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Fire safe furniture in a sustainable perspective

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"Fire safe furniture in a sustainable perspective"

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Abstract

Fire safe furniture in a sustainable perspective

Loose furnishings, such as upholstered furniture, mattresses and textiles, are very important for the early stages of fires. Such products can be easily ignited, contribute to rapid spread of fire and produce a lot of smoke and heat when they burn. This limits the time and opportunity for evacuation and fire rescue. The regulation of fire properties of interior textiles, armchairs, sofas and mattresses has been discussed nationally and internationally for many years, without resulting in more stringent requirements for such products, at least not on a harmonized level.

Fire safety and environmental considerations are important factors that are often set against each other. It is therefore important to promote the development of safe and fireproof furnishings that are environmentally friendly throughout their life cycle, and which satisfy other requirements that are usually imposed on this product group.

The main objective of this project has been to contribute to new knowledge about how fire safety associated with loose interior design can be improved through developing products that meet sustainability and circularity requirements. These new products shall have fire performance comparable to flame retarded reference products but will rely on construction techniques and materials containing small amounts or no flame retardants. The new products shall be safe while in use and shall be recyclable at the end of life.

Sustainability and environmental impact analyses including life cycle analyses of furnishing materials have been performed, as well as fire tests for screening the fire performance of a selection of material combinations.

Combining a requirement for both *sustainable* yet *fire safe* furnishing is a complex task to solve. The more complex the material combination, the more difficult to predict both factors in parallel. Slight variations in components can potentially change the overall scoring of their performance.

Cotton, wool and polyester has been shown to have equally high sustainability scores, although cotton had relatively high environmental impact. Polyamide was identified as the fabric with the best environmental performer but scoring lower on sustainability.

The cushion material has great impact on fire safety because it may contribute with large amounts of heat energy and smoke. Polyurethane is by far the most common cushion material and comes in many variations, some including chemical fire retardants (FR). FR’s have not been included in in the sustainability and environmental impact analyses in this study, instead focus has been on exploring alternative methods of achieving comparable fire performance. In the case of cushion material, latex was identified as performing much higher on both sustainability and environmental impact than polyurethane. Unfortunately, latex was not a part of the fire testing series and was therefore not explored with regard to fire performance.

Future studies should explore the interaction of the fire performance properties of different materials identified as high sustainability and environmental impact performers, especially in full scale room fire experiments. Thorough knowledge about how different components (of high sustainability and low environmental impact) contribute to the fire performance and how these are maintained throughout the furniture's lifetime, would improve the possibility of fire safe furniture to be part of a circular economy.

Key words: Fire safety, furnishing, sustainability, life cycle analysis, environmental impact

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Content

Preface

This report was funded by Brandforsk, project 702-171. The aim of this project has been to generate new knowledge on the subject of sustainable and environmentally friendly yet fire safe furnishing.

We would like to thank the involved furnishing producers for valuable discussions, information and input to the project, as well as for supplying furnishing materials for fire experiments.

Karolina Storesund

Project manager

1 Introduction

Loose furnishings, such as upholstered furniture, mattresses and textiles, are very important for the early stages of fires. Such products can be easily ignited, contribute to rapid spread of fire and produce a lot of smoke and heat when they burn. This limits the time and opportunity for evacuation and fire rescue. The regulation of fire properties of interior textiles, armchairs, sofas and mattresses has been discussed nationally and internationally for many years, without resulting in more stringent requirements for such products, at least not on a harmonized level.

Fire safety and environmental considerations are important factors that are often set against each other. It is therefore important to promote the development of safe and fireproof furnishings that are environmentally friendly throughout their life cycle, and which satisfy other requirements that are usually imposed on this product group.

1.1 Background

A possible problem with introducing more stringent fire requirements is that it may increase the amount of flame retardant in circulation. Flame retardants have traditionally been a common solution for improving fire protection in interior products, but some of these have been found to be harmful to health and to the environment. Flame retardants can also affect other product properties, such as quality, comfort and the possibilities for recycling.

Interior design, with regard to loose furnishings, is of great importance for how a fire can develop in buildings, and this has been known for decades. The fire safety problems are described in a large number of publications and research reports [1–14]. Abroad, in the United Kingdom and California particularly, stringent fire safety demands have been placed on upholstered furniture. The United Kingdom imposed strict regulations on upholstered furniture and mattresses in 1988 [15], and analyses conclude that this measure has saved lives and property [16,17]. In recent years there has been increasing awareness about the fact that some flame retardants affect health and the environment negatively, and this has caused concern about the consequences of fire safety regulations on interior products. Flame retardants can affect health and the environment during the entire life of the product, including the production, use, and end of life phases. In addition, it is feared that flame retardants can make the smoke more poisonous when the product burns, thus increasing the danger to persons in the building and emergency responders during the extinguishing effort. The importance of flame retardant chemicals for health and the environment is a topic of great uncertainty, and must be carefully examined [9,18]. The European Furniture Industries Confederation (EFIC) has published a policy paper entitled "The Case for Flame Retardant Free Furniture", which argues against the use of flame retardants and for the harmonization of fire requirements for furniture in Europe [19].

In 2015, RISE Fire Research conducted a project for MSB, with the aim of exploring the possibilities for developing fireproof furniture without using flame retardants [14]. The report shows that it is possible to achieve significantly better fire performance than for a variety of conventional furniture by choosing and combining the furniture material in a smart way. This is a topic that is important to continue working on, and that is also relevant to other interior design products than furniture. The purpose must be to provide available and cost-effective materials that increase fire safety while preserving other important features for comfort, appearance, care and durability. It is also important that the materials can be recycled when the product is discarded.

1.2 Objectives

The main objective of this project has been to contribute to new knowledge about how fire safety associated with loose interior design can be improved through developing products that meet sustainability and circularity requirements. These new products shall have fire performance comparable to flame retarded reference products but will rely on construction techniques and materials containing small amounts or no flame retardants. The new products shall be safe while in use and shall be recyclable at the end of life. The steps taken toward achieving this objective are:

- Gather existing information about conditions and requirements
- Identify existing solutions and need for adjustments and optimisation
- Gather new knowledge through fire testing, selection of potential products
- Suggest how fire safety of furniture and textiles can be improved in an environmentally, sustainable and cost-effective manner

Research questions:

- Which fire technical requirements should one be able to put on loose furnishings and what significance (compared to with what you can expect in today's situation in Sweden / the Nordic countries) would it have on the fire propagation in a building fire?
- How to design fire safe, loose furnishings so that they meet the usual requirements for products and at the same time are sustainable in an environmental perspective?
- How to define fire requirements for loose fittings in order to counteract the need to use health and environmentally hazardous flame retardants?

1.3 Limitations

The project mainly focuses on the development of new furniture/furnishing for use in the private sector. Old solutions will be considered in order to evaluate whether or not they may still be suitable within a perspective of sustainability and circularity.

Limitations and assumptions associated with developing the sustainability and environmental impact analysis of loose furnishings are discussed in detail in Chapter 3.

2 Methods description

2.1 Literature review

The literature study summarizes existing knowledge of today's requirements for interior design with regard to fire safety and circular economy. It also includes information about ongoing discussions about the use of flame retardants in upholstered furniture and furnishings.

2.2 Interviews, seminars and meetings

The following activities were performed during the project period:

- Initial meeting with the reference group.
- Participation in the seminar “Möbler och Teknik” (“Furniture and technology”) in Borås 17th May 2018)
- Meeting and discussions with furniture producer (Kinnarps)
- Meetings and discussions with textile/yarn producer (Selbu ull)

2.3 Experimental set-up

Small scale fire test methods have been used to screen different material combinations. The main test methods used were the cone calorimeter method (ISO 5660-1) and model chair ignitions tests (EN 1021-2).

A flame exposure test accounts for the material’s propensity to ignite and spread a flame when the material is exposed to a small, open flame ignition source. To be able to screen many specimens during a limited period of time, two down-scaled experimental methods were tested:

- Flame exposure in the cone calorimeter, without the radiative heat exposure.
- Flame exposure of small, horizontally positioned specimens.

2.3.1 Cone calorimeter

The cone calorimeter was used for measuring time to ignition, heat release and smoke production and represents the radiative exposure on the material from an external fire that is developing in a room. The first 10 minutes have been the focus, i.e. the early stages of a fire which will affect the possibilities for evacuation.

The test specimens for the cone calorimeter tests were prepared with (100 × 100 × 50) mm^3 foam samples. The surface area of the wadding, when used, was 100×100 mm^2. The cover material was cut and stitched to cover both the top surface and the sides of the filling. The tests were performed using 35 kW/m^2 heat flux, with an electric spark igniter as the ignition source. The samples with foam and cover were tested in series of up to three parallel tests, their average results are presented in the report. Some specimens were only tested once. The specimens were placed in the specimen holder as described in ISO 5660-1 using a retainer frame. No wire grid was used.

2.3.2 Flame exposure of small, horizontally positioned specimens

Due to the large number of different material combinations as well as limited amounts of material, an ignition test was developed using the same size specimen as for the cone calorimeter test. The purpose of this test was to investigate the performance of the material when subjected to a small flame ignition source.

A method utilizing the cone calorimeter, without the radiator cone turned on, but with a small flame ignition source (as described in EN 1021-2) was quickly discarded, because it did not produce meaningful test results.

Instead, a screening method was used with small, horizontally positioned specimens, within an insulating “box” of mineral wool. Because of its limitations mainly related to only having a horizontal and not vertical surface, additional tests were performed according to EN 1021-2.

The specimens were positioned within an insulating frame of mineral wool slabs, surrounding the specimen on all sides except the top surface. The outer dimensions of the mineral sample holder were 20 × 20 cm, height 10 cm. The height of the specimen was 5 cm. The purpose of the insulating frame was to simulate the insulating effect from a larger piece of upholstery. A specimen placed in the insulating mineral wool frame is shown in Figure 2-1

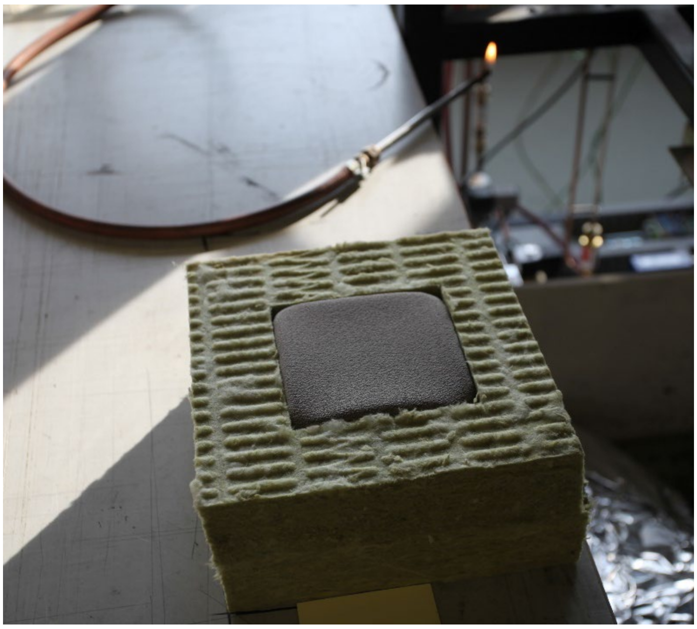

Figure 2-1 Specimen (10 cm × 10 cm × 5 cm) placed in a sample holder of mineral wool.

2.4 Sustainability and environmental impact characterization

The sustainability and the environmental impacts of representative loose furnishing materials have been examined in this work, together with a case study of sofa seat cushions. The sustainability of the materials was analysed using a selection of key performance indicators to identify the highest performers. The environmental impacts were estimated using life cycle assessment (LCA) methodology. Some background on both these methods is given in the following sections and the details about how they have been applied to this work are described in Chapter 3.

2.4.1 Sustainability analysis

Sustainability, as defined by the World Commission on Environment and Development, is "meeting the needs of the present without compromising the ability of future generations to meet their own needs" [20]. To achieve this goal, the United Nations Development Program created 17 measurable indicators of sustainability. These goals are shown in Figure 2-2. This project is primarily focused on goals 3, 9 and 12, "Good Health and Well-Being", "Industry, Innovation, and Infrastructure", and "Responsible Consumption and Production", respectively, as they apply to fire safety and the design and production of loose furnishings.

Figure 2-2 United Nations' Sustainability Development Goals [21].

The European Commission defines a circular economy as an economy where the value of products, materials and resources is maintained in the economy for as long as possible, and the generation of waste is minimized [22].

2.4.2 Life cycle assessment

LCA is a methodology that is used to predict the environmental impacts associated with the whole or partial life of a product, process or activity; the subject of the assessment is usually referred to as a “system” [23]. An LCA can be conducted in compliance with the procedures specified in the International Organization for Standardization (ISO) standards ISO 14040 [24] and ISO 14044 [25], or non-standardized life cycle *thinking* can be applied to virtually any situation. For this work a screening tool was developed based on life cycle thinking to compare the materials used in loose furnishings.

LCA is a method capable of assessing impacts across the full life cycle of a product or system, from materials acquisition through manufacturing, use, and end of life. Depending on the application, it is possible to examine the impact of only part of the life cycle, for example from cradle to gate, where the gate is some point in the life of the system being studied beyond which the life cycle has no further bearing. As depicted in Figure 2-3, a standard LCA study is structured to have four major components: Goal and Scope Definition, Inventory Analysis, Impact Assessment, and Interpretation of results. The development of an LCA is typically an iterative process in which each of these components is revised as new information from other components is acquired.

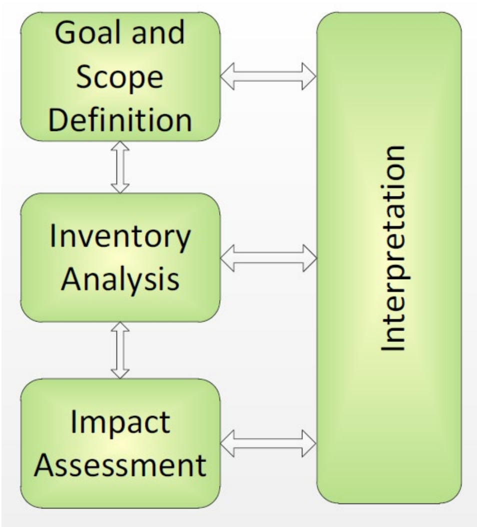

Figure 2-3: Components in an LCA analysis of a system.

The life cycle phases of a product or a system are assessed with respect to their impact on the environment (both good and bad) within this structure. The life cycle phases depend on the product or system but, for products, generally follow this pattern:

- Production (includes materials and manufacturing processes),
- Use (includes energy requirements, maintenance, during service life), and
- End of life (includes landfill, incineration, recycling).

The product or system being assessed could be nearly anything, for example, an LCA can be applied to the production of a warehouse (all or just part of it), or it could be used by politicians to examine the environmental consequences of policies and regulations, or it could be applied to internal industrial systems to, for example, optimize waste streams within a manufacturing facility. In this work life cycle thinking has been used to predict the environmental impacts of production of fire safe furnishings.

3 Sustainability and environmental impact analyses

3.1 Sustainability analysis

To meet the objectives of improved sustainability and circular economy in the context of this project, the following criteria were considered for selection of loose furnishing materials [26]:

1. Made from recycled raw material, at least partly
2. Recyclable final material, at least partly
3. Low energy requirements to transform raw materials into final material
4. Durability
5. Locally sourced raw materials

The materials chosen for analysis in this project were selected based on previous work [14], the literature, input collected from industry via interviews and workshops, and on the expertise of the project team. In keeping with the sofa case study, these materials are potentially suitable for use as sofa coverings, barrier material, wadding, and cushions, although they can also be applied separately or in combination to most loose furnishings. The results of the sustainability analysis are given in Table 3-2.

3.1.1 Circularity of materials

From a circular economy perspective, materials used in loose furnishings would ideally be made from recycled "raw" materials[1] and the final product materials would also be recyclable. In Sweden and Norway, upholstered furniture is normally not sorted into specific fractions that can be used in recycling, such as paper, glass, metal, plastics etc., but is normally categorized as residual waste and sent for incineration[2]. Seen strictly as an energy source recovered from incineration, plastics have the highest caloric content.

Recycling the entire furnishing is also a possibility, although the original documentation regarding fire performance may be lost when the furnishing is transferred between owners. The new owner of the furnishing may choose to change coverings or other components as well.

In the report "Hållbarhetsanalys av circulära möbeflöden" a linear business model (raw materials are transported and refined, sold, used and finally discarded) is compared with a piece of furniture in a circular business model (the furniture is reused and/or repaired in different phases of its life time, re-entering the consumption cycle). Different types of

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[1] In the context of this report, raw materials for loose furnishings can come from recycled stock and are not restricted to materials coming solely from nature.

[2] According to information gained in the RISE FR project "Brann i avfallsanlegg" (Fires in waste facilities) for the Norwegian Directorate for Civil Protection and the Norwegian Environment Agency, 2019.

furniture have different advantages to gain from a circular business model. In general, there may be smaller environmental impacts associated with light-weight, material efficient designs compared to heavy, complicated designs, but on the other hand, it could be more difficult to change from a linear to a circular business model for the heavy, complicated design. Upholstered furniture such as sofas and beds can be regarded as heavy, complicated products since they often contain several different materials, including large amounts of plastic (polyurethane upholstery foam). Therefor it would be beneficial to try to design the furniture as light and simple as possible [27]. In a fire safety context this would also be preferable because having less combustible material decreases the risk for ignition and development of a larger fire.

In Table 3-2 qualitative information is presented about the possibility of using recycled raw materials and recyclability of the finished furnishing material. In the table, “Yes” or “No” are used only when distinct information has been found; the other measures of recyclability are estimates based on interpretation of mixed information.

3.1.2 Low energy requirements

The embodied energy, which is the total energy used in each step of the process needed to create the textile, can be estimated by adding the energy required in two separate textile production steps. First is the energy needed to make the fibres used in the yarn (this energy is widely different when producing various fibres). Second is the energy used to weave or knit those yarns into a textile. The amount of energy processing needed to weave the yarn into a textile is relatively consistent among textiles. Whether the yarn is composed of wool, cotton, nylon or polyester, the thermal energy required per meter of material is 19000 - 23000 kJ and the electrical energy required per meter of material is 0.45-0.55 kWh [28]. The energy reported in Table 3-2 is the embodied energy for producing 1 kg of finished textile or other furnishing material.

3.1.3 Durability

It is difficult to get an idea of the extent of furnishings discarded each year, and hence the average life span of different types of furniture. According to an analysis in 2006, Norwegian consumers on average would discard their furniture every 13th year [26]. One way to increase the life of loose furnishings is allow the replacement of components at different intervals, for example cover materials could be replaced every five years and upholstery every ten years, while the frame lifetime could define the lifetime of the overall furnishing. If the durability is better, or if worn out components can be replaced, the furnishing can last longer. This will save not only the materials, but also energy and transport [27].

Designing a sofa for easy dismantling in order to facilitate replacing certain components is important in a circular business model [27]. In this case it is important to ensure that components designed to ensure fire safety, e.g. barrier materials between filling and cover, are not left out when the other materials are replaced.

In terms of fire safety, when components are replaced there is a potential for the replacement materials to fail to comply with the original fire performance requirements. For example, a Trevira CS cover could be replaced with an ordinary polyester cover, thus losing the fire performance of the original, inherently FR material. Cushions made of FR foam could be replaced with non-FR foam. Also, it is possible that a specific combination of materials having known fire safety properties may not behave the same way if one or more of the materials is replaced with something else.

The aesthetics of a piece of furniture can also affect its life span by becoming unfashionable or the user's requirement for form and function may change [27]. Fire safety properties do not always follow fashion or user's requirements on form or function. A soft and comfortable sofa often requires larger amounts of combustible filling materials. Over time, maintenance of the furnishing may also affect its fire performance due to deterioration of the material and leaching of the FR through washing or cleaning.

The durability of the materials studied in this project are listed in Table 3-2 in terms of their Martindale Index. The Martindale Index is a common measure for quantifying the abrasion resistance of textiles, especially when they are used for upholstery. The higher the value, the more resistant the material is to abrasion.

3.1.4 Locally sourced raw materials

The transport of raw materials between their sources and the production location can be a major factor for sustainability from a consumption of fossil fuels and air pollution perspective. To capture this aspect of sustainability, the primary sources of the materials studied in this project are presented in Table 3-2 according to their ISO 3166 Alpha-2 country code. A more extensive list of source countries for these materials is provided in Appendix A.

The environmental impacts of materials transport are included in the life cycle assessment.

3.1.5 Other considerations

Other considerations include material repairability, whether the material could meet regulatory restrictions, whether the material is adaptable to new design ideas, and the use of renewable (not petroleum-based) materials.

One part of the sustainability equation is resources efficiency. There are several ways to achieve this, including the use of sustainable materials that are not petroleum-based [27]. The most commonly used textile fibres are listed in Table 3-1. These fibres represent both natural and man-made, including petroleum-based, fibres that could be used in loose furnishings. Some of these fibres could be used in sofa coverings and barrier materials, however, the wadding and cushion materials are not listed here.

Table 3-1: Categories of commonly used fibres for textiles [29–31].

Natural fibres			
Crop (cellulose) fibres			Animal (protein) fibres
Seed fibres	Bast fibres	Leaf fibres	
Cotton	Jute	Abacá	Wool
	Flax	Sisal	Hair fibres
	Hemp	Henequen	Silk
	Ramie	Others	
	Kenaf		
Man-made fibres			
Organic		Inorganic	
Transformed natural fibres	Synthetic fibres		
Viscose	Acrylic	Glass fibre	
Rayon	Aramid	Carbon fibre	
Modal	Elastane	Metallic fibre	
Lyocell	Modacrylic	Ceramic	
Elastodiene (rubber)	Polyamide		
Others	Polyester		
	Polyolefins		
	Others		

Of the fibres listed in Table 3-1, only the synthetic and inorganic fibres are non-renewable. Other aspects of sustainability, such as circularity, energy requirements, durability, and local sourcing are explored further in the following text and in Table 3-2.

3.1.6 Sustainability of loose furnishing materials

Qualitative measures of sustainability of a range of textiles and furnishing materials that are commonly used as coverings, barriers, wadding and cushions in a variety of loose furnishings are listed in Table 3-2. These materials were selected based on the amount of sustainability information available and the need to preserve a representative range of materials. In some cases, insufficient information was available, which is denoted by NA.

Blended fabrics (a mixture of two or more different fibres) such as polyester-cotton and cotton-modal-polyester fabrics are excluded from Table 3-2 because these textiles can be comprised of virtually any percentage of different materials. It is possible to make a very rough approximation of the sustainability of blended materials by combining their relative performance based on the percentage of the materials used in the blend. However, if one or more of the materials used in the blend is not recyclable this may affect the recyclability of the textile. Also, the energy estimate will likely be higher for blends due to the extra step of creating a textile from more than one type of fibre.

3.1.7 Discussion of results

Generally speaking, if the final textile or material is recyclable then the raw materials used to produce it are also recyclable. Depending on the ability to separate dissimilar materials in blends, the converse may not be true. The *natural materials cotton, wool and latex (rubber) have good recyclability* for their final textile or material, however, no information was available about whether wool and latex are made from recycled materials. The *synthetic materials polyester, polyamide, polyurethane, glass fibres and* *aramid fibres are made from recyclable raw materials and are also recyclable as finished products*.

The bulk of the natural materials have about 60 MJ/kg of embodied energy, while latex foam has about ¼ this amount. Embodied energy is the total amount of energy needed to produce a material, product, or system. As a group, *the synthetic materials polyester, viscose, and polyurethane have about twice as much embodied energy as their natural counterparts*, with polyamide as an outlier having about 4 times as much embodied energy.

It was not possible to find a Martindale Index for all the materials in this project. Based on the available information, cotton is the only material having a Martindale Index below 50000.

Considering Sweden as the production location for loose furnishings using the materials listed in Table 3-2, the closest locations for the raw materials are Denmark (Trevira CS polyester), Finland (Visil viscose), Germany, France and Italy (glass fibre), and Austria (Lenzing viscose and polyurethane). Turkey produces many loose furnishing materials (cotton, wool, modacrylic, polyester and wool wadding). The other materials are usually sourced from Asian countries. Recall that only the primary producers of the materials are listed in Table 3-2; it is possible that there are local sources for some of these raw materials. Based on the information above, *Trevira CS polyester, Visil and Lenzing viscose, glass fibre and polyurethane have the nearest material sources*.

It would be necessary to devise a weighting system to determine which materials are best when considering their recyclability, energy requirements, durability, and the location of their source; doing this was outside the scope of this project. If a very simplistic method of prioritising the materials is used, such as giving 1 point to the "best" performers in each sustainability category, and then taking 1 point away for non-renewable materials, the ranking would be:

1. Cotton, wool, polyester, and glass fibre, having 3 points each
2. Latex and polyurethane, having 2 points each
3. Polyamide and artificial leather, having 1 point each

Table 3-2 Circularity/sustainability aspects of selected textiles and furnishing materials. (References to the data listed in the table can be found in Appendix B.)

Material	Recycled raw material	Recyclable	Energy estimate (MJ/kg)	Durability (Martindale Index)	Source countries
Coverings					
Cotton	Yes	Yes [a1]	60 [b]	20000- 30000 [c]	CN, IN, TR, BR
Polyester (Trevira CS)	Yes	Yes [d]	127 (estimation, based on polyester)	>50000 [e]	DK
Wool	NA	Yes [f]	63 [g]	>50000	CN, UK, TR, IN
Polyester	Somewhat to Yes	Yes [h,i]	104-127 [j]	NA	CN, IN, PK
Polyamide 6,6 (nylon)	Somewhat to Yes	Yes [n]	250 [o]	NA	CN, IN, ID, MY
Modacrylic	No	No [k]	NA	NA	CN, TR, JP, TW
Artificial leather (50 % polyamide, 50 % polyurethane)	NA	No to Somewhat	NA	>50000 [j]	IN, JP
LenzingTM FR (viscose base)	No to Somewhat	No to Somewhat [l]	100+ (estimation, based on viscose fibre) [l]	NA	AT
Visil (viscose based)	No to Somewhat	No to Somewhat [q]	100+ (estimation, based on viscose fibre) [l]	NA	CN, FI
Barriers					
Glass fibre plain weave (100 % glass fibre)	Yes	Yes	48 [m]	NA	DE, FR, IT
Aramid fibre plain weave (100 % aramid fibre)	Yes	Yes	NA	NA	CN, RU, JP
Wadding					
Polyester wadding (100 % polyester)	Yes	Yes	127	>50000 [j]	CN, UK, TR, IN
Wool wadding	NA	Yes	63	NA	CN, UK, TR, IN
Cushion materials					
Polyurethane foam (100 % polyurethane)	Yes	Yes [n,o]	102 [p]	NA	CN, IN, AT
Latex foam, natural (rubber tree)	NA	Yes [q]	15-16 [r]	NA	CN, IN, TH

3.2 Life cycle assessment approach

3.2.1 Goal and Scope

LCA modelling provides estimates of the environmental consequences of using specific materials in loose furnishings. It is understood that there are many factors that affect decisions regarding the production of loose furnishings, and that environmental impact may not always be the most important factor; however, it is not possible to balance environmental considerations against other factors without knowledge of their nature and magnitude. The goal of this work is to make this knowledge available to producers of loose furnishings, through the use of a simple spreadsheet-based tool, so that they can more easily include sustainability and environmental impacts in their decision-making process.

The boundaries of the system used in the LCA model include the collection of raw materials, refining these materials, transport, production of textiles, barrier materials, wadding, and cushions, the use of the finished product (a sofa), and the end of life of the sofa cushion materials. The supply chain is followed to the most common sources of bulk materials. Since this is a comparative tool, the focus is on the differences in impacts when different combinations of materials are used.

The functional unit of the LCA model is 1 m^2 of sofa seat cushion having a lifetime of 8 years for cotton and 14 years for others.

3.2.2 Inventory Analysis

Quite a lot of information (inventory data) is needed in order to assess the environmental impact of a product. The quality of the LCA model depends heavily on the accuracy and completeness of the inventory data, which can be difficult to obtain. The inventory data has been obtained from open source data, the literature, and communication with a furnishing manufacturer. In all cases, basic units of the inventory data, such as 1 kg of a material, were analysed using LCA software and the results were exported to an Excel® spreadsheet and scaled to 1 m^2 of seat cushion material according to user input.

The inventory data include:

- Covering textiles
- Barrier textiles
- Wadding materials
- Foam materials

3.2.3 Impact Assessment

The ReCiPe 2016 Midpoint (H) impact assessment method [32,33] was used for this analysis because it is a generally well accepted method among LCA practitioners and because the impact categories it offers are relevant for the study of textiles and seating materials. The impact categories chosen for this study are listed in Table 3-3.

Table 3-3 Selected environmental impact categories for the constructed screening tool [34].

Environmental impact category	Description	Unit
Global warming	The potential of environmental pressures exerted by GHG emissions (such as carbon dioxide from combustion of fossil fuels or methane from agricultural production) to cause changes in the temperature of the atmosphere and thus to contribute to climate change.	kg CO_2 eq
Freshwater eutrophication	Eutrophication occurs when excessive amounts of nutrients, such as nitrate or phosphate, reach ecosystems, e.g. through the application of fertilisers or sewage, that damages natural environment.	Kg P eq
Terrestrial ecotoxicity	Ecotoxicity is caused by persistent chemical substances, i.e. substances, which are not degradable by the natural systems and exert toxic effects. They include, for example, dioxins from waste incineration, asbestos from insulation materials and heavy metals from various products.	kg 1,4-DCB
Land use	Land use competition is generally increasing and a result of multiple and growing demands, such as land for the production of food, feed, biofuels and biomaterials. This growing demand meets a limited stock of available productive land.	m^2a crop eq
Mineral resource scarcity	Reductions in the available stocks of metal ores and other minerals, potentially causing raw material shortages as a result of their unsustainable use.	kg Cu eq
Fossil resource scarcity	Reductions in the available stocks of fossil fuels that potentially causing shortages of these materials as a result of their unsustainable use.	kg oil eq
Water consumption	Water scarcity occurs in a situation, where the abstraction of fresh water is exceeding the rate of renewal in the respective water body, leading to water shortages or droughts.	m^3

3.2.4 Interpretation

The interpretation step in LCA involves analysis of the completeness and accuracy of the modelling process as well as analysis of the results. Conclusions and recommendations are made only after the model and results have been examined and the strengths and weaknesses identified.

There are two input parameters for the LCA screening tool: the density and the durability of the materials. The density for textiles is in units of kg/m^2 and the density of the foam is in kg/m^3. The durability is entered as service life (years). The service life was converted to years from the Martindale Index presented in Table 3-2 using a procedure described in Appendix D. A sensitivity analysis was conducted on these two parameters and the results show that the tool results change by 0.16 % for a 1 % change in both textile density and service life for all textiles except cotton, for which the results change by 0.28 %. The foam results are more sensitive, changing by 1.65 % for a 1 % change in input values. The details of this analysis are provided in Appendix E.

The uncertainty of the results varies dramatically depending on the material and the environmental impact category. An example of the uncertainty analysis results is shown in Figure 3-1 for global warming.

An example of the screening tool results for one set of input parameters is provided in Appendix H. These results are based on the specific inputs shown in Table 3-4 and will be different if other inputs are used.

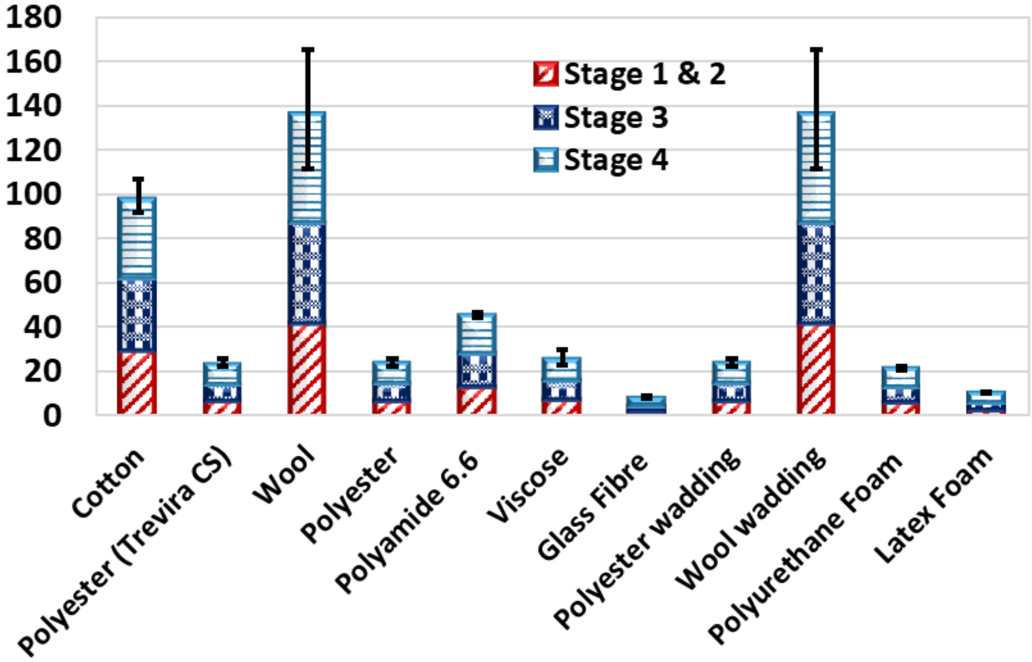

Figure 3-1: Example of uncertainty of sofa seat cushion materials for the global warming impact category

The primary strength of the LCA component of the tool developed in this project is that non-environmental experts can use it to estimate the environmental impacts of a limited number of seat cushion materials, comparing combinations that the users create. Another strength is that this tool can be expanded as new inventory data become available. The tool results are not especially sensitive to the user inputs, and the accuracy of both the inputs are relatively easy to ascertain by the user.

The main weakness of this tool is its dependency on high quality inventory data. Trade-offs in model accuracy are necessary when simplifying a complicated assessment process such as LCA. By scientific and engineering standards, LCA has a relatively high level of uncertainty that can be exacerbated by simplifications and assumptions, thus making the results less meaningful.

3.2.5 LCA-based Screening tool

The LCA-based screening tool was constructed as a simple spreadsheet, as shown in Table 3-4. The user can select materials, enter a density and the desired service life of the material, and then compare the environmental impacts of any combination of the materials. The user can select from covers, barriers, waddings, and cushions to create a wide variety of loose furnishings. By repeated use of the tool the user can compare the results of different combinations of materials. The calculation basis (functional unit) is 1 m2 of the material having a service life of 8 years for cotton and 14 years for others. The tool automatically compensates for materials having a service life different than 8 and/or 14 years respectively so that all materials are compared on the same basis. The tool does not include structural materials used in furniture, such as a sofa frame.

Table 3-4 A graphical view of the user input sheet of the screening tool.

Furnishing Part	Blend	Material	Percentage (%)	Weight (g/m2)	Foam, Density (Kg/m3)	Foam, Thickness (cm)	Service Life (years)
Cover	Yes	Cotton	55%	150			10
		Polyester (Trevira CS)	0%	200			
		Wool	0%	150			
		Polyester	45%	300			
		Polyamide 6.6 (Nylon)	0%	240			
		Viscose	0%	160			
			100%				
Barrier	No	Glass Fibre	100%	270			8
			100%				
Wadding	No	Polyester wadding	100%	200			10
		Wool wadding	0%	200			
			100%				
Cushion		Polyurethane Foam (Polyfoam)	100%		20	15	10
		Latex Foam, synthetic (styrene butadien)	0%		0	0	
			100%				

The materials in the tool are listed in Table 3-2, although some of these materials were not included in the tool due to lack of available information. The user can choose the materials individually or as a blend of different materials by specifying their percentages.

The tool provides users a range of material densities (g/m² for textiles or kg/m³ for foam) that are commonly used for loose furnishing materials, but the user can also input other densities. The user can also choose or enter a foam thickness (cm) and a desired service life (years). The guidance for these user input values is shown in Appendix E. Same as Appendix H, the figures that are shown in Appendix E are produced based on the inputs at Table 3-4. The figures will change if the user enters different inputs to the Table 3-4.

The tool results are reported in terms of kg/m² of material.

3.2.6 Screening tool construction

Four stages are considered within the LCA study as shown in Figure 3-2 based on a cradle to grave system. Packaging and distribution are not included in this analysis because they would be similar for all materials and thus would not contribute to a comparison.

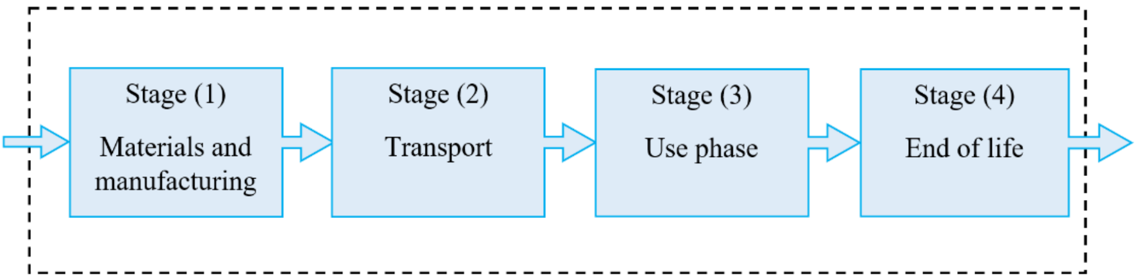

Figure 3-2 Relevant stages for the constructed LCA-based screening tool [35].

At stage (1) of Figure 3-2 there are some cases which the exact manufacturing processes were not available in the LCA software for a specific material. A surrogate process was used in these cases. For example, the manufacturing process of viscose was assumed similar to bast fibre (which it is available in the ecoinvent 3.4 database). Other materials that are assumed to have similar manufacturing process similar to bast fibre are polyamide 6.6, polyester, polyester (Trevira CS), and wool fibres. For the sake of simplicity, the fabrics are considered as woven materials. The waste materials that are produced during fibre production and/or textile manufacturing are assumed to be incinerated.

At stage (2) of Figure 3-2, the materials are assumed to be imported to Sweden from different source locations outside Sweden as presented in Appendix A. Two kinds of transport modes are considered. Since loose furnishing materials are not typically time-critical goods, long transport times are acceptable to save on transport costs. Therefore, sea transportation is assumed from source countries to Sweden (Gothenburg port). Otherwise, truck transportation to Sweden (Gothenburg port) is considered for land transportation. The second part of transport inside Sweden (from Gothenburg port to a manufacturing plant located in central Sweden) is assumed by truck transportation. Therefore, weighted average values that are based on the assumed imported weight percentage and corresponding transportation distances (from the assumed source countries to Sweden and/or manufacturing factory) are calculated and used for the transportation stage of the LCA study. These calculations are summarized and presented in Appendix C.

Stage (3) of Figure 3-2 includes two important elements that are considered during the use phase of a loose furnishing material (per kg) in the LCA study: first, the replacement of components of the furnishing by the consumer and second, the maintenance of materials (cleaning) that require electricity consumption. The assumptions related to stage (3) are presented in Appendix D.

Stage (4) of Figure 3-2 includes LCA studies related to the end of life of the materials. All waste coming from end of life stage is incinerated. A fraction of material quantities that were included in the replacement factor calculations were also added to the final waste for incineration process. All materials are assumed to be incinerated with energy recovery because loose furnishings are not typically recycled in Sweden.

3.2.7 Analysis of materials

An analysis of the materials selected for use in the screening tool was conducted to identify materials having the highest environmental impacts in the categories chosen for this study. The full life cycle of these materials is considered. The density and service life used for each material is shown in Table 3-5.

Table 3-5: Material input used in comparison of environmental impacts for 1 m^2 of each material

Furnishing Part	Blend	Material	Percentage (%)	Weight (g/m2)	Foam, Density (Kg/m3)	Foam, Thickness (cm)	Service Life (years)
Cover	Yes	Cotton	100%	150			10
		Polyester (Trevira CS)	100%	200			
		Wool	100%	150			
		Polyester	100%	300			
		Polyamide 6.6 (Nylon)	100%	240			
		Viscose	100%	160			
			600%				
Barrier	No	Glass Fibre	100%	270			10
			100%				
Wadding	No	Polyester wadding	100%	200			10
		Wool wadding	100%	200			
			200%				
Cushion		Polyurethane Foam (Polyfoam)	100%		20	15	10
		Latex Foam, synthetic (styrene butadien)	100%		20	15	
			200%				

The environmental impacts of 1 m² of each loose furnishing material listed in Table 3-5 are compared in Figure 3-3. This comparison is made using the absolute values for each impact category, thus the vertical axis is log-scale to make all the results visible. Note that wool and polyester are represented as both coverings and wadding using different densities.

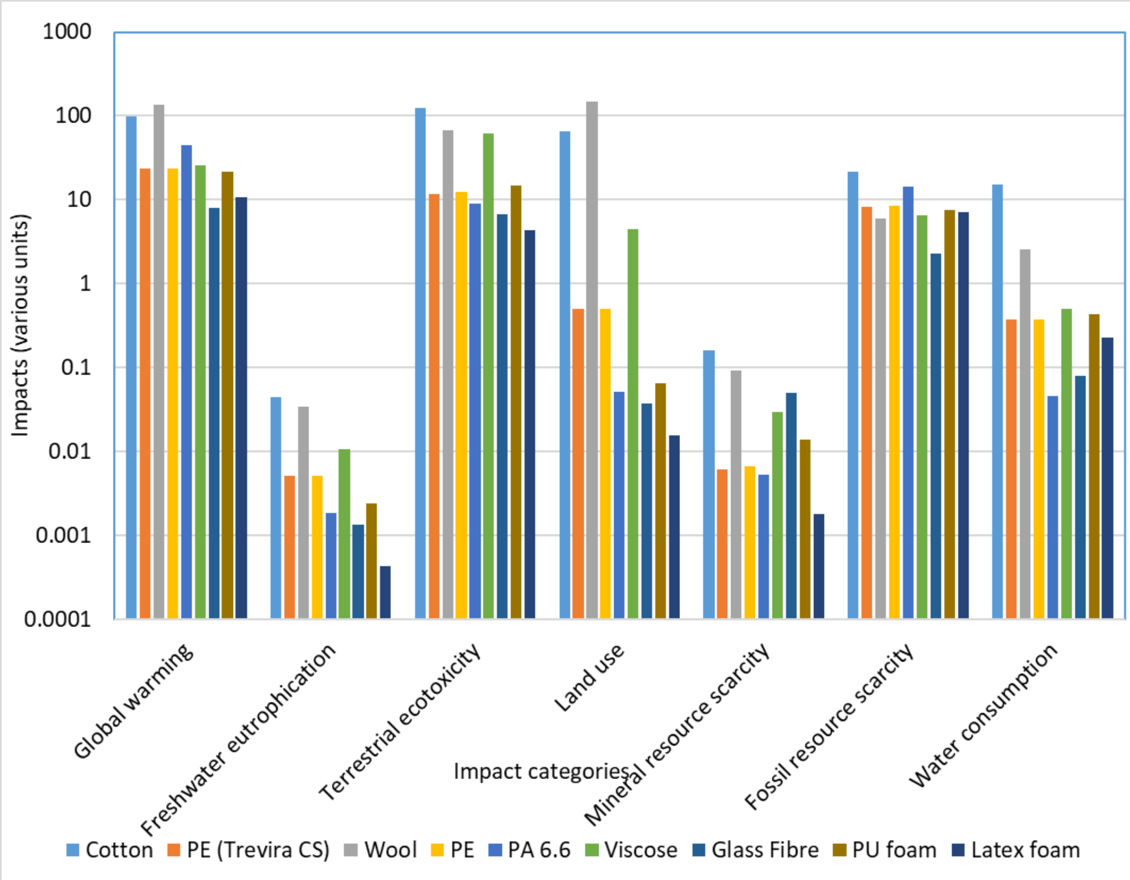

Figure 3-3: Environmental impacts of selected loose furnishing materials

The impacts associated with cotton and wool have significantly higher impacts than the other materials in all impact categories. Viscose also has higher impacts in several categories. Although cotton and wool are natural, renewable materials, they are environmentally intensive to produce, especially considering the land needed for crops and grazing.

3.2.8 Sofa case study

A sofa case study was used to illustrate the environmental trade-offs when designing and producing loose furnishings. The frame of the sofa is not included in the main analysis of sofa seat cushions because there are many kinds of sofa frames and their construction depends in large part on the intended use of the sofa. The materials used in the sofa frame (everything except the bottom and back cushions) for a commonly available sofa that seats two people were analysed separately to give a rough indication of the magnitude of the impacts of these materials compared to the back and bottom cushions. The materials for this case study sofa are listed in Table 3-6.

Table 3-6: List of materials in case study sofa, excluding back and bottom cushions.

Material	Weight (kg)	Comments
Wood	9,648	Softwood board
Particle board	21,101	Includes fibreboard
Cardboard	0,876	In arm rests
Metal hardware	2,443	Nuts, bolts, hinges
Plastic pieces	0,514	Washers, connectors, feet, structural parts
Covering	1,655	55 % cotton, 45 % polyester

Material	Weight (kg)	Comments
Barrier textile	0,489	Unknown light-weight material
Wadding	0,228	Polyester non-woven
Foam	1,439	Polyurethane of varying densities

The sofa used in this case study has two back cushions and two bottom cushions. Their materials are listed in Table 3-7. The coverings are easily removable for washing or replacement. The remainder of the sofa requires several hours to disassemble, making recycling of everything except possibly the cushion materials unlikely.

Table 3-7: Materials used in sofa case study cushions

Material	Weight (kg)	Comments
Coverings	1,870	55 % cotton, 45 % polyester
Barrier textile	0,476	Unknown light-weight material
Wadding	0,182	Polypropylene non-woven
Filling	5,460	Loose fluffy polyurethane
Foam	2,684	Polyurethane

The results of the materials analysis are shown in Figure 3-4 and compared with the results of a typical combination of materials for the back and seat cushions.

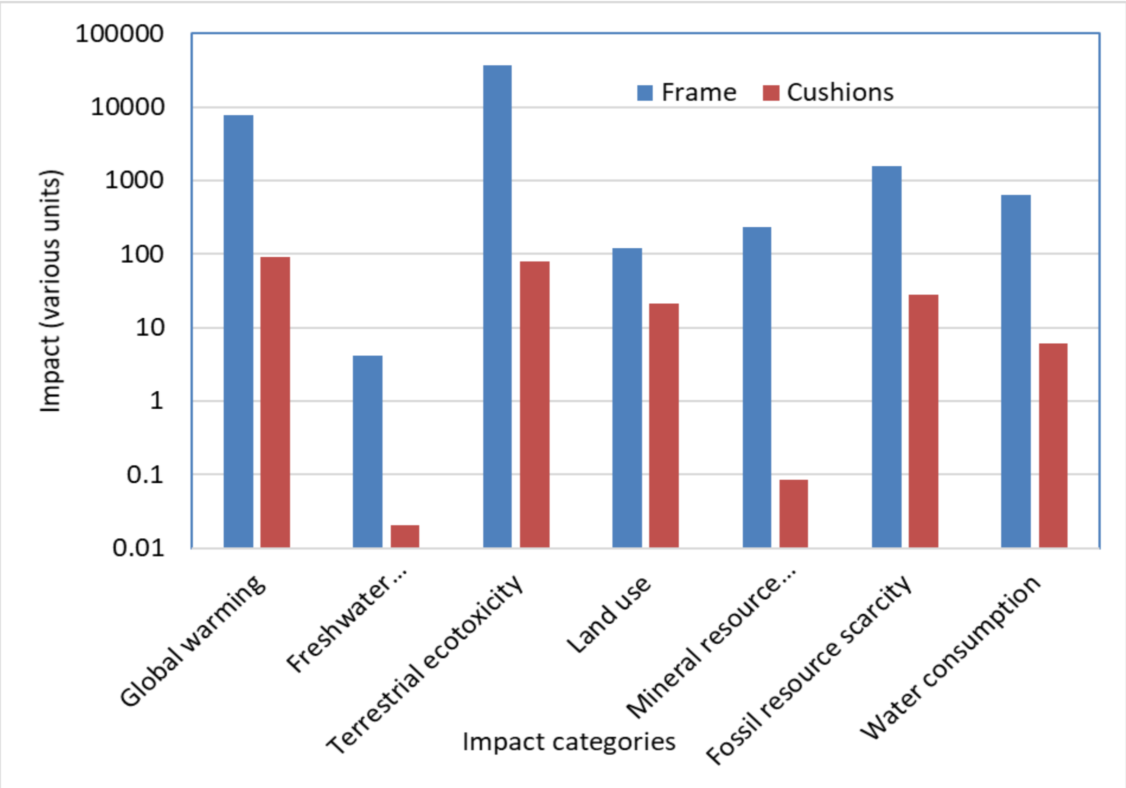

Figure 3-4: Absolute values of impacts of sofa frame (everything except cushions) compared with the cushions. Note that the vertical axis is log-scale to make all the impact category results visible.

The environmental impacts associated with producing the sofa frame are far larger than those associated with producing the cushions. Of course, the magnitude of the differences will change if other sofas or types of loose furnishings are compared.

3.2.9 Discussion of results

The environmental impacts of the full life cycle of the materials selected for this study were compared in Figure 3-3. The results show that cotton and wool have impacts that are much higher than the other materials in nearly every category. The importance of each category is dependent on the needs and interests of individuals using the results, therefore it is very difficult to impose a weighted rating system objectively. If a simple rating system similar to that used for analysis of the sustainability results is used here, giving 1 point to each material for having the lowest impact in a category, the results show:

- Coverings- Polyamide 6.6 (nylon) has 5 points, polyester, viscose, and wool have 1 point each, with a tie for viscose and PE
- Barriers- only one material in this category, so glass fibre has 7 points
- Wadding- Polyester has 6 points, wool has 1 point
- Foam- Latex has 7 points, with a tie with polyurethane for one category

3.3 Flame retardants in a sustainability/environmental perspective

The use of flame retardants (FRs) complicates the sustainability and environmental impacts of materials because the materials become difficult, to recycle when FRs are present [36]. The public perception of FRs tends to be negative because of the toxicity and eco-toxicity issues caused by many of the ingredients in FR compounds. Some of the FR ingredients are listed by REACH as being a dangerous substance and are consequently being phased out of production. On the other hand, FRs can act to delay or prevent ignition and can inhibit the spread and growth of fire. If the positive aspects of FRs can be achieved without the use of toxic or eco-toxic compounds this conflict could become a win-win situation.

FRs are commonly divided into four groups: inorganic, organo-phosphorous, nitrogen-containing, and halogenated. FRs can be transported into the environment via a variety of routes and be found in air, soil, water, and sediments far from their original location [37]. Depending on their type and reactivity, FRs can have a range of environmental impacts, including but not limited to bioaccumulation, persistence, human and eco-toxicity and stratospheric ozone depletion. Indirect effects of FRs may include depletion of energy, land, and mineral resources.

Depending on the product, there may be viable alternatives to using the most damaging FRs, such as replacing them with less damaging FRs. Associations such as pinfa[3] and certification organisations such as OEKO-TEX®[4] exist that promote the use of FRs that are relatively less damaging to the environment. Care must be used to avoid shifting the impacts of FRs when substituting one type for another. For example, if a halogenated FR is replaced with a non-halogenated FR it may appear that the environmental impact is

[3] https://www.pinfa.eu/
[4] https://www.oeko-tex.com/se/business/business_home/business_home.xhtml

reduced on a 1 kg basis, but more non-halogenated FR may be needed to achieve the same level of fire performance, thus reducing or negating the per kg advantage.

Considering the impacts of using FRs in products, it is highly desirable to find alternative methods of achieving comparable fire performance. For this reason, and because there are many types of FRs but very little information about the FRs that were used in the loose furnishing materials in this study, FRs were not included in the sustainability and environmental impact analyses.

4 Fire safety requirements for upholstered furniture and mattresses

There are many different standards for fire testing loose furnishings, such as upholstered furniture and mattresses. Which standard that is relevant depends on where in the world the furniture is sold as well as the end use of the furniture. There are also specific industry requirements in areas such as shipping, railway and automotive industries. This chapter describes the most common standards used on the Scandinavian market. However, since many companies also export upholstered furniture and mattresses outside the Scandinavian market, requirements for UK and USA are also described since these countries have the most restrictive regulations. The principles for fire testing of loose furnishings and details of the test standards are given in Appendix I.

4.1 Europe

Loose furnishings sold on the European market shall fulfil the General Product Safety Directive (GPSD) 2001/95/EG [38]. Despite this European directive, there are no harmonized regulations and requirements for upholstered furniture and mattresses. It is the responsibility of each EU country to legislate and determine the requirements but also to conduct surveillance on their territory. National authorities should check whether products available on the market are safe, and that product safety legislation and rules are applied. National authorities can also impose sanctions when necessary [38].

Countries such as UK, Ireland, Germany, France, Portugal, Spain, Italy, Norway, Sweden and Finland have introduced fire requirements for loose furnishings. These requirements mainly cover public areas such as hospitals, prisons, hotels, theatres etc. However, for the domestic environment most countries lack fire requirements. Only UK, Ireland and the Nordic countries have fire requirements for the domestic environment.

For the countries that do have fire requirements, the most common test standards used are EN 1021-1 (cigarette) and EN 1021-2 (match flame equivalent) for upholstered furniture and EN 597-1 (cigarette) and EN 597-2 (match flame equivalent) for mattresses [39–42]. Sweden and Norway only require the cigarette standards though and this is for the domestic market. UK and Ireland are the countries with the most stringent legislation compared to the rest of Europe and are therefore described further below.

4.2 Scandinavia

In Sweden product safety are legislated in the Product Safety law, which is based on the EU General Product Safety Directive (GPSD) 2001/95/EG [38]. The Product Safety law is handled by the Swedish Consumer Agency, and since the Product Safety law is as vague about the requirements as the directive, the agency therefore refers to EN-standards on their website [43]. Upholstered furniture for domestic use in Sweden should fulfil SS-EN 1021-1 [39] and mattresses SS-EN 597-1 [40], which have adopted the EN standard without any additions. Both these test methods have a cigarette as ignition source and the products must be able to withstand a smouldering cigarette without igniting. The test standards are further described in Appendix I.

The Norwegian regulations are also based on the GPSD. A Norwegian regulation (Regulations on ignitability of mattresses and upholstered furniture) states that mattresses and upholstered furniture shall resist ignition when exposed to a smouldering cigarette, in accordance with “acknowledged norms” [44]. Two such acknowledged norms are NS-EN 1021-1 and NS-EN 597-1, respectively, which also have adopted the EN standard without any additions.

4.3 The United Kingdom (UK)

The United Kingdom is the country with the most comprehensive fire regulations on upholstered furniture and mattresses in Europe, and the regulations also apply to Ireland. For domestic environments, filling materials in upholstered furniture or mattresses must comply with the "The Furniture and Furnishings (Fire) (Safety) Regulations 1988" (with amendments 1989, 1993 and 2010) (here referred to as "FFR") [15]. FFR was introduced in 1988 after an increase in the number of domestic fires and fire fatalities in UK in the 1960s and 1970s. A large part of these fires involved furniture with polyurethane foam. The polyurethane foam had replaced more naturally fireproof materials such as horsehair, and also provided cheaper furniture that everyone could afford. The introduction of FFR strengthened the existing requirements for making covers more difficult to ignite and also introduced a new fire demand for foam fillings [17,45]. A more detailed description of the FRR and the test methods it refers to are given in Appendix I.

The effectiveness of FFR to reduce the number of fires in upholstered furniture and mattresses is well documented since the introduction in 1988. Comparing the time period prior to the introduction of FFR (1981-1985) to the time period 2002-2007, the number of fires, accidents and fire deaths have decreased substantially compared to other types of fires, see Table 4-1. Although the frequency of, and number of fatalities from, furniture/mattress-related fires decreased after 1988, they are still more lethal than other fires, and cigarettes/matches still remain as the most common ignition sources. A number of ignition sources are also more common than earlier, e.g. lighters, which indicates that some risk factors increase rather than decrease [17].

Table 4-1. Comparison of number of fires, non-fatal casualties and deaths for furniture and mattress related fires between 1981-1985 and 2002-2007 in the UK [17].

Change between 1981-1985 och 2002-2007 in number of:	Furniture and furnishings fires	Other fires
Fires	-37 %	-10 %
Non-fatal casualties	-26 %	+75 %
Deaths	-64 %	-44 %

Due to the success of the FFR, not much research has been done to identify weak parts of the legislation. However, the fact that FFR is 30 years old has made the Department for Business, Innovation & Skills (BIS) launch a review to analyse if the legislation is still effective or if it needs to be updated. In recent years, concerns about the use of chemical flame retardants have increased. Actual, potential and alleged negative effects on health and the environment, especially from brominated flame retardants, have been reported, and BSI therefore wants to update FFR to reduce the use of flame retardants. FFR do not actually prescribe the use of flame retardants in upholstered furniture and mattresses, but in practice this has become the most cost-effective way for manufacturers to meet the test requirements. However, BIS believes that the flame retardants used in foam fillings are of less dangerous nature, so the work has focused on reducing flame retardants used in the covers [45,46].

4.4 The United States (USA)

Outside Europe, USA is the country in the world with the most stringent requirements on loose furnishings, especially on mattresses where federal requirements apply in all states. For upholstered furniture there are no federal requirements and each state is free to determine their own requirements. California is the state that places the most stringent requirements on upholstered furniture, which are to be fire tested according to Technical Bulletin 117 (TB 117). TB 117 is only mandatory in California, but many other states also refer to these standards in their regulations [47].

4.4.1 Upholstered furniture

In California, the “Bureau of Electronic and Appliance Repair, Home Furnishings and Thermal Insulation" is responsible for developing standards (Technical Bulletins) for upholstered furniture. In October 1975, Technical Bulletin 117 (TB 117) was introduced, called "Requirements, Test Procedures and Apparatus for Testing the Flame Retardance of Filling Materials Used in Upholstered Furniture". TB 117 was applied to all upholstered furniture sold in California, regardless of where they were manufactured. The purpose of the standard was to limit and reduce the number of fires in upholstered furniture, which accounts for a large proportion of fire-related deaths and injuries each year.

In the first version of TB 117, two types of ignition sources were used; a gas flame equal to a match flame, and a smouldering cigarette. On January 1, 2014, a revised version of TB 117 (referred to as TB 117-2013) was published. All manufacturers of textile products for upholstered furniture were forced to comply with this new version by January 1, 2015 latest. In TB 117-2013, the gas flame ignition source has been removed. Only the smouldering cigarette ignition source remains, and the test is mainly based on the test standard ASTM E-1353-08a, with some modifications [48]. The reason why the gas flame was removed in the new version is an increasingly intensive debate on flame retardants and their risks, such as reduced fertility and increased risk of cancer [49]. In order to comply with exposure to a gas flame ignition source, manufacturers have usually added flame retardants in the foam. By removing the gas flame ignition source from TB 117-2013, the legislators are hoping to see a potentially significant reduction in the use of chemical flame retardants.

In TB 117-2013, cover fabrics, barrier materials (interliners), resilient filling materials and decking materials are tested separately, in combination with standard materials.

Only component (material) testing is required, the final product is not tested. Manufacturers can therefore produce upholstered furniture without needing to fire test the final material combination, as long as they choose materials meeting the requirements of TB 117-2013. The test procedure according TB117-2013 is further described in Appendix I.

4.4.2 Mattresses

For beds and mattresses, federal requirements are mandatory in every state for the entire USA. The requirements are given in two standards called 16 CFR Part 1632 and 16 Part CFR Part 1633, covering ignition conditions. 16 CFR Part 1632 is an ignition test using a smouldering cigarette as ignition source. 16 CFR Part 1633 is a large-scale flammability test where a mattress is exposed to a larger ignition source consisting of a horizontal and a vertical gas burner which together gives a heat output of 27 kW. These burners simulate burning beddings and during the test, the heat released from the product is measured.

Unlike TB 117-2013, where materials are tested separately with standard materials, beds and mattresses are always tested with the final combination of materials. The bed or mattress should also be constructed as the finished product, complete with, for example, spring systems and frame structure. For description of the test procedure according to 16 CFR Part 1632 and 16 CFR Part 1633, see Appendix I.

4.5 Fire propagation in a building fire

The negative contribution to fire development from upholstered furniture and mattresses has been known for decades, as already mentioned in this report. The topic has been studied in many research projects over the years, both internationally and in Scandinavia. In a survey performed by the Norwegian Fire Protection Association among Norwegian fire services in 2006, all respondents did assess the contribution from upholstered furniture in dwelling fires as either very high or relatively high [50]. Fire tests of upholstered furniture and mattresses have shown that the peak heat release from such objects can be as high as 2.5 MW [1,7]. The heat effect from the furniture alone will then be sufficiently high to cause flashover in a living room. Flashover is regarded as a critical event in the fire development because it represents a high risk of fire spread to other parts of the building.

The speed of fire development and the time to flashover are important factors for the possibility to escape from fire. Furniture with better fire properties will increase the available time to escape because such furniture will contribute less to the fire development than regular products. Modern types of upholstered furniture are identified as an important factor contributing to a more rapid fire development and a shorter time to flashover in modern dwellings than in homes before approximately 1970. UL in the USA performed a series of fire tests, where living rooms were equipped with either modern furniture or furniture according to the quality level in the 1950s [51]. While time to flashover in the rooms with the oldest furniture was about 30 minutes or more, the rooms with modern furniture reached flashover in less than 5 minutes.

The different test methods mentioned in the previous sections are based on different strategies with regard to fire safety. One aim is to prevent ignition of a furnishing object when exposed to an ignition source of a certain size. Another aim is to prevent that the furnishing object would contribute significantly to an already established fire and lead to escalation of the fire.

Some test methods are used to document that the upholstered furniture or mattress can withstand exposure from a smaller ignition source without being ignited for a certain time. Ignition would here mean either sustained flaming or sustained smouldering combustion or both. Furniture that pass such test methods will in principle represent a safety barrier against ignition by smaller fire sources, like smouldering cigarettes, glowing embers and match flames. Test methods using a smouldering object as an ignition source are intended to give protection against smouldering fires, in particular fires that start in upholstered furniture and mattresses because a lit cigarette ignites the materials. This has been, and still is, a very common scenario in dwelling fires, and also a cause of many fatal fires [52,53].

Other test methods document the furnishing object's ability to withstand exposure from a flaming object - either with the purpose that sustained flaming or smouldering are not developed, or with the requirement that limited amounts of heat and smoke should be released. Common flaming ignition sources used in such tests are wooden cribs of different sizes, newspaper cushions and propane burners. The smallest flames are used to test the ignitability of the objects when exposed to smaller flaming sources, like match- and lighter flames. Larger flaming sources are used to simulate burning items of different sizes, e.g. burning clothes or pillows in a bed, or flaming objects placed in an upholstered seat by arsonists.

Finally, there are test methods that simulate a scenario where the furniture is exposed to heat flux, and possibly also glows or flames, from a developed fire in the room. Furnishing that can withstand exposure from a developed fire without contributing significantly to the heat release and smoke production will also not contribute significantly to the escalation of the fire.

One proposed fire safety strategy for furniture, is the principle of parallel requirements for surfaces on walls and ceiling and for the upholstered furniture and mattresses in the same area [7]. If the requirements to the surface of walls in an area are strict (e.g. as requirements for wall surfaces in escape routes) the fire safety requirements to the furnishing should also be strict. The heat effect from a combustible furniture, such as a sofa, alone could be sufficiently high to cause flashover in an escape route, despite strict fire requirements for the surface linings.

5 Experiences from standardized fire testing

RISE has been performing fire tests on upholstered furniture and mattresses for a long time and gathered experience on material behaviour. Depending on the material combination and choices of materials, the fire properties of the end-use product will differ. The intended market where the product will be sold decides which test method/standard to follow and which ignition source to be used during the test. For smaller ignition sources, such as a glowing cigarette and a match flame, the demands on the materials or material combination in the product are less than for a larger ignition source such as a wooden crib.

To be able to pass the necessary test criteria, there are different ways of controlling the fire properties of the product. One way is to add chemical flame retardants to the filling and/or the cover of the product. Another way is to use a barrier material between the foam filling and the cover. This barrier material will protect the foam from a direct contact with the ignition source. Most of the stored energy is within the foam filling, which makes it a more critical component in the furniture or mattress than for example the cover in terms of fire safety.

Certain textile fibres are inherently flame retardant such as Trevira CS®. This means that the flame retardant is bound to the polyester fibre on a molecule level, which prevents the chemicals from migrating out of the fibre during use. Migration of flame-retardant chemicals is often an issue and can potentially be harmful to the health of the people using the treated furniture. Also, the efficiency of the flame retardancy may be reduced over time.

Other fibres, like aramids, do not easily ignite and are known to char rather than burn with an open flame. Nomex is such a fibre and is commonly used in fire fighters' protective clothing. However, these types of fibres are expensive and might affect the comfort properties of the furniture.

5.1 Material behaviour

The nature of the materials used in an upholstered furniture or a mattress affects the fire properties.

Fire behaviour of natural fibres

When natural fibres such as cotton, wool, flax or horsehair are exposed to a smouldering ignition source they tend to start smouldering, which may develop into flaming ignition given the right circumstances. The chemical composition of a textile is important for whether smouldering combustion can develop, particularly the content of alkali metals and alkaline cations [54]. For cellulose based textiles, the content of sodium and potassium ions is an important reason for development of a smouldering fire. Potassium ions are naturally found in cotton, while sodium is added through staining processes. For cover fabrics of cellulose-based fibers the probability of developing smouldering combustion increases with increasing weight of the textile [2].

Wool is one of the materials that has the highest resistance to ignition when exposed to a smouldering cigarette, and the ignition resistance increases with the weight of the textile [3,55]. Wool is often considered as a fibre with built-in flame retardant properties due to the complex chemical and physical structures, and because of the chemical composition [56].

When exposed to flaming ignition sources, these materials will ignite, but there are large differences in ignitability between the different fibres. As an example, wool would tend to withstand a larger ignition source compared to cotton.

Fire behaviour of synthetic fibres

Synthetic fibres such as polyester, polyamide and acrylic tend to melt away from a flaming ignition source at first. The material then either ignite with sustained flaming, alternatively would any flames self-extinguish. When exposed to a smouldering ignition source, these materials tend not to start smouldering themselves but to melt and disintegrate.

Polyurethane foam (PUR), which is commonly used as filling, tends to smoulder when exposed to a smouldering ignition source and to burn with an open flame when exposed to a flaming ignition source. The density of the foam has a more profound impact on the ignition propensity for smouldering ignition than for flaming ignition. The lower the density, the higher the risk of smouldering ignition. The most commonly used densities of PUR foam on the market will not be easily ignited by a smouldering ignition source such as a glowing cigarette, whilst flaming ignition will pose a consistent problem.

When combining natural and synthetic fibres, and exposing them to a flaming ignition source, a “candle wick effect” can sometimes be observed where the natural fibre acts like the wick and the synthetic fibre acts as the candle grease.

Investigation of fire properties of cover fabrics made from natural fibres has shown that the smouldering propensity of a cotton fabric seems to increase when the area weight increases. Also, the risk of ignition from a smouldering ignition source is increased for cellulosic fibres and the use of flame retardant treatments does not seem to be effective. Some properties of cover fabrics that can influence the ignitability and propagation of a fire are [57]:

- Material content
- Yarn thickness
- Thread count
- Area weight
- Thickness
- Surface configuration (smooth, pile, etc.)
- Charring ability
- Melting ability

In the sections below, the experiences from fire testing performed at RISE are described for different types of materials, typically materials used in upholstered furniture and mattresses. Comments are made for when some type of action is likely needed to control the fire properties of the materials in order to pass the test. The test methods evaluated are:

- EN 1021-1 (glowing cigarette)
- EN 1021-2 (match flame equivalent)
- BS 5852:2006, ignition source 5 (wooden crib 5)

The chosen materials are in combination with a non-flame-retardant polyurethane (PUR) foam with approx. density of 30 kg/m^3.

5.1.1 Natural fibres

Fabrics made from natural fibres such as cellulose tend to char and so protect the underlaying filling material from coming into direct contact with the ignition source. However, the heat transfer to the filling material is more of a problem when a furniture combination is exposed to smouldering ignition sources. This heat transfer can be sufficient to start a smouldering combustion in the filling material [57].

Table 5-1 Experiences from tests according to EN 1021-1.

Fibre / material	**Reaction when exposed to ignition source (cigarette)**	**Need for control measures**	**Comment**
Leather	Charring	No	The glow/smoulder of the cigarette is not likely to penetrate the leather and affect the PUR filling
Cotton	Charring/Glowing/smouldering	Normally not	The area weight of the cotton fabric can influence the test result. Higher area weight is usually more protective
Wool	Charring/Glowing/smouldering	Normally not	The area weight of the wool fabric can influence the test result

Table 5-2 Experiences from tests according to EN 1021-2.

<table>
<tr><th>Fibre / material</th><th>Reaction when exposed to ignition source</th><th>Need for control measures</th><th>Comment</th></tr>
<tr><td>Leather</td><td>Charring</td><td>No</td><td>The leather will normally just char on the surface and will protect the PUR filling underneath.</td></tr>
<tr><td>Cotton</td><td>Charring/Glowing/flaming</td><td>Normally not</td><td rowspan="2">Depending on the area weight of the fabric the PUR filling underneath might be affected.</td></tr>
<tr><td>Wool</td><td>Charring/Glowing/flaming</td><td>Normally not</td></tr>
</table>

Table 5-3 Experiences from tests according to BS 5852:2006, ignition source 5 (wooden crib 5).

Fibre / material	Reaction when exposed to ignition source	Need for control measures	Comment
Leather	Charring/Glowing/flaming	Yes, adding FR to the leather and/or the PUR foam. Alternatively adding a fire barrier.	The leather will most likely be penetrated, exposing the PUR foam underneath. The thickness of the leather will have an impact on the results.
Cotton	Charring/Glowing/flaming	Yes, adding FR to the cotton and the PUR foam. Alternatively adding a fire barrier.	The area weight of the cotton fabric can influence the test result
Wool	Charring/Glowing/flaming	Yes, adding FR to the wool and the PUR foam. Alternatively adding a fire barrier.	

5.1.2 Synthetic fibres

When exposing a material combination made of synthetic fabric and a PUR filling to a smouldering ignition source, there is a build-up of staled melted material underneath the ignition source preventing a smouldering ignition of the filling material. The energy from the smouldering ignition source goes to melt the material and so the heat transfer to the filling, even when partly exposed, is not large enough to ignite the filling [57].

The outcome of the test with a flaming ignition source is quite the opposite. When exposed to an open flame, the fabric will quickly melt away and expose the filling, which can then easily be ignited.

Table 5-4 Experiences from tests according to EN 1021-1.

Fibre / material	Reaction when exposed to ignition source (cigarette)	Need for control measures	Comment
Polyester	Melting	No	The cigarette will most likely not come into direct contact with the underlaying PUR filling
Polyamide	Melting	No	
Artificial leather	Melting	No	
Polypropylene hygienic cover	Melting	No	

Table 5-5 Experiences from tests according to EN 1021-2.

Fibre / material	Reaction when exposed to ignition source (cigarette)	Need for control measures	Comment
Polyester	Melting/flaming	Yes, FR for the PUR or add a barrier.	The ignition source will most likely burn through the cover and expose the PUR to direct flaming
Polyamide	Melting/flaming	Yes, FR for the PUR or add a barrier.	
Artificial leather	Melting/flaming	Yes, FR for the PUR or add a barrier.	
Polypropylene hygienic cover	Melting/flaming	Yes, FR for the PUR or add a barrier.	

Table 5-6 Experiences from tests according to BS 5852:2006, ignition source 5 (wooden crib 5).

Fibre / material	Reaction when exposed to ignition source (cigarette)	Need for control measures	Comment
Polyester	Melting/flaming	Yes, FR for the cover fabric and PUR or add a barrier.	The ignition source will burn through the cover and expose the PUR to direct flaming
Polyamide	Melting/flaming	Yes, FR for the cover fabric and PUR or add a barrier.	
Artificial leather	Melting/flaming	Yes, FR for the cover fabric and PUR or add a barrier.	
Polypropylene hygienic cover	Melting/flaming	Yes, FR for the cover fabric and PUR or add a barrier.	

5.1.3 Filling material

The most commonly used filling material in upholstered furniture and mattresses is foamed polyurethane (PUR). PUR is a petroleum based product and can be modified in order to better resist ignition. In its original form it is easily ignited both from smouldering and flaming ignition sources. Due to PUR being made from petroleum it contains much energy which is quickly released when ignited.

Rubber is another foamed material that is used as filling. Natural rubber is made from the latex found in certain trees and is therefore often named “Latex”. There are also synthetic or mixed natural/synthetic latex foams. Synthetic latex where developed during the second world war when the delivery of natural latex from the East was restricted. The fire behaviour of latex is similar to PUR, it is easily ignited and contains much energy.

Less frequently used filling materials can be from cotton or wool waddings, and hair from various sources such as horse. These natural materials often experience progressive smouldering when exposed to smouldering ignition sources but generally behave well when exposed to flaming ignition sources. The flaming often self-extinguish when the flaming ignition source is removed, but progressive smouldering is likely to continue. Natural rubber as well as cotton or wool waddings and also horsehair is more commonly used in mattresses than in other types of upholstered furniture.

Wadding layers made from polyester is also commonly used in upholstered furniture. The fire behaviour of these can vary greatly. In many cases the wadding just melts away from the ignition source and does not contribute to the fire. However, in some cases the binder content in the wadding can be easily ignited and thereby increase the burning behaviour of the wadding.

6 Fire testing

6.1 Material selection

Different alternative solutions for improving the fire properties have been investigated within the project, including using existing materials in new ways (e.g. loose wool fibre wadding instead of polyester wadding), improving the fire properties of different materials (e.g. blending wool fibre with flame retardant fibre), and also the potential of new materials (such as the three-dimensional thermoplastic upholstery material as substitute for polyurethane foam).

The material combinations for testing, shown in Table 6-1, have been selected based on these approaches:

- Adjustments in the material combinations
    - Wool wadding between the cover and polyurethane foam.
- Adjustments in fabric composition
    - Blends of wool and Flamestop® (see description below).
    - Blends of cotton and polyester respectively, with modacrylic.
- Substitution of PUR with an alternative material.
    - Three-dimensional thermoplastic fibre web structure.

6.1.1 Adjustment in the material combinations

One approach has been to investigate the use of wool as a component in furnishing. Wool, being perceived as a natural, sustainable fibre is also known for its relatively good fire properties. As described in chapter 5, there is normally no need to add control measures in order for furniture with wool cover to pass EN 1021-1 and -2. This is, however, dependent on the area density of the fabric. For larger ignition sources measures may be necessary in order to achieve the required fire safety level.

Using loose and dense wool fibre between the cover material and the PUR foam was investigated, as was different variations of cover textiles where wool was blended with various concentrations of fibres having flame retardant properties. Textiles have been specifically selected and produced for this project for studying their fire properties [58,59]. Table 6-1 presents the variations tested and described in this report.

The material combinations have been compared to reference test specimens, namely:

1. Non flame-retardant polyurethane foam with a cotton cover (ID 5 in Table 6-1)
2. Conventional sofa, available on the European market (ID 14 in Table 6-1)

6.1.2 Adjustments in fabric composition

Flamestop® is a Schoeller yarn containing 50 % fine Merino Wool, 50 % Lenzing™ FR, which according to the producer, is an inherently flame-resistant cellulosic fibre (Modal fibre production process). Both the Flamestop® yarn and the Lenzing™ FR claim to have sustainable aspects [60]. The textile samples were tested together with a 35 kg/m^3 non flame-retardant polyurethane foam.

6.1.3 Substitution of polyurethane foam towards an alternative material

The three-dimensional web structure is a new material that can be used as upholstery for both furniture and mattresses as an alternative to polyurethane foam. The web is made of a hollow, thermoplastic fibre, that can be extruded in different variations with respect to density and thickness.

Table 6-1 Composition of the specimens.

ID	Cover material			Wadding/Barrier material			Upholstery filling
	Composition	**Description**	**Measured area density [g/m²]**	**Composition**	**Description**	**Area density [g/m²]**	
1	28 % Flamestop® 72 % wool	Plain weave	291				PUR non flame-retardant 35 kg/m3
2	21 % Flamestop® 79 % wool	Plain weave	247				
3	8 % Flamestop® 92 % wool	Plain weave	270				
4	0 % Flamestop® 100 % wool	Plain weave	183				
5 (reference)	100 % cotton	Plain weave	148				
6	Cotton	Plain weave	148	100 % wool	Dense felt	~600	
7	Cotton	Plain weave	148	100 % wool	Loose wadding	~140	
10	75 % cotton 25 % modacrylic	Dense felt	530±80				
11	25 % cotton 75 % modacrylic	Dense felt	530±80				
12	75 % polyester 25 % modacrylic	Dense felt	530±80				
13	25 % polyester 75 % modacrylic	Dense felt	530±80				
14, 15 (reference)	55 % cotton 45 % polyester	Plain weave	321				Polyester cluster fibre fill

Table 6-1 Composition of the specimens, cont'd.

ID	Cover material			Wadding/Barrier material			Upholstery filling
	Composition	Description	Measured area density [g/m²]	Composition	Description	Area density [g/m²]	
17							3D thermoplastic fibre web structure
18	100 % cotton	Plain weave	148				
19	97% polyester postconsumer recycled / 3% polyester	Crêpe	212				
20	97% polyester postconsumer recycled / 3% polyester	Crêpe	212				PUR non flame-retardant 35 kg/m³
21	97% polyester postconsumer recycled / 3% polyester	Crêpe	212				Standard PUR 30 kg/m³
22	100 % Polyester	Herringbone weave	313				
23	100 % recycled polyester	Hopsack weave	276				
24	54% wool, 44 % recycled polyester, 2 % polyamide	Dobby weave	307				

Table 6-1 Composition of the specimens, cont'd.

ID	Cover material			Wadding/Barrier material			Upholstery filling
	Composition	**Description**	**Measured area density [g/m2]**	**Composition**	**Description**	**Area density [g/m²]**	
25	97% polyester postconsumer recycled / 3% polyester	Crepe	212				High resilience PUR foam 32 kg/m³
26	100 % Polyester	Herringbone weave	313				
27	54% wool, 44 % recycled polyester, 2 % polyamide	Dobby weave	307				
28	100 % recycled polyester	Hopsack weave	276				
29 (reference)	100 % cotton	Plain weave	148				Standard PUR 30 kg/m³
30 (reference	100 % cotton	Plain weave	148				High resilience PUR foam 32 kg/m³
31	97% polyester postconsumer recycled / 3% polyester	Crepe	212	Glass	Twill	80	PUR non flame-retardant 35 kg/m³
32	97% polyester postconsumer recycled / 3% polyester	Crepe	212	Glass	Twill	80	3D thermoplastic fibre web structure

6.2 Cone calorimeter results

The test results from testing different material combinations in the cone calorimeter are presented in Figure 6-1 to Figure 6-14.

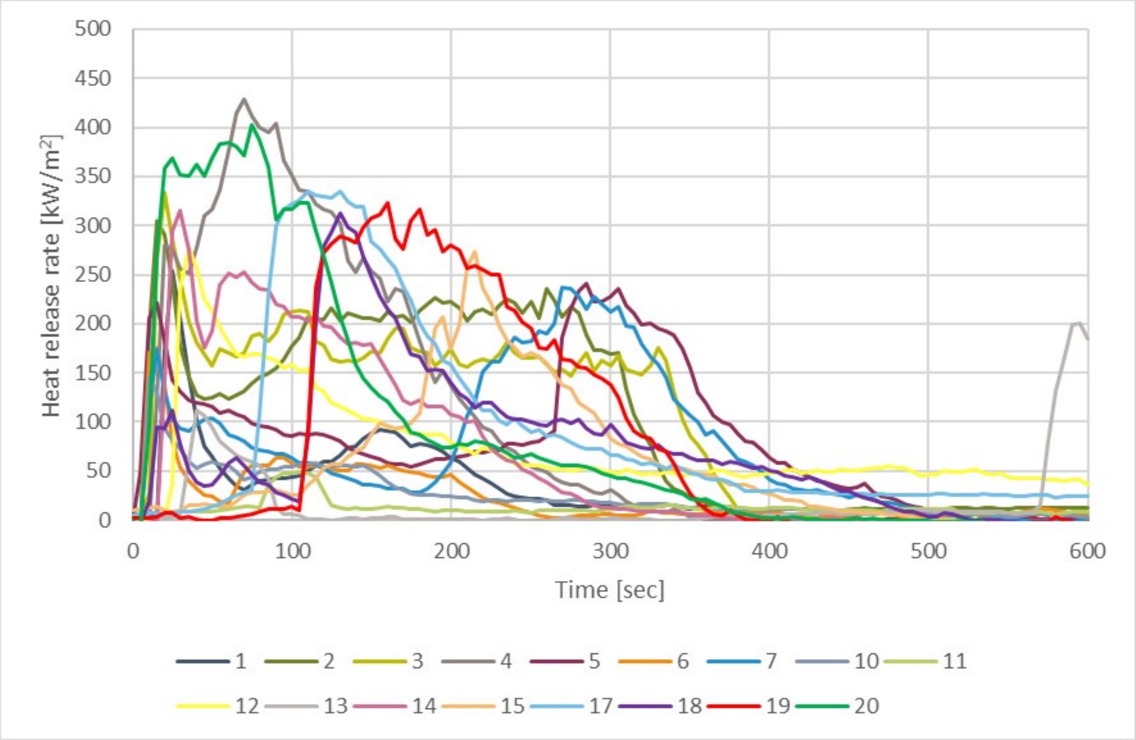

Figure 6-1 Heat release rate, various material combinations. For specimen ID, see Table 6-1.

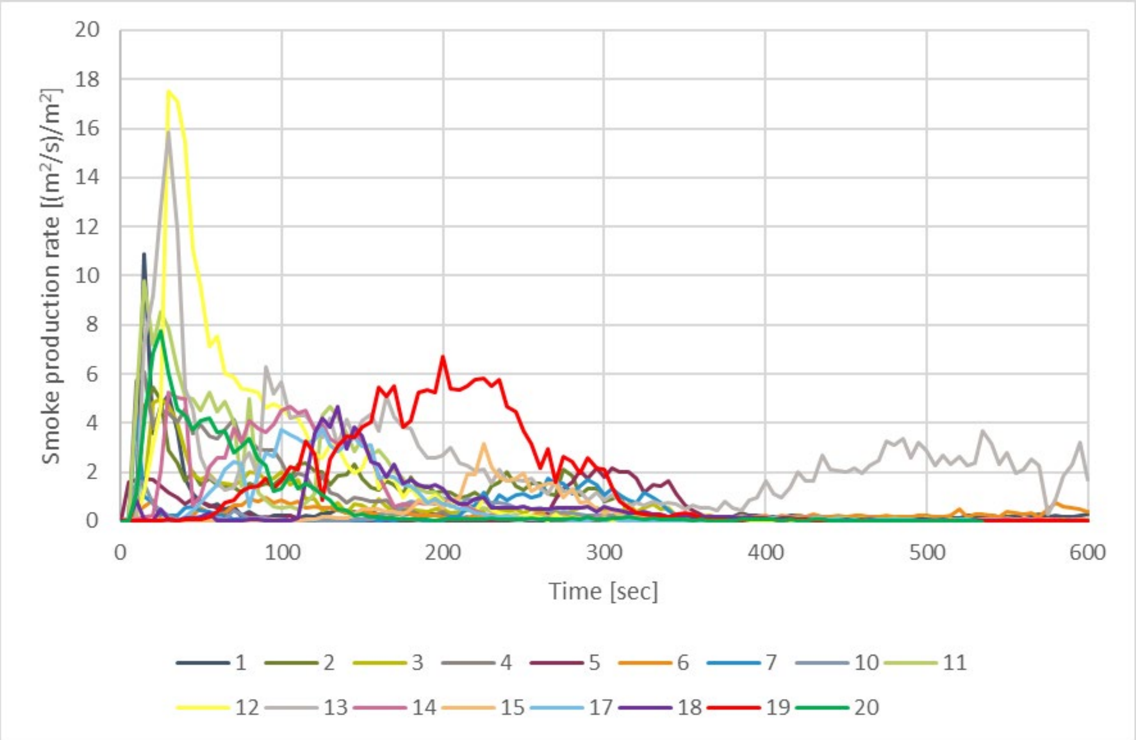

Figure 6-2 Smoke production rate, various material combinations. For specimen ID, see Table 6-1.

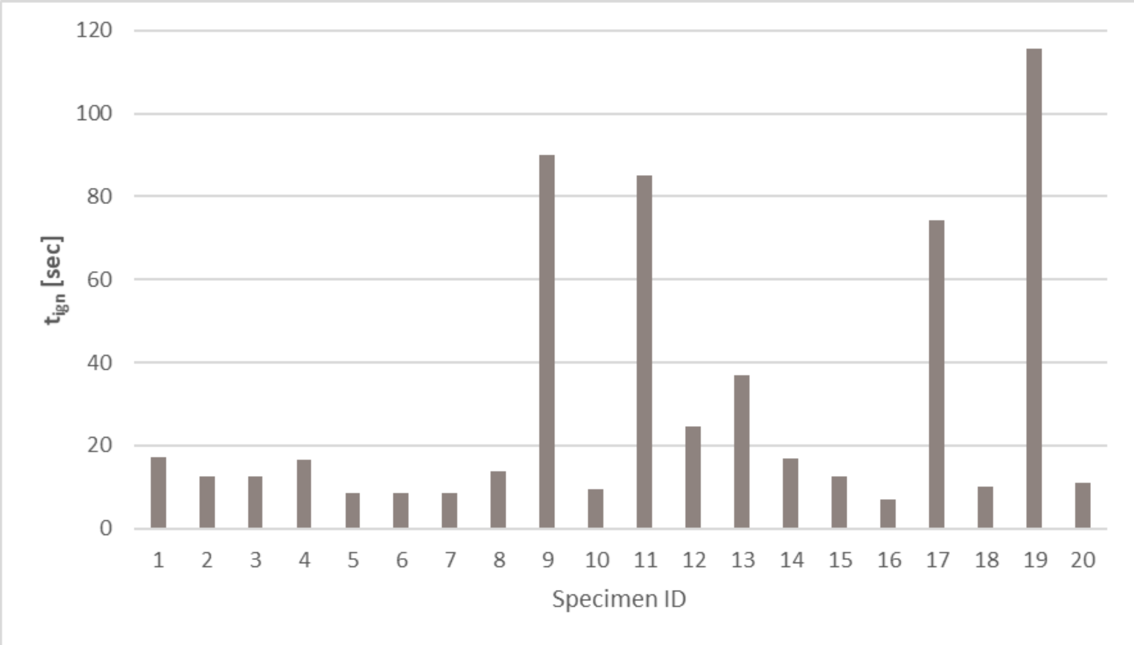

Figure 6-3 Average time to ignition (sec) for the complete set of tested specimens. For specimen ID, see Table 6-1.

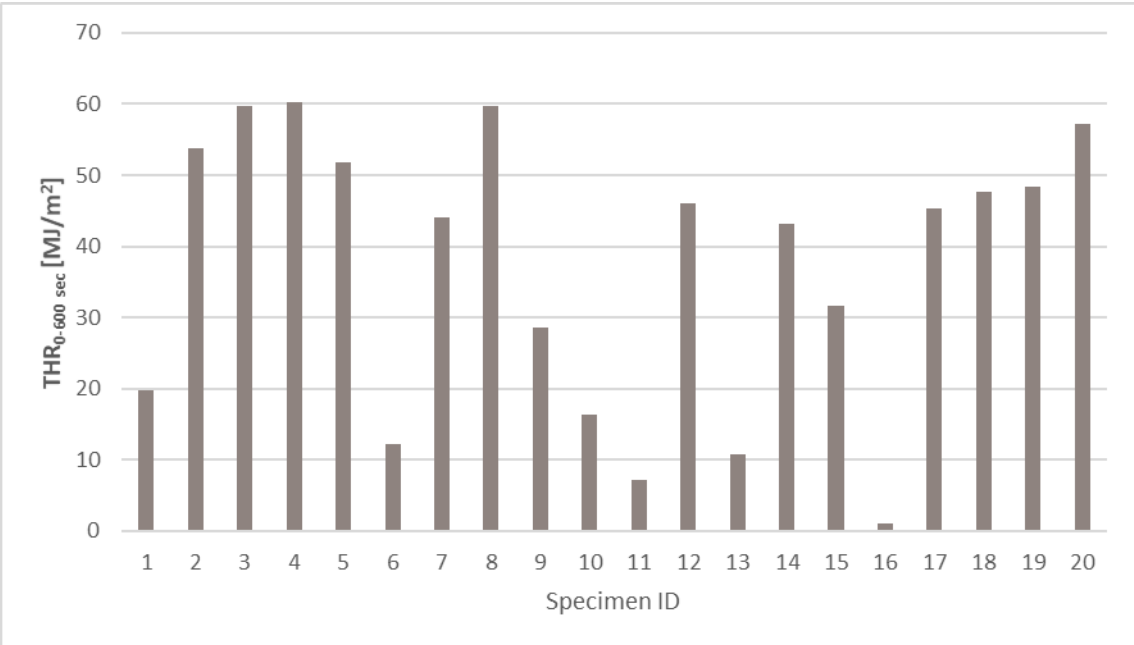

Figure 6-4 Average total heat released 0-600 sec for various material combinations. For specimen ID, see Table 6-1.

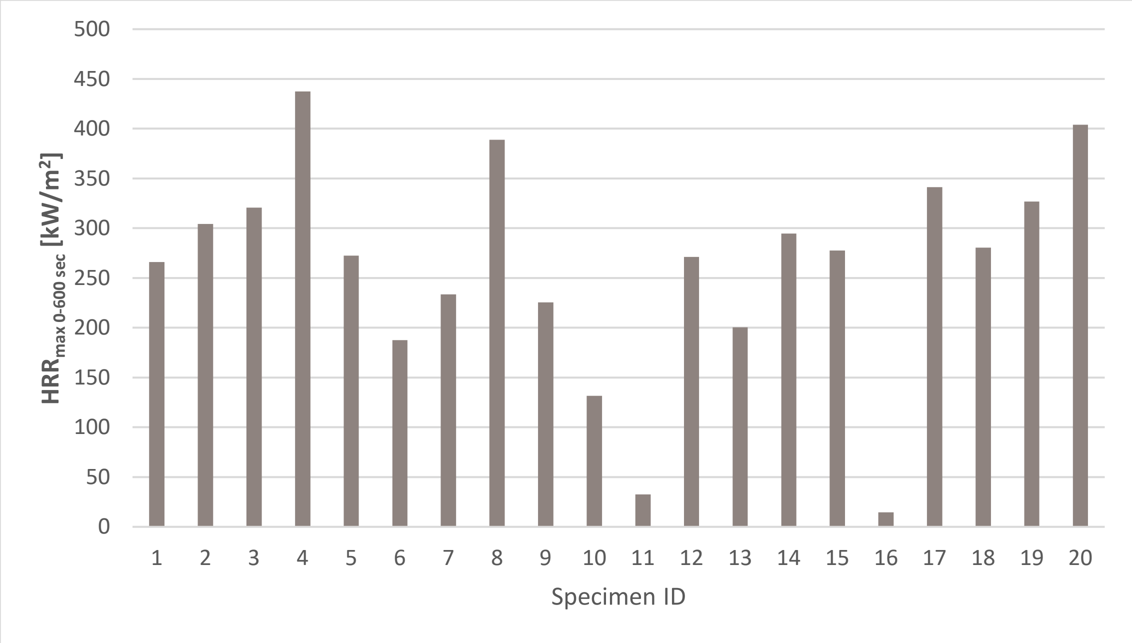

Figure 6-5 Average peak heat released 0-600 sec for various material combinations. For specimen ID, see Table 6-1.

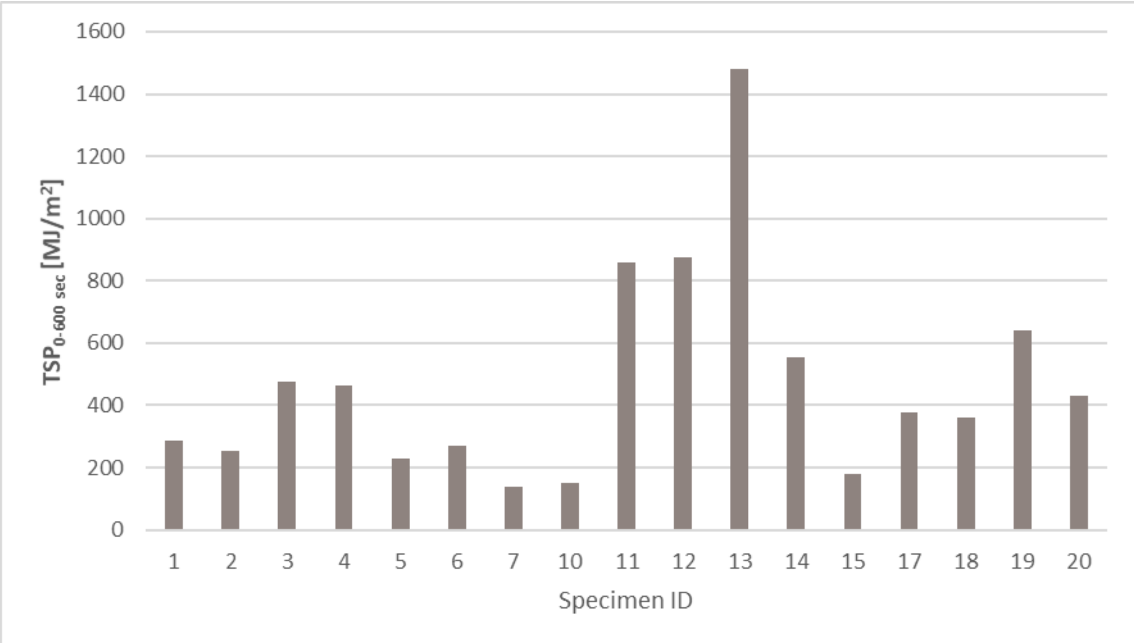

Figure 6-6 Average total smoke production 0-600 sec for various material combinations. For specimen ID, see Table 6-1.

6.2.1 Blends of wool/Flamestop®

Figure 6-7 and Figure 6-8 below show the heat release rate and smoke production rate specifically for the following materials, all tested together with non-flame-retardant polyurethane foam, 35 kg/m3:

ID	Cover material
1	28 % Flamestop® 72 % wool
2	21 % Flamestop® 79 % wool
3	8 % Flamestop® 92 % wool
4	0 % Flamestop® 100 % wool

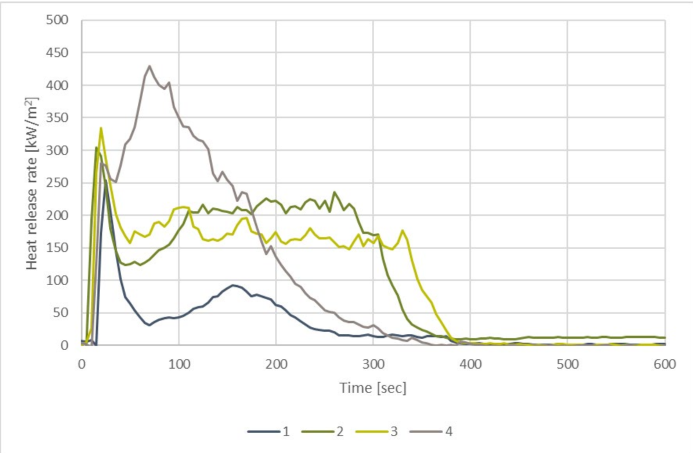

Figure 6-7 Heat release rate from cone calorimeter testing of polyurethane foam covered with different compositions of wool/Flamestop® textiles. For specimen ID, see Table 6-1.

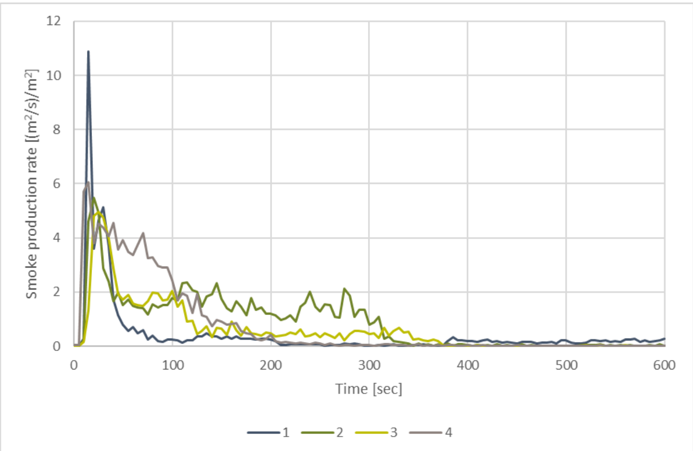

Figure 6-8 Smoke production rate from cone calorimeter testing of polyurethane foam covered with different compositions of wool/Flamestop® textiles. For specimen ID, see Table 6-1.

6.2.2 Blends of cotton and polyester respectively with modacrylic

Figure 6-9 and Figure 6-10 below show the heat release rate and smoke production rate specifically for the following materials, all tested together with non-flame-retardant polyurethane foam, 35 kg/m3:

ID	Cover material
10	75 % cotton 25 % modacrylic
11	25 % cotton 75 % modacrylic
12	75 % polyester 25 % modacrylic
13	25 % polyester 75 % modacrylic

,

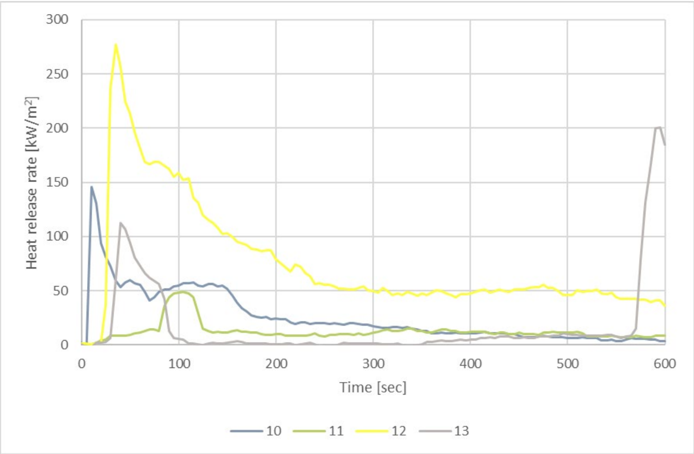

Figure 6-9 Heat release rate from cone calorimeter testing of polyurethane foam covered with different compositions of modacrylic with either cotton or polyester.

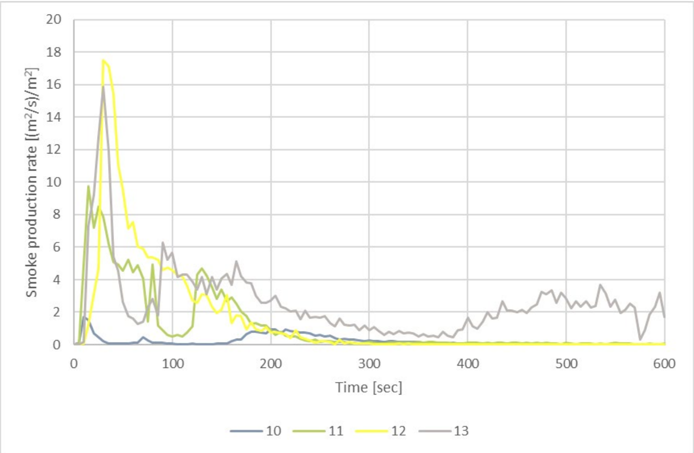

Figure 6-10 Smoke production rate from cone calorimeter testing of polyurethane foam covered with different compositions of modacrylic with either cotton or polyester.

6.2.3 Wool wadding

Figure 6-11 and Figure 6-12 below show the heat release rate and smoke production rate specifically for the following materials, all tested together with non-flame-retardant polyurethane foam, 35 kg/m³:

ID	Cover material	Wadding
5 (reference)	100 % cotton	No wadding
6	Cotton	Dense wool felt
7	Cotton	Loose wool wadding

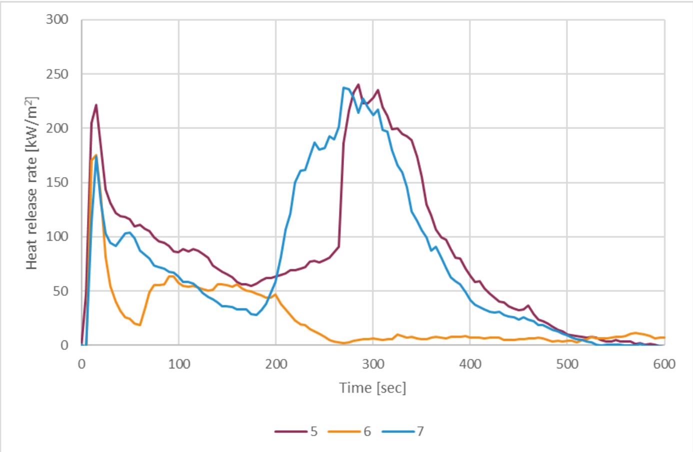

Figure 6-11 Heat release rate from cone calorimeter testing of polyurethane foam covered with cotton fabric combined with wool wadding, compared to reference materials of cotton fabric on polyurethane foam.

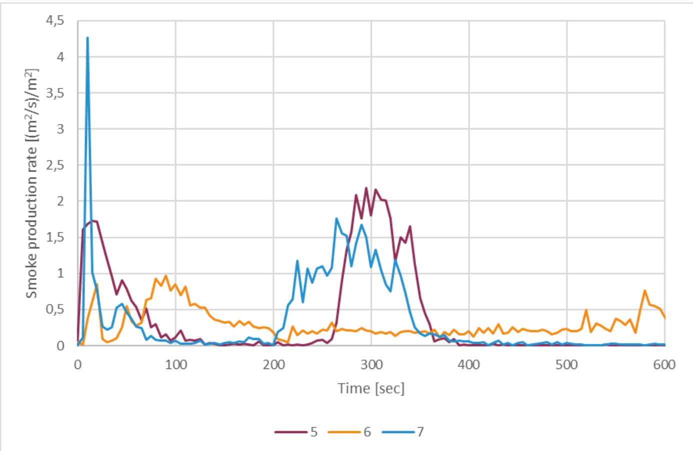

Figure 6-12 Smoke production rate from cone calorimeter testing of polyurethane foam covered with cotton fabric combined with wool wadding, compared to reference materials of cotton fabric on polyurethane foam. For specimen ID, see Table 6-1.

6.2.4 Alternative upholstery material

Figure 6-13 and Figure 6-14 below show the heat release rate and smoke production rate specifically for the following materials:

ID	Cover material	Filling
5 (reference)	100 % cotton	PUR non flame-retardant, 35 kg/m^3
14 (reference)	55 % cotton 45 % polyester	Polyester cluster fibre fill
17	No cover	3D thermoplastic fibre web structure
18	100 % cotton	
19	97% polyester postconsumer recycled / 3% polyester	
20	97% polyester postconsumer recycled / 3% polyester	PUR non flame-retardant, 35 kg/m^3

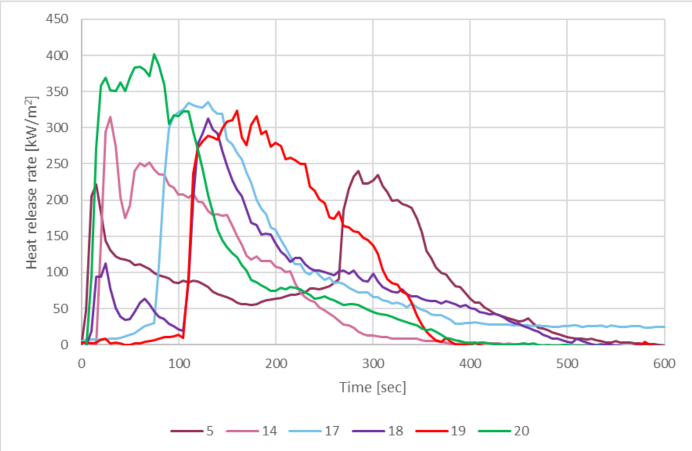

Figure 6-13 Heat release rate from cone calorimeter testing of 3D thermoplastic fibre web compared to reference materials of cotton fabric on polyurethane foam.

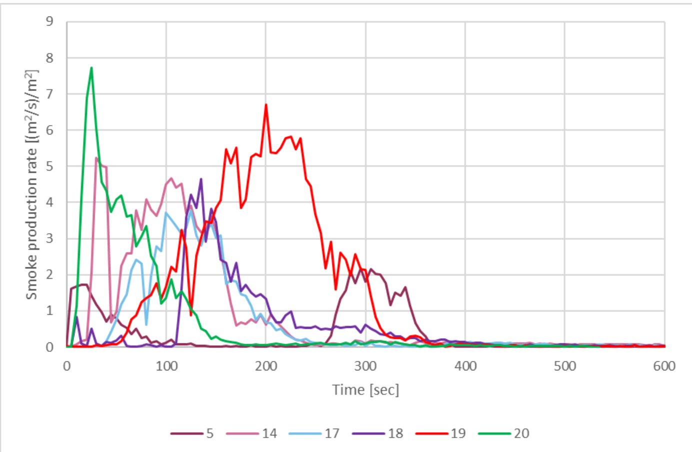

Figure 6-14 Smoke production rate from cone calorimeter testing of 3D thermoplastic fibre web compared to reference materials of cotton fabric on polyurethane foam.

6.3 Flame exposure

Pictures of all test series are presented in Appendix J.

Two new polyurethane foams were introduced for these tests; standard polyurethane foam, 30 kg/m3 and high resilience polyurethane foam, 32 kg/m3. It is not known whether they contain chemical flame retardants, but the fire properties when tested in the cone calorimeter of standard polyurethane foam was compared to those of the standard non-flame-retardant polyurethane foam, 33 kg/m3 that have been used elsewhere in the project and found sufficiently equal.

Large differences with same foam (standard polyurethane foam, 30 kg/m3), but different density polyester fabric (Figure 6-15a and Figure 6-15b):

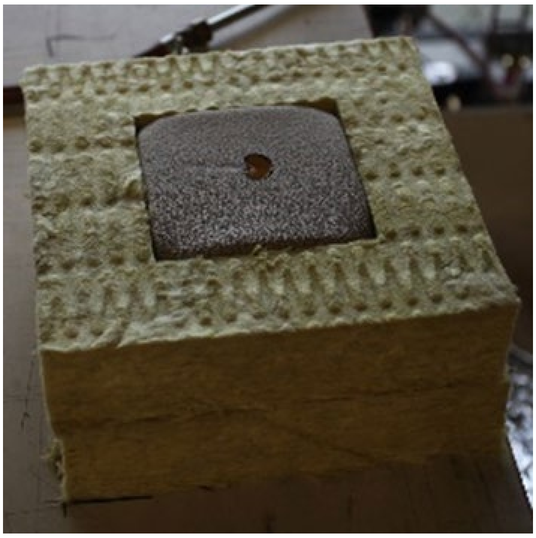

Figure 6-15a: 100 % polyester, 313 g/m^2. No ignition

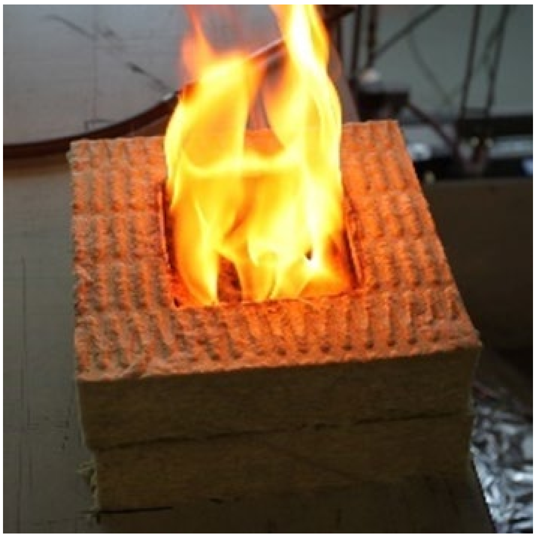

Figure 6-15b: 100 % recycled polyester, 276 g/m^2. Flaming combustion.

Different behaviour of different foams, Figure 6-16 and Figure 6-17.

Reference cotton fabric on standard polyurethane foam (30 kg/m^3)

Figure 6-16a: o seconds after ignition.

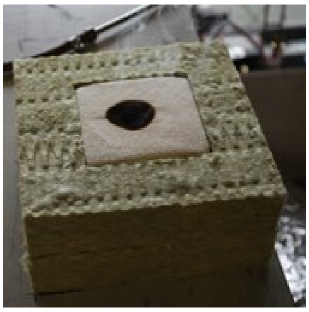

Figure 6 16b: 1 min. Smouldering fire.

Figure 6-16c: 4 min. Smouldering fire.

Reference cotton fabric on high resilience polyurethane foam (32 kg/m^3)

Figure 6-17a: o seconds after ignition.

Figure 6-17b: 1 min. Flaming.

Figure 6-17c: 4 min. Flaming.

3D thermoplastic fibre web structure compared to standard polyurethane foam, standard cotton fabric. Similar behaviour for both filling materials.

Reference cotton fabric on non flame-retardant polyurethane foam, 35 kg/m^3

Figure 6-18a: 0 sec

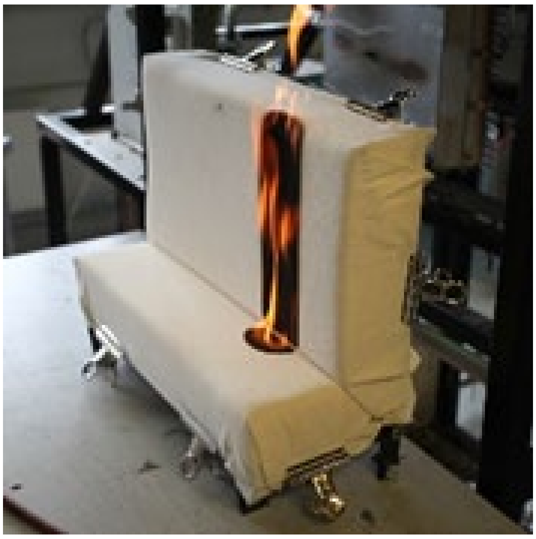

Figure 6-18b: 30 sec

Reference cotton fabric on 3D thermoplastic fibre web structure

Figure 6-19a: 0 sec

Figure 6-19b: 30 sec

3D thermoplastic fibre web structure compared to standard polyurethane foam, polyester fabric. Similar behaviour for both filling materials.

Polyester, (97% Polyester postconsumer recycled / 3% polyester), Crepe, 212 g/m2 on non flame-retardant polyurethane foam, 35 kg/m3

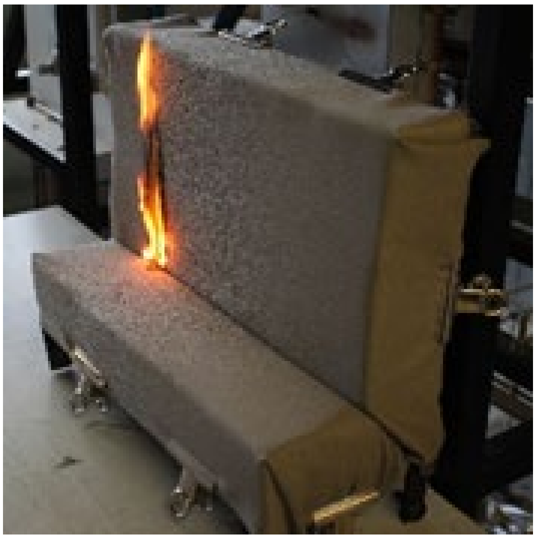

Figure 6-20a: 0 sec

Figure 6-20b: 30 sec

Polyester, (97% Polyester postconsumer recycled / 3% polyester), Crepe, 212 g/m^2 on 3D thermoplastic fibre web structure

Figure 6-21a: 0 sec

Figure 6-21b: 20 sec

The effect of glass fibre barrier between fabric and filling material. 3D thermoplastic fibre web structure compared to standard polyurethane foam, polyester fabric. The glass fibre fabric barrier is effective, slightly more sofor the polyurethane foam.

Polyester, (97% Polyester postconsumer recycled / 3% polyester), Crepe, 212 g/m^2, with glass fibre barrier on non flame-retardant polyurethane foam, 35 kg/m^3

Figure 6-22a: 0 sec

Figure 6-22b: 60 sec

Polyester, (97% Polyester postconsumer recycled / 3% polyester), Crepe, 212 g/m^2, with glass fibre barrier on 3D thermoplastic fibre web structure

Figure 6-23a: 0 sec

Figure 6-23b: 60 sec

7 Discussion

Consumer requirements

It has been challenging to find alternative filling materials to replace the commonly used polyurethane foam. Polyurethane has the advantage of being durable, versatile and low cost, but with the disadvantage, from a fire safety perspective, of being a very combustible material. The fire safety issues of polyurethane foam have been dealt with for many years and the most common solution has been to add chemical flame retardants to either the foam itself or to the fabric that covers the foam.

There is a need for product development, taking into account both sustainability and fire safety simultaneously. This combination may be easier on the non-private market than for the private consumer market because of the difficulties in tracing the furnishing and materials, especially for consumer products. If a piece of furniture is to be recyclable it must be possible to take it apart. Being able to take a product apart means that components that add to the fire performance can be changed or removed, which would be challenging for the documentation of the fire performance of the furniture as a whole.

Test methods

When test methods are required that are difficult to pass, the selection of material combinations will be demanding. Materials of low combustibility, alternatives to polyurethane foam and fire barrier materials can be part of the solution. The cover material will play an important part.

In cases where test methods require tests of single components it is not possible to take advantage of the interacting properties of combinations of materials. These types of requirements can force unnecessary use of chemical flame retardants.

There appears to be a variability of the ranking of materials tested under different conditions in this study. The least conservative of the test methods used was the horizontal small-scale flame exposure test. The lack of a vertical surface in which the flame can take hold results in specimens not developing a fire when expected. However, if a specimen does ignite and fire spreads using this method, it is a poor combination of materials. Also, the test method is simple to perform and provides a quick scan of different variations that enables simple screening out of poorly performing materials.

An important limitation to EN 1021-2 test method with the mock-up chair test, is that it is a materials test. It does not allow for different design features being part of the fire safety solution. A complete furniture may be tested with the corresponding ignitions sources; however, many material combinations lead to very high costs for testing.

Gaps between sustainability and fire safety

To evaluate where the gaps exist between sustainability, environmental impacts, and fire performance, the best performing materials identified in each of these analyses are summarised in Table 7-1 (sustainability and environmental) and the text below (fire performance). In Table 7-1 a material receives an x for each occurrence that it is a top performer in a sustainability or environmental category.

Table 7-1: Summary of sustainability and environmental best performers.

Material	Sustainability	Environmental
Covers		
Cotton	xxx	
Polyester (Trevira CS)	xxx	x
Wool	xxx	x
Polyester	xxx	x
Polyamide 6,6 (nylon)	x	xxxxx
Modacrylic	NA	NA
Artificial leather (50 % polyamide, 50 % polyurethane)	x	
LenzingTM FR (viscose base)		x
Visil (viscose based)		x
Barriers		
Glass fibre plain weave (100 % glass fibre)	xxx	xxxxxxx
Aramid fibre plain weave (100 % aramid fibre)	NA	NA
Wadding		
Polyester wadding (100 % polyester)	xxx	x
Wool wadding	xxx	x
Filling materials		
Polyurethane foam (100 % polyurethane)	xx	x
Latex foam, natural (rubber tree)	xx	xxxxxxx

Summary of fire performance:

The most important property of the cover is to protect the filling from the fire and the cover affects how a fire spreads into the filling. A fabric that melts away will expose the filling to the ignition source. Both ignition resistance and the fire behaviour affect the fire safety performance of different material combinations. Natural fibres such as cotton and wool do not normally need control measures in order to resist cigarette or flame ignition sources. However, the area density of these fabrics will be important. For larger ignition sources there is most probably need for control measures, such as flame retardants and fire barrier materials. Synthetic fibres normally resist ignition by a smouldering cigarette but will most likely need control measures in order to resist a flaming ignition source, even smaller ones. We have seen that speciality fibres such as modacrylic and viscose based fire-resistant fibres are able to improve the fire performance of various commodity fibres e.g. by blending the fibres into special yarns.

Cotton, wool and polyester had equally high sustainability scores, although cotton was a poor performer environmentally. Polyamide was clearly the highest environmental cover material; however, it is not used as commonly as cotton, wool, or polyester in loose furnishings. Understanding the reasons for this is outside the scope of this project.

Fire barriers, especially glass fabrics, do not contribute to fire development but can enhance the fire properties of the combination of materials in e.g. a sofa considerably.

On a per kg basis, glass fibre was one of the highest performing materials in this study from a sustainability and environmental perspective.

When using wadding, a relatively small amount is normally used. From previous work [14] it was shown that the polyester wadding did not considerably affect the fire performance. In this project it has been shown that wool wadding used between cotton cover and polyurethane foam only enhances the fire performance when the wadding is densely felted. A loose wool wadding does not seem to have a great effect as compared to cotton cover directly on the polyurethane foam. Also, it is indicated that it may produce more smoke initially. From a sustainability and environmental point of view, polyester and wool are equally good choices for wadding.

The filling of furnishing has the greatest impact on fire safety because it may contribute with large amounts of heat energy and smoke, and without any control measures the ignition resistance can be very low.

Although the 3D web filling showed some potential when tested in the cone calorimeter, it did not perform well when exposed to an open flame. Using a glass fibre barrier improves the fire performance, but it is still weaker than the polyurethane foam. Despite this, these types of new filling materials should be further explored to see if there are more suitable cover material to combine them with than what was tested here. A lower peak heat release rate is required, and it is important to slow down the fire development. It would also be interesting to investigate the behaviour of the 3D web filling in a large-scale room fire. Compared to non-flame-retardant polyurethane foam, the 3D web filling showed a lower heat release and a delayed fire development, so the cone calorimeter test results show a slight improvement as compared to polyurethane foam. A 3D web filling made of less combustible material would have been beneficial, but the material as the one tested in this study should be protected from ignition. The choice of cover material is important; a polyester fabric melts away from the flame, exposing the filling, which also have free access to oxygen because of the open structure of the filling. The effect of various barriers and wadding should also be investigated.

The comparison of latex and polyurethane foam as filling material in terms of sustainability and environmental impacts shows that latex is a much higher performer than polyurethane. In this context, on a per kg basis, latex was one of the highest performing materials in the study.

In the previous study [14] as well as in this one, it has been shown that a glass fibre fabric barrier between polyurethane foam and cover fabric increases the fire performance.

The potentially toxic and eco-toxic impacts of using FRs in products is motivation for exploring alternative methods of achieving comparable fire performance. For this reason, and because there are many types of FRs but very little information about the FRs that were used in the loose furnishing materials in this study, FRs were not included in the sustainability and environmental impact analyses.

Suggested fire safety requirements

A strategy where the same level of fire classification is required both for surfaces on walls and ceiling and for the upholstered furniture and mattresses in the same area was mentioned in section 4.5 (principle of parallelity). This could be a good idea and would mean an improved fire safety level in many areas. However, for buildings with the lowest requirements to surfaces on walls and ceilings – as e.g. ordinary dwellings - this would mean that the requirements to furniture also would remain low. However, if furniture with higher fire safety requirements were used in ordinary dwellings this would mean a large improvement in the fire safety level. Dwelling fires have a relatively high probability, and the consequences can be large. Most fatal fires take place in dwellings, the fires are often large and have spread to other rooms in the dwelling when the fire brigade arrives [49,50]. Furniture with better fire properties than today's standard could delay the fire development and prevent fire spread, and thereby increase the available time for evacuation and also improve the firefighters' possibility to mitigate the fire at an early stage.

To avoid any fire performance requirements as a means to reduce the use of flame retardants, is not a good idea. As a minimum, there should be a small flame ignition resistance requirement, to ensure that furniture is not easily ignitable. Although there may still be a conflict between fire performance and the use of chemical flame retardants, it is better to have low fire safety requirements, than no requirements at all. In that way, a focus is maintained upon reaching a certain fire performance level.

To gain more knowledge other tests can be performed additionally, e.g. large scale tests with heat release rate and smoke production measurements. Furniture with good fire performance with regards to fire development can cause a fire to be more suppressed instead of escalating violently with a free burning sofa releasing 1-2 MW.

Fire performance requirements on individual components should be avoided since this may force unnecessary use of chemical flame retardants.

8 Conclusions

- As a minimum EN 1021-2 should be required from furniture in the Nordic countries.
- To avoid forcing the unnecessary use of chemical flame retardants, there should not be fire performance requirements on individual material components.
- In order for furniture to be both sustainable and fire safe, there are limitations to both design (e.g. it should be possible to dismantle and recycle the individual material components) and use of materials (materials should in themselves be defined as sustainable, yet at the same time have satisfying fire performance).
- There is a potential in development towards alternatives to the combustible polyurethane foams.
- The interaction of fire performance properties of different materials should be studied further.
- We need to test more variations of material combinations and in larger tests (full size furniture) in order to better understand the mechanisms of materials and how design affects the fire performance.
- The following gaps between sustainability and fire safety have been identified:
    - The use of flame retardants makes it challenging to achieve sustainability, partly because polyurethane with flame retardants are difficult to recycle. Innovation is needed.
    - It is difficult to control fire performance of a product over time, in a circular economy. Knowledge is lost, products may change by substituting or removing components and some properties may fade with time. This is especially true for products on the private market.
- The sustainability and environmental impact performance of materials is subjective. The importance of each category is dependent on the needs and interests of individuals using the results, therefore it is very difficult to impose a weighted rating system objectively. For example, if renewable materials are very highly valued, wool and cotton would receive higher ratings. The rating system used in this study was very simple and transparent and a more sophisticated method could lead to different results.

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Appendix A Main materials producers around the world

Material	Main producers (source countries)
Cotton	China, India, Pakistan, Brazil, Uzbekistan, Australia, Turkey and United States[1].
Wool	Australia, China, United states, New Zealand, Argentina, Turkey, Iran, United Kingdom, India, Sudan and South Africa[2].
Polyester	China, Taiwan, Korea, India, Japan, Indonesia, Thailand, Pakistan, Malaysia, United States and West Europe[3].
Polyester Trevira CS	Has offices worldwide[4], Denmark.
Nomex (meta aramide)	China, United States, Western Europe, Japan and Russia[5,6].
Aramid fibre (para aramide)	United States (Kevlar), Northern Ireland (Kevlar), Teijin Ltd of Japan (Technora), Netherlands (Twaron) and Russia (Fenylene)[6].
Polyamide (nylon)	China, United State, Taiwan, Korea, India, Japan, Indonesia, Thailand, Pakistan, Malaysia, USA and West Europe [7,8].
Modacrylic	Japan (Kaneka Corporation), China (Fushun Rayva Fibre Co., Ltd.), Taiwan (Formosa Chemicals & Fibre Corporation), China (Tianjin GT New Material Technology Company Limited), and China (Fushun Huifu Fire Resistant Fibre Company Limited) and Turkey (AKSA) [9,10].
Viscose	China, India, Indonesia, Europe, Thailand, Taiwan, Japan, and North America[11].
Artificial leather	China, India, Japan, Taiwan, and United States[12].
Polyvinyl chloride (PVC)	China, United States, Germany, South Korea, Japan[13].
Modal	Austria (the company Lenzing fibres), India, China, Taiwan, Indonesia, United Kingdom and United States[14,15].
Jersey	United Kingdom, China, Turkey, Italy, Pakistan, United States, France, India, Germany, Bangladesh, Spain and Mexico[16].
Fleece (100% polyester)	China, Pakistan, Bangladesh, India, United Kingdom, Turkey, Spain and Taiwan[16].
Felted	China, United Kingdom, Turkey, Italy, India, Germany, France, south Korea, Argentina and United States[16,17].
Visil (viscose base)	China (Sateri) and Finland[18].
Lenzing FR	Austria[19]
Basofil fibers (Melamine fibre)	Germany (BASF AG)[20].
Glue	England, France, Italy, Portugal, Slovakia and Spain[21].
Glass fibre	North America: United States, Canada and Mexico Europe: Germany, United Kingdom, France, Italy, Russia, Spain and Benelux Asia Pacific: China, Japan, India, Southeast Asia and Australia Latin America: Brazil, Argentina and Colombia Middle East and Africa: Saudi Arabia, UAE, Egypt, Nigeria and South Africa[22]

Material	Main producers (source countries)
Polyurethane foam	China, India, Mexico and Central America, Russian Federation, Japan, Europe*, Africa and Middle East[23,24] *Europe: Austria, Belgium, Denmark, Estonia, Finland, France, Germany, Greece, Hungary, Ireland, Italy, Kosovo, Lithuania, Netherlands, Norway, Poland, Portugal, Romania, Russia, Serbia, Slovenia, Spain, Sweden, Switzerland, Turkey, Ukraine and United Kingdom
Latex foam	Natural rubber: Thailand, Indonesia, Vietnam, India, China, Malaysia, Philippines, Guatemala, Côte d'Ivoire, Brazil, Myanmar, Nigeria, Sri Lanka, Liberia, Cameroon, Mexico, Gabon, Ghana, Cambodia and Ecuador[25] Synthetic rubber: United States, Argentina, Brazil, and Mexico, United Kingdom, Germany, Spain, Italy, Turkey, France, Western Europe: Armenia, Hungary, Poland, Russia, Serbia, Czech Republic, India, Indonesia, China, South Korea, Thailand, Taiwan, Singapore, Japan, Iran, Saudi Arabia and South Africa[26]

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Appendix C Weighted average of transportation distances

Materials	Countries	% of import	Distance from sources to Gothenburg					Distance from Gothenburg to Kinnarps[a]		Total transportation distance for 1 kg material	
			Truck		Ship			Truck		Ship	Truck
			km	% km	Nautical miles[b]	km	% km	km	% km	km	km
Cotton	**China** Port of Hong Kong	40			10192 Suez Canal	188766	7550	129	51,6	13610	129
	India Kochi port	30			6955 Suez Canal	12881	3864	129	38,7		
	Turkey Istanbul port	25			3605 Strait of Gibraltar	6676	1669	129	32,25		
	Brazil Port of Rio de Janeiro	5			5687 Direct way	10532	527	129	6,45		
Wool	**China** Port of Hong Kong	40			10192 Suez Canal	18876	7550	129	51,6	11645	129
	United Kingdom Port of Immingham	20			494 Direct way	915	183	129	25,8		
	Turkey Port of Istanbul	20			3605 Strait of Gibraltar	6676	1335	129	25,8		
	India Port of Kochi	20			6955 Suez Canal	12881	2576	129	25,8		

Polyester	**China** Port of Hong Kong	45			10192 Suez Canal	18876	8494	129	58,05	15438	129
	India Port of Kochi	35			6955 Suez Canal	12881	4508	129	45,15		
	Pakistan Port of Karachi	20			6577 Suez Canal	12181	2436	129	25,8		
Polyester Trevira CS	**Denmark** Port of Ebeltoft	100			155 Direct way	287	287	129	129	287	129
Polyamide **(nylon)**	**China** Port of Hong Kong	40			10192 Suez Canal	18876	7550	129	51,6	16261	129
	India Port of Kochi	30			6955 Suez Canal	12881	3864	129	38,7		
	Indonesia Port of Jakarta	15			8992 Suez Canal	16365	2455	129	19,35		
	Malaysia Sungai Udang Port	15			8609 Suez Canal	15944	2392	129	19,35		
Viscose	**China** Port of Hong Kong	55			10192 Suez Canal	18876	10382	129	70,95	16889	129
	India Port of Kochi	30			6955 Suez Canal	12881	3864	129	38,7		
	Thailand Port of Laem habang	15			9516 Suez Canal	17624	2644	129	19,35		

Glass fibre	**Germany** Port of Wilhelmshaven	40			363 Direct way	672	269	129	51,6	2392	129
	France Port of La Rochelle	30			1122 Direct way	2078	623	129	38,7		
	Italy Port of Fumicino	30			2700 Strait of Gibraltar	5000	1500	129	38,7		
Polyurethane foam	**China** Port of Hong Kong	50			10192 Suez Canal	18876	9438	129	64,5	12658	489
	India Port of Kochi	25			6955 Suez Canal	12881	3220	129	32,25		
	Austria Wein to Gothenburg	25	1441	360				129	32,25		
Latex foam **(natural)**	**China** Port of Hong Kong	45			10192 Suez Canal	18876	8494	129	58,05	16527	129
	India Port of Kochi	35			6955 Suez Canal	12881	4508	129	45,15		
	Thailand Port of Laem Chabang	20			9516 Suez Canal	17624	3525	129	25,8		
Latex foam **(synthetic)**	China Port of Hong Kong	40			10192 Suez Canal	18876	7550	129	51,6	10515	129
	Spain Port of Huelva	30			1732 Direct way	3208	962	129	38,7		
	Turkey Port of Istanbul	30			3605 Strait of Gibraltar	6676	2003	129	38,7		

[a] The destination in Sweden is a generic point between Gothenburg and Stockholm and was chosen as a reasonably representative location for a Swedish manufacturer of loose furnishings. Sea transportation[5,6] and land transportation[7] distances are web-based data. Ports in source countries are considered to be in the middle of that country (not the farthest or closest distance to destination port in Sweden).

[b] Nautical miles is a unit used in measuring distances at sea in which 1 nautical mile is equal to 1,852 metres.

[5] 'Sea-distances.org', 2019. [Online]. Available: https://sea-distances.org/.
[6] 'World Port Source', 2019. [Online]. Available: http://www.worldportsource.com.
[7] 'Distance Calculator', 2019. [Online]. Available: http://www.distancecalculator.co.za/Info.aspx

Appendix D Assumptions used at the use phase stage

Based on experience, 1 min time is required to clean 1 m^2 per week by vacuum cleaner.

The vacuum cleaner is considered 1500W which means:

1500 W x 1 h (=60 min) » (1500/60) W x 1 min » 25 Wmin/week » 0.4167 Wh/week

Following calculations are based on assuming Martindale index as the minimum number of cycles that the fabrics can be used. Then, we will have the following assumptions:

Cycle per day: 10 times seating on the same seat.

Cycle per week: 7 x 10 = 70 cycle

Cycle per year: 52 x (7 x 10) = 3640 cycle

If we consider minimum cycle for example 30000 for cotton, then:

30000 cycle / 3840 cycle = 8.24 » almost 8 years

Electricity consumption for 8 years is:

8 years x (52 week/1 year) x (0.4167 Wh/1 week) = 173.35 Wh

Appendix E Sensitivity analysis of LCA screening tool input

Materials	Critical value	Default critical values (kg/m^2)	200% change in critical values (kg/m^2)	200% change percentage Results = (% change output)/(% change input)						
				Global warming (kg CO_2 eq)	Freshwater eutrophication (kg P eq)	Terrestrial ecotoxicity (kg 1,4-DCB)	Land use (m2a crop eq)	Mineral resource scarcity (kg Cu eq)	Fossil resource scarcity (kg oil eq)	Water consumption (m^3)
Cotton	Density	0.55	1.10	0.28	0.28	0.28	0.28	0.28	0.28	0.28
Polyester (Trevira CS)		0.31	0.63	0.16	0.16	0.16	0.16	0.16	0.16	0.16
Wool		0.31	0.63	0.16	0.16	0.16	0.16	0.16	0.16	0.16
Polyester		0.31	0.63	0.16	0.16	0.16	0.16	0.16	0.16	0.16
Polyamide 6.6		0.31	0.63	0.16	0.16	0.16	0.16	0.16	0.16	0.16
Viscose		0.31	0.63	0.16	0.16	0.16	0.16	0.16	0.16	0.16
Glass Fibre		0.31	0.63	0.16	0.16	0.16	0.16	0.16	0.16	0.16
Polyester wadding		0.31	0.63	0.16	0.16	0.16	0.16	0.16	0.16	0.16
Wool wadding		0.31	0.63	0.16	0.16	0.16	0.16	0.16	0.16	0.16
Polyurethane Foam		3.30	6.60	1.65	1.65	1.65	1.65	1.65	1.65	1.65
Latex Foam, synthetic		3.30	6.60	1.65	1.65	1.65	1.65	1.65	1.65	1.65
Cotton	Service lifetime	0.55	1.10	0.28	0.28	0.28	0.28	0.28	0.28	0.28
Polyester (Trevira CS)		0.31	0.63	0.16	0.16	0.16	0.16	0.16	0.16	0.16
Wool		0.31	0.63	0.16	0.16	0.16	0.16	0.16	0.16	0.16
Polyester		0.31	0.63	0.16	0.16	0.16	0.16	0.16	0.16	0.16
Polyamide 6.6		0.31	0.63	0.16	0.16	0.16	0.16	0.16	0.16	0.16
Viscose		0.31	0.63	0.16	0.16	0.16	0.16	0.16	0.16	0.16
Glass Fibre		0.31	0.63	0.16	0.16	0.16	0.16	0.16	0.16	0.16
Polyester wadding		0.31	0.63	0.16	0.16	0.16	0.16	0.16	0.16	0.16
Wool wadding		0.31	0.63	0.16	0.16	0.16	0.16	0.16	0.16	0.16
Polyurethane Foam		3.30	6.60	1.65	1.65	1.65	1.65	1.65	1.65	1.65
Latex Foam, synthetic		3.30	6.60	1.65	1.65	1.65	1.65	1.65	1.65	1.65

Appendix F User guide for user sheet of the LCA based screening tool

Option/Case	User guide
Weight g/m^2	Wool: 140, 160, 170, 190, 195 g/m^2 Cotton: 150, 153, 275 g/m^2 Polyester: 280, 380, 400 g/m^2 Glass Fibre: 100 - 1500 g/m^2 Polyamide 6,6: 150, 170, 240 g/m^2 Viscose (estimated as rayon): 130 to 170 g/m^2 Polyester (Trevira CS): 290, 319, 336, 350, 400, 460 g/m^2 Wool+Nylon: 75% W + 25% N .... 335 g/m^2 85 % W + 15% N .... 300 g/m^2 90 % W + 10% N .... 300, 550, 589 g/m^2 95 % W + 5% N .... 400, 450 g/m^2 Wool+Viscose: 70% W + 30% V .... 385, 500 g/m^2 Artificial Leather: 50% PU + 50% Polyamide ..... 420 g/m^2 Polyurethane: 100 to 500 g/m^2
Fabrics categories per density	Light weight fabric: 30-150 g/m^2 Medium Weight: 150-350 g/m^2 Heavy weight: 350+ g/m^2 https://blog.fabricuk.com/understanding-fabric-weight/
Minimum Martindale index	Cotton: 20000, 25000, 30000 Other materials: 500000
Maximum service lifetime	Cotton: 8 years Oil based fabrics: 14 years Latex, natural foam: 8 years Latex, synthetic (SBR latex foam): 14 years
Foam Density (kg/m^3)	Natural: Latex Foam 50 to 95 kg/m^3 Synthetic: Polyurethane Foam & Styrene butadien latex 20 to 80 kg/m^3
Foam, Thickness	Seat cushion: 5 to 6 inch » 12.7 to 15.24 cm Back cushion: 4 to 5 inch » 10.16 to 12.7 cm

Appendix G Comparison of environmental impact categories considering stages and/or main furniture parts

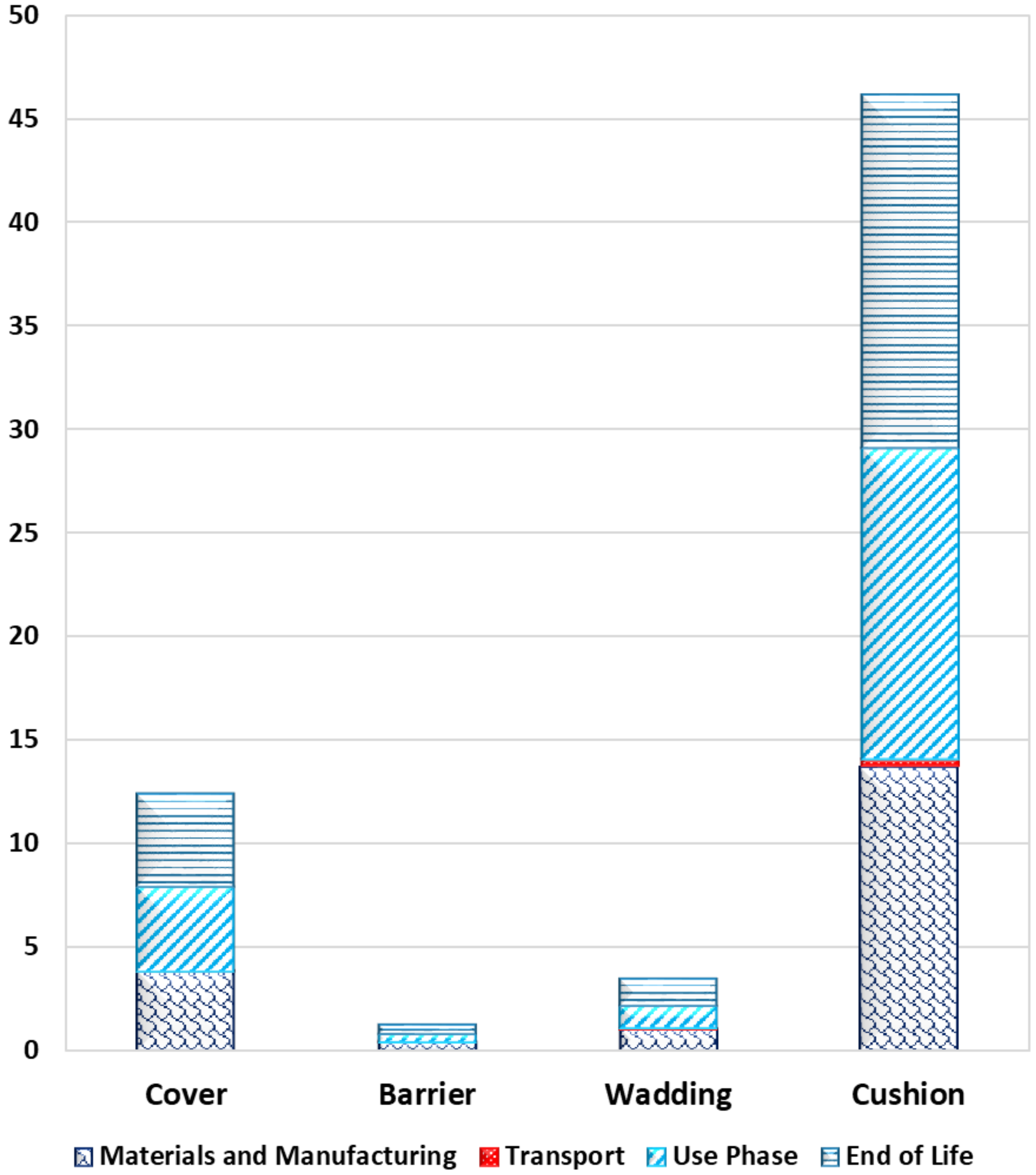

Figure G-1 Comparison of Global warming impact resulted from cover, barrier, wadding and cushion parts of a loose furnishing (per 1 m^2 of the material) at four stages including material and manufacturing, transport, use phase and end of life stages.

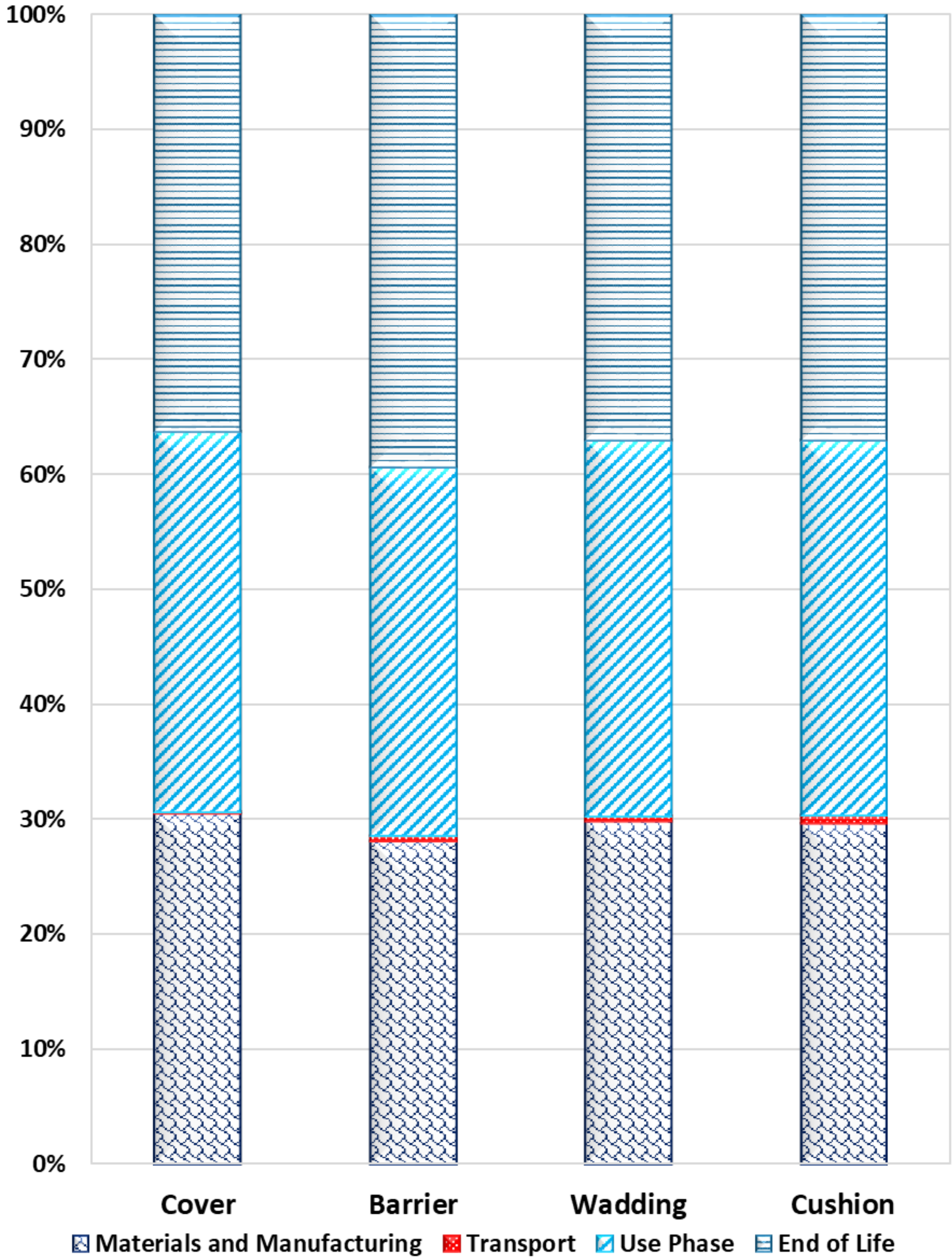

Figure G-2 Comparison of the percentage of the Global warming impact resulted from cover, barrier, wadding and cushion parts of a loose furnishing (per 1 m^2 of the material) correspond to the four stages including material and manufacturing, transport, use phase and end of life stages.

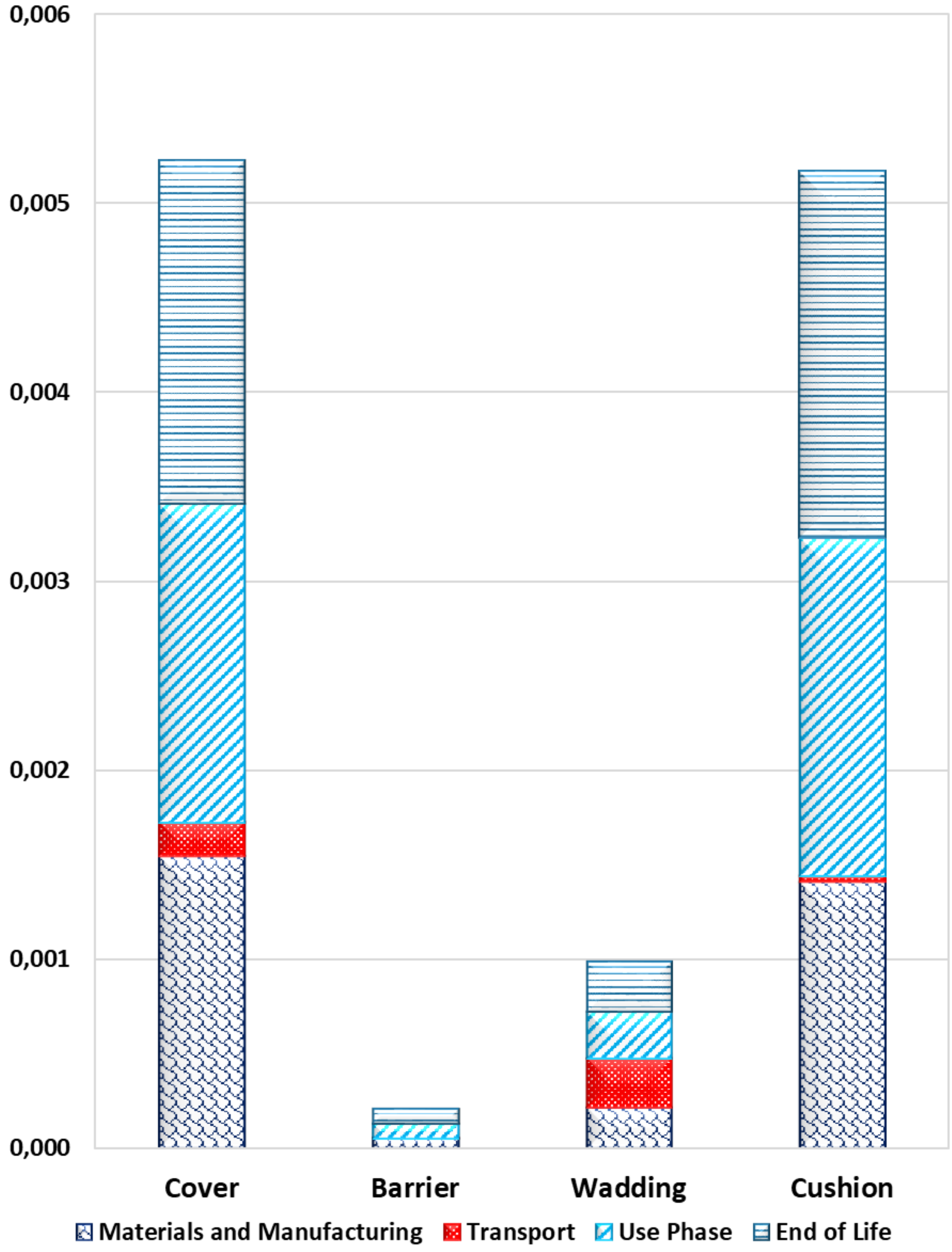

Figure G-3 Comparison of Freshwater eutrophication impact resulted from cover, barrier, wadding and cushion parts of a loose furnishing (per 1 m^2 of the material) at four stages including material and manufacturing, transport, use phase and end of life stages.

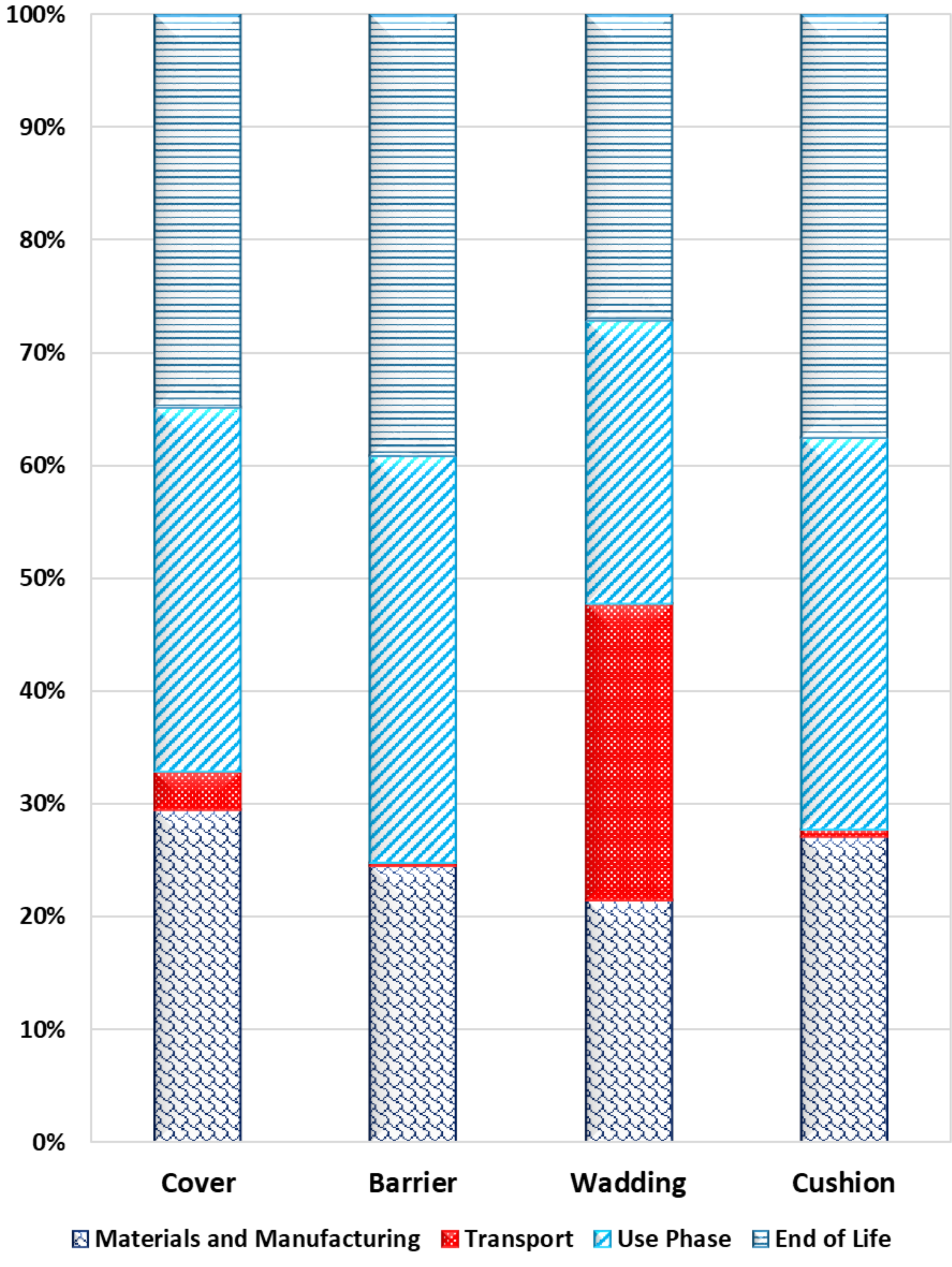

Figure G-4 Comparison of the percentage of the Freshwater eutrophication impact resulted from cover, barrier, wadding and cushion parts of a loose furnishing (per 1 m^2 of the material) correspond to the four stages including material and manufacturing, transport, use phase and end of life stages.

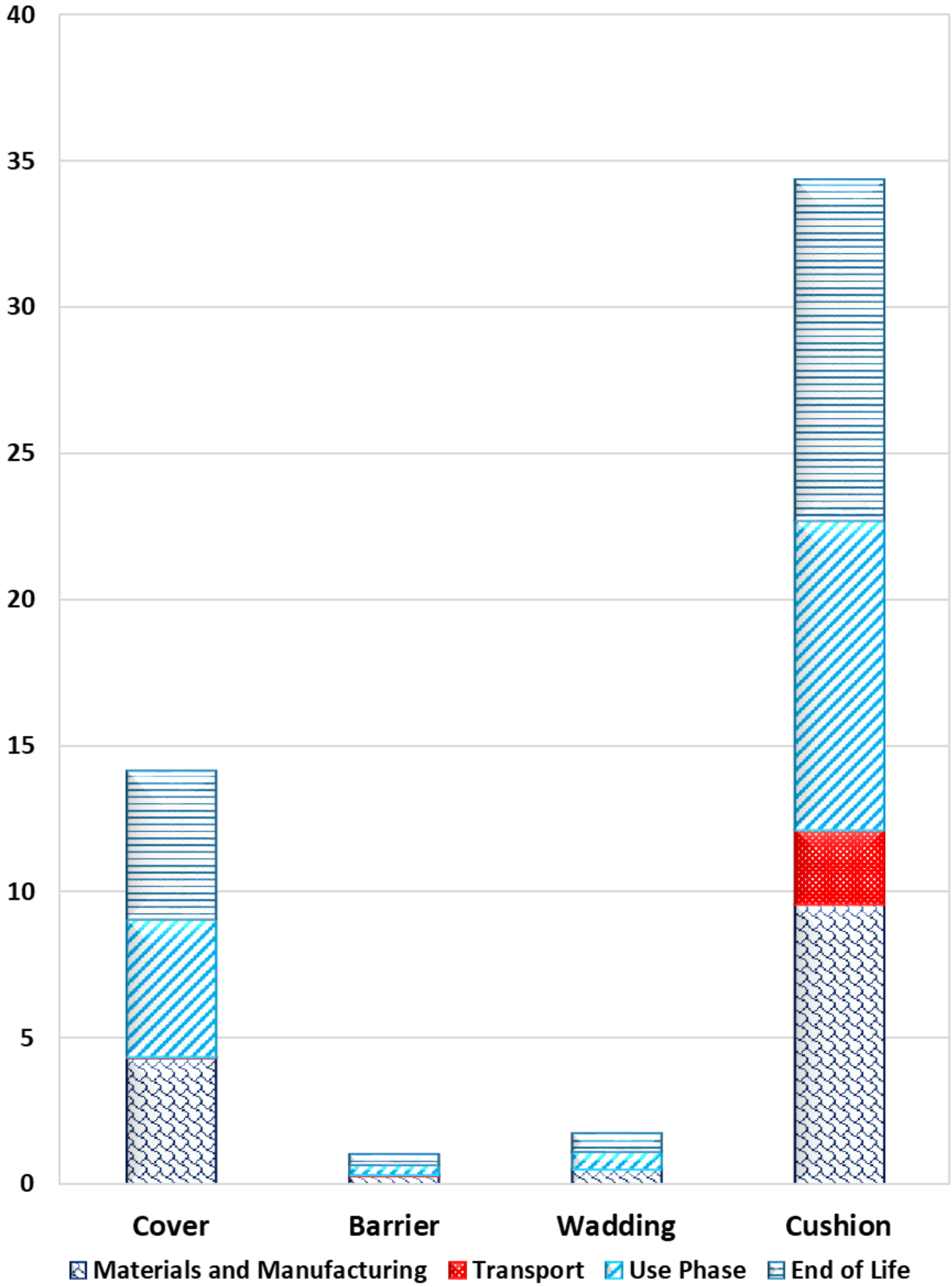

Figure G-5 Comparison of Terrestrial ecotoxicity impact resulted from cover, barrier, wadding and cushion parts of a loose furnishing (per 1 m^2 of the material) at four stages including material and manufacturing, transport, use phase and end of life stages.

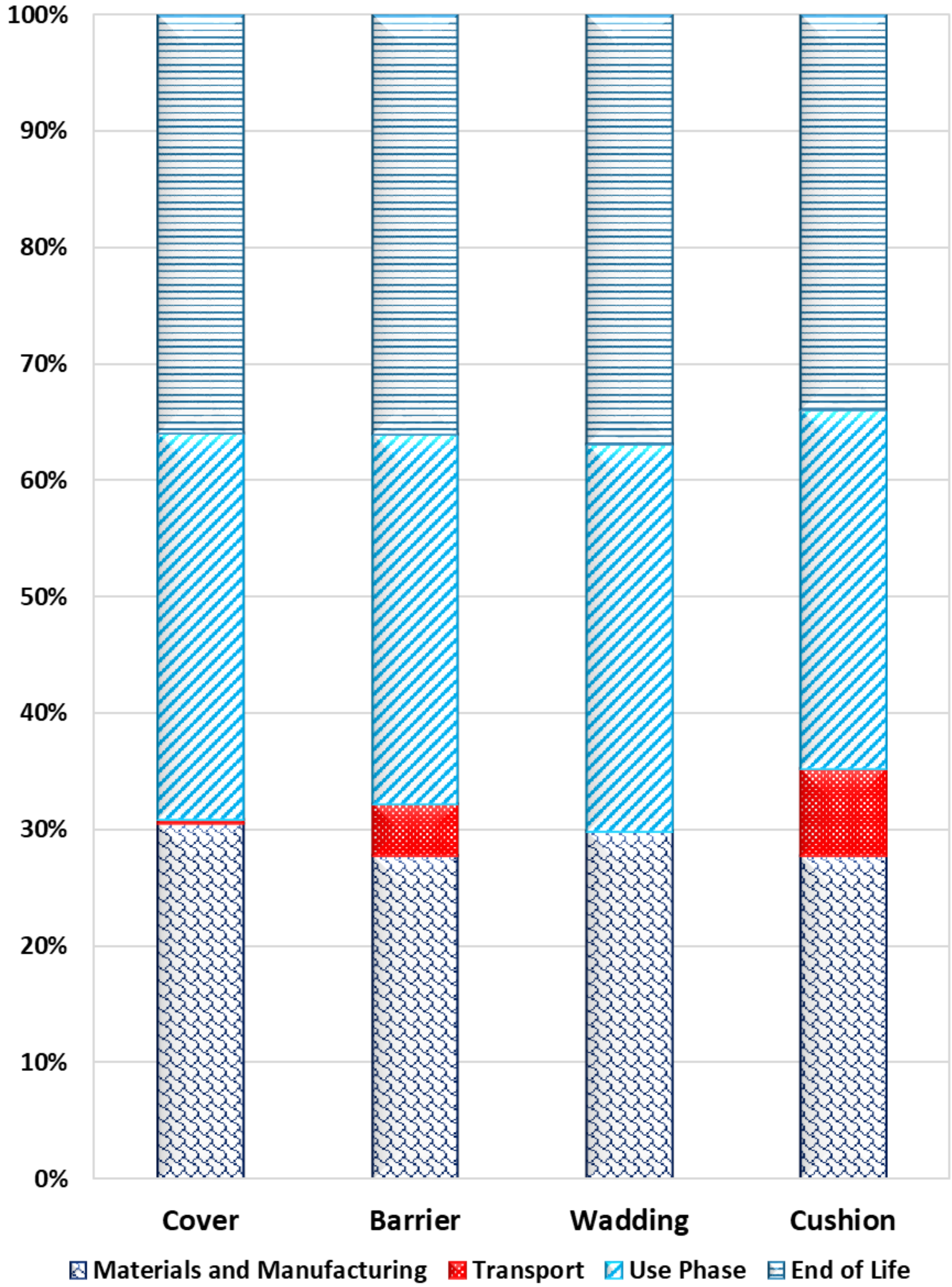

Figure G-6 Comparison of the percentage of the Terrestrial ecotoxicity impact resulted from cover, barrier, wadding and cushion parts of a loose furnishing (per 1 m^2 of the material) correspond to the four stages including material and manufacturing, transport, use phase and end of life stages.

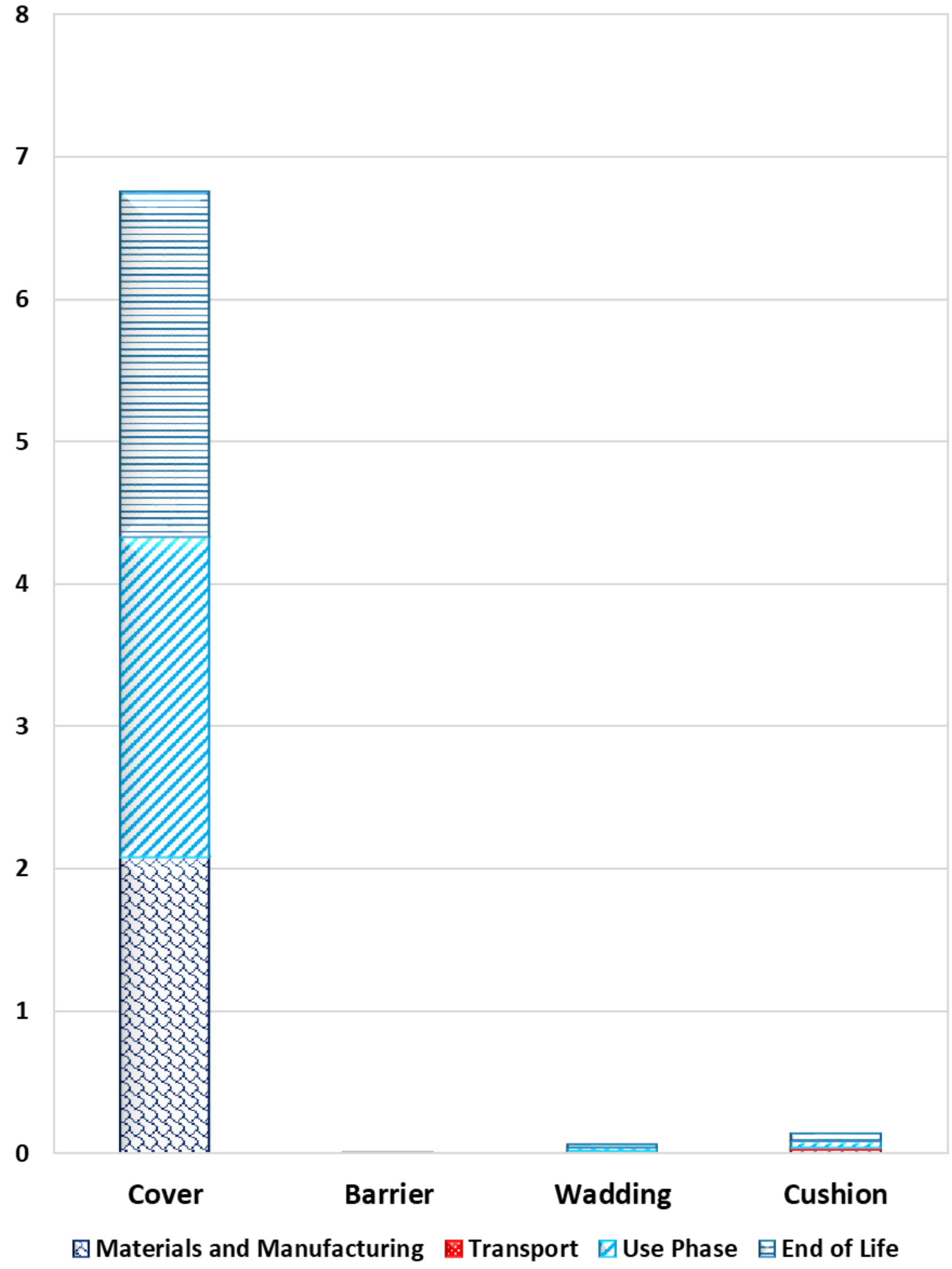

Figure G-7 Comparison of Land use impact resulted from cover, barrier, wadding and cushion parts of a loose furnishing (per 1 m^2 of the material) at four stages including material and manufacturing, transport, use phase and end of life stages.

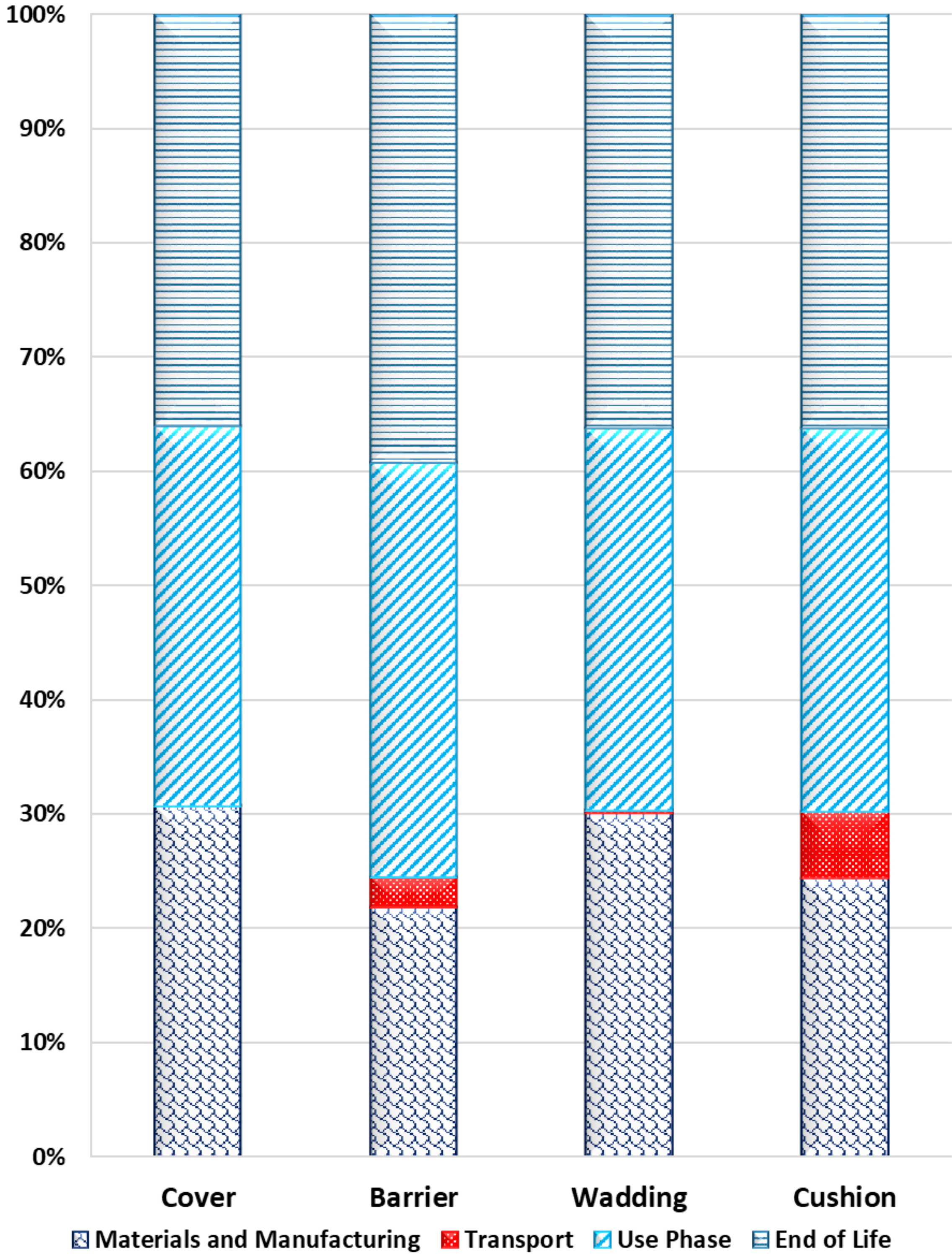

Figure G-8 Comparison of the percentage of the Land use impact resulted from cover, barrier, wadding and cushion parts of a loose furnishing (per 1 m^2 of the material) correspond to the four stages including material and manufacturing, transport, use phase and end of life stages.

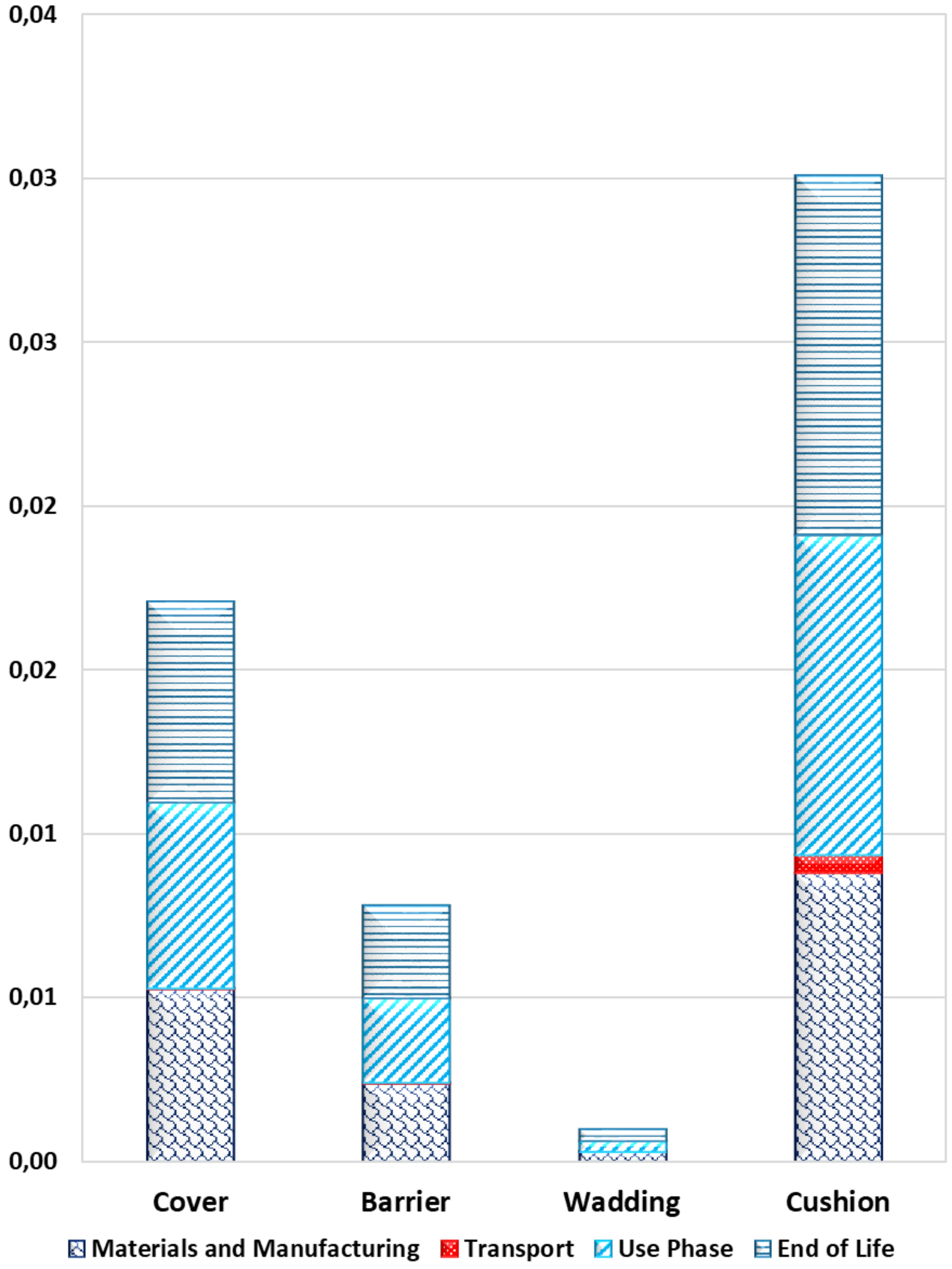

Figure G-9 Comparison of Mineral resource scarcity impact resulted from cover, barrier, wadding and cushion parts of a loose furnishing (per 1 m^2 of the material) at four stages including material and manufacturing, transport, use phase and end of life stages.

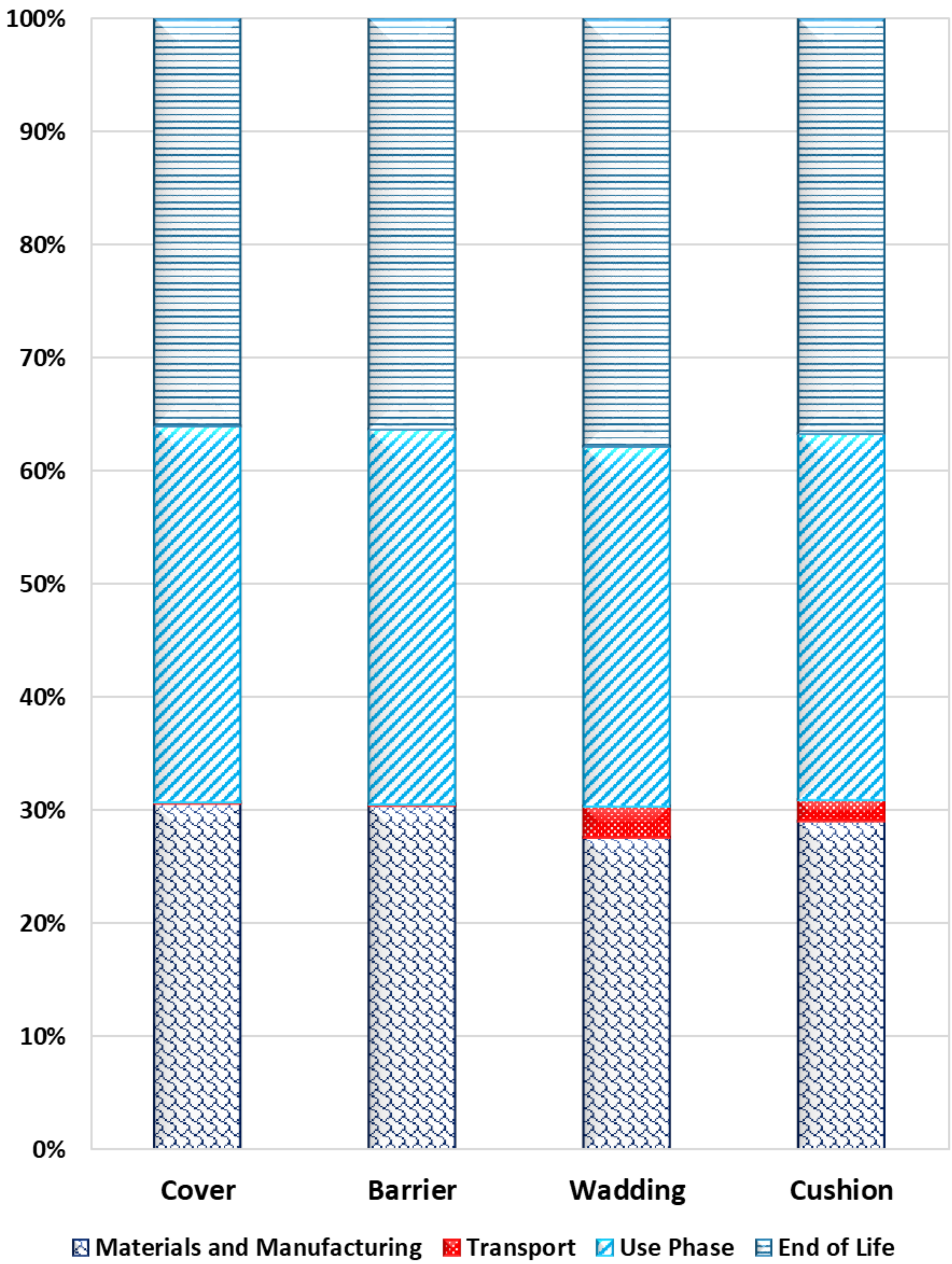

Figure G-10 Comparison of the percentage of the Mineral resource scarcity impact resulted from cover, barrier, wadding and cushion parts of a loose furnishing (per 1 m^2 of the material) correspond to the four stages including material and manufacturing, transport, use phase and end of life stages.

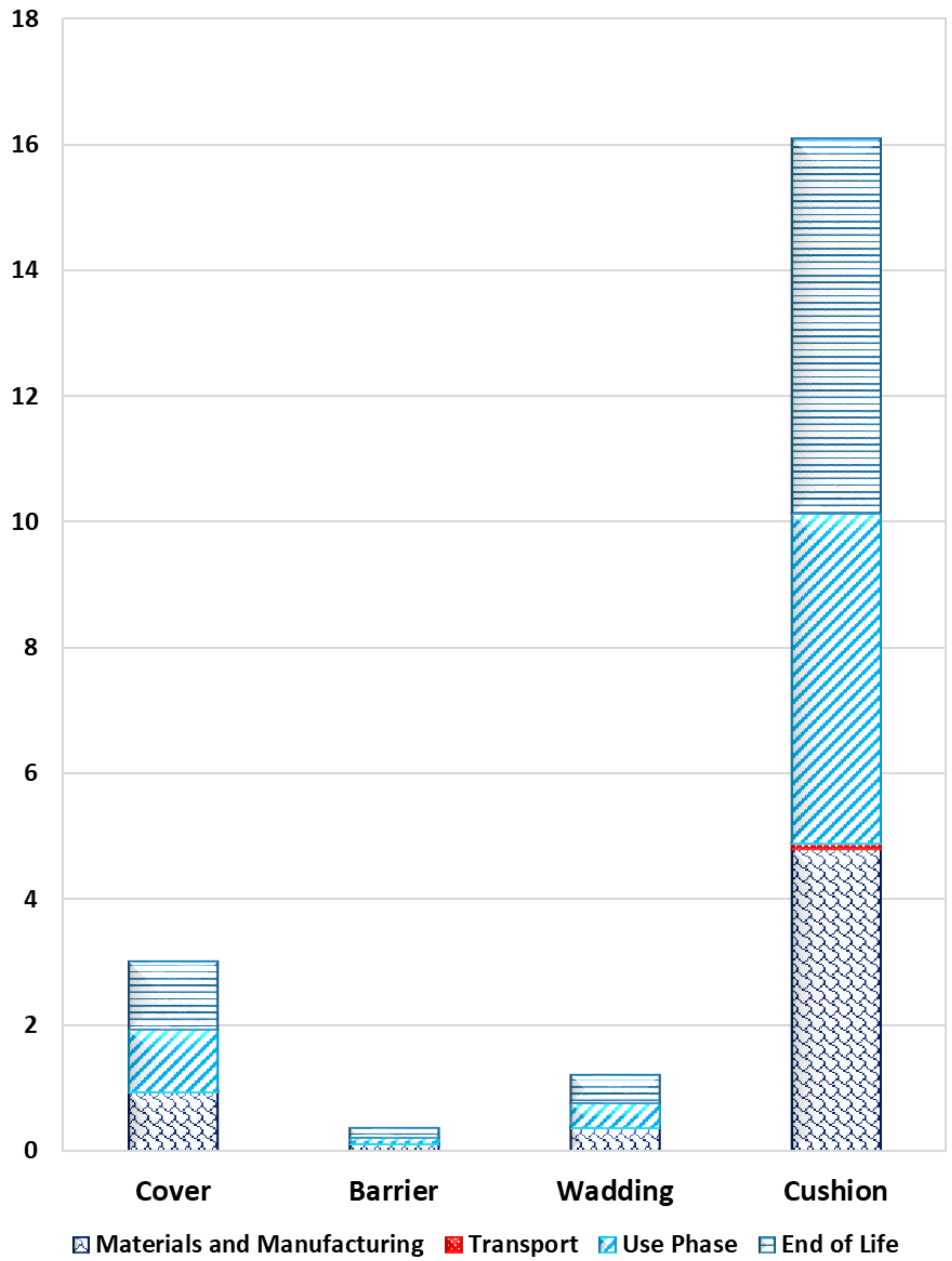

Figure G-11 Comparison of Fossil resource scarcity impact resulted from cover, barrier, wadding and cushion parts of a loose furnishing (per 1 m^2 of the material) at four stages including material and manufacturing, transport, use phase and end of life stages.

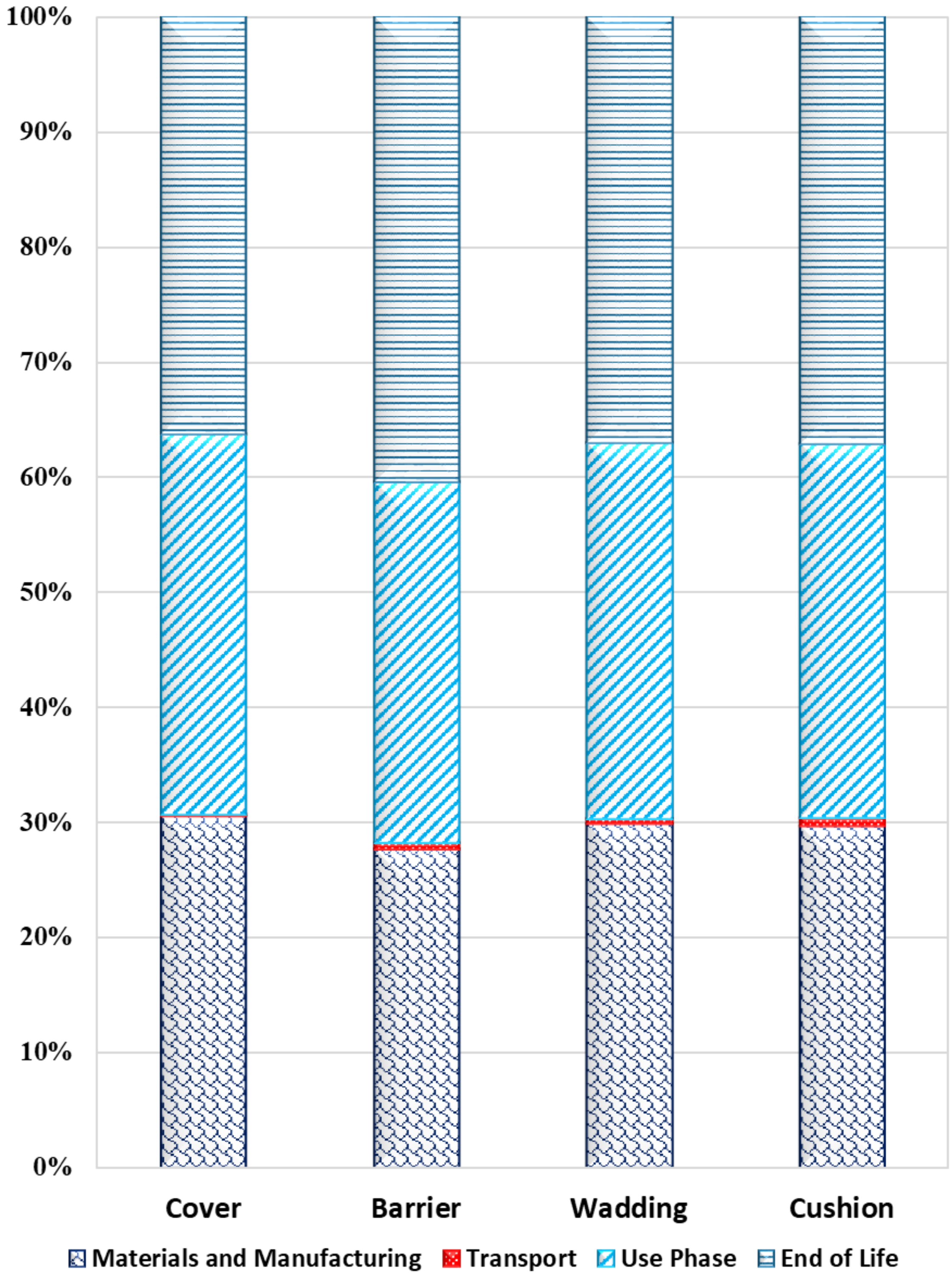

Figure G- 12 Comparison of the percentage of the Fossil resource scarcity impact resulted from cover, barrier, wadding and cushion parts of a loose furnishing (per 1 m^2 of the material) correspond to the four stages including material and manufacturing, transport, use phase and end of life stages.

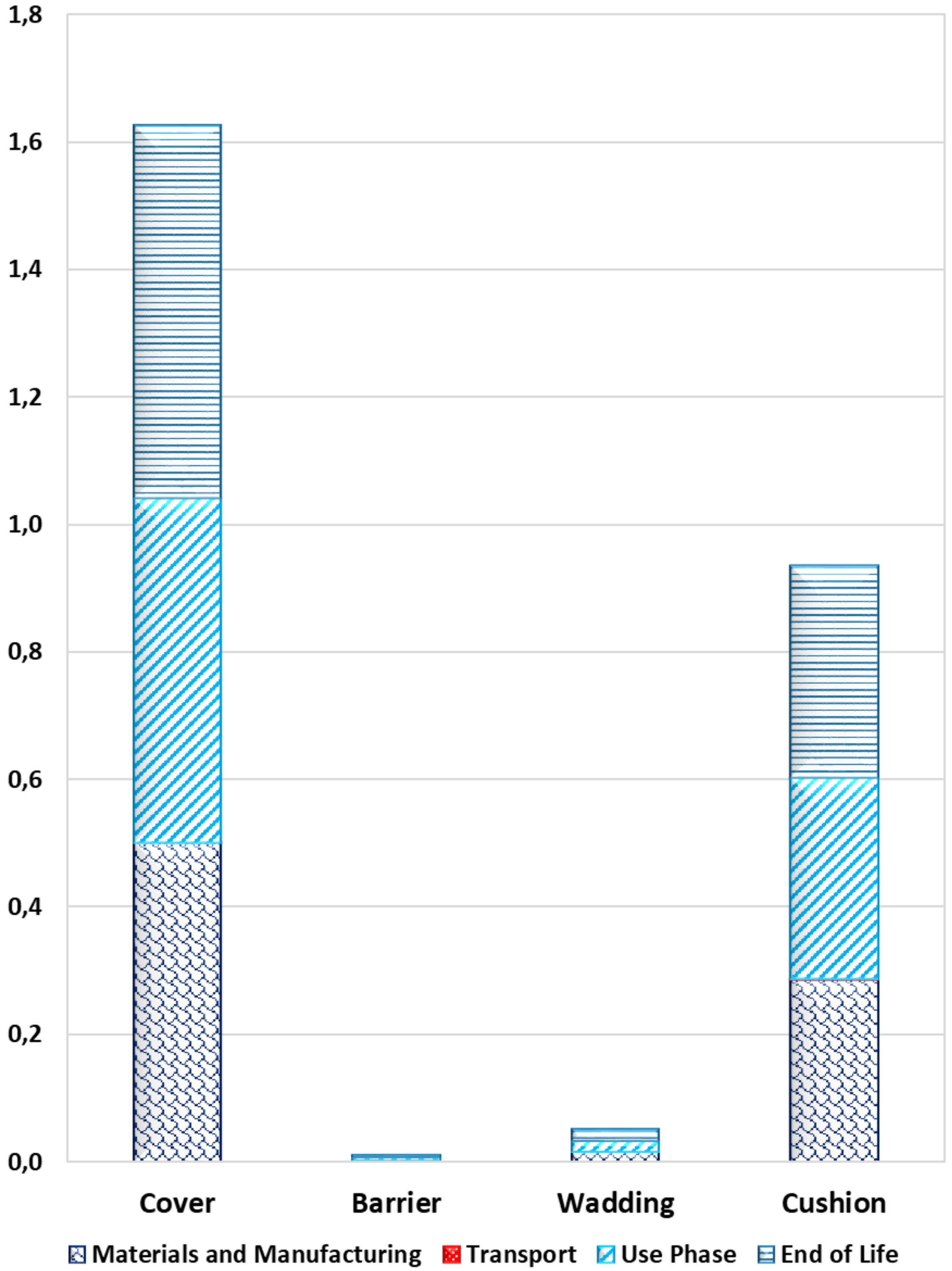

Figure G-13 Comparison of Water consumption impact resulted from cover, barrier, wadding and cushion parts of a loose furnishing (per 1 m^2 of the material) at four stages including material and manufacturing, transport, use phase and end of life stages.

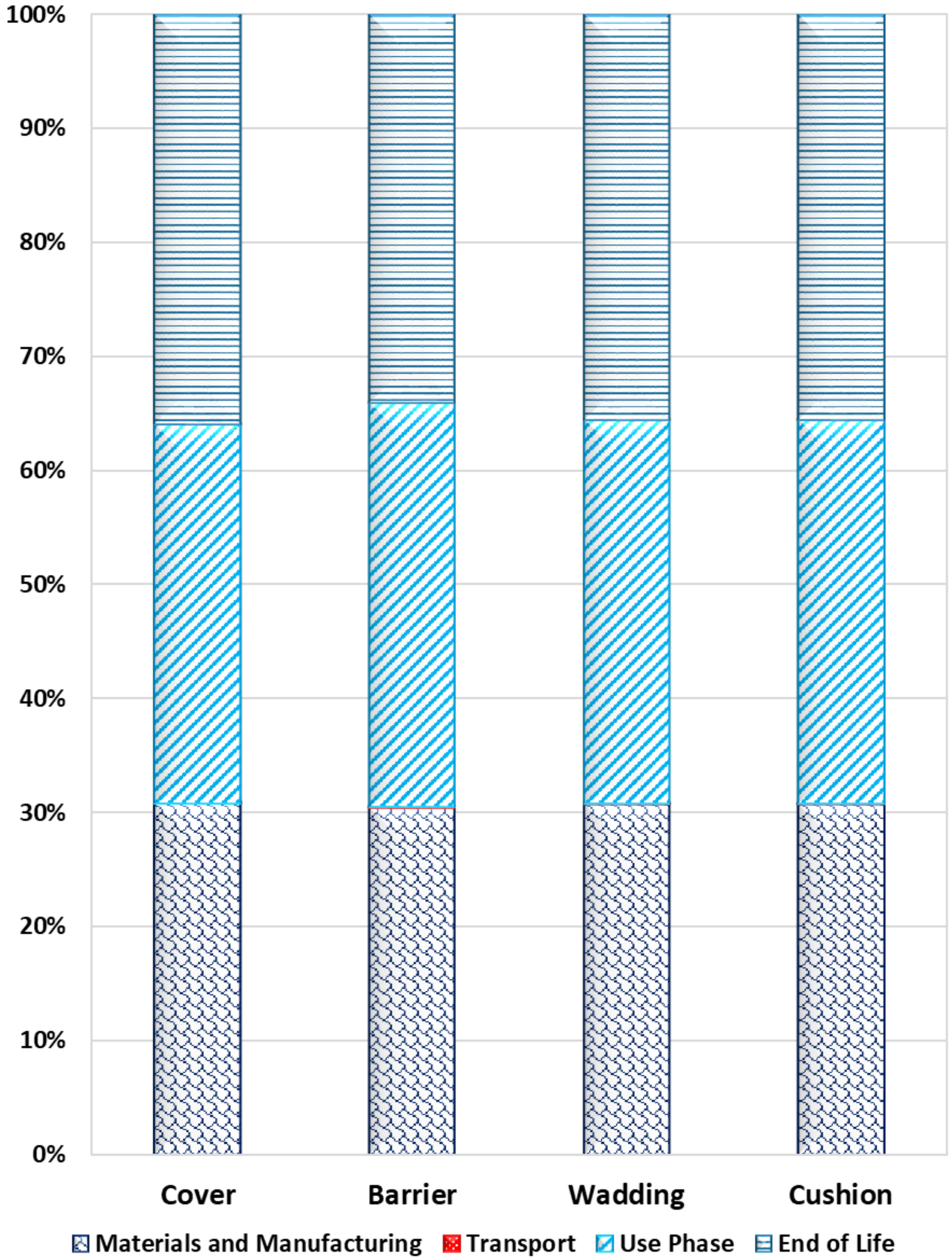

Figure G-14 Comparison of the percentage of the Water consumption impact resulted from cover, barrier, wadding and cushion parts of a loose furnishing (per 1 m^2 of the material) correspond to the four stages including material and manufacturing, transport, use phase and end of life stages.

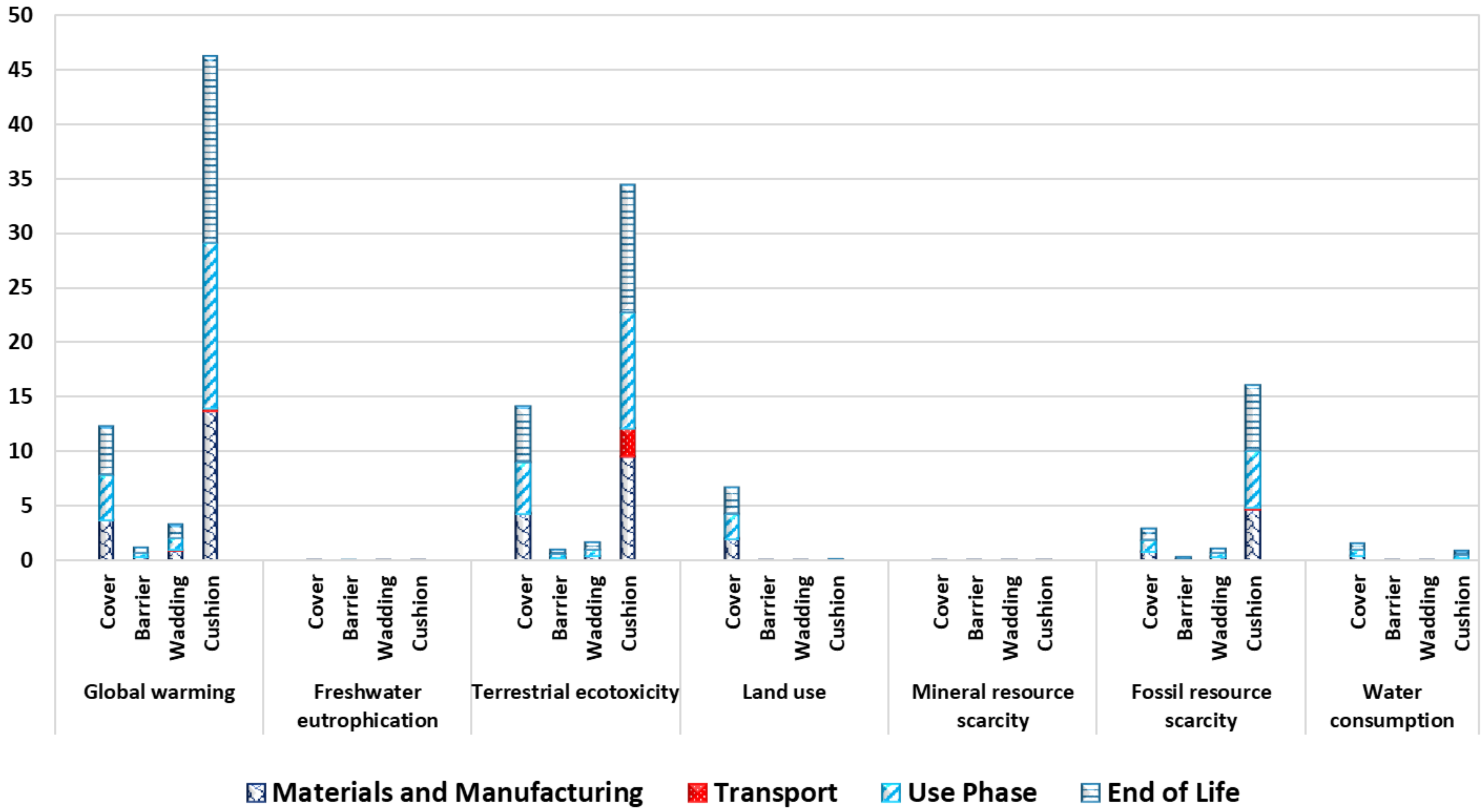

Figure G-15 Comparison of selected environmental impact categories resulted from cover, barrier, wadding and cushion parts of a loose furnishing (per 1 m^2 of the material) at four stages including material and manufacturing, transport, use phase and end of life stages.

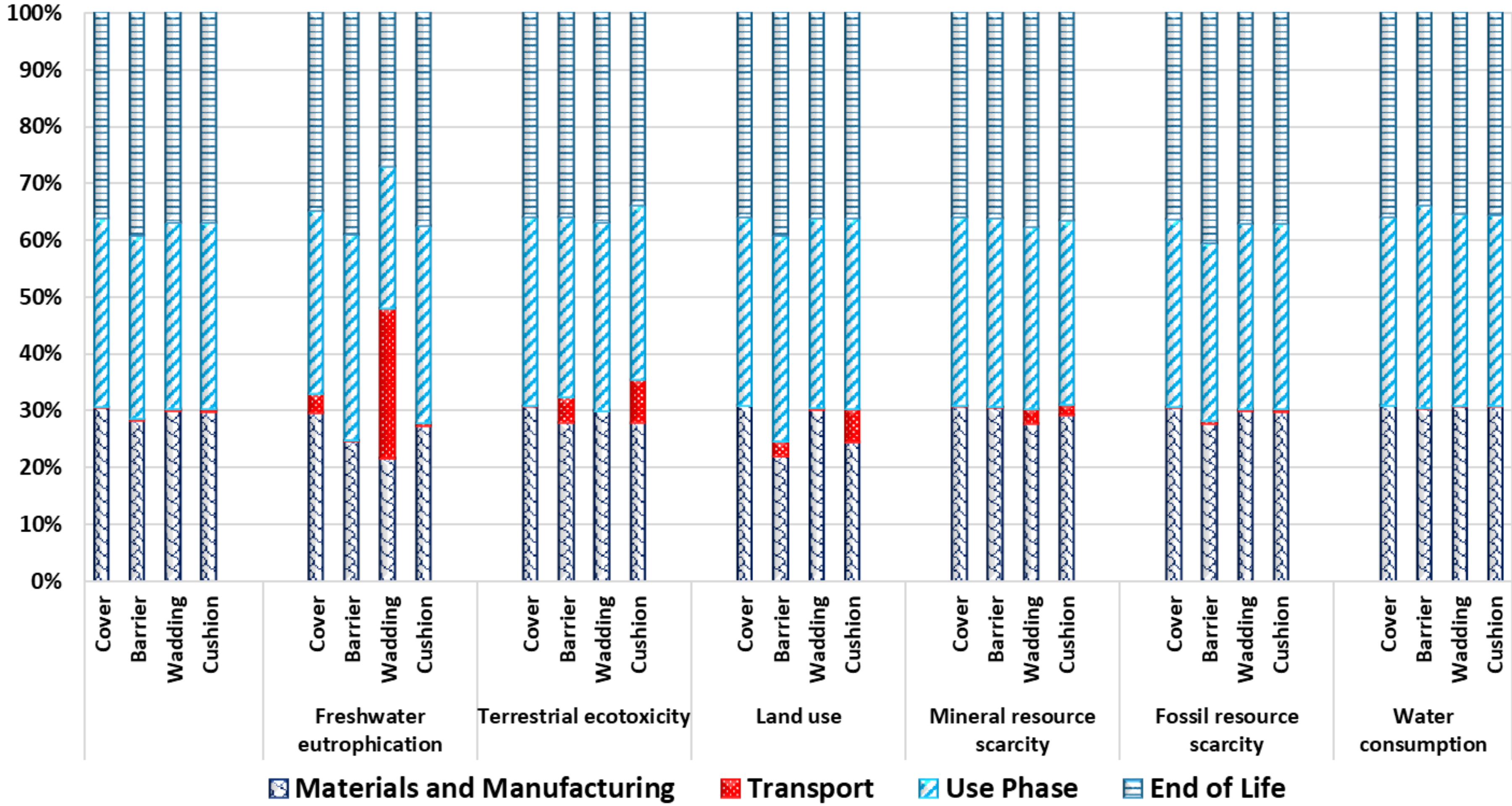

Figure G-16 Comparison of the percentage of the selected environmental impact categories resulted from cover, barrier, wadding and cushion parts of a loose furnishing (per 1 m^2 of the material) correspond to the four stages including material and manufacturing, transport, use phase and end of life stages

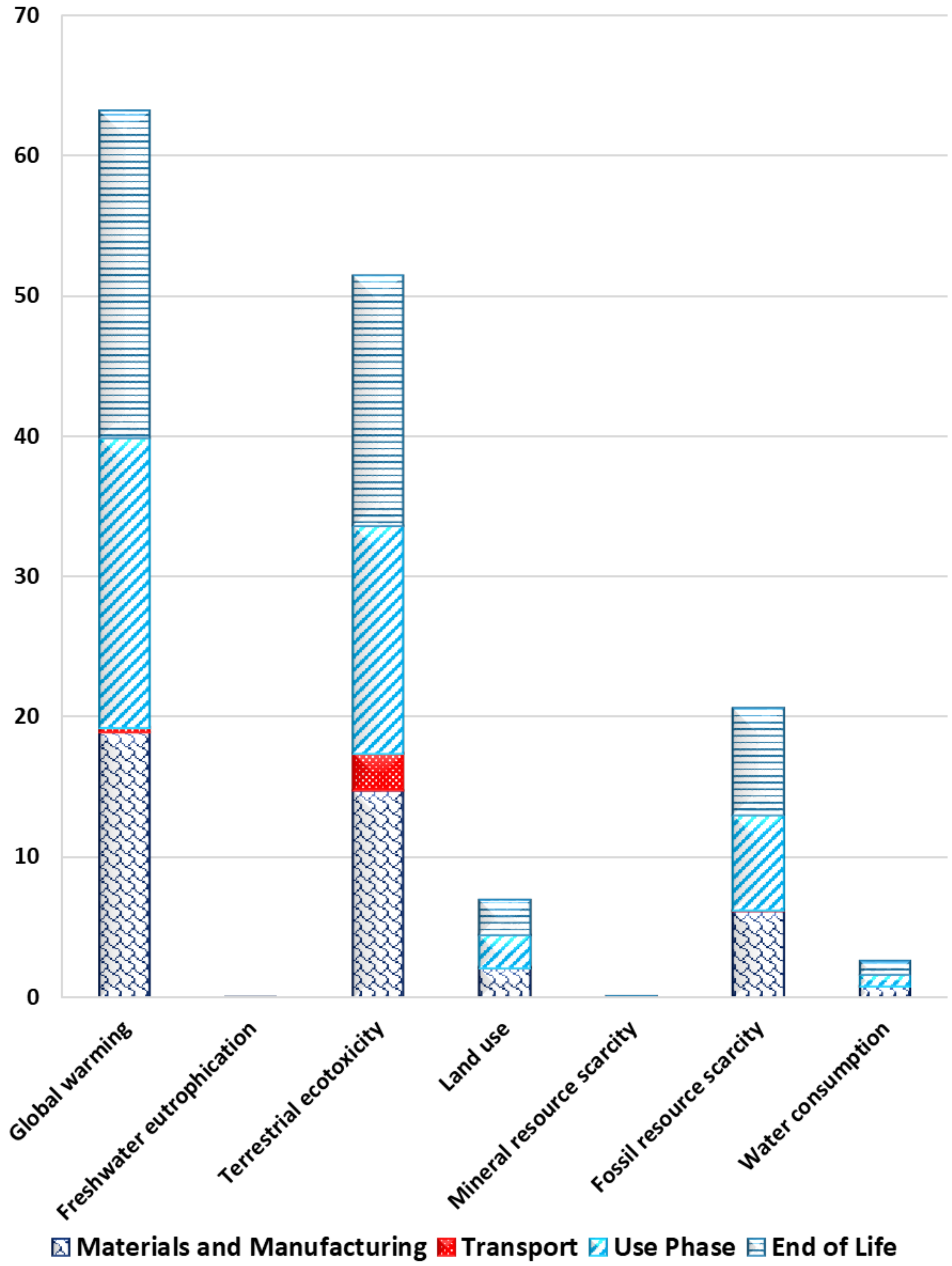

Figure G- 17 Comparison of selected environmental impact categories resulted from a loose furnishing (per 1 m^2 of the material) at four stages including material and manufacturing, transport, use phase and end of life stages.

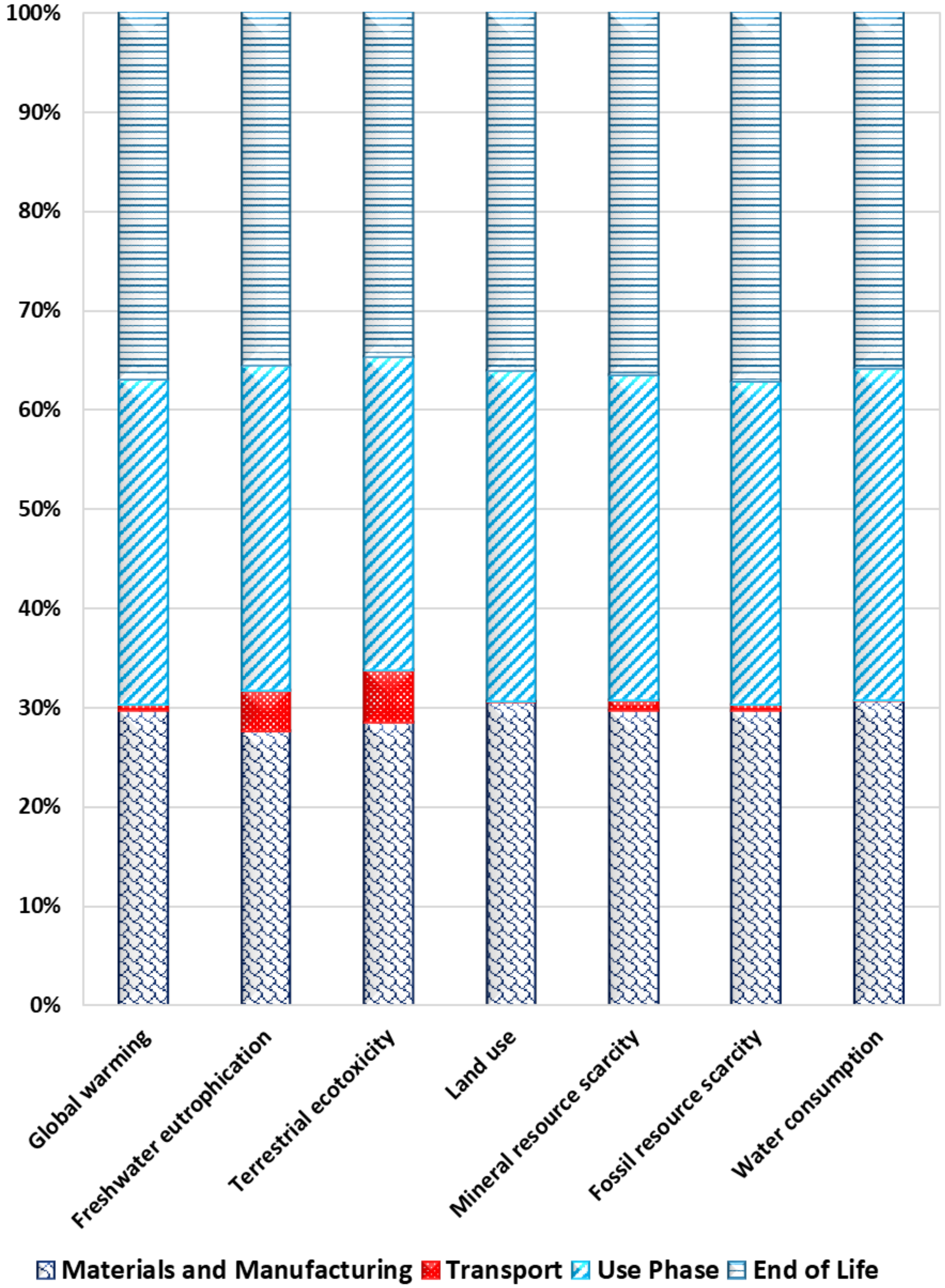

Figure G-18 Comparison of the percentage of the selected environmental impact categories resulted from a loose furnishing (per 1 m^2 of the material) at four stages including material and manufacturing, transport, use phase and end of life stages.

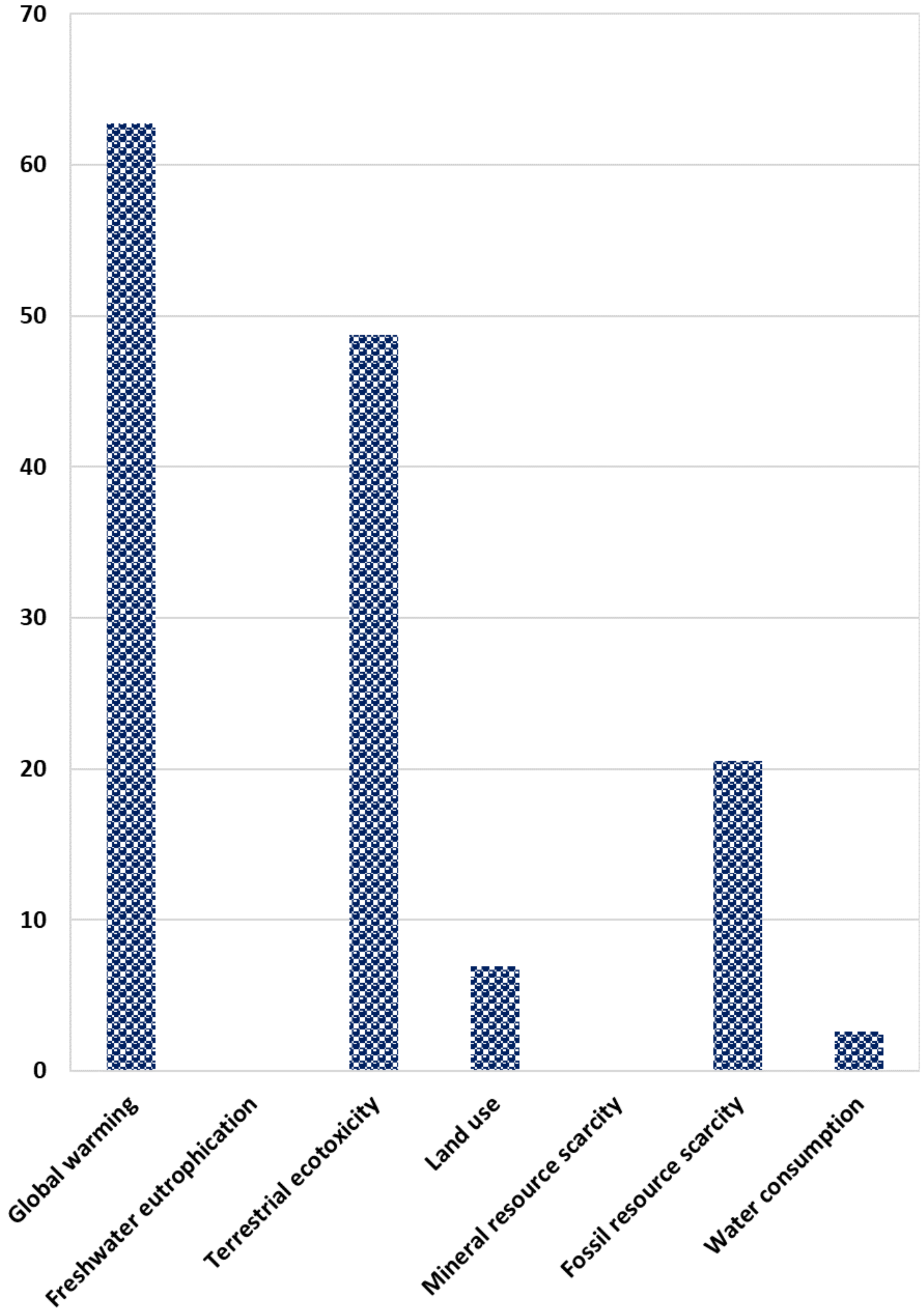

Figure G-19 Comparison of selected environmental impact categories resulted from a loose furnishing (per 1 m^2 of the material).

Appendix H Uncertainty analysis

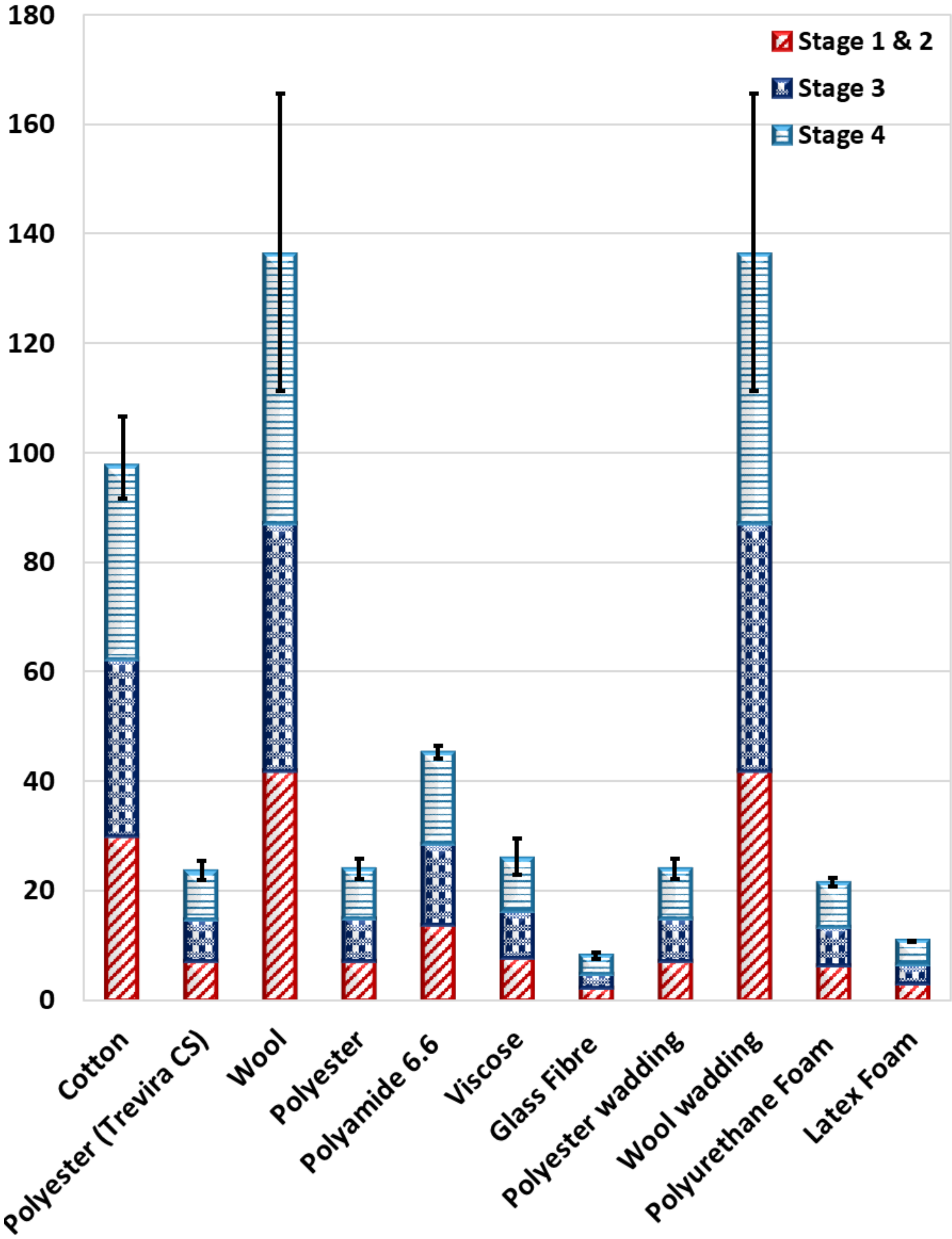

Figure H- 1 Comparison of uncertainty analysis of the Global warming impact category for the materials used in the study at materials and manufacturing & transportation, use phase and end of life stages. (Stage 1 and stage 2 are considered together.)

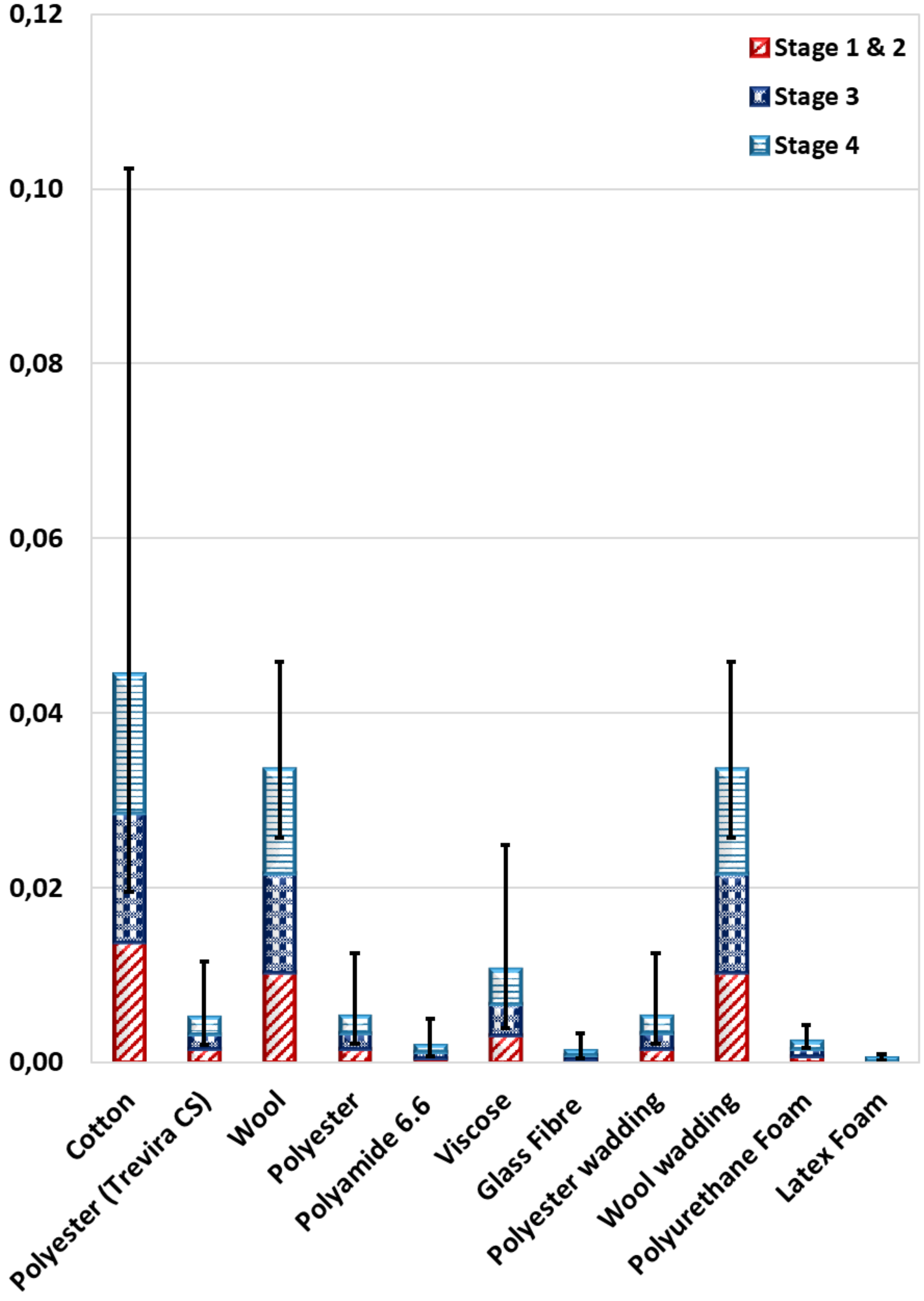

Figure H- 2 Comparison of uncertainty analysis of the Freshwater eutrophication impact category for the materials used in the study at materials and manufacturing & transportation, use phase and end of life stages. (Stage 1 and stage 2 are considered together.)

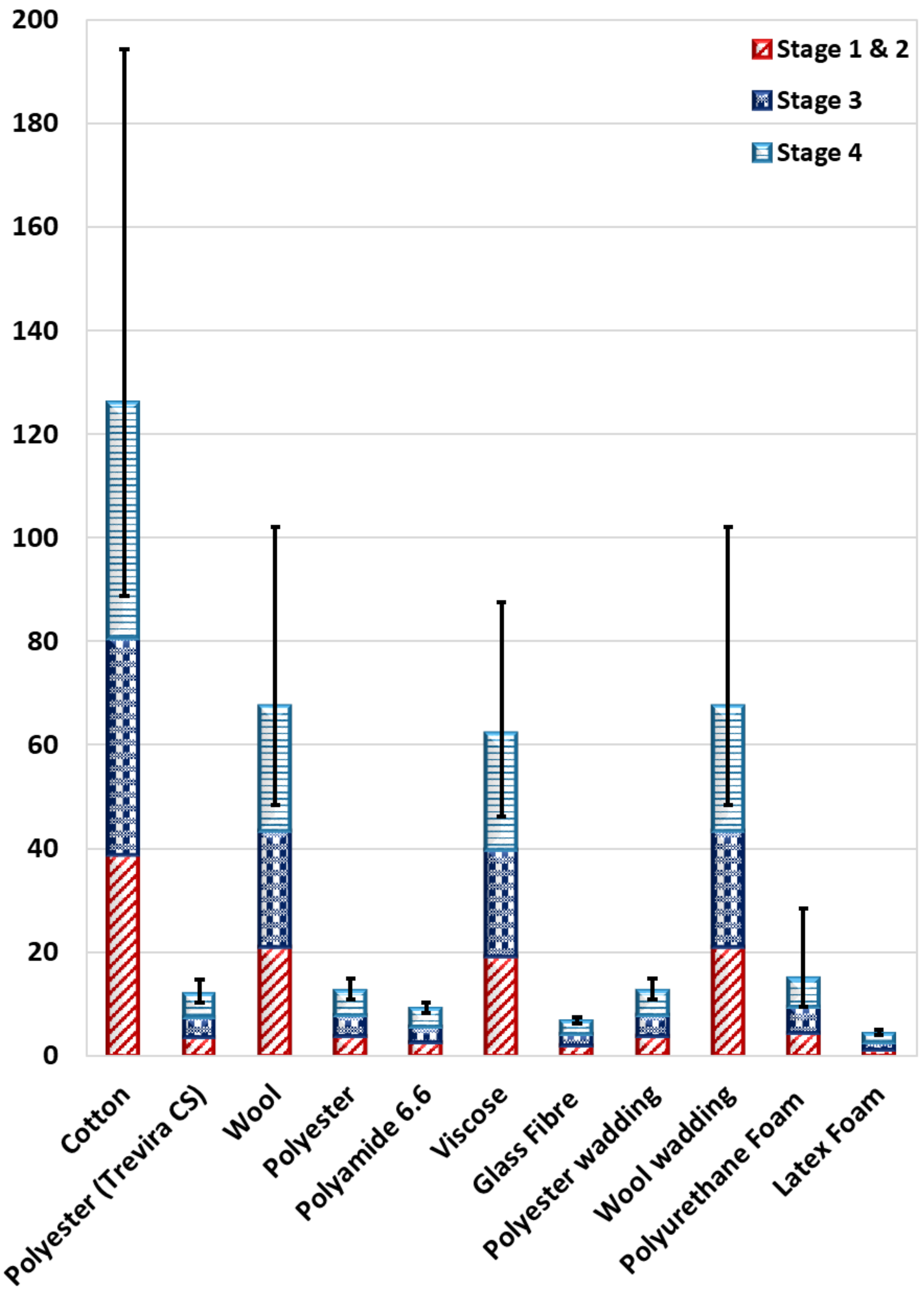

Figure H- 3 Comparison of uncertainty analysis of the Terrestrial ecotoxicity impact category for the materials used in the study at materials and manufacturing & transportation, use phase and end of life stages. (Stage 1 and stage 2 are considered together.)

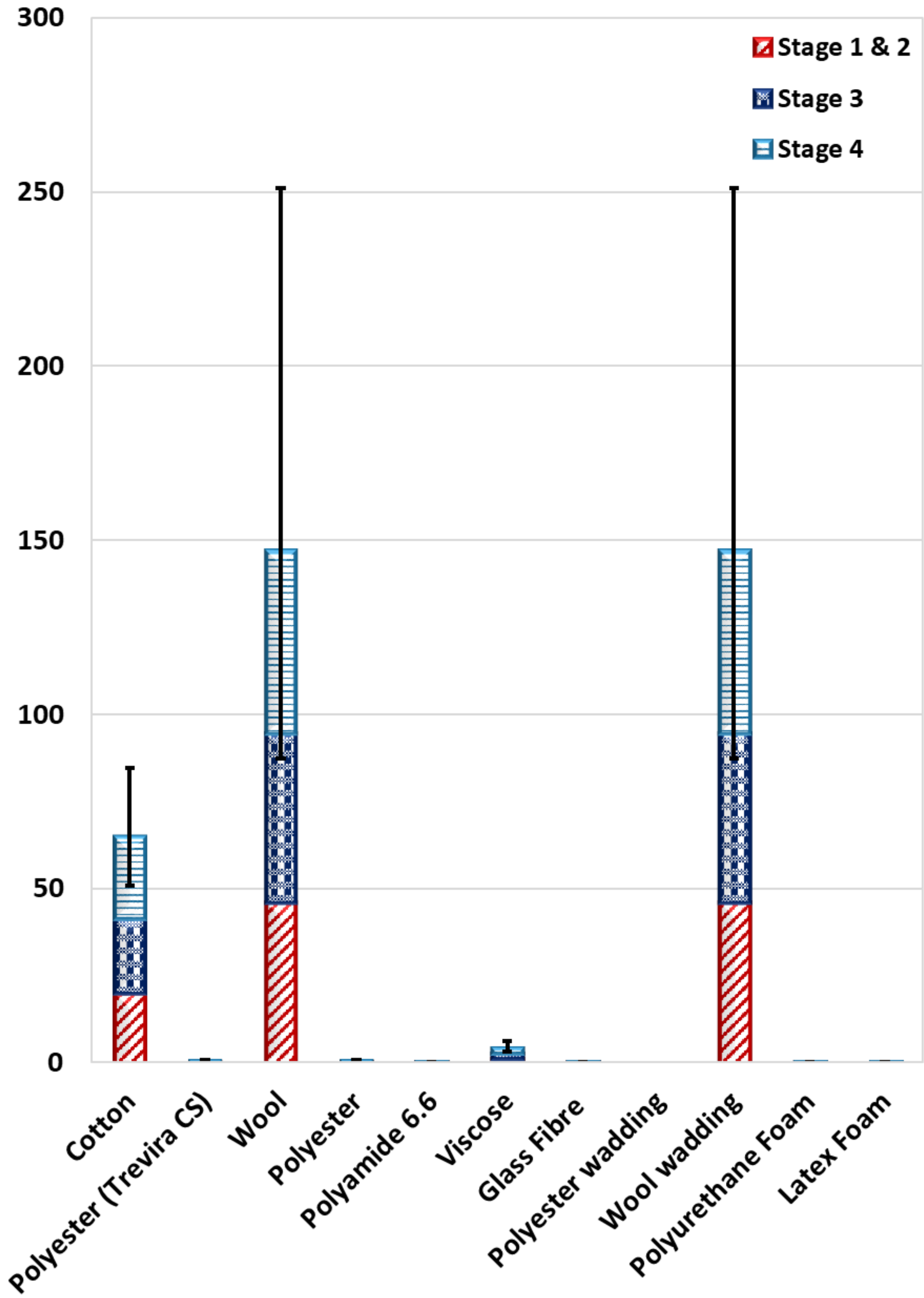

Figure H- 4 Comparison of uncertainty analysis of the Land use impact category for the materials used in the study at materials and manufacturing & transportation, use phase and end of life stages. (Stage 1 and stage 2 are considered together.)

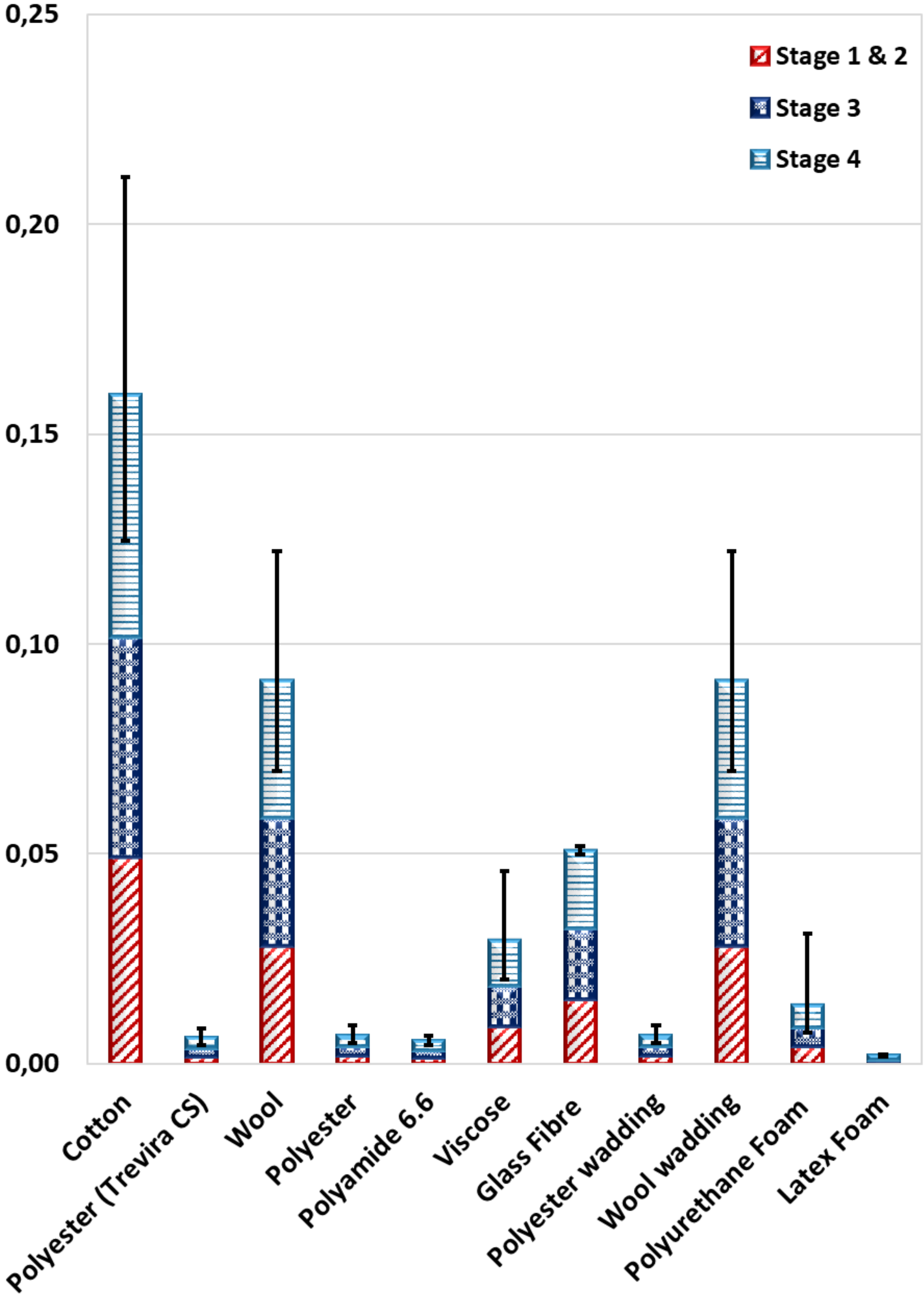

Figure H- 5 Comparison of uncertainty analysis of the Mineral resource scarcity impact category for the materials used in the study at materials and manufacturing & transportation, use phase and end of life stages. (Stage 1 and stage 2 are considered together.)

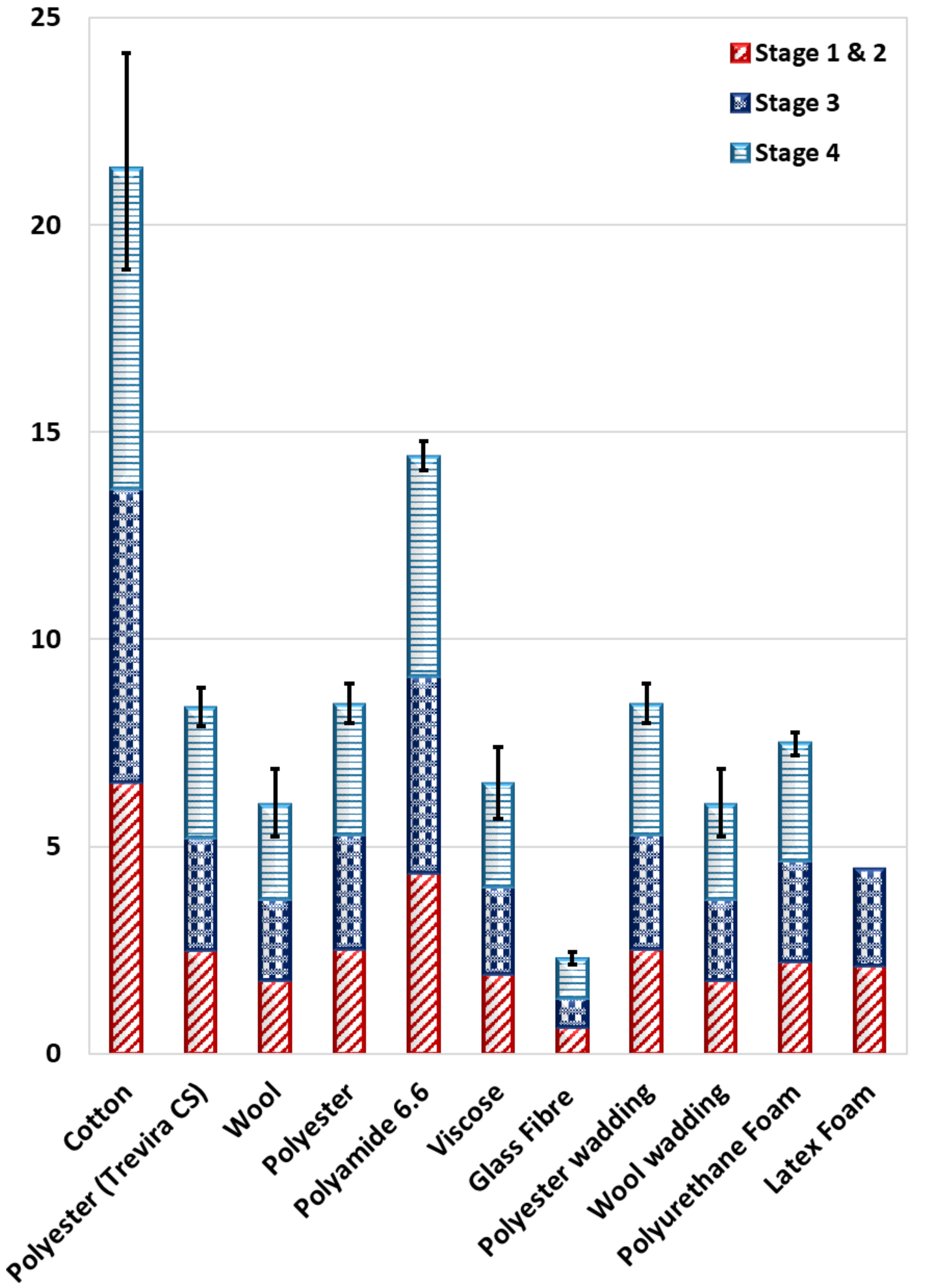

Figure H- 6 Comparison of uncertainty analysis of the Fossil resource scarcity impact category for the materials used in the study at materials and manufacturing & transportation, use phase and end of life stages. (Stage 1 and stage 2 are considered together.)

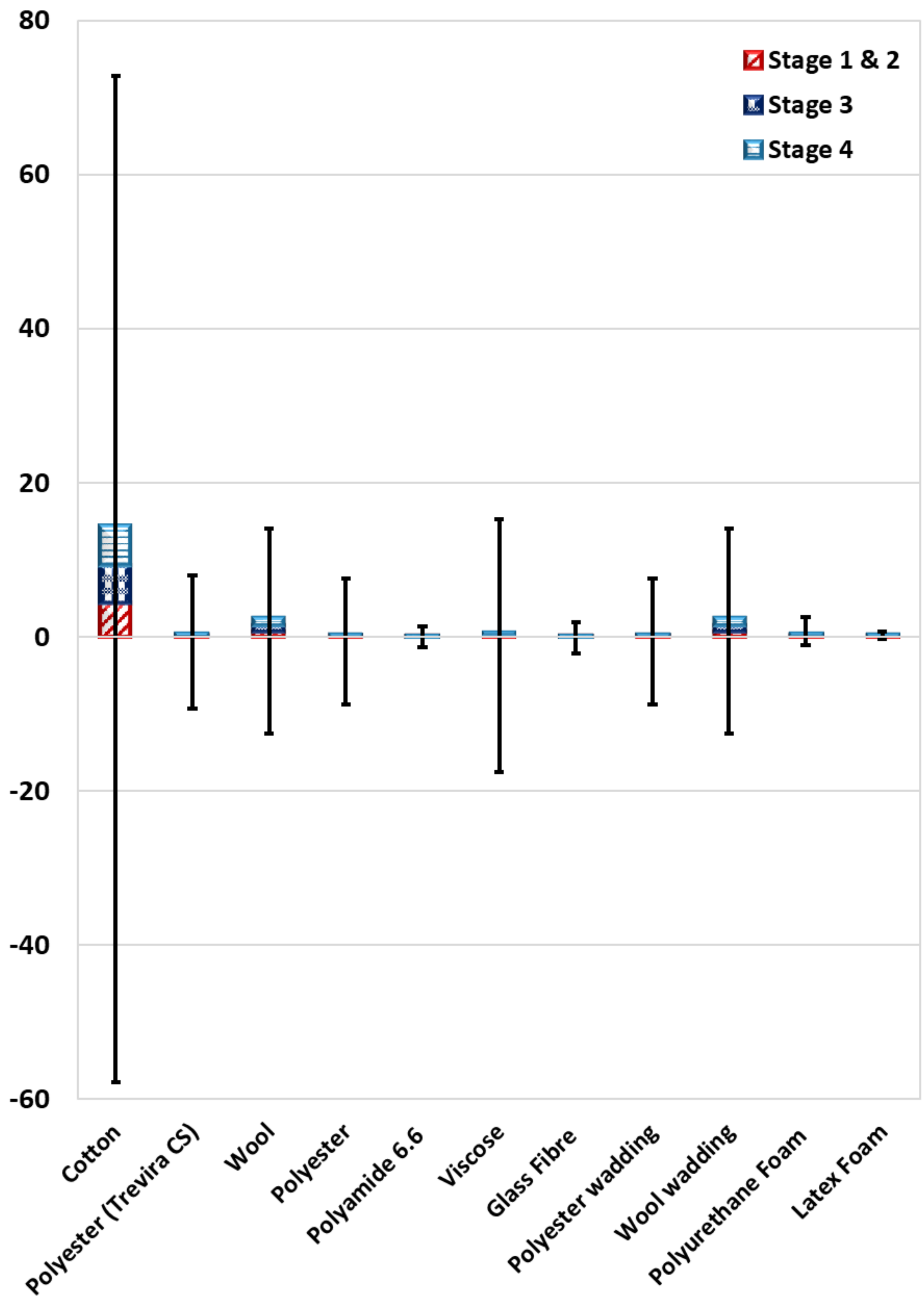

Figure H- 7Comparison of uncertainty analysis of the Water consumption impact category for the materials used in the study at materials and manufacturing & transportation, use phase and end of life stages. (Stage 1 and stage 2 are considered together.)

Appendix I Fire test methods for upholstered furniture and mattresses

It is important to be aware of the differences between ignitability testing and burning behaviour testing.

In testing of ignitability normally small ignition sources are used and the purpose is to investigate if a product can resist exposure from a specific ignition source (and only that source) without being ignited. If a product fulfils the ignitability requirements, it does not mean that the product is "safe" or could withstand other ignition sources. If using a larger ignition source or testing according to another test standard, the product may ignite and burn.

Testing of burning behaviour is performed to investigate how the product behaves after ignition. Usually the ignition sources used in these tests are larger and parameters such as heat release rate (heat production rate from the fire) and the total energy released are measured. Smoke production could also be measured but except for the Swedish Standard called SS 876 00 10, for nursing beds, it is not known to RISE if there are any other standard with smoke requirements.

I.1 Test methods for ignitability

The most common test methods used on upholstered furniture and mattresses are ignitability tests using small ignition sources like a smouldering cigarette and/or a small gas flame equalling a match flame. These ignition sources represent "smokers' material".

Progressive smouldering can occur in natural materials like cotton, but also in some synthetic materials like polyurethane foam, see example in Figure I- 1. Progressive smouldering is combustion without any visible flame and it usually produces large amounts of smoke. Progressive smouldering could also lead to open flaming, but this could take hours. Ignition can also occur with an open flame in both natural and synthetic materials, and the fire development is usually faster than for progressive smouldering.

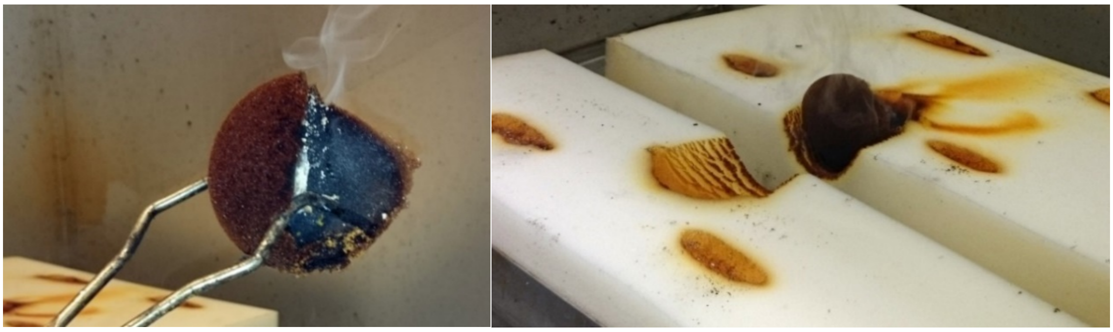

Figure I- 1 Example of progressive smouldering in polyurethane.

In addition to the smouldering cigarette and the match flame there are also other types of ignition sources such as wooden cribs, larger gas flames, paper cushions etc. These represent more challenging ignition scenarios, but they still test the ignitability of the product.

I.1.1 Test of upholstered furniture with smokers' materials

Probably the most common test method for testing upholstered furniture in Europe (except in UK) is the European standards EN 1021-1 and EN 1021-2:

- EN 1021-1:2014 Furniture – Assessment of the ignitability of upholstered furniture – Part 1: Ignition source smouldering cigarette.
- EN 1021-2:2014 Furniture – Assessment of the ignitability of upholstered furniture – Part 2: Ignition source match flame equivalent

The standards are used to assess the ignitability of material combinations, such as covers and fillings/foams used in upholstered seating, when subjected to a smouldering cigarette and a match flame equivalent (small gas flame) as ignition sources.

The tests are performed in a test cabinet with a calibrated air flow. The cover fabric and the filling are put in a test rig to create a small sofa with a 90° angle between seat and back, see Figure I-2. The ignition sources are placed in the junction between seat and back.

During the cigarette test (EN 1021-1) the test assembly is not allowed to smoulder after one hour from the beginning of the test. The test assembly is also not allowed to smoulder to the extremities of the specimen. The same requirements apply to EN 1021-2 where the test assembly is subjected to a small gas flame for 15 seconds. An additional requirement is that no flaming is allowed to continue for more than 120 seconds after removal of the burner tube.

Figure I- 2 Test set-up for testing according to EN 1021-1 (cigarette) and EN 1021-2 (match flame). The cover fabric and the filling are put in a test rig to create a small sofa with a 90° angle between seat and back. The ignition sources are located in the junction between seat and back. Note that the small gas flame is note located in the test position in the photo.

There are also several other test standards that use the same test rig and a cigarette and a match flame as ignition sources. Tests according to those standards are often similar but not always identical. There could be some differences in ignition sources, exposure times and number of tests, and it is therefore usually not possible to directly translate the results from one test method to an other. Examples of standards similar to EN 1021-1 and EN 1021-2 are:

- ISO 8191-1:1987 (cigarette test), ISO 8191-1:1987 (match flame)
- IMO 2010 FTP Code part 8 (cigarette and match flame) (previously called IMO Resolution A.652(16):1989)
- BS 5852:Part 1:1979 (cigarette and match flame)

The cigarettes used in these test standards are specified by length, weight, diameter and burning rate and the numbers differ somewhat between the different standards. It is actually difficult to find suitable cigarettes for testing that fulfils the standard specifications. Since November 2011 all cigarettes sold on the EU market must be “Reduced Ignition Propensity (RIP)” cigarettes, i.e. they should self-extinguish if nobody is smoking them. Therefore, this type of cigarettes is not suitable for fire testing. The best way is therefore to use cigarettes (non-RIP) especially developed for fire testing, such as the cigarette called “Standard Reference Material (SRM) 1196”, sold by National Institute of Standards and Technology (NIST) in USA.

I.1.2 Test of mattresses with smokers’ materials

The ignitability of mattresses and upholstered bed bases, when subjected to a smouldering cigarette and a match flame equivalent as ignition sources are commonly tested in Europe according to EN 597-1 and EN 597-2.

- EN 597-1:2016 Furniture – Assessment of the ignitability of mattresses and upholstered bed bases – Part 1: Ignition source smouldering cigarette.
- EN 597-2:2016 Furniture – Assessment of the ignitability of mattresses and upholstered bed bases – Part 2: Ignition source match flame equivalent.

The tests can be performed either in full scale or in small scale. For a full scale test a mattress with scale 1:1 is required. For a small scale test, the test specimen shall be rectangular in shape and of minimum size 450 mm x 450 mm x nominal thickness of the finished mattress, see Figure I-3. The type of proposed edge finishing system shall be incorporated, e.g. plain, piped or taped edge. Representative tension shall be maintained in the cover. The proposed mattress finish shall be represented in the test specimen, e.g. tufted or quilted.

The tests are performed in a test cabinet with a calibrated air flow. The test specimen is located on top of a steel rig. Depending on the finish of the mattress, ignition sources are placed on the flat surface, at tape edges, at quilted locations, tufts etc. During the cigarette test (EN 597-1) the mattress is not allowed to smoulder after one hour from the beginning of the test. The mattress is also not allowed to smoulder to its full thickness within the duration of the test. For EN 597-2 the test assembly is subjected to a gas flame equivalent to a match flame for 15 seconds. No flaming is allowed to continue for more than 120 seconds after removal of the burner tube. The mattress is also not allowed to smoulder to its full thickness, and the flame front is not allowed to reach the lower margin, either side or pass through the mattress' full thickness within the duration of the test.

Figure I- 3 Test set-up for EN 597-1 (cigarette) and EN 597-2 (match flame). The test specimen is located on top of a steel rig. Depending on the finish of the mattress, ignition sources are placed on the flat surface, at tape edges, at quilted locations, tufts etc.

I.2 Test methods for burning behaviour

Test of burning behaviour is performed to investigate how the product behaves after ignition. Usually the ignition sources used are larger than for ignition tests, and parameters such as heat release rate and the total energy produced are measured. There are no European (EN) standards for testing of burning behaviour of upholstered furniture or mattresses. Some countries have their own standards and examples of these are:

- The Nordic countries have standards called NT FIRE 055[8] for mattresses and NT FIRE 032[9] for upholstered furniture. Sweden uses these standards for high risk environments such as prisons and psychiatric wards.
- In USA the federal standard 16 CFR Part 1633 is used to test the burning behaviour of mattresses for domestic environment.
- In California TB 133 is used to test the burning behaviour of upholstered furniture for public environment.

I.3 Test methods used in UK

UK is the country in Europe with the most extensive regulation for upholstered furniture and mattresses. The requirements are somewhat different for public areas compared to domestic environments.

I.3.1 Domestic environments

For domestic environments all items of upholstered furniture should meet "The Furniture and Furnishings (Fire) (Safety) Regulations 1988" as amended in 1989, 1993 and 2010 (here called UK regulation). The regulations are divided into five sections (Schedule 1-5) for fire testing, see Table I-1 and Table I-2, but the regulations also have additional sections (Schedule 6-8) dealing with labelling. For each type of filling the regulations refer to a specific test method and an ignition source. In some cases the UK regulation has other requirements than given in the specific standards. One example is test of polyurethane foam according to Schedule 1, Part 1. This schedule refers to testing with ignition source 5 (crib 5) according to standard BS 5852:Part 2. In the standard requirements it is not allowed to smoulder or burn through the full thickness or to the extremities of the test specimen. However, in the UK regulation this requirement can be ignored provided that the resultant mass loss is less than 60 g.

Table I-1 Contents of The Furniture and Furnishings (Fire) (Safety) Regulations 1988" with amendments. Note that the tests are performed according to the specified standard but with the modifications and criteria given in the regulations.

SECTION	COMPONENT	TEST METHOD/STANDARD
Schedule 1, Part I	Polyurethane foam – slab or cushion form	BS 5852:Part 2, Ignition source 5
Schedule 1, Part II	Polyurethane foam in crumb form	BS 5852:Part 2, Ignition source 2
Schedule 1, Part III	Latex Rubber form	BS 5852:Part 2, Ignition source 2
Schedule 2, Part I	Ignitability test for non-foam filling materials singly	BS 5852:Part 2, Ignition source 2
Schedule 2, Part II	Ignitability test for composite fillings for furniture other than mattresses, bed bases, cushions and pillows	BS 5852:Part 2, Ignition source 2
Schedule 2, Part III	Composite test for ignitability of pillows and cushions with primary covers	BS 5852:Part 2, Ignition source 2
Schedule 2, Part IV	Composite test for ignitability of pillows and cushions with primary covers	BS 6807, Ignition source 2
Schedule 3	Ignition resistance test for interliner	BS 5852:Part 2, Ignition source 5
Schedule 4, Part 1	Cigarette test applied to upholstery composites	BS 5852:Part 1, Ignition source 0 (smouldering cigarette)
Schedule 4, Part II	Cigarette test applied to "invisible covers", such as covers underneath cushions etc.	BS 5852:Part 1, Ignition source 0 (smouldering cigarette)
Schedule 5, Part I	Match test applied to all visible covers	BS 5852:Part 1, Ignition source 1 (match flame equivalent)

Schedule 5, Part II	Match test for stretch covers	BS 5852:Part 1, Ignition source 1 (match flame equivalent)
Schedule 5, Part III	Match test for invisible parts of covers	BS 5852:Part 1, Ignition source 1 (match flame equivalent)

Table I-2 Simplified overview of the ignition sources used for testing composite materials according to The Furniture and Furnishings (Fire) (Safety) Regulations 1988" with amendments.  equals ignition source 5 (crib 5) or ignition source 2.

Filling type	Schedule 1			Schedule 2			
	Part 1	Part 2	Part 3	Part 1	Part 2	Part 3	Part 4
Foam:							
Polyurethane, Slab or cushion							
Polyurethane, crumb							
Latex rubber							
Non-foam:							
Single filling							
Composite fillings:							
Furniture							
Pillows/Scatter Cushions							
Mattresses/futons							

Material	Schedule 3	Schedule 4		Schedule 5		
	-	Part 1	Part 2	Part 1	Part 2	Part 3
Fire-Barriers/Interliners:						
Interliner						
Upholstery composites (Cigarette Resistance):						
Visible						
Non visible						
Covers (Match resistance):						
Visible/permanent						
Stretch						
Non-visible						

The test methods mentioned in Table I-2 are BS 5852-1, BS 5852-2 and BS 6807. BS 5852-1 is very similar to EN 1021-1 and EN 1021-2. It uses the same test rig and also uses a cigarette (source 0) and a match flame (source 1) as ignition sources. The main difference is the application time of the match flame. EN 1021-2 has 15 s of application time of the gas burner compared to 20 s in BS 5852-1. However, in EN 1021-1 and EN

1021-2 three tests are performed on each upholstery combination compared to two tests in BS 5852-1.

Tests according to BS 5852-2 are performed in a similar way as for EN 1021-1/-2 and BS 5852-1 but the test rig and the ignition sources (sources 2-7) are larger, see Figure I-4.

Figure I-4 Example of ignition sources used for BS 5852-2 testing. On the left photo ignition source 7, 5 and 2 can be seen from the left to right. The right photo shows an example of testing polyester wadding in combination with a standard FR-treated polyester fabric as described in Schedule 2, Part I. Ignition source 2 is used.

BS 5852:Part 1 and BS 5852:Part 2 were actually withdrawn by BSI (British Standards Institution) but are still used since the UK regulations still refer to the test methods. BS 5852:1990 is a revision and a merging of BS 5852:Part 1 and BS 5852:Part 2. In the most recent revision of the standard, BS 5852:2006, the tests and ignition sources from BS 5852:Part 1 are no longer represented. Instead the standard refers to EN 1021-1 and EN 1021-2 for the cigarette and match flame tests.

The test according to BS 6807:1986 is very similar to EN 597-1 and EN 597-2. The same test rig is used but the ignition sources are the same as in BS 5852:Part 2; either larger gas flames or wooden cribs (Source 2-7). Also BS 6807 has been revised and the latest version is from 2006. The old version from 1986 is still used though, since the UK regulations refer to it.

I.3.2 Public environments

For public environments there are no mandatory regulations for upholstered furniture and mattresses. However, “The General Product Safety Regulations 2005” basically means that it is forbidden to sell an unsafe product (applies to domestic environment as well). Additionally, the general fire safety for a building is assessed based on “The Regulatory Reform (Fire Safety) Order 2005”. Based on this there is an assessment of a building which includes materials, structures, emergency exits, fire detection, etc. Also the use of the building as well as the activities in the building are included in a risk analysis. These characteristics then determine the fire authority's decision on the fire safety requirements for a building. To help them, the fire department has fire standards for furniture and beds that specify different types of fire tests based on a risk assessment.

The most common way to show that a mattress is “safe” is to test and classify it according to BS 7177:2008, see Table I- 4. This standard can also be used on mattresses in domestic environment and should then fulfil the “Low Hazard” category, which means testing according to EN 591-1 and EN 597-2. Mattresses delivered to hospitals, hotels, etc. are recommended to meet the "medium hazard" category which means the tests mentioned above as well as the ignition source 5 in accordance with BS 6807. BS 7177 also contains recommendations for periodic testing in production.

Table I- 3 Performance requirements for mattresses for different hazard categories according to BS 7177. Note that mattresses for domestic use (low hazard) must also fulfil The Furniture and Furnishings (Fire) (Safety) Regulations 1988” with amendments.

	DOMESTIC USE (LOW HAZARD)	**MEDIUM HAZARD**	**HIGH HAZARD**	**VERY HIGH HAZARD**
Standard/ Requirement	BS EN 597-1:1995 and BS EN 597-2:1995	BS EN 597-1:1995 and BS EN 597-2:1995, and BS 6807:2006, Clause 9, Ignition source 5	BS EN 597-1:1995 and BS EN 597-2:1995, and BS 6807:2006, Clause 9, Ignition source 7	BS EN 597-1:1995 and BS EN 597-2:1995, BS 6807:2006, Clause 9, Ignition source 7 + additional requirements at the discretion of the specifier with high hazard requirements as a minimum
Typical examples	Domestic dwellings	Hospitals Services’ messes Daycentres Hotels Hostels Old people’s home Holiday camp chalets Boarding schools Halls of residence at universities and colleges	Certain hospital wards Offshore installations Hotels Hostels Old people’s home	Prison cells Locked psychiatric accommodation

For upholstered furniture in public environments there is a similar standard called BS 7176: 2007+A1:2011, see Table I- 5.

Table I- 4 Performance requirements for upholstered furniture for different hazard categories according to BS 7176.

	LOW HAZARD	**MEDIUM HAZARD**	**HIGH HAZARD**	**VERY HIGH HAZARD**
Standard/ Requirement	BS EN 1021-1:2006 and BS EN 1021-2:2006	BS EN 1021-1:2006 and BS EN 1021-2:2006, and BS 5852:2006, Clause 11, Ignition source 5	BS EN 1021-1:2006 and BS EN 1021-2:2006, and BS 5852:2006, Clause 11, Ignition source 7	BS EN 1021-1:2006 and BS EN 1021-2:2006, and BS 5852:2006, Clause 11, Ignition source 7 + additional requirements at the discretion of the

				specifier with high hazard requirements as a minimum
Typical examples	Offices Schools Colleges Universities Museums Exhibitions Day centres	Hotel bedrooms Public buildings Restaurants Services' messes Places of public entertainment Public halls Public houses and bars Casinos Hospitals Hostels	Sleeping accommodation in certain hospital wards and in certain hostels Offshore installations	Prison cells Locked psychiatric accommodation

I.4 Test methods used in the USA

I.4.1 Mattresses

On the US market all mattresses produced or imported must fulfil two types of fire tests, one ignitability test with cigarettes and one open flame (burning behaviour) fire test in large scale.

The first test method the mattress must fulfil is 16 CFR Part 1632. A total of six complete mattresses ready for sale shall be tested. The top surface (sleeping surface) of the mattress is tested. Cigarettes are placed on smooth surfaces, seams, tufted locations, quilted locations, tape edges etc. of the mattress. A minimum of 18 cigarettes shall be used during each test. The mattress is divided into two equal sections. One section is covered with a 100 % cotton bed sheet. The other section remains uncovered. A minimum of 9 lighted cigarettes are placed on the uncovered top section and a minimum of 9 lighted cigarettes are placed on the covered section. A second piece of cotton sheeting is then placed over the latter group of cigarettes. The test is completed when all cigarettes have burned their complete length. The char damage length shall not be more than 2 inches (5.1 cm) in any direction from the nearest point of any individual cigarettes. This procedure is repeated 6 times.

Since July 1st 2007, mattresses must also fulfil another federal standard called 16 CFR Part 1633. During testing a mattress or a mattress set is located on top of a steel rig and exposed to two T-shaped burners with a total burner heat output of 27 kW, see Figure I-5. The side burner is applied for 50 seconds and the top burner is applied for 70 seconds. The fire is then allowed to develop freely and the heat release rate (HRR) is measured continuously. The peak rate of heat release should not exceed 200 kW and the total heat release during the first 10 minutes of the test should not exceed 15 MJ. A total of 3 mattresses are tested.

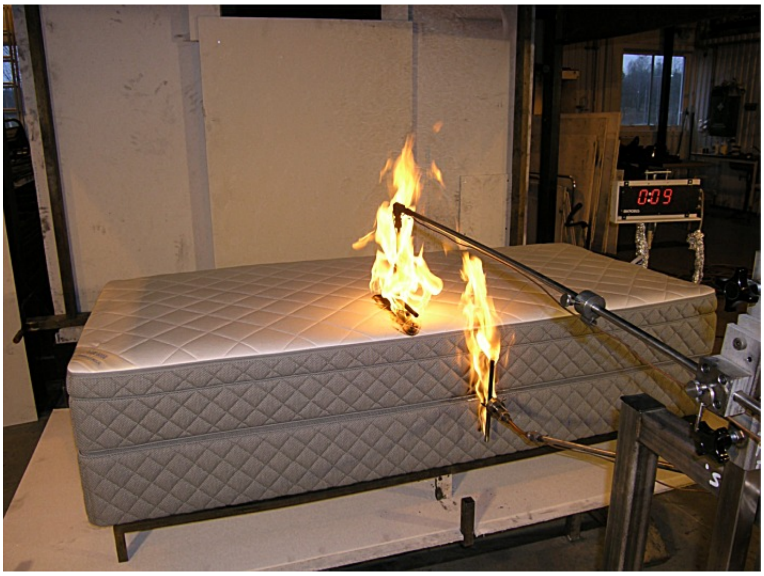

Figure I- 5 During testing according to 16 CFR Part 1633 a mattress is exposed to two T-shaped burners with a total burner heat output of 27 kW. During the test the heat release rate and the total energy developed are measured.

I.4.2 Upholstered furniture

For upholstered furniture there are no federal requirements in the USA. Instead there is a voluntary regulation by UFAC (Upholstered Furniture Action Council). The state of California is an exception.

In California upholstered furniture for domestic environments should fulfil Technical Bulletin 117-2013 (TB 117). TB 117-2013 is a test method for assessing smoulder resistance of cover fabrics, barrier materials, resilient filling materials, and decking materials for use in upholstered furniture. All materials are tested together with standardized foam and fabrics. The end-use material combination is not in the scope of this standard.

The material to be tested is mounted in a test rig together with the applicable standard material, see Figure I- 6. A smouldering cigarette is placed in the junction between the seat and the back in the mock-up assembly. Observations are made to establish the occurrence of any smouldering and/or flaming ignition of the materials. The length of the charring in the assembly is also measured to evaluate compliance.

Figure I- 6 Example of TB 117 test set-up of a filling in combination with a standard fabric. A glowing cigarette is placed in the junction between the seat and the back in the mock-up assembly.

California also has a test method called ”Technical Bulletin 133” (TB 113), that is used for furniture in public environments. During testing a square gas burner with a heat output of 20 kW is positioned centrically on top of the seat, see Figure I-7. The gas burner is positioned on the test specimen for 80 seconds and then removed. The fire is then allowed to develop freely and the heat release rate (HRR) is measured continuously. The peak rate of heat release should not exceed 80 kW and the total heat release during the first 10 minutes of the test should not exceed 25 MJ.

Figure I-7 During testing according to TB 133 a square gas burner with a heat output of 20 kW is positioned centrically on top of the seat for 80 s. During the test the heat release rate and the total energy developed are measured.

Appendix J Fire testing – flame exposure

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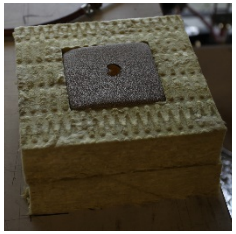
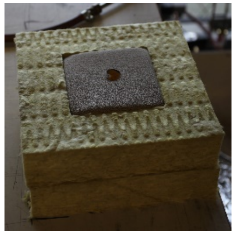
21						
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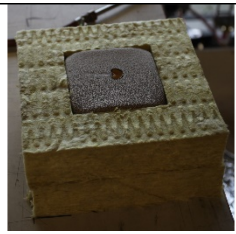
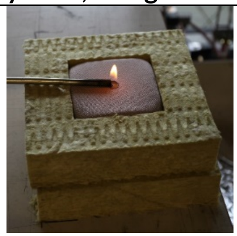
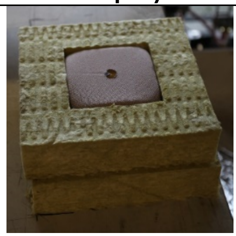
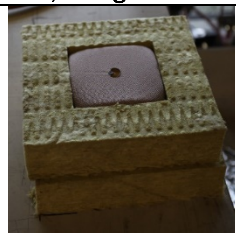
21						
	End of exposure	0 sec	End of test			
100 % Polyester, 313 g/m². Foam: Standard polyurethane foam, 30 kg/m³.						
22						
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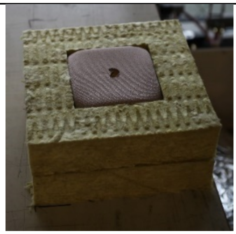
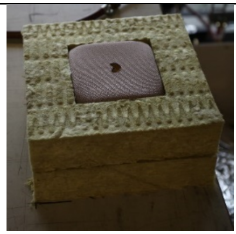
22						
	End of exposure	0 sec	End of test			
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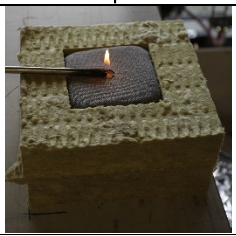
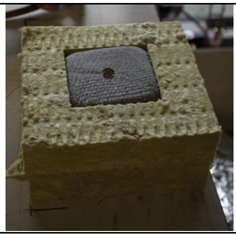
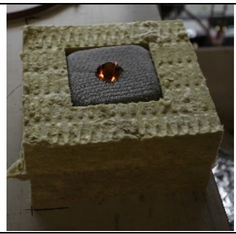
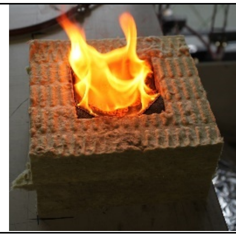
23						
	End of exposure	0 sec	30 sec	60 sec	90 sec	120 sec
23						
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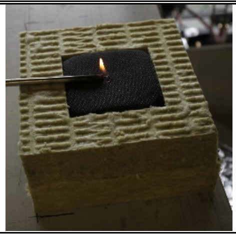
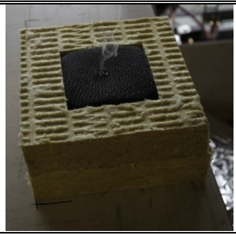
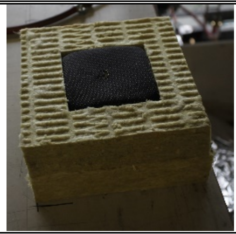
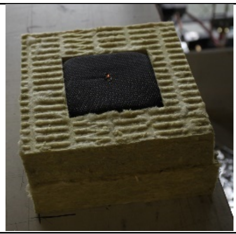
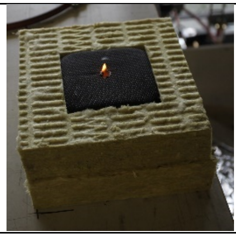
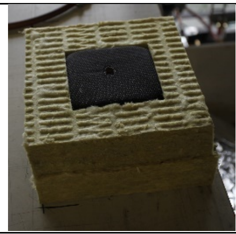
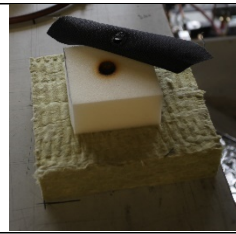
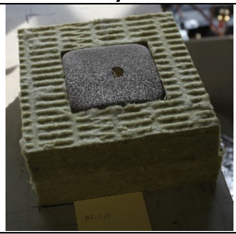
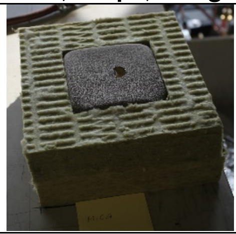
24						
	End of exposure	0 sec	End of test			
24						
	End of exposure	0 sec	10 sec	20 sec	60 sec	End of test
Polyester, 97% Polyester postconsumer recycled / 3% polyester, Crepe, 212 g/m². Foam: High resilience polyurethane foam, 32 kg/m³.						
25						
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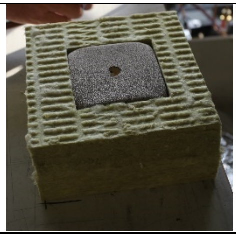
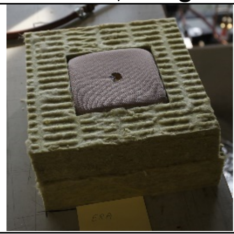
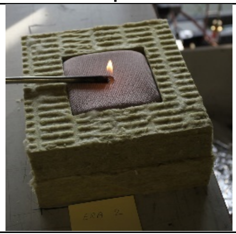
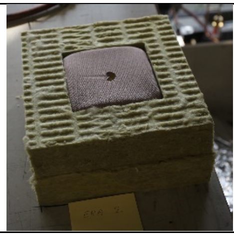
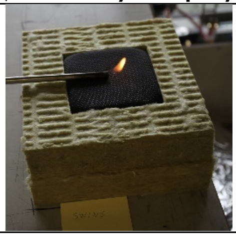
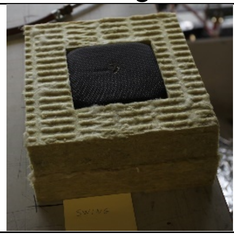
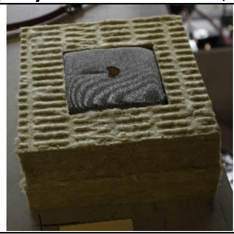
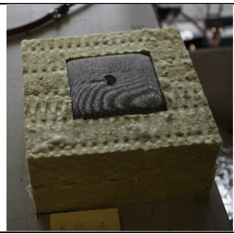
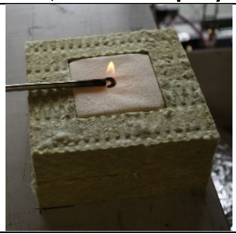
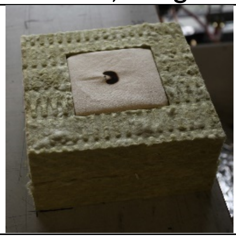
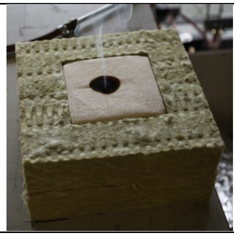
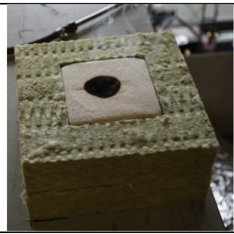
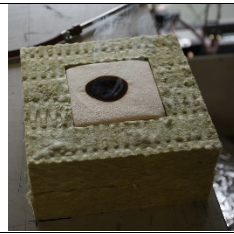
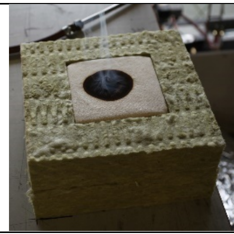
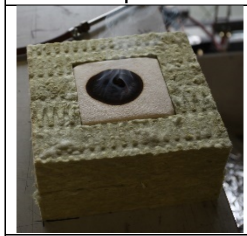
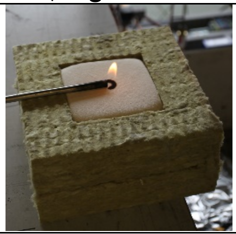
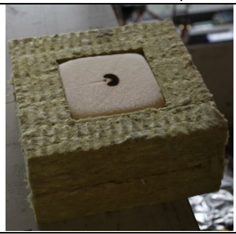
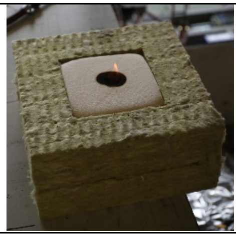
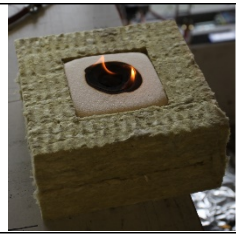
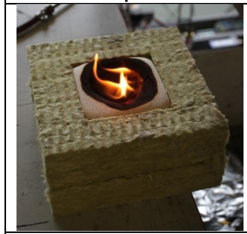
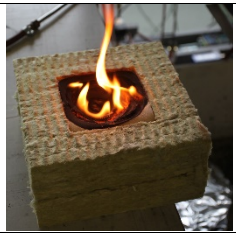
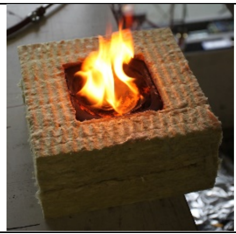
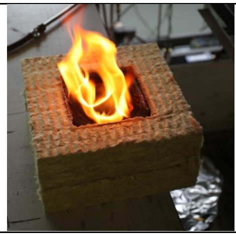
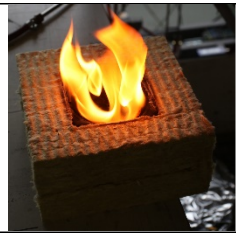
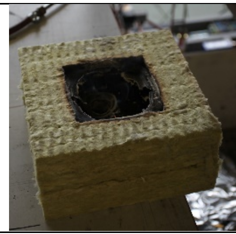
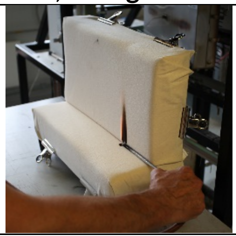
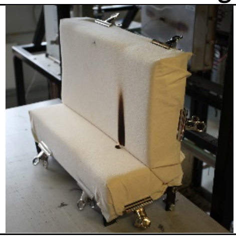
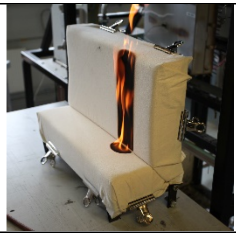
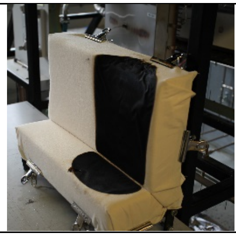
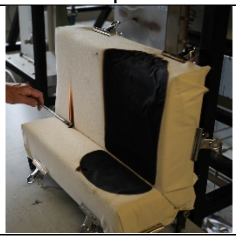
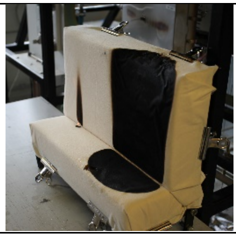
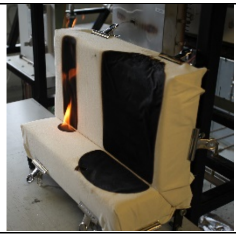
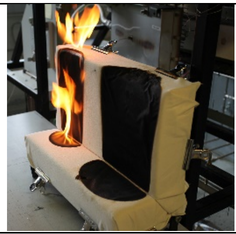
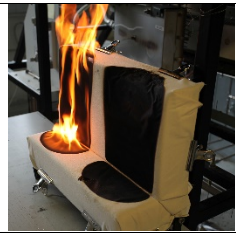
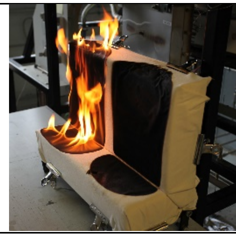
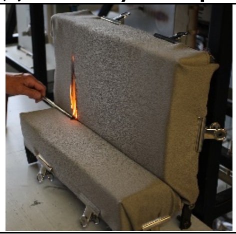
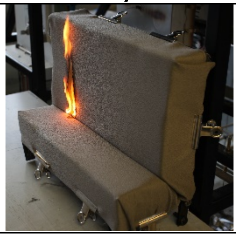
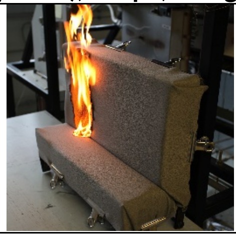
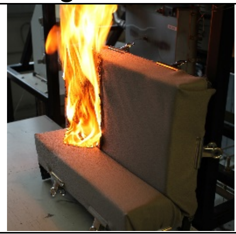
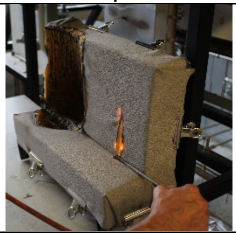
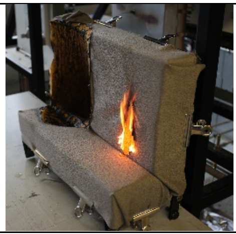
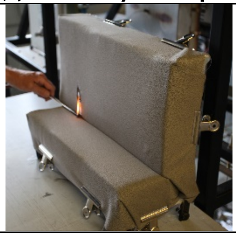
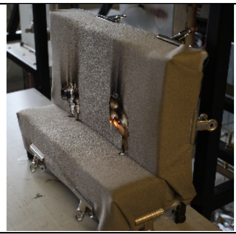
25						
	End of exposure	0 sec	End of test			

100 % Polyester, 313 g/m². Foam: High resilience polyurethane foam, 32 kg/m³.						
26						
	End of exposure	0 sec	End of test			
26						
	End of exposure	0 sec	End of test			
54% wool, 44 % recycled polyester, 2 % polyamide. 307 g/m². Foam: High resilience polyurethane foam, 32 kg/m³.						
27						
	End of exposure	Right after exposure	End of test			
27						
	End of exposure	0 sec	End of test			

100 % recycled polyester, 276 g/m^2. Foam: High resilience polyurethane foam, 32 kg/m^3.						
28						
	End of exposure	0 sec	End of test			
28						
	End of exposure	0 sec	End of test			
100 % Cotton, Standard polyurethane foam, 30 kg/m^3.						
29						
	End of exposure	0 sec	30 sec	60 sec	90 sec	120 sec
						
	150 sec	180 sec	4 min	4 min 40 sec		

100 % Cotton, High resilience polyurethane foam, 32 kg/m³.						
30						
	End of exposure	0 sec	30 sec	60 sec	90 sec	120 sec
						
	150 sec	180 sec	3 min 30 sec	4 min	4 min 30 sec	4 min 50 sek
100 % Cotton, Filling: PUR non flame-retardant 35 kg/m³						
5						
	End of exposure	0 sec	30	60		
5						
	End of exposure	0 sec	30	60	90	120

100 % Cotton, 3D thermoplastic fibre web structure						
18						
	End of exposure	0 sec	30	60	90	
18						
	End of exposure	0 sec	30 sec			
Polyester, (97% Polyester postconsumer recycled / 3% polyester), Crepe, 212 g/m^2. Filling: 3D thermoplastic						
19						
	End of exposure	0 sec	20 sec			
19						
	End of exposure	0 sec	20 sec			

Polyester, (97% Polyester postconsumer recycled / 3% polyester), Crepe, 212 g/m². Filling: PUR non flame-retardant 35 kg/m³						
20						
	End of exposure	0 sec	30 sec	60 sec		
20						
	End of exposure	0 sec	30 sec	55 sec		
Polyester, (97% Polyester postconsumer recycled / 3% polyester), Crepe, 212 g/m2. Barrier: glass fibre. Filling: PUR non flame-retardant 35 kg/m³						
31						
	End of exposure	0 sec	30 sec	60 sec		
31						
	End of exposure	0 sec	30 sec	45 sec		

Polyester, (97% Polyester postconsumer recycled / 3% polyester), Crepe, 212 g/m2. Barrier: glass fibre. Filling: 3D						
32						
	End of exposure	0 sec	30 sec	60 sec	90 sec	120 sec
						
	130 sec					
32						
	End of exposure	0 sec	30 sec	60 sec	90 sec	120 sec

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