuse fraction (RRF^{t}), can be added as a third input, which is required to calculate the waste material ($WM_{m,q}^{t}$) from the first hand outflow. The amount of landfilled- and recycled material are calculated using functions 7 and 8:

$$RM_{m,q}^{t} = O1_{m,q}^{t} * (1 - RF^{t}) * MRF^{t} + O2_{m,q}^{t} * MRF^{t} \qquad (7)$$

$$LM_{m,q}^{t} = O1_{m,q}^{t} * (1 - RF^{t}) * (1 - MRF^{t}) + O2_{m,q}^{t} * (1 - MRF^{t}) \qquad (8)$$

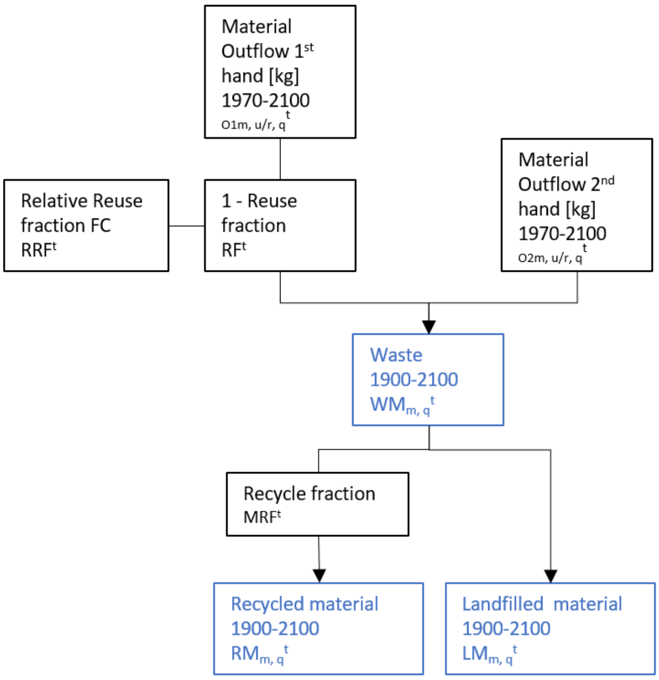


Figure 6: Calculation flowchart of recycling function. Recycling function calculates total waste and returns: recycled material and landfilled material in Mt. Black boxes carry input data, blue boxes contain primary calculations.

2.6.1. Material Recycle fraction (MRF^t)

The recycle fraction used in the model is based on a report by the EEB, which estimates that 10% of total European furniture waste is recycled per annum, relative to 90% incineration or landfill (Forrest et al., 2017). No further information is available on the ratio between landfilled and incinerated material: the amount of 'landfilled material' should thus be understood as a combination of both. The recycle fraction is assumed to be applicable for the whole of the European region.

2.7. Data: company inquiry, household survey, material database

Not all required data is available in the literature. Gaps in the data have been filled with a company inquiry, a survey on household furniture, and a material database. The methods used to collect this data are described in this section.

2.7.1. Company inquiry

An important initial gap in the data required for the model calculation is information on furniture intensity per residential area or 'unit furniture per square meter' averages (F). This information can be provided per square meter (or per capita/ household) and can be derived from various types of household inventory lists. One way to obtain this data is through a company inquiry: it is expected that inventory lists can be provided by notary offices (inheritance of household effects), law-firm curators (foreclosure sales) and insurance companies (household content insurance applications and accident reports). A selection of such Netherlands-based companies are contacted with a request for data. Insurance companies are also asked about the calculation of their inventory value meter, assuming they use household furniture composition averages to determine insurance packaging prices.

2.7.2. Survey on household furniture

Additionally to the company inquiry, furniture intensity (F) data is obtained from a survey on household furniture, which is conducted specifically for this project, in which respondents are asked to make an inventory of their furniture, based on the model furniture categories. For the survey, Google Forms is used. An overview of the survey questions is included in Appendix G. Respondents are further asked to specify some household characteristics: number of people in the household, residential area, residential surface and (net) income. Respondents are shown an indicative picture per furniture category and are then asked to make an inventory of their home furniture per category based on similarity with the picture. Input is asked per product category for a 'total of items' and the 'total of second hand items'. The latter is to determine the share of second hand furniture per product category. The sample is taken from as diverse a cross-section of the population as possible with varying household composition and level of income, but is limited to the (indirect) social network of the researcher.

The furniture intensity (F) is then calculated, by dividing the input from 'total of items' per category by the household residential surface, the results of which are then averaged by category.

The reuse fraction per product category is calculated by summing the total number of second hand items per furniture category and dividing this by the total number of items in that category. The overall reuse fraction is calculated as the mean of the reuse fractions per product category.

The relative reuse factor per product category (RRF^t) can be determined by dividing the relative share of second hand furniture per category by the total share of second hand furniture. This relative reuse factor can be used to characterise a given total reuse factor per product category.

2.7.3. Material database

Information on the material intensities of the product categories is derived from various sources, with a preference for LCA based data as this is often standardized and verified. All product information is combined into a material database:

First, specific furniture products are allocated to the model product categories based on functional and physical similarity and manufacturer description. The product's material composition is then expressed in twelve material categories: Aluminium, Concrete, Glass (fibre), Glue, Paint & Coatings, MDF, Metals excl. Steel & Aluminium, Paper & Cardboard, Plastics, Steel, Textiles & Leather, Wood. From there, a product category average in terms of material composition is derived. Model material categories have been established based on some common furniture materials. This allocation is based on similarity between the physical properties of the materials for some aggregate categories (e.g. 'metals excl. steel & aluminium', 'paper & cardboard', 'plastics') or based on function (e.g. 'leather & textiles' category which is meant for materials that are primarily used for upholstery). In some instances, material categories are made separately for specific materials such as steel and aluminium because of their relative ease of recovery. Glue, Paint & Coatings make a separate category for their (presumed) difficulty of recovery.

Product material compositions are assumed to be constant, meaning that these are expected not to change markedly over time (e.g. because of new developments in furniture engineering or production).

Information on product lifetimes (L) is also included in the material database, for which averages are derived per product category.

2.8. Model output and evaluation

The model output shows the projected development over time of the total European furniture stock [Mt], with the relative contribution per material category, per product category or divided by first and second hand stock. Furthermore, the model shows the total amount of recycled material and landfilled material per year per material category. The required primary material is determined by subtracting the recycled material from the first hand inflow. The respective recyclability of the material categories is not taken into account in the determination of the recycled material and the calculation of the required primary material.

These results combined provide a comprehensive understanding of the dynamics of the European furniture stock. This can be used to assess the implications of CE policy for the development of the furniture material stock, for example, it can be determined which furniture product categories are best suited for CE initiatives, in terms of their seize, attractiveness for reuse and material recyclability, and the subsequent implications for stock development. It can help assess the feasibility and implications for stock development of such policy suggestions proposed by (Forrest et al., 2017; Gullstrand Edbring et al., 2016).

2.9. Scenario analysis

Two scenarios have been defined to see how CE policy on the reuse and recycling of furniture would influence the model results. First is the ‘baseline’ scenario, which simulates business as usual conditions. This means that the reuse fraction (6%) and recycle fraction (10%) stay constant over time. In the ‘reduced waste scenario’, it is assumed that reuse of furniture increases due to active CE policy: in the reduced waste scenario the reuse fraction increases with 1% per year (from 2021) until the reuse fraction reaches a level similar to that of the household survey results (=35%). Also the recycling of waste furniture is assumed to increase with 2% per year (from 2021) until the recycling fraction reaches 50%. Both scenarios make use of the same IMAGE datasets based on the SSP2 scenario, in the calculation of the required stock.

3 Results

3.1. Company inquiry results

The company inquiry did not yield any useful results and is therefore not included in the model or in the model data. This section describes the main findings of the company inquiry. Multiple organisations were contacted with a request for data: insurance companies (n=15), Notary offices (n=6), miscellaneous (n=3). Also bankruptcy reports were found on law firm websites that are publicly available (n=8).

In the case of bankruptcy reports provided by law firms, and inheritance inventory lists provided by notary offices, the information lacks sufficient detail to derive furniture intensities. Inventory lists or 'estate contributions' are generally provided as an aggregated value without further specification on the product level. Only in some instances, when a specific furniture product is of significant value, the product is included specifically in the inventory.

In the case of insurance companies, information is confidential and all organisations that were contacted do not cooperate with research activities. Other organisations have been contacted that may have comparable information available: the Consumentenbond was asked about the data used for their research on inventory value meters used by insurance companies. However, they did not respond within a reasonable timeframe. The Meertens Institute holds the printed results of a survey (n=227 respondents) on furniture possession in the Netherlands 'Ik woon hier heel gewoon-Nederlanders en hun interieur' by Hester Dibbits and Arjette van der Mark (Dibbits & van der Mark, 2006), but its research depository in Amsterdam was inaccessible due to the Covid-19 world pandemic. Lastly, the national statistic bureau of the Netherlands (CBS) indicated that they only monitor price trends and consumer spending for furniture, the data of which is incompatible with the methodology used in this study. An overview of the organisations that have been contacted is included in Appendix H.

3.2. Survey results

The Raw input from Google forms has been processed and harmonized in Microsoft Excel (e.g. harmonizing regions, separating comma-separated results, etc.). 115 people have responded to the online survey on furniture, each representing the household they are part of. Seven of these responses are considered unusable because of mistakes in the entries. In three instances this was because the respondents failed to enter a usable (numerical) value for their residential surface area. In two cases, the total number of second hand furniture items was larger than the general total of furniture items for some categories. In two instances, the residential surface area entered could not correspond with the number of people in the household (e.g. 10 m^2 on 10 people). This brings the total of useful survey entries to 108.

The majority of respondents are from the Netherlands (n=91). Three respondents are from outside the EU (Canada, Egypt, USA). The other respondents are from various countries within the European Union (including UK). Household composition of the respondents varies, ranging from 1 to

9 people in a single household. All respondents come from the (indirect) social network of the researcher. Given the composition of the social network of the researcher, households vary from students and student homes, to singles, couples, and families with children, with a bias towards students and people from urban areas.

The survey provided the optional possibility to enter a net yearly income. The sample (n=58) reflects different income groups, ranging from a net yearly income of 0 to 150k euro. The survey sample shows a mean net income of 32740 euros per year per household, which is comparable to the Dutch average standardized income per household of 29500 per year (CBS, 2020). Where people entered two digits for net yearly income, this is assumed to be in thousands.

Residential surface area ranges from 11 (NL) to 766 m2 (USA). The average floorspace per capita of the survey is 44.15 m_2 per capita (41.74 m_2 for European regions only) which is low in comparison to the average Dutch floorspace per capita of 65 m_2 per capita. This is likely the effect of a relatively high contribution of respondents who live in urban areas. In one instance, where residential surface area was indicated to be "average size two bed flat", the residential surface area was assumed.

Although the survey sample is relatively small, reliability of the results depends mainly on the representativeness of the sample for Dutch/ European households. Based on the comparison in this section, most survey results are not expected to change markedly with a bigger survey sample.

3.2.1. Furniture per square meter averages based on survey

Item	Unit/m2
Armchair	0.016971
Bar stool	0.003233
Big closet	0.04326
Office chair	0.022551
Chair	0.085478
Desk	0.023917
Dining table	0.019197
Small closet	0.024424
(Double) bed	0.025807
Mattress	0.037459
Side table	0.03253
Sofa	0.011931
Stool	0.015175
Container	0.013251

Table 2: furniture intensities based on survey on household furniture

Furniture per square meter averages are calculated per furniture product category for each household, by dividing the total of items per household by the household residential surface and calculating the mean over all households. From here, the total average is calculated. The amounts of furniture per square meter based on the survey results are used in the study model (F), and are included in table 2.

3.2.2. Second hand share average per income group based on survey

Not all respondents filled in their net yearly income, as this was optional. Of the respondents that did fill in their net yearly income, second hand shares of furniture per income group or 'quintile' are derived. Quintiles are identified by ordering the sample data based on yearly net income, after which four cut-point values (quintile cut-off points) are identified, dividing the sample into five groups equally represented by 20% of the sample total. As the sample is not divisible by five, the first four price quintiles are filled with an equal share of the sample and the difference is compensated in the fifth quintile with a slightly reduced share. The second hand share of furniture per household is determined by dividing the total number of first hand items by the total number of second hand items. From there, second hand averages are determined per quintile. Although hard conclusions are not possible given sample size, these preliminary results seem to support earlier research findings that economic reasons are the most important motivation for buying second-hand furniture (Adnan et al., 2018; Bednárik & Pakaine Kovats, 2010; Gullstrand Edbring et al., 2016): not only do respondents in the first two quintiles more often have second hand furniture, the incidence of high second hand shares is also more frequent in low quintiles relative to high quintiles (Figure 7).

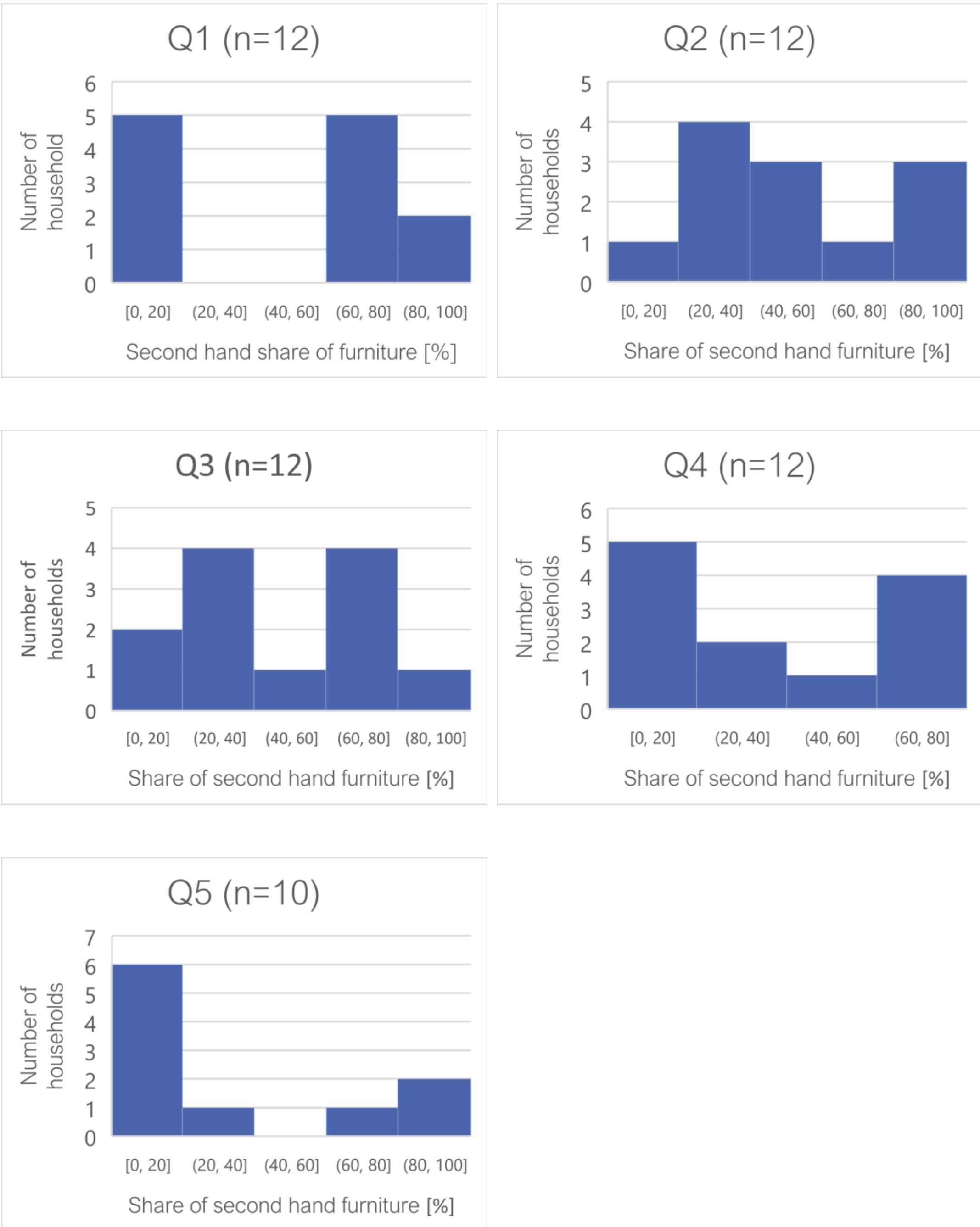


Figure 7: Share of second hand furniture per quintile, based on survey on household furniture. Figure shows quintile and number of households in the quintile sample (n). Bin width is 20%.

3.2.3. Second hand share per product category based on survey

The survey shows that on average 33.9% of the sample furniture stock is second hand. Compared to data from the furniture reuse network (FRN) in the UK, which shows that roughly 6% of the total furniture waste in weight is delivered as reuse by its members every year (Forrest et al., 2017), the share of reuse from the survey is high. One reason for this can be the relatively high representation of students in the sample, who might be more inclined to buy second hand furniture in view of a fast rental turnaround for student rooms. The second-hand share of the double bed, single bed, mattress, stool and container categories, are significantly lower compared to other product categories. This corresponds with the findings of (Gullstrand Edbring et al., 2016), showing that consumers respond negatively to soft material second hand furniture products, such as those including textiles and upholstery and furniture with a high perceived intimacy with the previous owner (such as beds). Outliers are the stool and container product categories, of which the products are made primarily from hard materials, but nevertheless show relatively low levels of reuse. Also, the armchair product category has a relatively high second-hand share (approximately 46%), even compared to regular chairs (42%), while armchairs are often upholstered and contain textile (Smardzewski, 2015).

3.2.4. Relative reuse factor (RRF) based on survey

The relative reuse factor (RRF) is used to weigh the general reuse factor of the model (which is based on literature) per product category, which is assumed to yield a more realistic reuse dynamic. The relative reuse factor is based on the survey and is calculated by dividing the second hand share per product category by the average second hand share of all categories. The mattresses, single bed, and container categories are reused significantly less. The small closet, armchair and dining table categories are reused relatively often. The relative reuse level per product category is shown in figure 8.

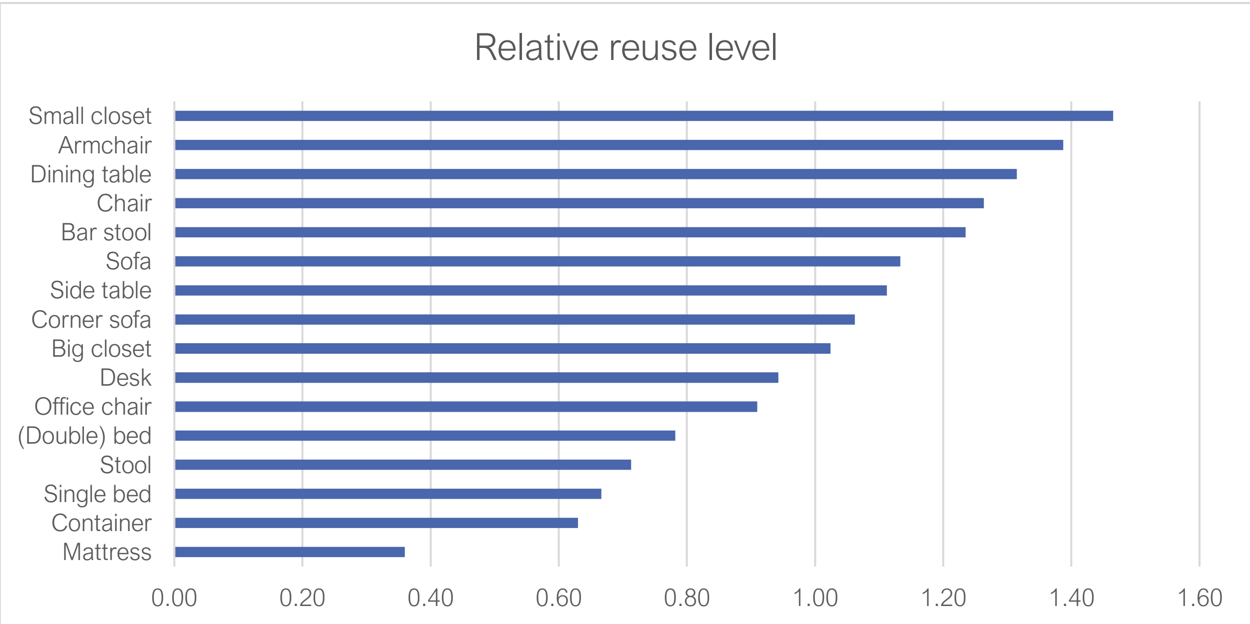


Figure 8: Relative reuse level per product category based on household survey

3.3. Material database results

The material database contains material- and lifetime data on 14 product categories, based on a total of 75 products. The material database holds the information on the material composition and lifetimes of the specific products within those categories as well as total category averages. No specific data was found for the single bed and corner sofa product categories, these are therefore excluded from the material database results. Product data is based on environmental product declarations (EPD's), information found in LCA databases, and (LCA) studies. Table 3 shows an overview of the material database characteristics. The table gives an overview of the product categories (Item), the number of products within the category samples (N), the average lifetime per category (L) and the average weight per category (Average weight MD). To check the results, the average product weights of the material database are compared to average weights of similar products provided by the UK Reuse network (Average weight FRN), which are included in table 3 (Reuse Network UK, 2021). The material information on product level comes from various sources, which are also included in table 3 per product category (Source). All environmental product declarations are referenced with the name of the database (Environdec, 2021). Individual EPD reports are referenced in Appendix F and in the material database (SM3). In most sources, the material composition on the product level has been determined, following LCA methodology and reporting standards.

Item	N	L [years]	Average weight MD [kg]	Average weight FRN [kg]	Compared FRN product	Source
Armchair	3	15	23.96233	25	Armchair	(Environdec, 2021)
Bar stool	2	15	8.66	-	N.A.	(Environdec, 2021)
Big closet	6	11.66667	177.814	55	Wardrobe, double	(Environdec, 2021; Geng, Ning, Zhang, & Yang, 2019; Iritani, Silva, Saavedra, Grael, & Ometto, 2015; Wang, Su, & Zhu, 2016)
Office chair	6	13.33333	14.88717	12	Office chair	(Environdec, 2021; Gamage, McLaren, & McLaren, 2008)
Chair	11	15	7.276091	6	Chair, not padded	(Environdec, 2021)
Desk	3	15	36.331	27	Desk, wooden	(Environdec, 2021)
Dining table	5	15	64.2092	30	Table, dining	(Environdec, 2021)
Small closet	5	15	51.8952	25	Chest of drawers	(Environdec, 2021)
(Double) bed	3	15	108.4695	25	Bed base, double	(Geng et al., 2019; Hoxha & Jusselme, 2017)
Mattress	7	9	34.03843	22	Mattress, single	(Deliege, Nijdam, & Vlaanderen, 1997; Glew, Stringer, Acquaye, & McQueen-Mason, 2012; Rocha, 2013)
Side table	8	15	23.84613	15	Coffee table	(Environdec, 2021; Hoxha & Jusselme, 2017)
Sofa	7	14.64286	62.51633	65	2 piece suite, sofa	(Andersson, Simonson, Rosell, Blomqvist, & Stripple, 2003; Environdec, 2021; Hoxha & Jusselme, 2017; Wang et al., 2016)
Stool	2	15	5.08	6	Stool	(Environdec, 2021)
Container	7	15	63.374	-	N.A.	(Environdec, 2021)

Table 3: Overview of the material database characteristics. The column on the left shows the product categories. The N column shows the number of products within the product category. The L column shows the average lifetime per product category. The average weight per product category of the material database (MD) is compared to average weights provided by the recycle network (FRN) (Reuse Network UK, 2021) for similar products (Compared FRN product). Note: lifetime averages per product category are sometimes based on fewer products than the category total (N). Individual EPD reports are referenced in Appendix F and in the Material Database (SM3)

3.3.1. Material composition averages per product category

As described in section 2.7.3, allocation of the raw materials to the model material categories is largely based on similarities between the physical properties of the materials found in the source literature. A total of 73 materials found in literature are allocated to 11 model material categories. An overview of the allocated materials is included in the material database in the supplementary material (SM3). Every product category in the database thus shows the material composition two times: by its original material composition as reported by the source, and with a material composition expressed in model material categories. An average material composition per product category is then derived from the products within the category, based on the model material categories. All material compositions per product category (in mass percentage) are shown in figure 9.

Studies on furniture material composition are scarce and focus on very diverse furniture products. Often these studies are lacking in the level of detail in the description of the material composition. However, some studies that contained information on product material compositions are included in the material database, for example: a study on the environmental impacts of furniture and appliances in net-zero energy buildings, which includes detailed material compositions of some furniture products, including double beds and sofas (Hoxha & Jusselme, 2017), and a study which looks into climate change mitigation potential of China's furniture sector, which includes material information on beds, sofas and office chairs (Geng et al., 2019).

Also various LCA studies that provide material characteristics for specific furniture products are included in the Database. Examples are: (Wang et al., 2016) with an LCA study on some wood based products, including a two drawer desk, sofa and four-door wardrobe, and (Gamage et al., 2008) who conduct an LCA on a chair product.

LCA databases such as EcoInvent, contain material information on some furniture products. In the material database, only the information of one mattress product is included from EcoInvent (Rocha, 2013).

The primary source of information on material compositions of various furniture products is the international database for environmental product declarations (EPD's), Environdec. The Environdec EPD system is the result of a long-standing collaborative project between the Swedish Environmental Protection Agency (SEPA) and industry. The EPD system provides third party verified, product specific LCA data complying with ISO 14025, TS/14027, 14040 and EN15804 (European norm for LCA assessment) research and reporting standards (Environdec, 2021). Environmental product declarations give a detailed view of material compositions for (manufacturer) specific products in weight or mass percentage, determined through standardized procedures.

As there is very little information available on the material composition of furniture products, the material database also includes variants of the same product. These variants can be based on size, e.g. the Caddy container, which comes in three different sizes. Variants can also depend on design, e.g. the OVO dining table is available in two designs (round and rectangular) and two sizes per type and the Bisley Drawer unit, which has three distinctly different designs (Laterfile, Systemfile, Essentials). Lastly, (Geng et al., 2019) distinguish two assembly scenarios 'less wood' and 'more wood', with different material compositions for the same product, of which the material composition is originally provided by (Hoxha & Jusselme, 2017). The material compositions for the products of both scenarios, as well as the material composition of the original product statistic, are included in the database (Double) bed category.

In some instances, where the material composition was expressed in mass percentage, the material weight (in kg) has been calculated by making use of the total product weight. (Hoxha & Jusselme, 2017) provided MDF contents in cubic meter volume, which has been converted to weight by assuming an average density for MDF. (Deliege et al., 1997) provides the material composition of various types of mattresses per service unit of 1 m_2 of mattress surface. This has been converted to a total material composition per mattress unit by assuming an average surface for a 'full size' mattress.

3.3.2. Lifetime averages per product category

Wherever product lifetimes are provided in the literature, these are included in the material database. Lifetime averages per product category can therefore be based on less products than are listed in the product sample of table 3. Lifetime averages lean heavily on information derived from EPD's. Of important note is the distinction between 'reported lifetime' and 'expected lifetime'. Reported lifetimes are the assumed product lifetimes used in LCA modelling and are often based on the expected duration of the use phase of the product. The expected lifetime is the expected technical lifetime of the product which can be significantly longer. However, as there is little information available on expected lifetimes and reported lifetime is well-documented in the product environmental declarations, lifetime averages per product category are determined based on reported lifetimes.

3.3.3. Review of Material database results

Some material averages and lifetime averages are based on available information of only a few product items (e.g. both the stool and bar stool category are based on two products, n=2). This means that the averages can be biased towards a group of items within a single product category, for example: towards wood products in the stool category; or towards higher end products at the expense of cheaper products. Especially information derived from product environmental passports seem to be biased towards high- end furniture products that are made from more expensive material such as hardwood and metal.

Four product categories have notably deviating weight averages, compared to data from the UK Reuse network (see table 3). These are the: big closet, small closet, (dining) table and (double) bed categories. The average weight of double beds (108 kg) is high relative to the FRN mean (25 kg). This is likely related to the fact that the FRN provides the average weight for the bed base only, excluding the headboard. Given the very low FRN weight, it can also be assumed that the bed slats are excluded in the FRN data. Including these in the FRN data would significantly reduce the weight difference with the MD results. Also, the (double) bed category is based on multiple variants of the same relatively heavy-weight product which would explain the remainder of the weight difference.

Another noticeable difference in weight average is in the big closet category: 178 kg relative to 55 kg from the FRN. This can be related to the fact that the big closet category contains some relatively heavy products, such as the Vis Storage System (175 kg) and two variants of the same relatively heavy MDF product (219 and 131 kg). One especially high end product made from various exotic hardwoods in the big closet category has been excluded because of its very high relative weight. The dining table category is heavy because it exclusively consists of high end hardwood and aluminium products.

Also the small closet category is heavy relative to the FRN mean, with 52 and 25 kg respectively. Furthermore, the small closet category contains a high amount of steel in its material composition, as the sample contains four products from the Koleksiyon Collection 800 series which are primarily made from steel. Also of note is that the mattress category includes a significant amount of wood (8%) in its material composition because of one Scandinavian mattress product (see figure 9).

Lastly, following the product category distinction of the study model (table 1): the big closet, small closet, sofa, stool and side table categories are aggregate categories, consisting of (functionally) different products that can vary relatively significantly in shape and size. The material database results for these categories might therefore not be fully representative.

Model data is prepared using Microsoft Excel. All of the (Excel) data files are included in the supplementary material (SM3). All of the Material database results – material compositions, average lifetime and average weight per product category- is included in appendix E.

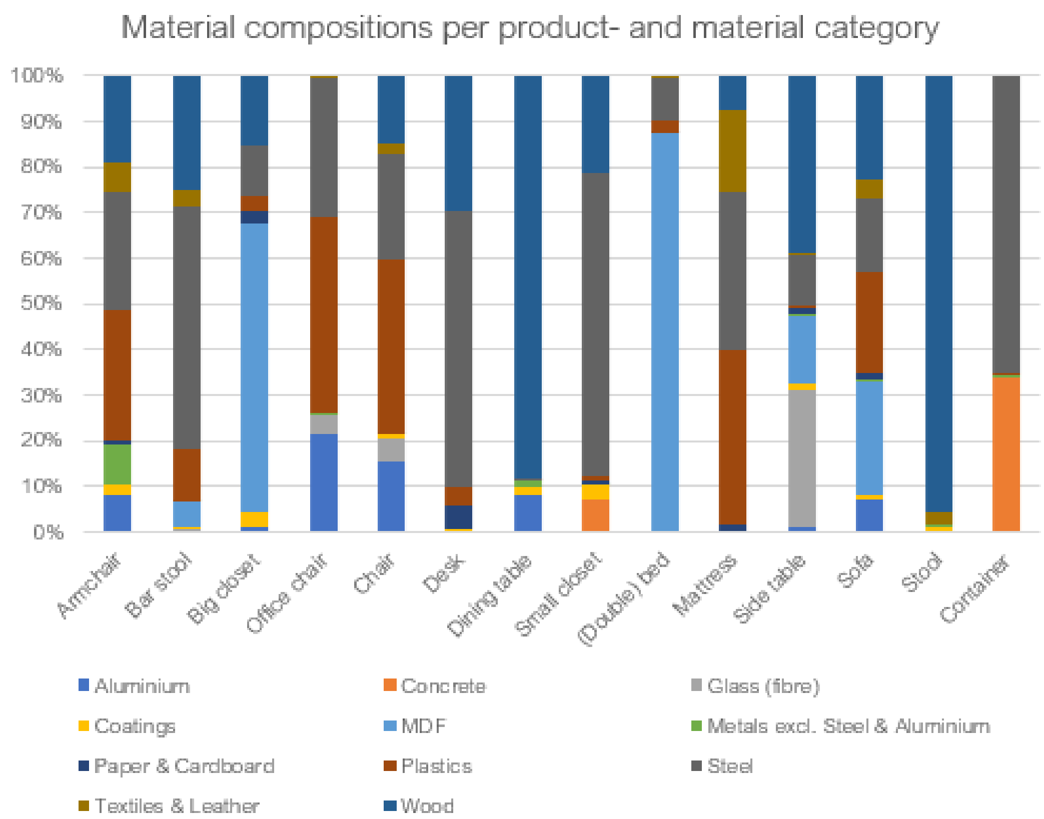


Figure 9: Material composition per product category

3.4. Model results

This chapter shows the results of the Study model. Figure 10 shows the projected development over time of the total European stock in Mt, organised by furniture category. According to the study model results, the current in-use European furniture stock will grow with roughly 97 Mt (or 20%), from 487Mt in 2021 to 584 Mt in 2050. Stock saturation is assumed to happen towards the end of the century as a result of saturation (and eventually decline) of the European population as projected by IMAGE.

What stands out is the high contribution of the big closet (bookcases, wardrobes, etc.) category (41%) and the (double) bed category (15%) to the in-use stock total of 2021. Although both categories are expected to have a significant contribution because of their relative high product size and occurrence in the survey sample, it should also be taken into account that the weight of both product categories is high relative to FRN data, as already discussed in section 3.3.

Figure 11 shows the same projected development over time of total European furniture stock in Mt, divided by material category. The projections show especially high contributions to the total stock from the MDF (40% or 352 kg/ capita), steel (21% or 187 kg/ capita) and wood (19% or 169 kg/capita) categories. Although wood and steel are common materials in furniture, and the EU furniture market is characterised as a high-end furniture market as already discussed in section 1.2, their relative contributions are affected by the overrepresentation of (high end) furniture items made from these materials in the material database (e.g. dining tables and small closets), as already discussed in section 3.3. Despite the fact that MDF is already the largest material category in the model results, it should be taken into account that this material group might further increase with a more realistic product sample in the material database: currently, the small closet category does not contain any MDF product. Also, kitchen cabinets are excluded from this study, which are often made from materials related to the MDF material category (Gonzalez-Garcia et al., 2011).

The contribution of material categories that are relatively easy to recycle (steel, aluminium, wood, paper & cardboard) is significant relative to materials that are hard to recycle (such as plastics and MDF). Given the fact that only 10% of European furniture is recycled (Forrest et al., 2017), this suggests that there is a lot of room for improvement on the recycling of waste furniture, as will be illustrated by the scenario analysis results.

Although it is hard to find any reliable data on (European) furniture stocks and flows in tonnes in the literature to compare the results, the European Environmental Bureau estimates that Europe consumes approximately 9 Mt of domestic furniture per year, based on Eurostat statistics (Forrest et al., 2017). This is lower than the study model results, which estimates the yearly inflow of domestic furniture at 36 Mt (in 2021). However, the PRODCOM (Eurostat's production statistics database) based categories are very broad and the contents of these categories cannot be viewed: it is therefore hard to assess if PRODCOM covers an equal range of furniture products. Moreover, PRODCOM statistics do not have a 100% coverage of production and trade and do not include used and second-hand goods (PRODCOM, 2017). Nevertheless, according to EEB estimates, the biggest contributing categories to yearly consumption are wooden furniture (3 Mt), kitchen furniture (2.5 Mt), mattresses (1.8 Mt) and metal furniture (1.25 Mt). This suggests that Kitchen cabinets are a major product category, which is not included in the study model results.

Although the high contribution of the mattress category according to EEB estimates might be surprising, the mattress category is also the third largest contributor in the study model results (3.4 Mt in 2021).

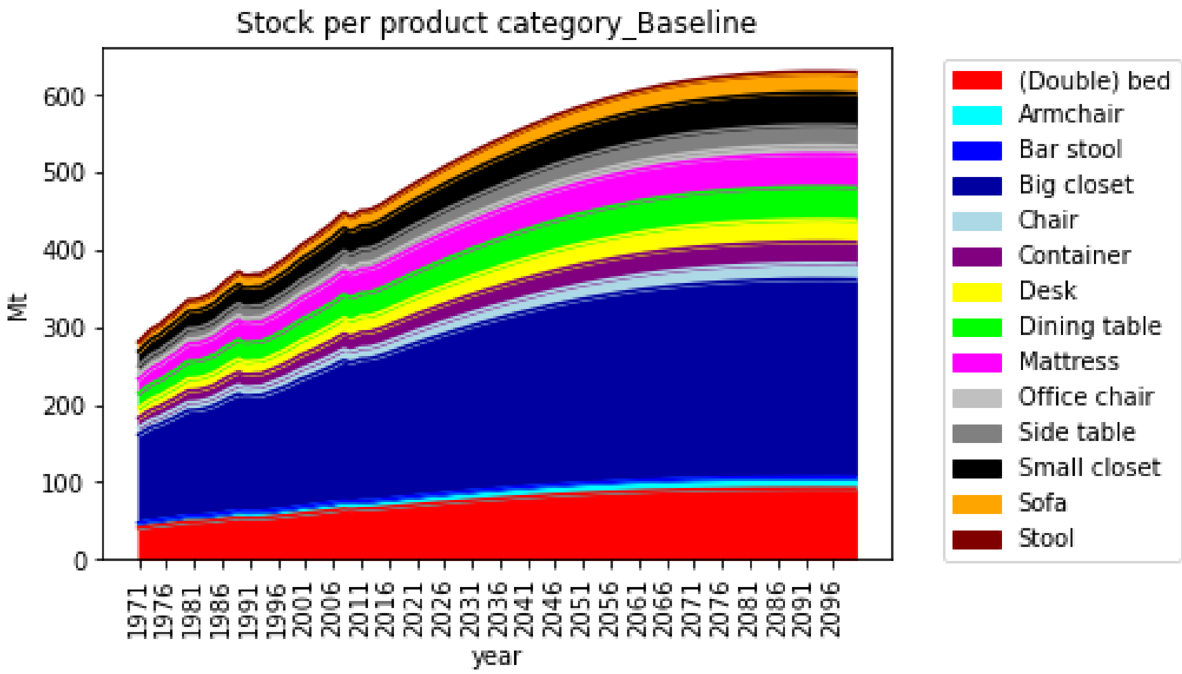


Figure 10: Results Study model. Graph shows projected development over time of total European furniture stock in Mt, divided by furniture category. Based on IMAGE SSP2 'Middle of the road' scenario.

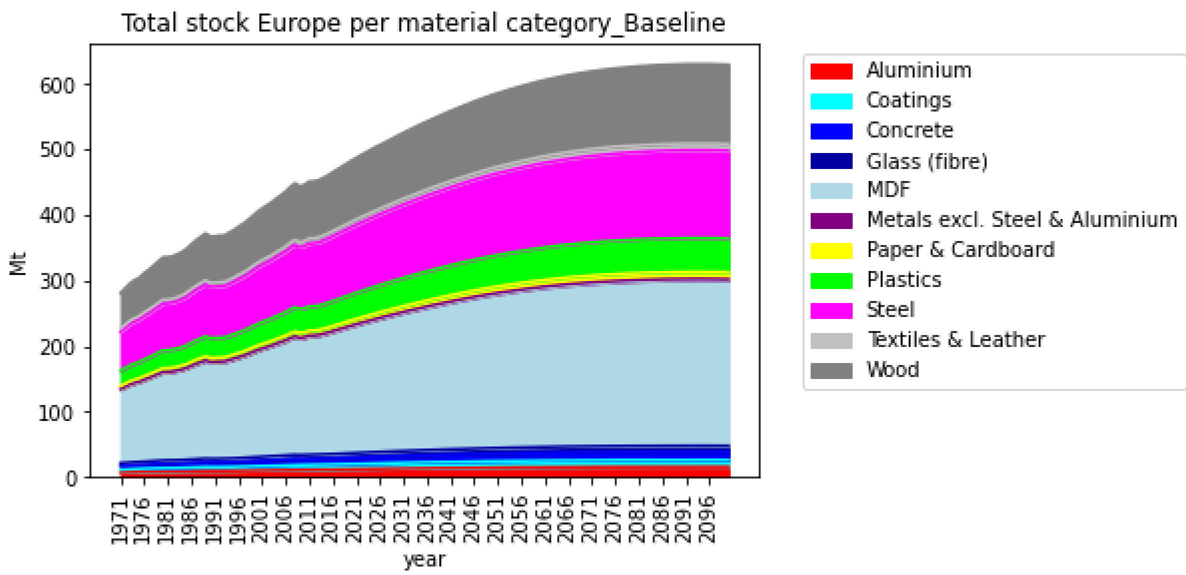


Figure 11: Preliminary results Study model. Graph shows projected development over time of total European furniture stock in Mt, divided by material category. Based on IMAGE SSP2 'Middle of the road' scenario.

3.4.1. Comparison with apparent consumption stock assessment based on PRODCOM data

As an order of magnitude check, the study model results in units are also directly compared to PRODCOM data for two product categories: assuming a steady state stock, an apparent consumption stock assessment, based on PRODCOM production- and trade data for swivel chairs and mattresses, estimates the stock for swivel chairs at around 200 million units, where the stock for mattresses is estimated at 1200 million units, including both residential and commercial products. A description of the apparent consumption calculation based on PRODCOM data is included in appendix A. Given that PRODCOM does not have full data coverage (PRODCOM, 2017), the apparent consumption estimates are expected to be on the low side.

As stated in the literature review, on average 82% of furniture consumption is for home use (Forrest et al., 2017)). Therefore, it is expected that the study model should yield stock estimates at roughly 82% of the apparent consumption based stock assessment with PRODCOM data for similar categories, as these include statistics on commercial furniture. The apparent consumption results are compared to the study model baseline 2021 results, which estimate the stock for mattresses at 892 million units (74% of apparent consumption estimate) and the stock for office chairs at 537 million units (287% of apparent consumption estimate) (figure 12).

Given a European population of 553.5 million people in 2021 based on the IMAGE population data, this puts the mattress stock in the right order of magnitude, but suggests an overestimation of the swivel/ office chair category. The overestimation of the swivel chair stock by the study model can have several causes, most likely of which is an overrepresentation of students (that often have office chairs) in the survey sample data. However, based on these impressions, the results of the study model in units furniture seem a good first approximation of the European furniture stocks in units.

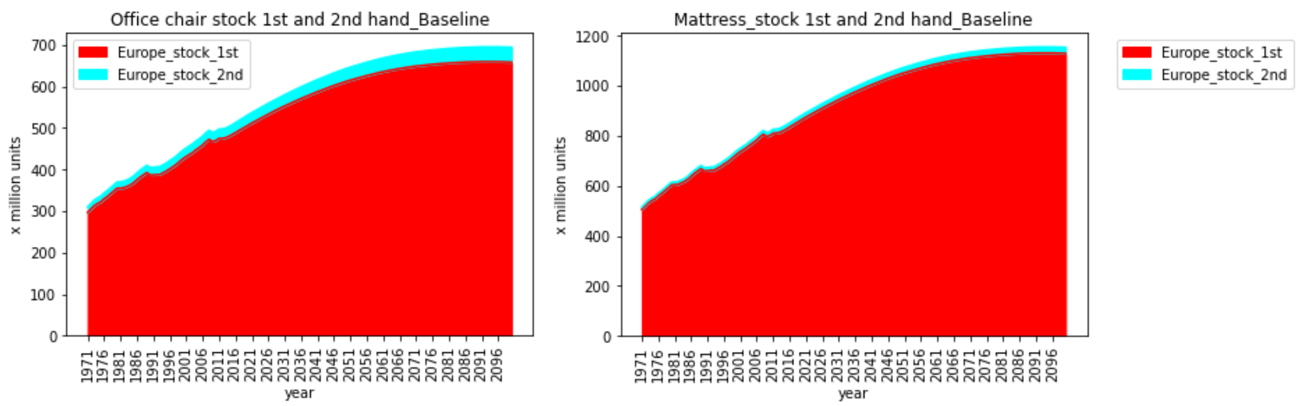


Figure 12: Assessment of European stock development of swivel/ office chairs and mattresses with the study model based on the 'baseline' scenario in million units. This can be compared to the stock assessment based on apparent consumption with PRODCOM production- and trade statistics.

3.5. Scenario analysis results

Two scenarios are compared: the 'baseline scenario' and 'reduced waste scenario'. The scenarios are not intended to reflect any real life situation or pathway: the results from the scenario analysis are meant to illustrate how (governmental) policy can be simulated in the study model and how policy decisions could influence the dynamics of the furniture market.

The relative share of the first and second hand stock to the stock total, landfilled- and recycled material, and the required primary material are compared between the two scenarios, with a special focus on the current in-use stock (2021) and the projected stock and flows for 2050. The total stock composition in terms of product- and material categories does not change markedly between both scenarios and is not included in this section.

3.5.1. Stock first and second hand

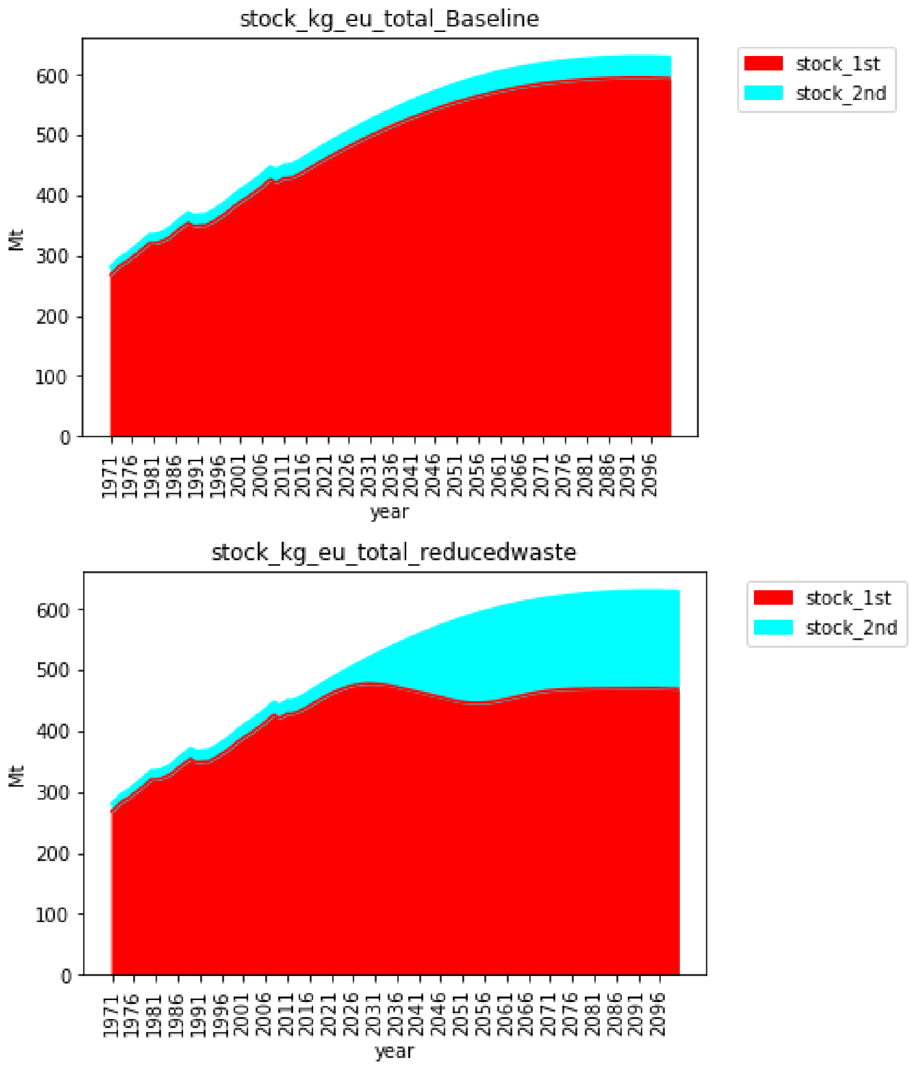


Figure 13: Results of the study model for the share of the second hand stock in the stock total, in the baseline and reduced waste scenario. Results are presented in Mt.

In the baseline scenario, the share of second hand furniture in the required stock keeps relatively constant over time, given the reuse fraction of 6%. In the baseline scenario, the second hand stock gradually increases to 5.24 % of the total stock in 2050. This share is lower than the general reuse fraction of 6% because of the weighing of the reuse fraction with the relative reuse factor (RRF^t) per furniture product. In the reduced waste scenario, the share of second hand furniture increases to over 23% of the total stock in 2050, as the reuse fraction increases gradually between 2021 and 2050. The results for the share of second hand furniture to the stock total of both scenarios is shown in figure 13.

3.5.2. Landfilled material

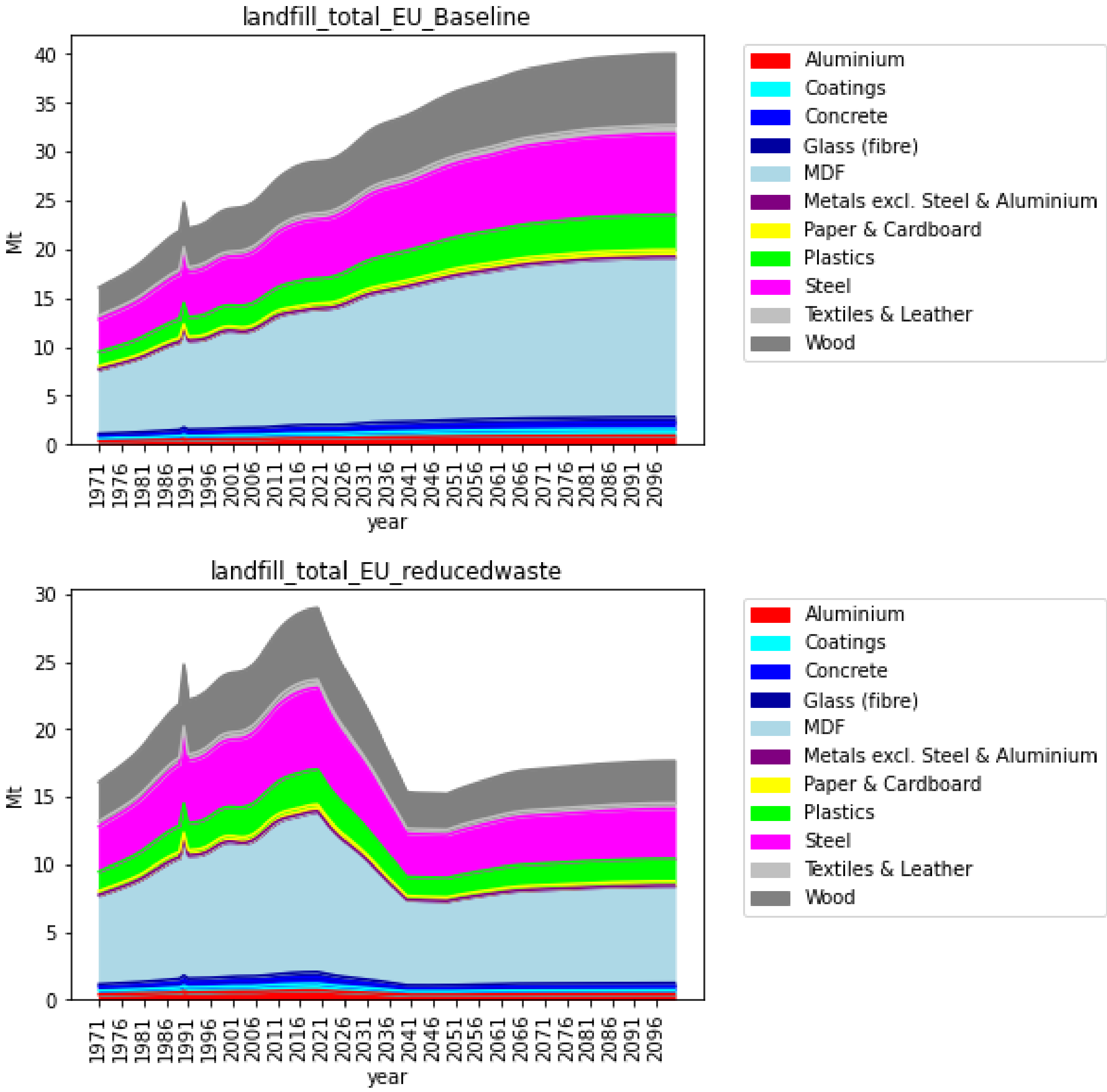


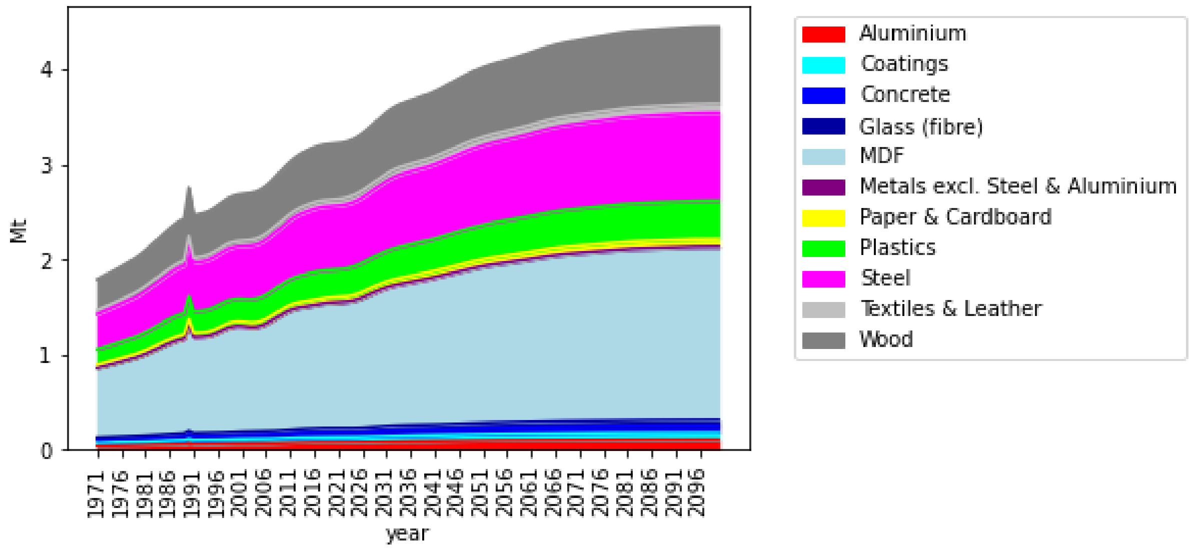
Figure 14: Results of the study model for the amount of landfilled material per material category in the baseline and reduced waste scenario. Results are presented in Mt.

The amount of landfilled material per year, as projected for both scenarios, is shown in figure 14. The peak in landfilled material around the year 1990 must be attributed to the decline in required stock in that year in Central Europe. The negative inflow correction of the model allocates the surplus of furniture of that year to the first hand outflow on top of the natural outflow, which leads to an outflow peak. As the outflow of material increases, so does the landfilled (and recycled) material.

According to the model baseline results, between 30 and 36 Mt of furniture waste is being landfilled or incinerated each year in Europe in the period 2021 to 2050. This is high compared to estimates from the European Environmental Bureau, which estimates the total European furniture waste at a total of 10.78 Mt per year, or 3.75% of total municipal solid waste, equalling furniture consumption (Forrest et al., 2017). Given a 10% recycle fraction, this would bring the total of landfilled or incinerated material to 9 Mt per year, according to the EEB. However, as EEB estimates are based on PRODCOM statistics, these estimates should be considered to be on the low side, as already discussed in section 3.4.

In the baseline scenario, the amount of landfilled material increases steadily with the increasing stock outflow, towards 36 Mt in 2050. In the reduced waste scenario, the amount of landfilled material decreases rapidly from 2021 onwards, as the fraction of recycled material increases, down to a total of roughly 15 Mt in 2050.

3.5.3. Recycled material



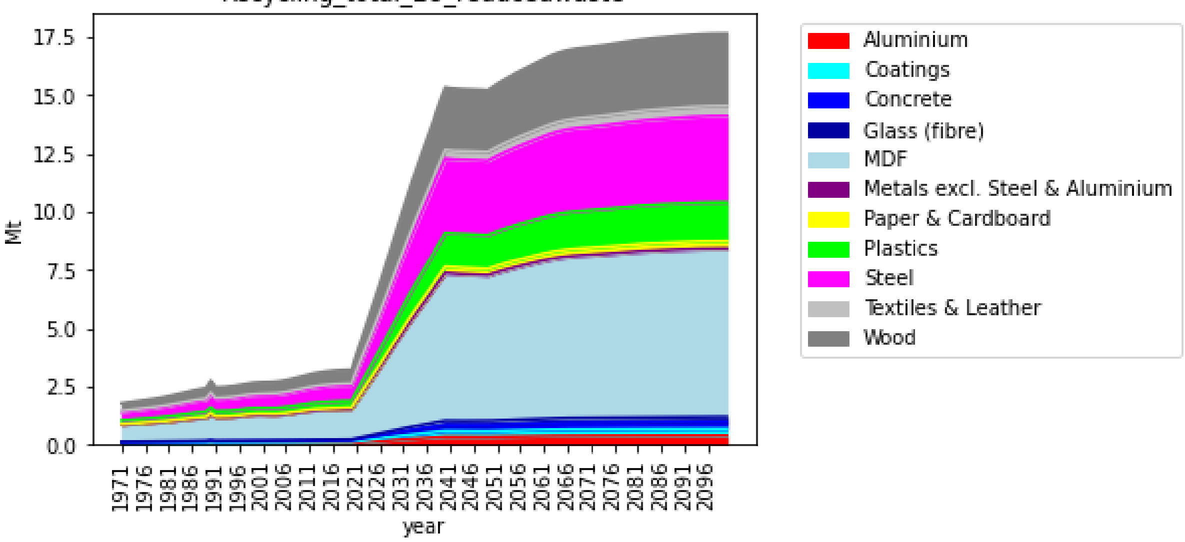


Figure 15: Results of the study model for the amount of recycled material per material category, in the baseline and reduced waste scenario. Results are presented in Mt.

The amount of recycled material increases steadily in the baseline scenario with the increasing stock outflow, towards 4 Mt in 2050. The baseline pattern for the recycled material is similar to that of the landfilled material, as described in section 3.5.2 and is shown in figure 15. As a size comparison, based on the study model results for the baseline scenario: an estimated 3.2 Mt of furniture material was recycled to a total waste outflow of 32 Mt in 2018, relative to scrapped passenger cars and light goods vehicles where 5.673 Mt of parts and materials were reused or recycled to a total waste of 6.1 Mt, or 93% (Eurostat, 2020).

The EEB estimates the total amount of recycled material per year at roughly 1 Mt, based on the same recycle fraction (10%) as the baseline scenario (Forrest et al., 2017), which puts the study model results in the right order of magnitude.

In the reduced waste scenario, the amount of recycled material increases rapidly after 2021 as the fraction of recycled material increases, until 50% of the outflow gets recycled from 2045 onwards. The study model project that over 15Mt of material is recycled in 2050 in the reduced waste scenario. Some elements should be taken into consideration when reviewing the results on recycled furniture material: recyclability of the material categories has not been taken into account in these scenarios. This can vary significantly between material categories where some categories are highly recyclable (e.g. steel) and others are very hard to recycle (e.g. MDF and coatings). Recyclability can also vary between and within product categories, where some products are relatively easy to recycle such as wooden tables and chairs, and some are harder to recycle such as mattresses, due to the complexity of their design (Bell, Fitzsimons, Harding, & Perry, 2019). Also, an increase of recycling from 10 to 50 percent would possibly require a significant increase in recycling capacity and improved logistics of furniture waste. Moreover, recycling on industrial scale might not be feasible for all material categories.

3.5.4. Required primary material

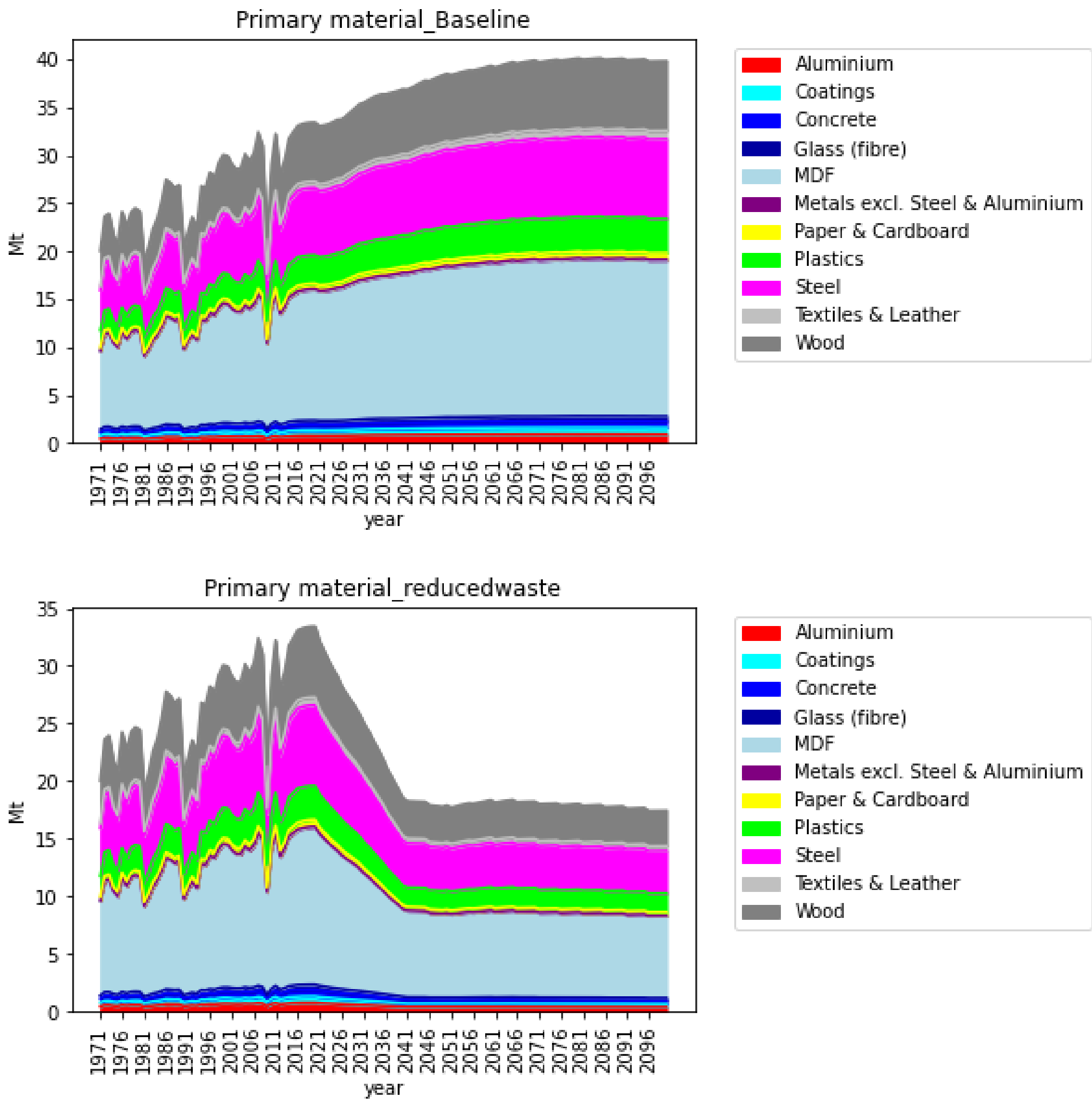


Figure 16: Results of the study model for the amount of required primary material per material category in the baseline and reduced waste scenario. Results are presented in Mt.

The Primary material in figure 16 shows the amount of virgin material that is needed to fulfil the required furniture stock. The inflow of material fluctuates towards 2021, but this can be attributed to variations in required furniture stock, for which the IMAGE data on population and residential floorspace is largely based on published data as described in section 2, but is projected after the study year (2021).

In the baseline scenario, the required primary material increases as the required stock increases, towards a total of 38.5 Mt in total in 2050. In the reduced waste scenario, the required primary material declines steadily after 2021 as the result of both the increase in reuse factor and recycling factor, down to less than 18 Mt in 2050, which is less than half compared to the baseline. If more furniture is being reused, this results in a higher contribution of the second hand stock to the required stock, meaning that less furniture needs to be produced, thus reducing the need for primary material. Also, increasing the amount of material that is being recycled (and feeding the recycled material back into the furniture production system), means a decrease in demand for primary materials.

It is hard to directly compare the European primary material consumption for furniture products that is projected by the study model with total European material consumption statistics, as most model material categories are incompatible aggregates of various material types. One material that is directly comparable is steel. The model projects an (annual) primary steel demand for furniture of 7 Mt (or 12.7 kg/ cap/ year) in 2019, compared to a total European apparent steel consumption of 1.54 Mt in 2019 according to (EUROFER, 2020). This indicates that the model projections for steel are significantly overestimated. This is most likely related to an overestimation of steel in the material compositions of some product categories as already discussed in section 3.3. It can also be attributed to an overestimation related to the input data (e.g. total floorspace) or to an overestimation in units of some specific product categories that contain steel, such as office chairs. However, this does not say anything about the model projections for the other material categories.

The results show that gradually increasing the recycle fraction with 2% per year and the reuse fraction with 1% per year, could almost cut the demand for primary materials in half by 2041-2046.

3.6. Sensitivity analysis method

Based on the results of the study model, some significant variables are identified for a sensitivity analysis, to see how a change in the input variable would influence the model results. The results of the model, according to the changes in the different sensitivity analysis variables, are compared to the results of the Baseline scenario for the year 2021. Five variables are altered in the sensitivity analysis:

SA1: Product lifetimes are increased with 20% and results are compared for primary material, recycled material and landfilled material. This major increase in lifetime can be justified, given the often significant differences between reported lifetime and expected lifetime of furniture products.
SA2: The average weight of the big closet category (177.81 kg) is reduced to match the average weight for big wardrobes as reported by the FRN network (55 kg) (Reuse Network UK, 2021). This is a major change (69%), but can be justified given the very high average weight of the big closet category according to the Material Database results. The big closet category is the biggest contributing product category from a weight perspective and has the second highest product intensity per unit residential surface (after chairs) and should illustrate the significance of the material database assumptions. Results are compared for required stock, required primary material, recycled material and landfilled material. Given the relative size of the big closet category, and the fact that MDF is the biggest contributing material category to the category material composition: results are also compared for the required stock for MDF and required primary MDF.
SA3: Product intensities per unit floorspace are reduced with 5% and the results are compared for required stock, required primary material, recycled material and landfilled material.
SA4: The Scandinavian mattress product is excluded from the mattress category in the material database, which reduces the average category weight with 11.99% and completely eliminates wood from the category material composition. Results are compared for required stock, required primary material, recycled material, landfilled material, required stock for wood and required primary wood.
SA5: The general reuse fraction (RFt) is increased with 10% relative to the Baseline scenario. Results are compared for required primary material, recycled material, landfilled material and the 2nd hand share of the required furniture stock total.

Sensitivity is calculated as a dimensionless value, by dividing the percentual change in output by the percentual change in the input variable. A sensitivity of 1 means that a percentual change in the input variable leads to a similar change in the output variable. Calculating the sensitivity helps to compare the relative effect of changes in the input variables and to see which input variables have the most significant influence. Minor variations in percentual changes and sensitivity between some output variables (e.g. between recycled and landfilled material) can be a result of rounding the stock- and flow results.

3.7. Sensitivity analysis results

In this section, the results of the sensitivity analysis are described per change in the input variable.

3.7.1. Sensitivity analysis product lifetimes (SA1)

In the first sensitivity analysis (SA1), product lifetimes are extended with 20%. Expected lifetimes for multiple furniture products can be significantly longer than the reported lifetimes which are used to derive product lifetime averages (see section 3.3.2), which justifies the significant change in product lifetimes for this sensitivity analysis. The results from the sensitivity analysis shows that a 20% increase in product lifetimes affects most model flows significantly, resulting in an average flow reduction of 14% and an average sensitivity of -0.74. This effect makes sense considering that only product flows (required primary material, recycling and landfilling of discarded furniture) are lifetime dependent: an increase in lifetime would results in a reduction of furniture leaving the stock, reducing recycling and landfilling of furniture. In turn: if less furniture is discarded, less primary furniture needs to be produced, therefore also resulting in a reduction of the inflow. The results of SA1 are shown in table 4. This sensitivity analysis shows that product lifetimes are an important model assumption regarding the flow- related results.

SA1 2021	Baseline value [Mt]	SA1 value [Mt]	% change	Sensitivity
Primary material	33.07	28.54	-13.8	-0.69
Recycled material	3.22	2.72	-15	-0.75
Landfilled material	29	24.48	-15.6	-0.78

Table 4: Results of SA1 relative to the Baseline results. Table shows the output variable, baseline value, the SA1 value, the percentual change between the SA1 and Baseline value and the sensitivity.

3.7.2. Sensitivity analysis big closet category (SA2)

In the second sensitivity analysis (SA2), the material composition of the big closet category is calculated by making use of mass percentages for the material composition, which are derived from the material database. These can then be multiplied with the average weight for big wardrobes as reported by the FRN network (Reuse Network UK, 2021), which yield the results of table 5.

Big closet		
Material category	Mass %	Adjusted amount [kg]
Aluminium	0.013587	0.747298
Concrete	0	0
Glass (fibre)	0	0
Coatings	0.028018	1.540992
MDF	0.634652	34.90586
Metals excl. Steel & Aluminium	0	0
Paper & Cardboard	0.026477	1.456241
Plastics	0.035122	1.931715
Steel	0.1103	6.066474
Textiles & Leather	0	0
Wood	0.151844	8.351423
Total	1	55

Table 5: Material composition of big closet category according to SA2.

Reducing the average weight of the big closet category (177.81 kg) to match the FRN average (55 kg), means a reduction in weight relative to the Material Database of (-)69%. Some relevant results of SA2 are compared to the results of the baseline scenario and are shown in table 6, together with the percentual change of the results and the calculated sensitivity. The required stock reduces with (-)28% with the change in average weight for the big closet category, with a corresponding sensitivity of 0.41. The effect is high given the fact that only one product category has been altered. In SA2, the Double bed category surpasses the big closet category as the biggest contributing product category to the stock total. The stock per product category according to SA2 is shown in figure 17. Also, as big closets are the biggest contributing product category and are primarily made of MDF, the change in average weight significantly affects the required amount of MDF, with a sensitivity of 0.64 for the required MDF stock. This is therefore included in the results of table 6. The stock per material category according to SA2 is shown in figure 18. These results might be a better reflection of the real life situation, given the very high average weight of the big closet category according to the Material Database results. Although the sensitivity is high, it should be noted that the big closet category is by far the biggest product category in the baseline: changes in the material composition of different product categories would have a less significant effect.

SA2 2021	Baseline value [Mt]	SA2 value [Mt]	% change	Sensitivity
Required stock	486.7	350.3	-28.1	0.41
Primary material	33.07	23	-30.5	0.44
Recycled material	3.22	2.2	-31.3	0.45
Landfilled material	29	20.1	-30.7	0.44
Required stock MDF	194.98	108.4	-44.4	0.64
Primary MDF	13.45	7.1	-47.2	0.68

Table 6: Results of SA1 relative to the Baseline results. Results are compared for the year 2021. The table shows the output variable, baseline value, the SA1 value, the percentual change between the SA1 and Baseline value and the sensitivity. Sensitivity is calculated by dividing the percentual change in output value by the percentual change in the input variable.

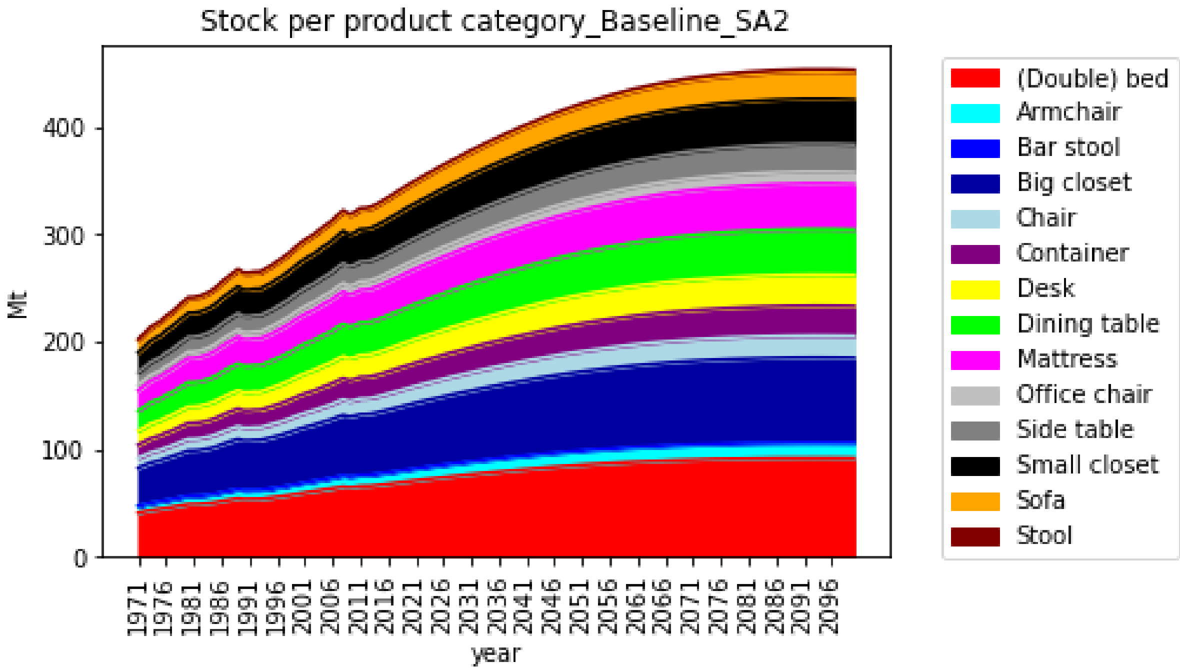


Figure 17: Stock per product category according to SA2. The Double bed category surpasses the big closet category as the biggest contributing product category. The in-use stock for the year 2021 reduces in SA2 to 350.3 Mt, relative to 486.7 Mt in the baseline. .

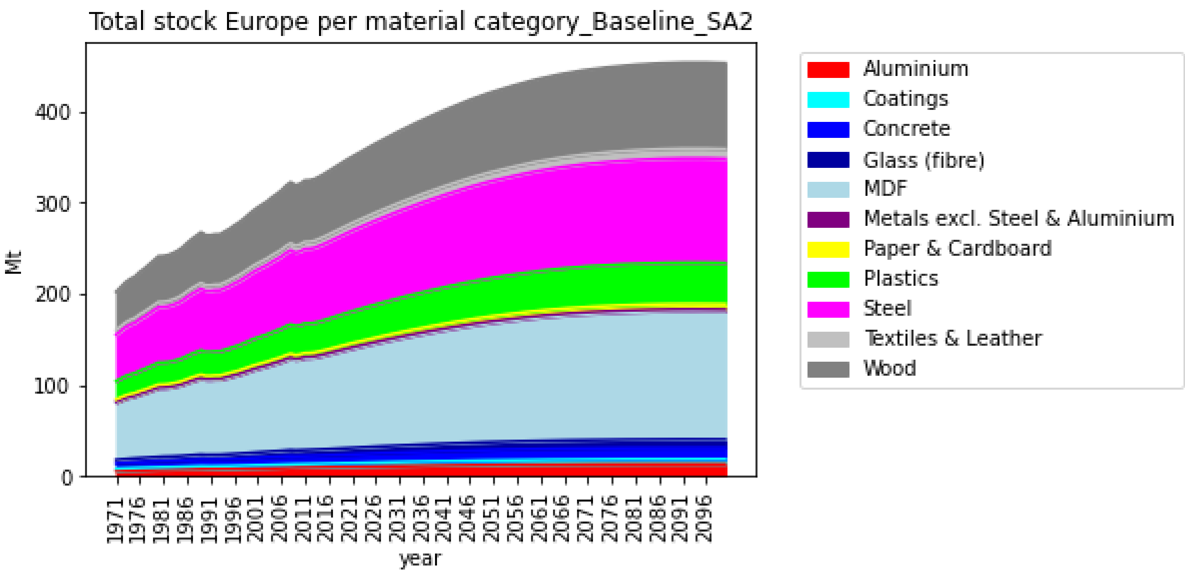


Figure 18: Stock per material category according to SA2. The MDF material category reduces significantly to 108.4 Mt, relative to 195 Mt in the baseline, which indicates the relative importance of the big closet category to the results for the MDF material category.

3.7.3. Sensitivity analysis furniture intensities (SA3)

For the third sensitivity analysis (SA3), the furniture intensities per unit residential floorspace, as derived from the survey on household furniture, are reduced by 5%. This leads to a reduction of the required stock results of 5%, with a sensitivity of 1. This means that a change in the furniture intensities variable leads to a similar change in the model results, which indicates that the study model leans heavily on furniture intensity assumptions. The results of SA3 are included in table 7. Similar results should also be expected for the stock results in units. This significant effect is expected, considering the fact that furniture intensities per unit residential floorspace is a direct driver for required stock.

SA3 2021	Baseline value [Mt]	SA3 value [Mt]	% change	Sensitivity
Required stock	486.7	462.4	-5.1	1.01
Primary material	33.07	31.4	-5.1	1.03
Recycled material	3.22	3.06	-4.4	0.88
Landfilled material	29	27.5542	-5.0	1

Table 7: Results of SA1 relative to the Baseline results. Results are compared for the year 2021. The table shows the output variable, baseline value, the SA1 value, the percentual change between the SA1 and Baseline value and the sensitivity. Sensitivity is calculated by dividing the percentual change in output value by the percentual change in the input variable.

3.7.4. Sensitivity analysis mattress category (SA4)

Excluding the Scandinavian mattress product from the category averages reduces the average weight for the mattress category from 34.04 to 29.96 kg or a reduction of (-)11.99%. Excluding the Scandinavian mattress product also (slightly) changes the material composition of the product category and completely eliminates wood from its composition. This change of the mattress category material composition results in a 0.8% decrease of the total required stock (2.71% decrease for the required stock for wood specifically) and a sensitivity of 0.08 which is negligible. The results of SA4 are included in table 8.

Despite the fact that the change in material composition of the mattress category only results in a 3.95% decrease in required primary wood in 2021, this percentual change in the results is significant (sensitivity of 0.33) given the relatively small change (11.99%) in the material composition of only one product category. However, considering that all wood is eliminated from the category material composition in this sensitivity analysis, the effect is limited.

SA4 2021	Baseline value [Mt]	SA4 value [Mt]	% change	Sensitivity
Required stock	486.7	482.78	-0.8	0.07
Primary material	33.07	32.7	-1.1	0.09
Recycled material	3.22	3.19	-0.9	0.08
Landfilled material	29	28.67	-1.1	0.09
Required stock wood	93.53	91	-2.7	0.23
Primary wood	6.07	5.83	-4.0	0.33

Table 8: Results of SA1 relative to the Baseline results. Results are compared for the year 2021. The table shows the output variable, baseline value, the SA1 value, the percentual change between the SA1 and Baseline value and the sensitivity. Sensitivity is calculated by dividing the percentual change in output value by the percentual change in the input variable.

3.7.5. Sensitivity analysis reuse fraction (SA5)

In the fifth sensitivity analysis (SA5), the reuse fraction is increased with 10%. Varying the general reuse fraction by 10% has a negligible effect on required primary material (sensitivity of -0.05), recycled material (sensitivity of -0.06) and landfilled material (sensitivity of -0.06). It does however, have a significant effect on the share of second hand furniture of the total required stock (sensitivity of 0.61). This result is interesting as it shows that an increase in the use of second hand furniture only has a limited effect on the consumption of primary material for the production of new furniture. The results of SA5 are included in table 9.

SA5 2021	Baseline value [Mt]	SA5 value [Mt]	% change	Sensitivity
Primary material	33.07	32.91	-0.5	-0.05
Recycled material	3.22	3.2	-0.6	-0.06
Landfilled material	29	28.84	-0.6	-0.06
SA5 2021	Baseline value [%]	SA5 value [%]	% change	Sensitivity
Share 2^{nd} hand stock	5.24	5.56	6.1	0.61

Table 9: Results of SA1 relative to the Baseline results. Results are compared for the year 2021. The table shows the output variable, baseline value, the SA1 value, the percentual change between the SA1 and Baseline value and the sensitivity. Sensitivity is calculated by dividing the percentual change in output value by the percentual change in the input variable.

4 Discussion

All during the study process, research efforts were impeded by a lack of data, both in qualitative and quantitative terms. Also, as this study was conducted during the worldwide Covid- 19 pandemic of 2020-2021, research inquiries were complicated by pandemic measures which for example led to the closing of the Meertens institute research depository in Amsterdam. Gaps in data have been filled to best effort, and much of the data gathered for this study, such as the material database for furniture products and the survey on Household furniture possession, should be considered first efforts in a yet underexplored, but comprehensive subject. Much data is still lacking on various furniture products and types, product lifetimes, and furniture consumption. That being said, this chapter aims to address some of the more significant uncertainties related to the data and methods used in this study.

4.1. Material database assumptions

A significant limitation of the study are the material content averages per furniture category. The principal source for these averages are the product environmental passports from the Environdec database, which generally show a bias towards high end furniture. This has a twofold effect: 1) on the material averages per product category which are biased towards higher-end material categories (e.g. wood, steel and leather relative to MDF and plastics) 2) on the material level, material categories are biased towards higher- end, heavier materials (e.g. hardwoods relative to pine in the wood category). This can be clearly illustrated by the table category, which has a relatively high average weight (64 kg) and a high (hard)wood content (57 kg) and the small closet category which also has a high average weight (52 kg) and a high steel content (34 kg), which skews the results towards these product- and material categories.

Also, because of data limitations, some material averages are based on only a few products. In some cases this has strong implications for the results, as illustrated by the stool category which is skewed towards a wood product and the (double) bed category which is skewed towards an MDF product. Also, the mattress category contains wood because of the inclusion of a high end Scandinavian mattress: given the high contribution of the mattress category to the stock total, this might have impacted the results for the wood material category. Including more data on the material compositions of furniture products, such as manufacturer data, would yield more realistic material averages per product category. Also, subdividing product categories- for example: dividing the sofa category into regular sofa, corner sofa, sleeping sofa and chaise longue categories- would yield more comprehensive results.

The principal source for product lifetimes (L) are the product environmental passports. The choice for reported lifetime over expected lifetime has important implications for the results, as reported lifetimes are significantly shorter. Assuming higher (expected) product lifetimes would significantly influence the results: as products are kept longer in stock, less inflow of new products (and primary material) is needed.

4.2. Survey sampling errors

An important limitation to the study is in the furniture survey sample, both in size and composition. From a quantitative perspective, the size of the survey sample is relatively small (n=108). A second (or larger) sample would allow for a reliability assessment of the results.

Although efforts have been made to maximize the diversity of the sample to reflect the diversity of real life household compositions, some qualitative limitations have to be discussed: first is a bias towards students, which are overrepresented in the survey sample, given the social network of the researcher. This is reflected for example in the relatively high estimated stock for the office chair category. Also, the study by Edbring et al. show that the economic driver toward buying second hand furniture is even higher among students (Gullstrand Edbring et al., 2016), which might have biased the results towards higher shares of second-hand furniture (in low income groups). Also, the survey sample is overrepresented by respondents from urban areas, where residential floorspace is normally lower relative to rural areas, the result of which might be an overestimation of furniture per square meter averages. This in turn could influence the study model estimations (in units).

Furthermore, most respondents are Netherlands based. Although European member states are relatively uniform, there might be notable differences in household furniture composition or furniture per residential floorspace between EU countries that are not accounted for in the model. This can be for example countries with a more prominent outdoor-culture (Southern Europe) relative to countries with a dominant indoor-culture (Northern Europe). This limitation becomes more apparent if the model would be used to assess furniture stocks in regions outside of Europe, where cultural differences can also significantly affect the types of furniture and materials used.

Some inaccuracy is possible in the survey method. Inventories conducted by the respondents of their furniture, are dependent on an individual interpretation of the pictures provided per product category, which could lead to an over- or under estimation of more ambiguous furniture categories (e.g. small closet, big closet, side table).

4.3. Model assumptions

Most issues regarding the model outcomes are related to anomalies in the model data, especially the data from the survey on household furniture and the material database, as already discussed in the previous sections (4.1 and 4.2) and the results chapters for the survey (section 3.2) and material database (section 3.3). Other points of discussion related to assumptions made in the methodology are discussed in this section.

4.3.1. Required stock discussion

For the calculation of the required stock it is assumed that residential floorspace is a representative driver for furniture product ownership. However, some furniture product categories might not correlate well with residential floorspace, for example: an increase in residential floorspace (for example in higher income groups) does not necessarily mean an increase in certain products such as dining tables and beds. Other drivers such as population or number of households might be more suitable for these product categories.

Another model assumption is the year 1900 as the model cut-off, which means that (some) antique furniture is excluded. This might lead to an overestimation of the required stock, as some real life demand will be already fulfilled with antique furniture.

4.3.2. Reuse and recycling fractions discussion

The reuse fraction assumed in the model (6%) is based on data from the UK reuse network, as already discussed in section 2.5.3. However, as this reuse fraction is relatively low, the data from the reuse network might not reflect the share of furniture reuse in the UK as a whole. Furthermore, by lack of data, the UK reuse fraction is used as a substitute for the EU region as a whole, where in reality this could vary significantly between countries.

The recycle fraction assumed in the model (10%) is based on a report by the EEB, as already discussed in section 2.6.1. This recycle fraction is an EU average and is used for the EU region as a whole and for all product categories individually. However, recycle fractions can vary significantly between countries, between products: e.g. most mattresses are disposed of via landfill as they are composites of many different materials which makes recycling difficult (Glew et al., 2012), and maybe more importantly between material categories: e.g. recycling of medium density fibreboard (MDF) is a complex process relative to wood (Wan, Want, Barry, & Shen, 2014), and some materials in the coatings category might not be recyclable at all.

4.3.3. DSM function discussion

In the DSM function, product lifetimes are static with a mean lifetime per product category for every year. Also, as there is no data available on lifetimes of second-hand products, the same lifetime is assumed that is used for first- hand products. This might not be a good reflection of the real life situation, in which products deteriorate over time and use cycles of second hand products are shorter. Furthermore, the same standard deviation fraction is used for all product categories and per year. In a real life scenario, there might be more variance in lifetimes between product categories, e.g. between mattresses which overall have a relatively fixed lifetime, and dining tables, which can vary heavily in their use cycles.

The survival function in the DSM function is based on a folded normal distribution. More data would be needed to see which lifetime distribution best represents furniture lifetime data. Other lifetime distributions, such as the Weibull or Gamma distribution (Muller et al., 2014), might be better suited.

For the negative inflow correct it was assumed that any ‘surplus’ in furniture will immediately be discarded in the year of occurrence, resulting in an outflow peak. Alternatively, a surplus in furniture could be allowed in the model, with the surplus furniture surviving alongside the required furniture stock. The surplus in furniture can then be discarded more gradually. This might be a better representation of a real life scenario in which the required furniture stock decreases. The negative inflow correction results in a negative stock value for very old age cohorts, with a very small amount of surviving furniture, which are set to a 0 value as described in section 2.5.1. This might have negligible effects on the overall 1st hand stock estimates.

5 Recommendations for further research

This chapter is intended to provide suggestions for further research. Furniture in general is an underexplored but comprehensive research subject and there are diverse opportunities to build on some of the research efforts described in this study. This chapter consists of three parts: in the first part (section 5.1) further research is suggested on the data level, where there are significant gaps. The second and third part (section 5.2 and 5.3 respectively) are suggestions to advance and improve on the model and scenario methods used in this study.

5.1. Data suggestions for further research

Given the fact that there is very little information available on furniture generally, and on material stocks in furniture specifically, there are multiple opportunities to expand on the research and modelling efforts presented in this study. First would be to expand the body of data on furniture, the furniture sector and furniture consumption, both in terms of quantity and quality. Examples of required data: more data on material compositions of furniture products, data on furniture product lifetimes, data on furniture possession (consumption, use cycle, reasons of disposal), second-hand furniture consumption, data on recycling of furniture, etc. Already during the course of this project, new environmental product declarations for multiple furniture products have been added to the Environdec database, which could be included in the material database.

Wherever possible, this data should be specified to different world regions, preferably also per income group. As the model and DSM function already allow data input for all 26 IMAGE regions, no major adaptions of the model are necessary to assess furniture stocks of IMAGE regions other than Europe.

Very little information is available on the second hand consumption of furniture, this could be further explored generally or per furniture product specifically. Also, although there is already some research available on the recycling of furniture (Daian & Ozarska, 2009; Forrest et al., 2017; Glew et al., 2012), more information is needed on the recyclability of different furniture products and material categories, which can inform more comprehensive scenario analyses.

The household survey used in this study could be expanded to include more furniture categories (e.g. kitchen cabinets), possibly tailored to specific regions. Furniture categories can also be subdivided into different category types, e.g. dividing the sofa category into regular sofa, corner sofa, sleeping sofa and chaise longue categories as described by (Smardzewski, 2015), each with a specified material intensity.

Another option would be to expand research efforts to include office furniture. This would require its own data on commercial furniture- and consumption (e.g. through a company survey). This would be a worthwhile addition, given that office furniture is estimated to account for 18% of total yearly furniture consumption according to the EEB (Forrest et al., 2017). Optionally, a similar method as used in this study would be possible for commercial furniture, using service sector floorspace estimates from (Deetman et al., 2020).

5.2. Model suggestions for further research

The study model makes use of residential floorspace as the main driver, characterised with a furniture (material) intensity. Additionally, the use of other drivers such as population or number of households could be explored. Also, as the model allows for a distinction in urban and rural floorspace, furniture intensities (F) can be tailored to urban and rural areas. This could be done by adding an extra input in the survey on household furniture, asking respondents to specify their residential area.

Currently, the recycle fraction is specified per product category in the model. Building on the notion of expanding the data on the recyclability of furniture, recycle fractions could be tailored to material categories with only minor adaptions of the study model.

The reuse factor could be weighted per income group: based on the results of the survey on household furniture, relative reuse factors can be determined per income group in a similar way as relative reuse factors are determined per product category, by dividing the mean share of reuse per quintile by the overall mean reuse share. Such an income based relative reuse factor could be used to weigh the overall reuse fraction per quintile, which might lead to more realistic results. This is especially interesting, given the fact that income level and product pricing is the main driver for buying second hand furniture products (Bednárik & Pakaine Kovats, 2010; Gullstrand Edbring et al., 2016), as already discussed in section 1.2.1.

Given more data on product lifetimes, lifetimes can be made time dependent in the model relatively easily. Standard deviations of product lifetimes can be made product- and time dependent. Given extra data on furniture product lifetimes, another suggestion is to see which lifetime distribution best represents the furniture lifetime data. Suggestions are Weibull or gamma lifetime distributions (Muller et al., 2014).

The current implementation of the negative inflow correction of the DSM function could be changed, to discard a surplus in furniture more gradually over time and keeping a surplus of furniture longer in stock, similar to the model developed by (Pauliuk & Heeren, 2019). Additionally, the first hand stock correction (based on the relative contribution of the age cohorts to the total stock) leads to negative stock values in old age cohorts, which are corrected to zero: a different stock correction could be considered, which does not lead to negative stock values in old age cohorts.

Currently, most European furniture is either being landfilled and incinerated or recycled (Forrest et al., 2017). If more options of furniture disposal such as repair, refurbishment, remanufacturing, or alternative modes of consumption such as access-based consumption and collaborative consumption, as proposed by (Gullstrand Edbring et al., 2016) become more apparent, these development could be the starting point of new modelling efforts.

Currently, average product category weights are dependent on products within the category. Alternatively, average product category weights can be assumed based on available data (e.g. such as the average product weights as reported by the furniture reuse network (Reuse Network UK, 2021)). The material composition can then be determined by making use of mass percentages derived from the material database, in a similar way as is done with the big closet category for sensitivity analysis SA2 (section 3.7.2)

As a final note: the model allows for future adaption, if more data on furniture becomes available. Most model variables can be changed (by year, by product- or material category, and/ or per income group) based on newfound data, such as: dynamic reuse fraction, relative reuse factor, recycle fraction, product material compositions, product lifetimes.

5.3. Scenario analysis suggestions for further research

The scenarios in this study are meant to illustrate how the model works and how the model can be used to assess the effects of governmental CE policy. Scenarios can be made more comprehensive, by modelling real life CE cases. Some suggestions for further scenario analysis:

In the scenarios presented in this study, only IMAGE datasets based on the SSP2 scenario have been used in the calculation of the required stock. Other SSP scenarios can be used to see how more severe changes in population or residential floorspace (as a measure of affluence) would affect furniture stock development. Suggestions for different SSP scenarios are the SSP1 'Sustainability – Taking the Green Road' scenario, which assumes significant reductions in consumption of resources and energy, reduced inequality, respecting environmental boundaries and the SSP5 'Fossil-fuelled development - Taking the Highway' scenario, which assumes highly energy- and resource intensive, rapid growth of the global economy (Riahi et al., 2017).

From a scenario perspective, an interesting option would be to model a changing product lifetime over time based on assumptions on technological advances in products and production- and recycling methods. Also, scenarios could be defined for changing product material compositions over time, based on real life developments, such as the shift from more durable- to cheaper furniture materials (Forrest et al., 2017), as described in section 1.2. As already described in section 1.7, most emissions from furniture are related to resource consumption, which makes furniture an ideal target for circular economy modelling and -policy efforts.

Furthermore, an option would be to model real-life developments in reuse and recycling, per product- and material category, e.g. based on governmental recycling targets or policy aimed to stimulate the reuse of furniture, or ambitious commercial take-back schemes such the one recently introduced by IKEA (Blackall, 2021).

6 Conclusion

This study's goals were to provide a first assessment of the size, dynamics and development of the material stocks in European household furniture and to contribute to the body of knowledge on major material stocks and dynamic stock modelling. For this purpose, the study was set up in two parts: an inventory, in which the historic and current European material stock in household furniture is estimated. In the second part, future stock development is projected based on two scenario's, to illustrate how CE policy could influence the dynamics of material stocks in European household furniture. For the inventory part, the following research question and sub-questions were defined:

1. What are the major material stocks and flows related to European household furniture?
   1.1 What types of furniture can be distinguished and how should they be categorised?
   1.2 What are the material contents of these furniture categories?
   1.3 What are the lifetimes of these furniture categories?
   1.4 How much furniture is in stock in European households?
   1.5 What furniture flows can be distinguished?

Regarding sub-question 1.1 a total of 14 furniture product categories are defined and analysed in the study model. Regarding sub-questions 1.2 and 1.3, data on material contents and lifetimes of these furniture categories have been gathered into a material database and averages have been derived per furniture category. Regarding sub-question 1.4, a survey on household furniture possession was conducted which yielded furniture intensities per m_2 of residential floorspace. Together with IMAGE data on population and floorspace per capita, and material estimates per product category from the material database, these furniture intensities were used to estimate furniture product- and material stocks for Europe. According to the model estimates, the biggest three in-use material stocks for furniture are MDF (40% of total or 352 kg/ capita), steel (21% of total or 187 kg/ capita) and wood (19% of total or 169 kg/capita). Regarding sub-question 1.5, three major material flows are distinguished for further analyses: required primary material, recycled material and landfilled material.

All of these efforts were combined in a dynamic material stock assessment model, which made it possible to project stock development over time. This model is used in a scenario analysis in the second part of this study. For this purpose, a second research question and sub-question were defined as follows:

2. How will material stocks and flows in European household furniture develop in the future?
   2.1 How can scenarios be used to forecast future development of European material consumption for household furniture?

Regarding sub question 2.1: two scenarios were defined, the 'baseline' scenario and 'reduced waste scenario', to illustrate how CE policy can affect furniture material dynamics. The baseline scenario is meant to represent 'business as usual' conditions, with no changes in historic patterns. The 'reduced waste scenario' represents a hypothetical scenario in which active CE policy stimulates the reuse and recycling of furniture. These scenarios are used to project per product- and material category:

the first hand stock, second hand stock, first hand outflow, second hand outflow, first hand inflow and second hand inflow, the results of which are used to project the amount of landfilled- and recycled material and the required primary material.

Following business-as-usual patterns in the 'baseline scenario', the total material stock for furniture is projected to increase with roughly 97 Mt (or 20%) to 584 Mt, towards 2050. The total amount of landfilled and recycled material is estimated to be 36 Mt and 4 Mt respectively in 2050. The total amount of required primary material is estimated to increase to 38.5 Mt in total in 2050.

In the reduced waste scenario, the total amount of landfilled material is estimated to decrease to 15 Mt in 2050, where the amount of recycled material is estimated to increase to 15 Mt. Also the amount of required primary material is estimated to decrease to less than 18 Mt in 2050. The results show that gradually increasing the recycle fraction with 2% per year and the reuse fraction with 1% per year, could cut the demand for primary materials in half by 2050.

The results of the sensitivity analysis show that the model is sensitive to (changes in) the input variables of product lifetimes (L), product material composition (I_m) and furniture intensities per unit residential floorspace (F).

This study is a first attempt to address some of the more significant gaps in the available data on furniture and to model major material stocks and flows in European household furniture. Given the lack of data, various assumptions had to be made that strongly influences the study model outcomes. Given a comparison with European apparent consumption for steel, the material stock projections seem to be an overestimation for this category. When comparing furniture stocks in units to apparent consumption estimates based on European production- and trade statistics, projections in units seem to be in the right order of magnitude for mattresses, but somewhat overestimated for office chairs. Overall, estimations and projections seem to be in the right order of magnitude for most product- and material categories with some outliers due to a lack of data and inevitable model assumptions. On the whole, this study can be a valuable point of departure for further research efforts on European or even global furniture.

Given the size and resource intensity of European (household) furniture stocks and flows, and the astonishingly low recycling of furniture waste, it is the authors conviction that furniture should be given a separate waste status, similar to that of cars as set out in the end-of-life vehicle directive (European Commission, 2000): materials inside furniture should be labelled and furniture manufacturers should develop dismantling guidelines for their products to ease repair, remanufacturing and recycling. Targets should be set on the country level for the recycling of waste furniture and for the use of recycled (furniture) material in primary production. Given successful results from the vehicle industry, such measures are promising.

Let's wake up to furniture waste.

7 References

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Appendix

Appendix A Data Comparison with ProdCom data

PRODCOM (Production Communautaire, or 'community production') data is used to derive an apparent consumption estimate which is used to compare with the model results.

PRODCOM provides detailed statistics on European production and trade for a wide range of products, including furniture. It has to be noted that PRODCOM only provides 'flow data', which means that additional calculations, based on a number of assumptions, are necessary to derive a stock. From the PRODCOM data, the 'apparent consumption' of some furniture products can be derived. Apparent consumption is an estimation of consumption, of which the general formula is: 'production + imports – exports' (PRODCOM, 2017). If a steady state stock is assumed, and with a known lifetime for the furniture products, the (yearly) in- and outflows can be interpolated for the whole reference period.

Only the PRODCOM statistics from 2011 to 2019 are reviewed. Firstly, because classification conventions changed after 2007 (NACE Rev 1.1 > Nace Rev. 2 from 2008). With this change in classification, also the product group headings and compositions changed, meaning that they cannot be easily compared. Secondly, because there is a change in the number of categories for furniture specifically after 2011, which indicates a similar change in product groups. Only the data from 2011 to 2019 are homogeneous in classification and therefore directly comparable (PRODCOM, 2017).

Based on the PRODCOM user guide, the 'sold value', provided by PRODCOM for a range of specific- and non-specific furniture products, is assumed to be equal to the apparent consumption, meaning that production statistics have been complemented with trade statistics (PRODCOM, 2017).

Two PRODCOM groups of furniture, which are similar to the model furniture categories, are selected for comparison with the model data. Swivel seats with variable height adjustments (PRODCOM code 31001150) and an aggregate group of Mattresses (PRODCOM code 31031230, 31031250, 31031270, 31031290). Both come with specific drawbacks, which should be noted. First, PRODCOM provides data for all furniture, including furniture used in commercial applications. This has implications for the swivel seat category (e.g. which are used in offices) and mattresses (e.g. which are used in hotels). Secondly, PRODCOM does not provide a specification of its own categories on the product level. Comparison is therefore based on an assumed similarity between PRODCOM and the study furniture categories.

For the selection of products in the reference period of 2011 to 2019, the results show a relatively consistent inflow of products with no great outliers toward maximum or minimum values. Therefore, steady state inflow (or stock) can be assumed for both furniture categories, meaning that historic- and future yearly inflow are assumed to be the 2011-2019 average.

A manual (Excel) dynamic stock model is then used to calculate stock development for the selected PRODCOM furniture categories (Deetman, 2020). The same lifetimes are assumed that are used in the model, which are primarily derived from Environmental Product Declarations and are used as the mean for a Weibull lifetime distribution, which in turn is used for the calculation of the stock. The results are compared to the results from the model.

Appendix B Weight factor calculation

The 'weight factor' parameter is based on the assumption that higher income groups can afford more expensive furniture and that this prime furniture in turn is heavier than their relatively cheaper counterpart. The weight factor in the base model is based on an exploratory comparison of furniture products with different prices within the same product category. For the base model, these categories are: kitchen tables, kitchen stools and double beds. Products from various retailers are allocated to quintiles based on price, of which the mean price and mean weights are determined. From there, relative weight factors are derived.

The 'weight factor' shows the relation between the price and weight of furniture products and is defined as the weight of a furniture product per price quintile, relative to the average weight.

The weight factor is determined based on sample data for three product categories: (Dining) table (n=53), Chair (n=68) and (Double) bed (n=60). The weight factor per product category is shown in table i. The sample data is gathered through preliminary product research by (von Köckritz, 2020). For the (Double) bed category, 'bed slats' are included for products wherever they are not provided. Bed slats price and weight per functional units are based on two IKEA products (n=2). Data is ordered according to the product price/FU. Four cut-point values (quintile cut-off points) of price per functional unit are identified, dividing the sample into five groups equally represented by 20% of products each. As product samples are often not divisible by five, the fifth quintile can hold a slightly smaller sample. The mean price and weight per functional unit are determined per quintile and in total: the relative difference per product or 'weight factor' is then calculated by dividing the means per quintile (€/FU(q) and kg/FU(q)) by the total means (€/FU(T) and kg/FU(T)). A general weight factor is determined by averaging the relative means per product. The relative difference in weight, relative to price per product is shown in figure i. The general weight factor is used for all other product categories.

Quintile	Dining table	Chair	(Double) bed	General
Q1	0.558643	0.769879	0.623754	0.650759
Q2	0.710561	0.852825	0.776893	0.780093
Q3	0.884883	0.824666	0.897377	0.868976
Q4	1.110083	1.173948	0.953596	1.079209
Q5	1.899348	1.441797	1.748379	1.696508

Table i: Weight factor per quintile for four product categories and a general weight factor.

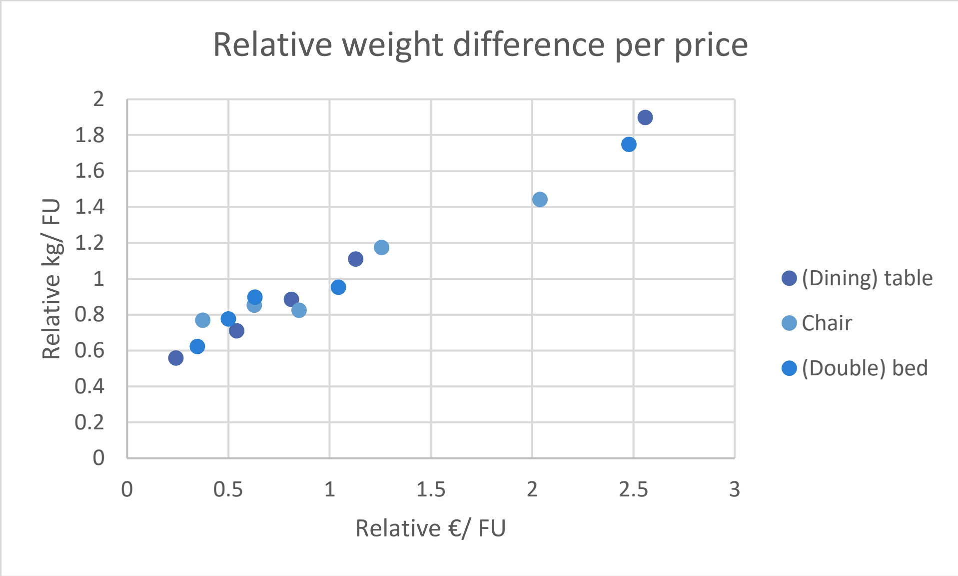


Figure i: *Relative weight difference per price. Figure shows relative weight per price (per FU) for three products: (Dining) table, Chair, (Double) bed.*

Appendix C Base model description

At the core of the base model is a stock driven dynamic model, originally developed in Python by (Pauliuk & Heeren, 2019) and previously used in a study by (Deetman et al., 2020) for modelling global material stocks and flows for residential and service sector buildings. The same code is integrated in the structure of the base model. However, despite the fact that similar calculation principles are used, the study model does not make use of the model developed by (Pauliuk & Heeren, 2019) directly. The original source code of the base model is available as supplementary material (see supplementary material SM2).

Some (IMAGE) data is defined for a shorter period then the model timeframe. To prevent an initial inflow pulse in the model start year (1971), a function has been defined to linearly interpolate data for historic data (e.g. population), back to 1926 (when it is assumed that stock=0). In its base form, the ultimate outcome of the model is a total weight in kg per furniture product for all of the model regions. The model takes a selection of datasets, some provided by IMAGE (e.g. urban and rural population, poverty gap, Gini coefficients), some provided by the researcher (material compositions per furniture category, furniture per square meter, furniture lifetimes, etc.).

The driving principle of the base model is an amount of (a specific type of) furniture per square meter. The furniture categories used for the base model are: kitchen cabinet, wardrobe, sofa, dining table, computer table, table, chair, double bed, single bed, clothes hanger, sofa table. The input for these categories (furniture per square meter, lifetime, material composition, etc.) is partly based on two articles (Gonzalez-Garcia et al., 2011; Hoxha & Jusselme, 2017), but consists largely of mock data. The base model uses IMAGE data on population and residential floorspace, which is characterised per urban/ rural area and income group (Stehfest et al., 2014). The same datasets are used in the study model. The base model provides a number of parameters, which are based to varying degrees on scientific literature. The following subsections will discuss these parameters individually:

Sufficiency
The 'sufficiency' parameter builds further on the presumed relation between income level and furniture ownership and considers the amount of furniture per square meter as a 'furniture need' that can be fulfilled according to level of income. Lower level incomes (Q1, lower 20% of income level) are then assumed to be less able to sufficiently fulfil their furniture need, resulting in a lower sufficiency factor, relative to high income groups (Q5, upper 20% of income level) that exceed their furniture need. The sufficiency calculation is based on Poverty Gap- and Gini coefficient data provided by IMAGE. The sufficiency factor is not included in the study model.

Second-Hand fraction
The model also accounts for second hand furniture as a fraction of the total stock. Based on the assumption that the share of second hand furniture increases with lower income groups, the second hand fraction decreases from lower to higher income groups. In the study model, the second hand stock is calculated (using principles of flow-driven stock analysis), based on a reuse fraction from the outflow of the first hand stock.

Appendix D Notes on IMAGE 3.0

The principal source with regard to the IMAGE framework is the model description published by the Dutch PBL (Netherlands Environmental Assessment Agency) 'Integrated assessment of Global Environmental change with IMAGE 3.0; Model description and policy applications' (Stehfest et al., 2014). Additionally, the part of the PBL website dedicated to IMAGE is a valuable source of information, including tabs with the framework summary and detailed descriptions of the model components (IMAGE, 2020).

IMAGE 3.0 distinguishes 26 World regions, based on similarity and relevance for global environmental issues (Stehfest et al., 2014). An overview of the regions can be found on the IMAGE website (IMAGE, 2018).

A core element of the IMAGE framework are the 'Shared Socioeconomic Pathways' (SSP's), which are storylines that describe possible pathways of global environmental change and, complemented with resulting assumptions on key drivers, provide consistent modelling input for the various IMAGE sub-models (Stehfest et al., 2014).

IMAGE SSP scenarios provide data for a number of drivers in 'Population', 'Economy' and 'Trade'. A summarized selection from the IMAGE table on model drivers (Stehfest et al., 2014, p. 62): 'population' (number of people per region), urban population fraction (urban/ rural split of population), GDP per capita (Gross domestic product per capita per region), GINI coefficient (as a measure of income disparity in a population), etc. These drivers differ markedly between the SSP scenarios.

Appendix E Material database results

Appendix E1 Material compositions per product category [item]

Item	Material	Amount [kg]
Armchair	Aluminium	1.98333333
Armchair	Concrete	0
Armchair	Glass (fibre)	0
Armchair	Coatings	0.48
Armchair	MDF	0
Armchair	Metals excl. Steel & Aluminium	2.08
Armchair	Paper & Cardboard	0.27
Armchair	Plastics	6.80466667
Armchair	Steel	6.19433333
Armchair	Textiles & Leather	1.58
Armchair	Wood	4.57
Bar stool	Aluminium	0
Bar stool	Concrete	0
Bar stool	Glass (fibre)	0.05
Bar stool	Coatings	0.05
Bar stool	MDF	0.47
Bar stool	Metals excl. Steel & Aluminium	0.01
Bar stool	Paper & Cardboard	0
Bar stool	Plastics	0.985
Bar stool	Steel	4.605
Bar stool	Textiles & Leather	0.305
Bar stool	Wood	2.185
Big closet	Aluminium	2.416
Big closet	Concrete	0
Big closet	Glass (fibre)	0
Big closet	Coatings	4.982
Big closet	MDF	112.85
Big closet	Metals excl. Steel & Aluminium	0
Big closet	Paper & Cardboard	4.708
Big closet	Plastics	6.2452
Big closet	Steel	19.6128
Big closet	Textiles & Leather	0
Big closet	Wood	27
Office chair	Aluminium	3.19
Office chair	Concrete	0
Office chair	Glass (fibre)	0.64
Office chair	Coatings	0.01033333
Office chair	MDF	0
Office chair	Metals excl. Steel & Aluminium	0.00516667
Office chair	Paper & Cardboard	0
Office chair	Plastics	6.429
Office chair	Steel	4.5
Office chair	Textiles & Leather	0.11266667
Office chair	Wood	0

Item	Material	Amount [kg]
Chair	Aluminium	1.11818182
Chair	Concrete	0
Chair	Glass (fibre)	0.38127273
Chair	Coatings	0.05854545
Chair	MDF	0
Chair	Metals excl. Steel & Aluminium	0.01472727
Chair	Paper & Cardboard	0
Chair	Plastics	2.76781818
Chair	Steel	1.68836364
Chair	Textiles & Leather	0.16909091
Chair	Wood	1.07809091
Desk	Aluminium	0.03666667
Desk	Concrete	0
Desk	Glass (fibre)	0
Desk	Coatings	0.13333333
Desk	MDF	0
Desk	Metals excl. Steel & Aluminium	0
Desk	Paper & Cardboard	1.98
Desk	Plastics	1.45633333
Desk	Steel	21.9913333
Desk	Textiles & Leather	0
Desk	Wood	10.7333333
Dining table	Aluminium	5.2
Dining table	Concrete	0
Dining table	Glass (fibre)	0
Dining table	Coatings	1.1636
Dining table	MDF	0
Dining table	Metals excl. Steel & Aluminium	1.0204
Dining table	Paper & Cardboard	0
Dining table	Plastics	0.0032
Dining table	Steel	0.026
Dining table	Textiles & Leather	0
Dining table	Wood	56.796
Small closet	Aluminium	0.0956
Small closet	Concrete	3.516
Small closet	Glass (fibre)	0
Small closet	Coatings	1.6992
Small closet	MDF	0
Small closet	Metals excl. Steel & Aluminium	0.167
Small closet	Paper & Cardboard	0.394
Small closet	Plastics	0.5314
Small closet	Steel	34.292
Small closet	Textiles & Leather	0
Small closet	Wood	11.2

Item	Material	Amount [kg]
(Double) bed	Aluminium	0
(Double) bed	Concrete	0
(Double) bed	Glass (fibre)	0
(Double) bed	Coatings	0
(Double) bed	MDF	94.5814667
(Double) bed	Metals excl. Steel & Aluminium	0
(Double) bed	Paper & Cardboard	0.419
(Double) bed	Plastics	2.85566667
(Double) bed	Steel	9.94333333
(Double) bed	Textiles & Leather	0.67
(Double) bed	Wood	0
Mattress	Aluminium	0
Mattress	Concrete	0
Mattress	Glass (fibre)	0
Mattress	Coatings	0
Mattress	MDF	0
Mattress	Metals excl. Steel & Aluminium	0.01142857
Mattress	Paper & Cardboard	0.54714286
Mattress	Plastics	13.0391429
Mattress	Steel	11.8137143
Mattress	Textiles & Leather	5.99842857
Mattress	Wood	2.62857143
Side table	Aluminium	0.23575
Side table	Concrete	0
Side table	Glass (fibre)	7.1805
Side table	Coatings	0.31295813
Side table	MDF	3.5648
Side table	Metals excl. Steel & Aluminium	0.056375
Side table	Paper & Cardboard	0.32075
Side table	Plastics	0.109125
Side table	Steel	2.732875
Side table	Textiles & Leather	0.018
Side table	Wood	9.315
Sofa	Aluminium	4.53075
Sofa	Concrete	0
Sofa	Glass (fibre)	0
Sofa	Coatings	0.4502125
Sofa	MDF	15.6525
Sofa	Metals excl. Steel & Aluminium	0.32825
Sofa	Paper & Cardboard	0.85625
Sofa	Plastics	13.831375
Sofa	Steel	9.974625
Sofa	Textiles & Leather	2.78375
Sofa	Wood	14.10862

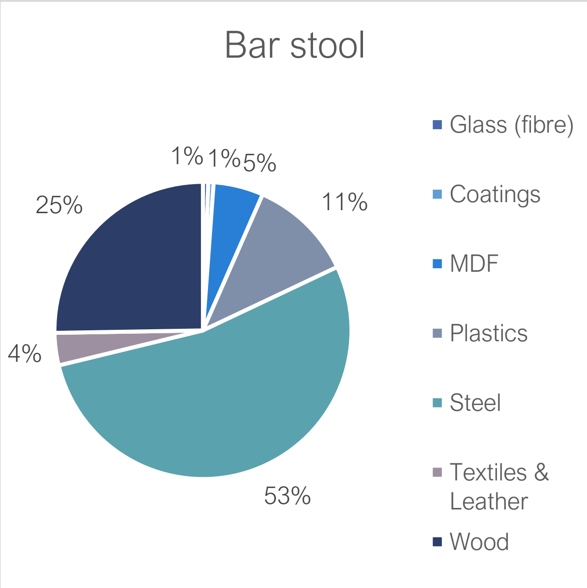
Item	Material	Amount [kg]
Stool	Aluminium	0
Stool	Concrete	0
Stool	Glass (fibre)	0
Stool	Coatings	0.065
Stool	MDF	0
Stool	Metals excl. Steel & Aluminium	0.01
Stool	Paper & Cardboard	0
Stool	Plastics	0
Stool	Steel	0
Stool	Textiles & Leather	0.145
Stool	Wood	4.86
Container	Aluminium	0
Container	Concrete	21.5685714
Container	Glass (fibre)	0
Container	Coatings	0
Container	MDF	0
Container	Metals excl. Steel & Aluminium	0.09057143
Container	Paper & Cardboard	0
Container	Plastics	0.40485714
Container	Steel	41.31
Container	Textiles & Leather	0
Container	Wood	0

Appendix E2 Average lifetimes and weights per product category

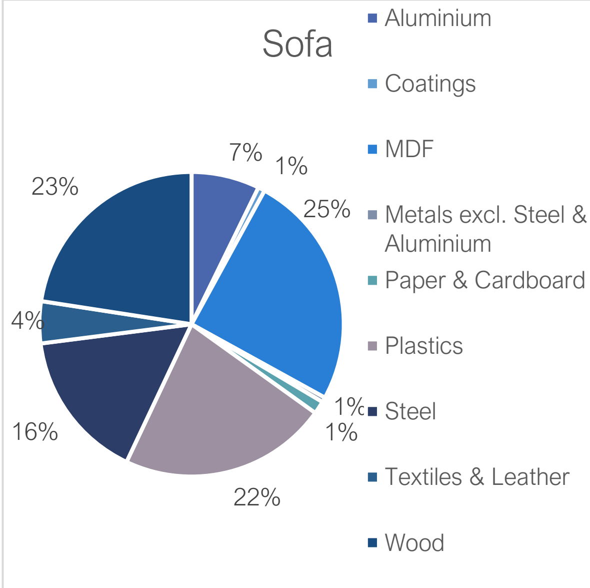
Product lifetimes	[Years]
Armchair	15
Bar stool	15
Big closet	11.66667
Office chair	13.33333
Chair	15
Desk	15
Dining table	15
Small closet	15
(Double) bed	15
Mattress	9
Side table	15
Sofa	14.64286
Stool	15
Container	15

Product weights	[kg]
Armchair	23.96233
Bar stool	8.66
Big closet	177.814
Office chair	14.88717
Chair	7.276091
Desk	36.331
Dining table	64.2092
Small closet	51.8952
(Double) bed	108.4695
Mattress	34.03843
Side table	23.84613
Sofa	62.51633
Stool	5.08
Container	63.374

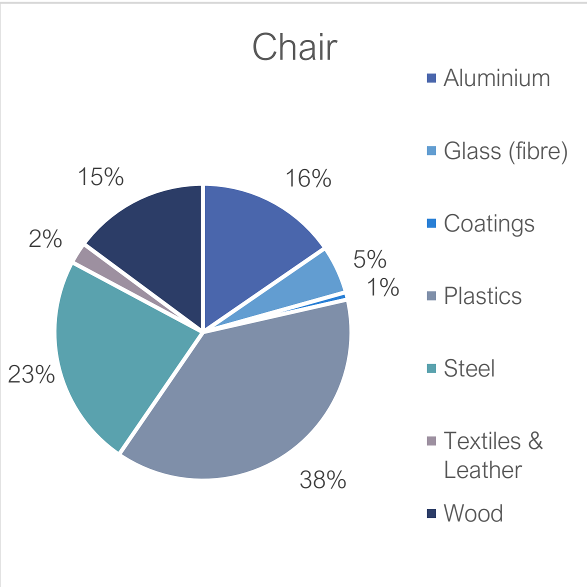
Appendix F Material compositions per furniture product category and sources



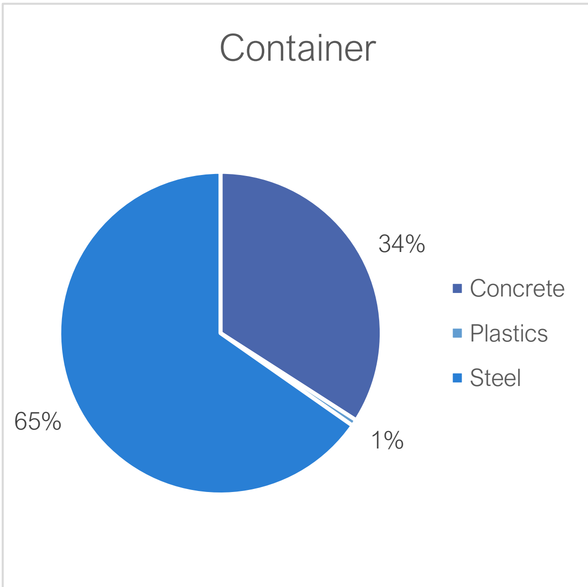
Bar stool: (Arper SpA, 2019a; Renuables Ltd, 2020b)



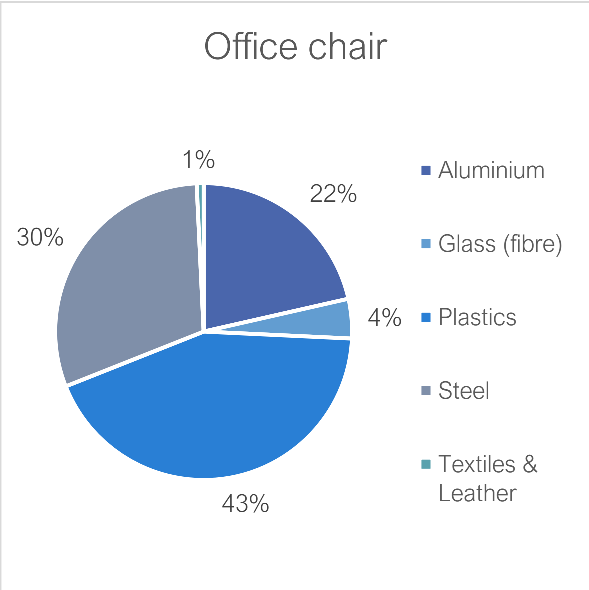
Sofa: (Andersson et al., 2003; Hoxha & Jusselme, 2017; Metsims Sustainability Consulting, 2018f, 2018h, 2018l, 2018o; Qualitnet SRL, 2020a; Wang et al., 2016)



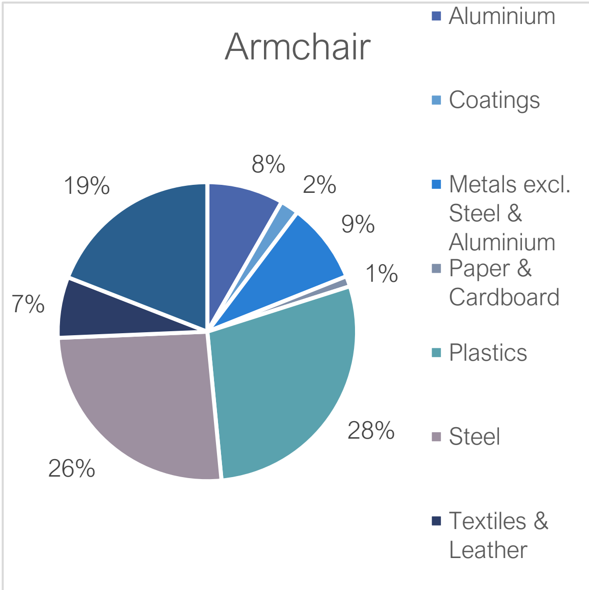
Chair: (Arper SpA, 2018a, 2019b, 2019c, 2019d; Ltd., 2020; Metsims Sustainability Consulting, 2009, 2018b, 2018g, 2018j, 2018v; Renuables Ltd, 2020a)



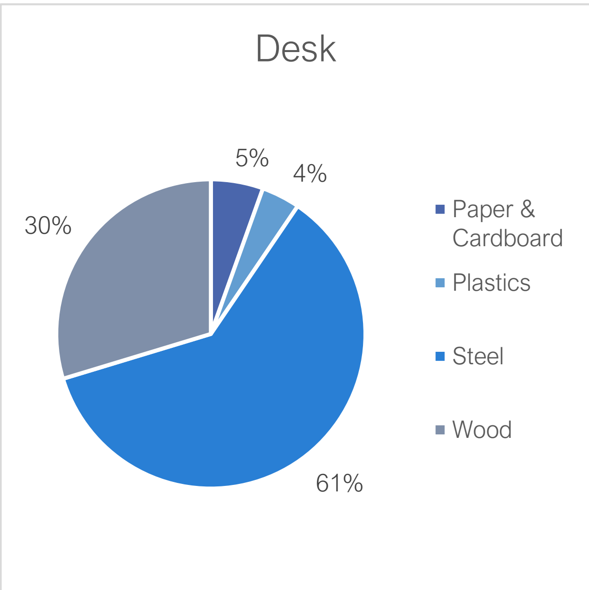
Container: (EuGeos Limited, 2019a, 2019b)



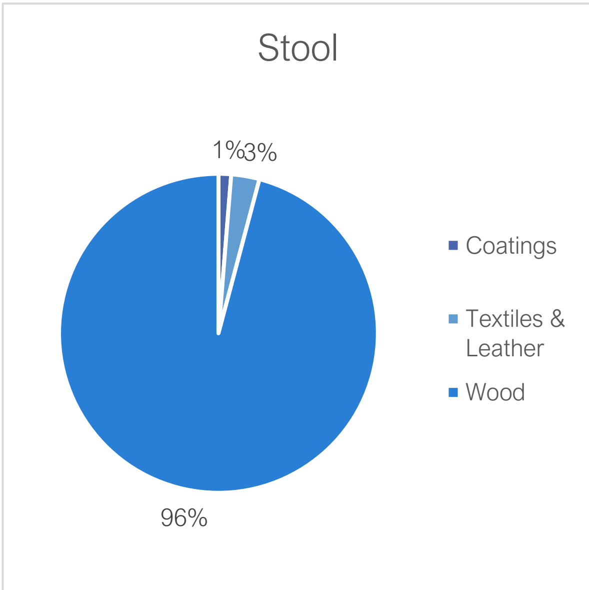
Office chair: (Gamage et al., 2008; Metsims Sustainability Consulting, 2018a, 2018d, 2018e)



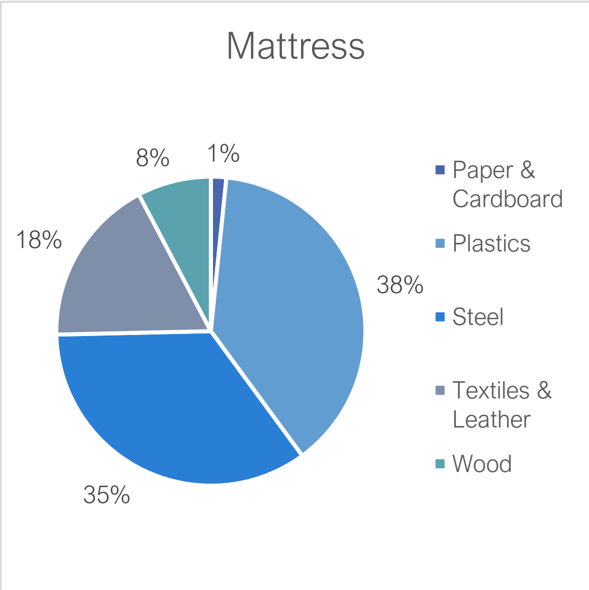
Armchair: (Greenize, 2019; Metsims Sustainability Consulting, 2018q; Qualinet SRL, 2020)



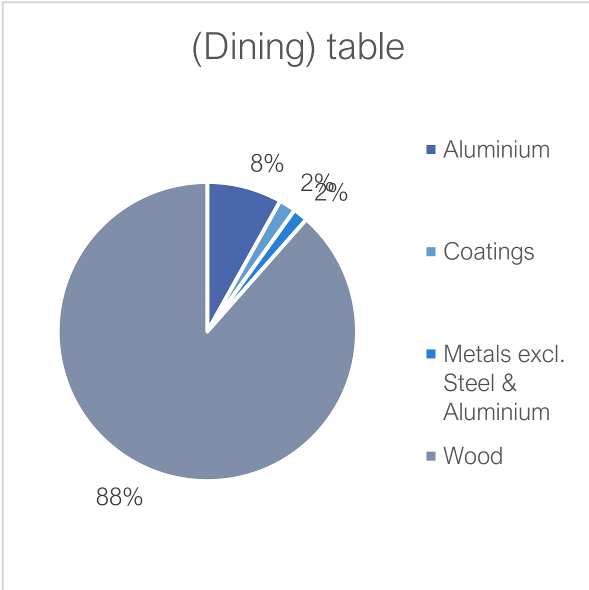
Desk: (Metsims Sustainability Consulting, 2018i, 2018r, 2018t)



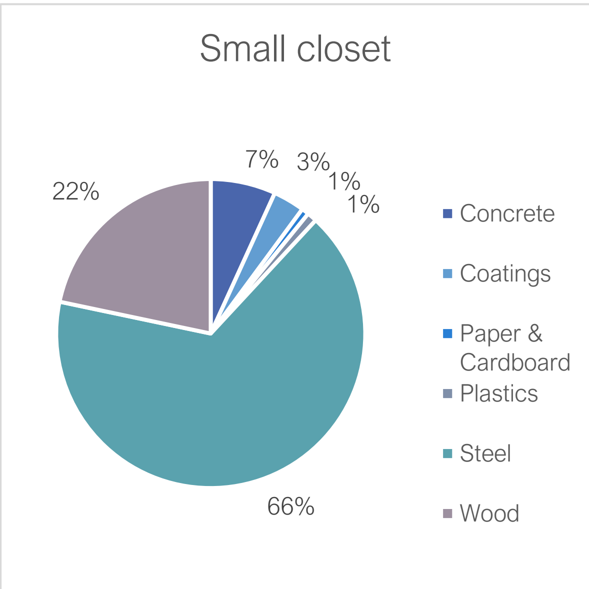
Stool: (Renuables Ltd, 2020b)



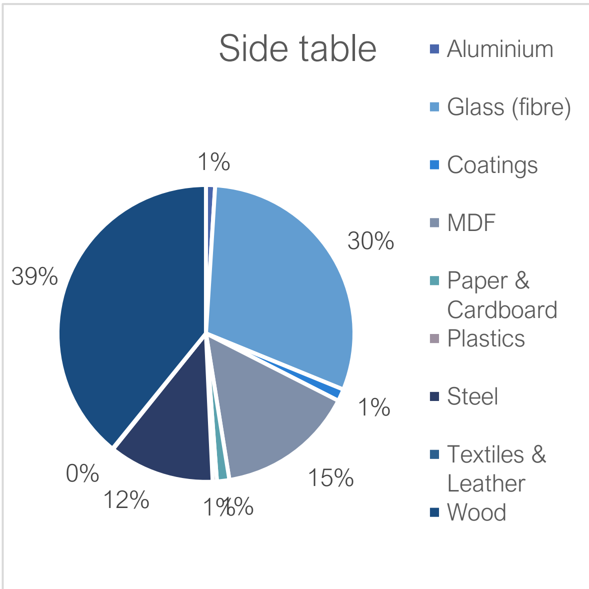
Mattress: (Deliege et al., 1997; Glew et al., 2012; Rocha, 2013)



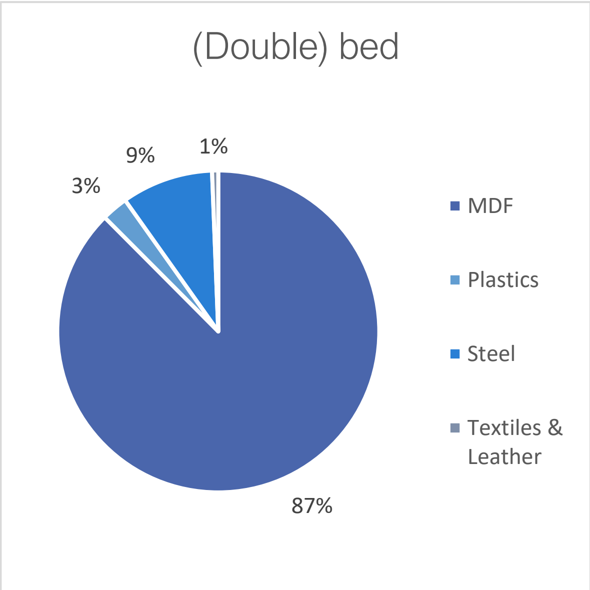
(Dining) table: (Qualitnet SRL, 2020b; Renuables Ltd, 2020c)



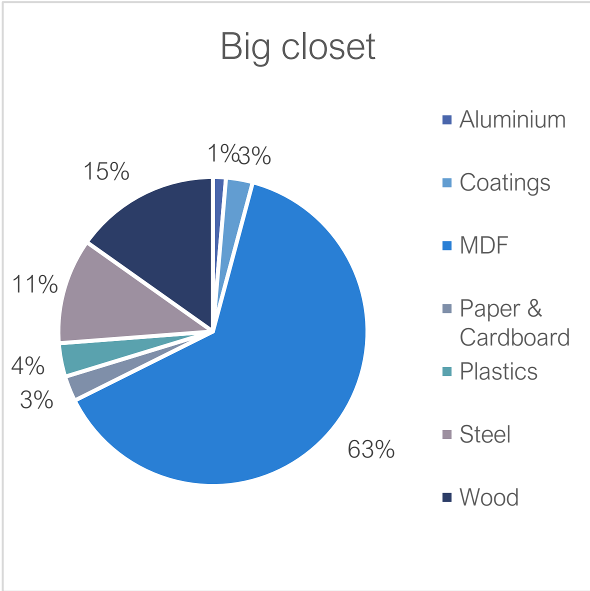
Small closet: (Arper SpA, 2020; Metsims Sustainability Consulting, 2018m)



Side table: (Arper SpA, 2018b; Metsims Sustainability Consulting, 2018c, 2018k, 2018n, 2018p, 2018s; Renuables Ltd, 2020c)



(Double) bed: (Geng et al., 2019; Hoxha & Jusselme, 2017)



Big closet: (Geng et al., 2019; Iritani et al., 2015; Metsims Sustainability Consulting, 2018u; Steelcase, 2020; Wang et al., 2016)

Furniture Survey

*Vereist

Questions on Household type

This section contains some general questions on your region and household type:

1. In which country do you live? *

____

2. With how many people do you live in a household? *

Markeer slechts één ovaal.

1	2	3	4	5	6	7	8	9	10
◯	◯	◯	◯	◯	◯	◯	◯	◯	◯

3. How many square meters (m2) of living space does your home have? *

____

4. (Optional) What is your households' yearly net Income? (In euro)

____

Questions on

Here follows a list of furniture types. Please indicate numerically how many of a certain type you have in your home. Please state how many items of a certain type you have in total and how many of these are second hand separated by a comma, like this: "Total, Second hand". Example: if you have 10 chairs in total in your home of which 4 chairs are second hand, write: "10, 4". If you do not have a certain product type, write "0, 0". Note: these are broad categories and allocation is based on similarity: your furniture does not have to match the picture exactly.

5. Arm chair *

6. Bar stool *

7. Bookcase & Closet *

8. Office chair *

9. Chair *

10. Corner sofa *

11. Desk *

12. Dining table *

13. Dresser, Low closet, TV cabinet *

14. Double bed *

15. Mattress *

16. Side table & Night stand *

17. Single bed *

18. Sofa *

19. Stool *

20. Container & Filing cabinet *

21. (Optional) If you have any comments on your answers, or if you want to add a product category yourself, please write them here:

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Google Formulieren

Appendix H Contact list company inquiry

Insurance Companies				
* = werken met inventariesatielijsten				
Organisation	Number	Mail	Notes	Contacted yes/no
ABN amro	0900 0024			Yes
Aegon	(+)31 88 344 1234		Do not support any research activities	Yes
Allianz	088 577 2828		Do not support any research activities	Yes
ANWB	088 269 2222	persdienst@anwb.nl	Mail with explanation (purpose, etc.)	Yes
ASR verzekeringen	030 257 9111	Contactformulier	Send in request through contact form (select studie/stage in topics)	Yes
Centraal Beheer	055 579 8000	reactie@centraalbeheer.nl	Send in request through mail	Yes
Nationale Nederlanden	088 663 0663		Do not support any research activities	Yes
FBTO	058 234 5678	info@fbto.nl	Send in request through mail	Yes
ING	020 228 8888		Do not support any research activities	Yes
Inshared	N.A.		Only contact form	Yes
Klaverblad*	079 320 4204		Do not support any research activities	Yes
OHRA	(+)31 026 205 2330		Only contact form	Yes
SNS Bank	030 633 3000		Only contact form	Yes
Zilveren kruis	00 31 33 445 68 70	gbr@zilverenkruis.nl		Yes
ZLM*	011 323 8880	secretariaat@zlm.nl	Send in request through mail	Yes

Notary offices				
Organisation	Number	Mail	Notes	Contacted yes/no
EJH Jansen	015 213 7050	info@notaris-jansen.nl	Send mail including phonenumber	Yes
Matzinger Eversdijk	070 358 8000	notaris@matzingereversdijk.nl	v.vannuss@matzingereversdijk.nl	Yes
Notaris Wienen	015 369 6240	info@notariswienen.nl	Send mail including phonenumber will call back Monday! 7/12	Yes
Notariaat Statenhaghe	N.A.		Only contact form	Yes
Notaris Vermeul	010 429 8077	info@notarisvermeul.nl		Yes
Heemskerk & Feijen notarissen	070 440 0222	info@heemskerkenfeijen.nl		Yes
Maes Notarissen	(+)31 (0) 10 445 3777	service@maesnotarissen.nl		Yes

Miscellaneous				
Organisation	Number	Mail	Notes	Contacted yes/no
Meertens Instituut		Lidy.jansen@meertens.knaw.nl	Closed due to Covid regulations	Yes
Consumentenbond	070 445 4545	contact@consumentenbond.nl		Yes
CBS		vsc.tunn@cbs.nl	Promovendus Jan Schoorman	Yes

Bankruptcy reports					
Organisation	Verslagnr.	Datum verslag	Notes	Contacted yes/no	Link
windtlegal	5	16/12/2020	Publicly available	No	https://www.windtlegal.com/media/files/Faillissementsverslagen/2020_08_27%20Verslag%203%20Waele.pdf
baxadvocaten	3	30/11/2020	Publicly available	No	https://www.baxadvocaten.nl/01/MyDocuments/Faillissementsverslag_3(8).pdf
florent	2	09/05/2019	Publicly available	No	https://www.florent.nl/wp-content/uploads/2016/08/OV-6.pdf
mannaertsappels	51	07/03/2019	Publicly available	No	https://www.mannaertsappels.nl/wp-content/uploads/2017/01/Verslag-51-4.pdf
davidslaw	7	18/05/2018	Publicly available	No	https://www.davidslaw.nl/wp-content/uploads/2016/02/Teve-Holland-Teve-Partners-Teve-Media-Group-10e-verslag-1.pdf
Velthuizenadvocatuur	1	11/02/2014	Publicly available	No	https://www.velthuizenadvocatuur.nl/wp-content/uploads/2017/11/miller1.pdf
benthemgratama	8	26/08/2015	Publicly available	No	https://www.benthemgratama.nl/app/uploads/2016/02/Telstar-verslag-015.pdf
VBK	14	02/10/2019	Publicly available	No	https://www.vbk.nl/sites/default/files/faillissementen/Verslag%2014%20Jurri%C3%ABns%20c.s..pdf