UNHCR
The UN Refugee Agency

DECARBONIZATION OPPORTUNITIES FOR RELIEF MATTRESSES

Exploring Sustainable Material Options for Relief Mattresses procured by UNHCR through a life cycle assessment (LCA) approach

Contents

Executive Summary

UNHCR, the UN Refugee Agency procures approximately 1.3 million mattresses annually for humanitarian response, which contributes significantly to its overall carbon footprint. The mattresses are primarily made from polyurethane (PU) foam derived from fossil-based materials. These materials are not only carbon-intensive but also present environmental and health risks due to toxic components and disposal challenges.

This report explores and evaluates alternative materials and production methods that could reduce the environmental impact of relief mattresses. It identifies six main options for improving the sustainability of PU mattresses:

- **Chemically Recycled Polyols** – obtained through depolymerization of post-consumer PU foam. This approach supports circular economy principles by turning waste into valuable raw materials, reducing both fossil resource dependency and plastic pollution. While current availability is limited, especially outside Europe, its potential for long-term pollution reduction and material recovery is high.
- **Bio-Based Polyols** – sourced from renewable biomass (e.g., soy, palm, castor), these provide a viable and readily available alternative with a substantially lower carbon footprint. However, bio-based polyols raise land use, food crop competition, and farming impacts.
- **CO_2-Based Polyols** – produced using captured carbon dioxide, these materials reduce GHG emissions but face technical and logistical challenges in scaling.
- **Metal Springs and Fibers** – durable, but heavy and complex to process, making them less efficient for transport and recycling.
- **Recycled Textiles** – utilize post-consumer textile waste to create low-carbon mattresses, with strong performance in environmental impact reduction.
- **Mechanically Recycled PU Foams** – a cost-effective method using mostly post-industrial and potentially post-consumer waste, though currently underrepresented in available production data.

A life cycle assessment (LCA) was conducted to compare these options based on their carbon footprint. Results show that:

- **Bio-based polyol mattresses** achieve a considerable reduction of CO_2 emissions (up to -41%).
- **CO_2-based polyol mattresses** offer moderate emission savings (-20% at best).
- **Chemically recycled polyol** mattresses can reduce emissions when used at high concentrations.
- **Recycled textile mattresses** present the lowest carbon footprint overall (-77%), despite their higher weight.
- **Spring mattresses** significantly increase emissions due to their heavy metal content (+234%).

The report concludes that transitioning to mattresses made with bio-based or recycled components offers environmental benefits. Among all alternatives, recycled textile mattresses are identified as the most promising solution due to their low carbon footprint and alignment with circular economy principles. UNHCR is encouraged to further explore and scale up the adoption of these sustainable options as part of its broader decarbonization strategy.

Chapter 1

Mattresses, technical background

1.1 Background information about UNHCR procurement of mattresses and their carbon footprint

UNHCR procures approximately 1.3 million mattresses annually. This product is primarily sourced locally due to its wide availability, low cost, and ease of production all over the world. As a result, procurement of this item has not been yet centralized at UNHCR. However, minimum technical standards have been developed to ensure the product is fit for purpose and meets quality requirements. Due to its heavy and bulky nature, the product is challenging to store and transport in large volumes during emergencies. This can increase per capita costs and cause delivery delays, ultimately reducing the efficiency of emergency response operations. Mattresses are typically made of polyurethane (PU) with a minimum density of 23 kg/m3. They come in two standard sizes: 190 x 80 x 10 cm for the lightweight version and 190x80x15 cm for the regular version. The procurement of these items results in the use of more than 6 000 tonnes of material (Figure 1 a) and the related emission of 43 000 tonnes of CO_2 annually (Figure 1 b).

FIGURE 1. ANNUAL FOOTPRINT FROM THE MATTRESSES PROCURED BY UNHCR:

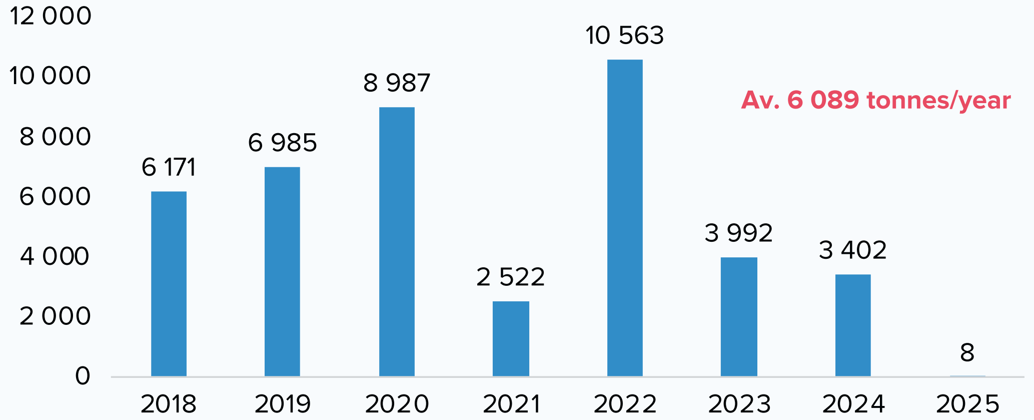

FIGURE 1 A: BULK MATERIAL WEIGHT

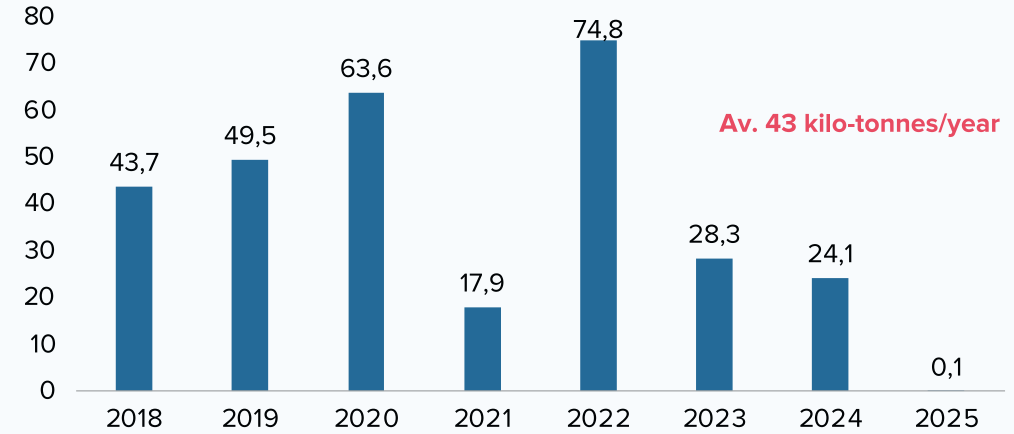

FIGURE 1 B: CARBON FOOTPRINT

Since mattresses account for approximately 15% of overall UNHCR's baseline emissions from procured Core Relief Items (CRIs), estimated at around 300 000 tonnes, reducing their associated carbon dioxide emissions represents a significant contribution to the organization's overall decarbonization efforts.

1.2 Mattress production and related environmental concerns

Mattresses are typically made from flexible polyurethane (PU) foams – a polymer produced by reacting two main components: polyol(s) and isocyanate(s). Blowing agent(s) are also used in the process, along with specific aids when needed to achieve certain foam properties[1] .

As one of the most widely produced polymers, PUs raise environmental concerns both during manufacturing and at their end of life. Most PUs are derived from petroleum-based materials, which are incinerated – contributing to CO_2 emissions - or disposed of in landfills, where they exacerbate ecosystem pollution (Figure 2). Moreover, some components of raw materials used for PU production can be hazardous to human health and harmful to the environment, causing ozone depletion. For example, isocyanates – classified as toxic even at low concentrations or through inhalation – are known to have carcinogenic and mutagenic effects on humans[2]. Some blowing agents, commonly used to create the cellular structure in foams, can contribute to ozone layer depletion. Although other impact categories are recognized, they fall outside the scope of this study, which is specifically focused on CO_2 emissions and global warming potential (GWP).

To address the environmental challenges associated with PUs, a range of solutions have been recently introduced on the market. These include the use of bio-based, recycled, or CO_2-based feedstock, which can help reduce the carbon footprint of PU production. Recycled feedstock can additionally contribute to the reduction of plastic pollution. Additionally, adopting energy-efficient processes and switching to clean energy sources for manufacturing also contributes to the reduction of carbon footprint. The development of non-isocyanate polyurethanes offers another promising alternative by reducing the toxicity typically associated with conventional PU synthesis, etc.

Implementing reverse logistics practices is also essential, as it not only helps reduce the volume of PU waste ending up in landfills – where it is difficult to treat and recycle – but also addresses the stage at which toxic substances are most likely to be released into the environment. Please refer to section 1.3 for potential material options to improve the sustainability of PU mattresses.

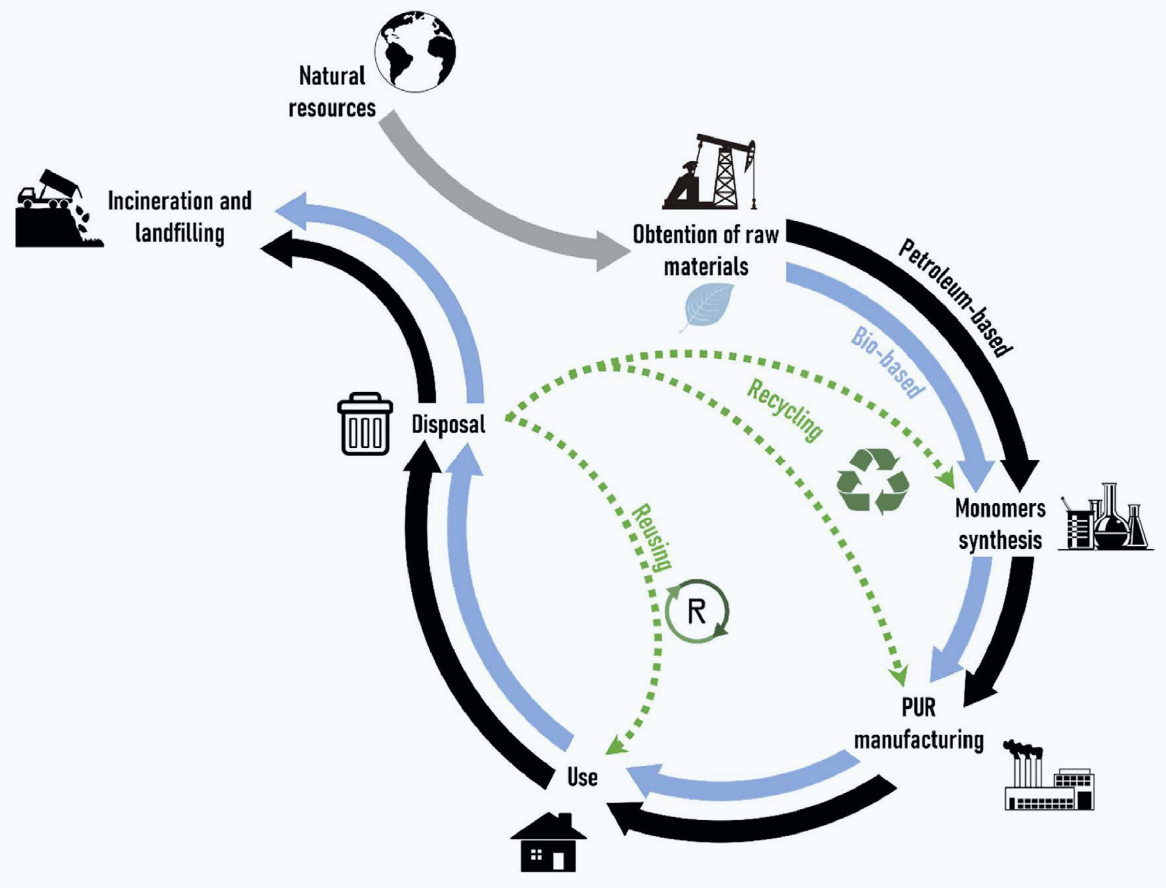

FIGURE 2. GENERAL SCHEME OF PU LIFE CYCLE[3]

[1] Dutta, A.S. (2018). 2 – Polyurethane Foam Chemistry. In T. Sabu et al. (Eds.), Recycling of Polyurethane Foams (pp. 17-27). Willian Andrew. https://doi.org/10.1016/B978-0-323-51133-9.00002-4

[2] Kapp, R.W. (2024). Isocyanates. In P. Wexler (Ed.), Encyclopedia of Toxicology (Fourth Edition) (pp. 663-694). Academic Press. https://doi.org/10.1016/B978-0-12-824315-2.00294-3

[3] Delavarde, A., Savin, G., Derkenne, P., Boursier, M., Morales-Cerrada, R., Nottelet, B., Pinaud, J., Caillol, S. (2024). Sustainable polyurethanes: toward new cutting-edge opportunities. Progress in Polymer Science, 151, 101805.

1.3. Material options to reduce carbon footprint of mattresses

Two main components are required to produce flexible PU foam: polyol (60-65%) and isocyanate (40-35%). Polyol is mixed with isocyanate and other additives, then poured into molds where it undergoes the foaming process. In terms of material composition, opportunities to reduce the environmental footprint can primarily be found at the raw material level – specifically in the polyol component. Recently, several 'sustainable polyols' have emerged on the market. These include more sustainable polyols derived from alternative feedstocks such as chemically recycled polyurethane foam, bio-based sources, and CO_2-based polyols. Another way to reduce the environmental footprint of PU mattresses is to consider alternatives made from entirely different materials, such as metal spring mattresses or those made of recycled textiles. The potential options for sustainable materials that could reduce the carbon footprint of PU mattresses considered in this paper are listed in Table 1.

Table 1. Potential options for sustainable materials that can reduce the carbon footprint of PU mattresses

Options	Mattresses' material	Material that can reduce carbon footprint	Max. theoretical content (%)
Reference baseline*	PU made of 100% virgin fossil-based polyol	-	-
Option 1	PU made with the inclusion of chemically recycled polyol	Chemically recycled polyol	Up to 80% in polyol composition Which is up 48%** in the overall material composition
Option 2	PU made with the inclusion of bio-based polyol	Bio-based polyol	Up to 100% in polyol composition Which is ~60% in the overall material composition
Option 3	PU made with the inclusion of CO_2-based polyol	polyethercarbonate polyols from carbon dioxide	Up to 100% in polyol composition Which is ~60% in the overall material composition
Option 4	Metal springs and fibers	Metal springs and fibers (preferably recycled)	No maximum material composition specified because this applies to PU material. Springs and textiles have different compositions, so this approach has not been considered.
Option 5	Textile (fibers)	Waste textile (fibers)	
Option 6	PU	Mechanically recycled PU foams: PCR (post-consumer recycled) and/or PIR (post-industrial recycled) PU	Up to 100%***

*PU mattress made with the use of 100% virgin fossil-based polyol is considered a reference mattress (Option 0).
** Considering a maximum of 60% polyol of the total material composition
*** Lack of production data from manufacturers did not allow the inclusion of complete LCA for this option

1.3.1 Option 1: Use of chemically recycled polyol

One viable option to reduce the carbon footprint of PU foam is the use of recycled polyols[4]. Recycled polyols are typically obtained through the chemical recycling of post-consumer PU foams. This process, also known as depolymerization, offers an alternative to traditional mechanical polymer recycling. Rather than simply reprocessing plastic waste into lower-grade materials, chemical recycling breaks down polymers into their original components (monomers), which can then be used to synthesize new polymers without significant loss of material properties (Figure 3).

Chemically recycled polyols offer several advantages over virgin polyols derived from petrochemicals. They help reduce dependence on finite fossil resources, mitigate environmental pollution from plastic waste, support a circular economy by closing the material loop, and potentially reduce the overall life-cycle carbon footprint of the product. Several chemical corporations have already developed cost-effective chemical recycling processes that ensure the quality and stability of recycled polyols (see Table 2).

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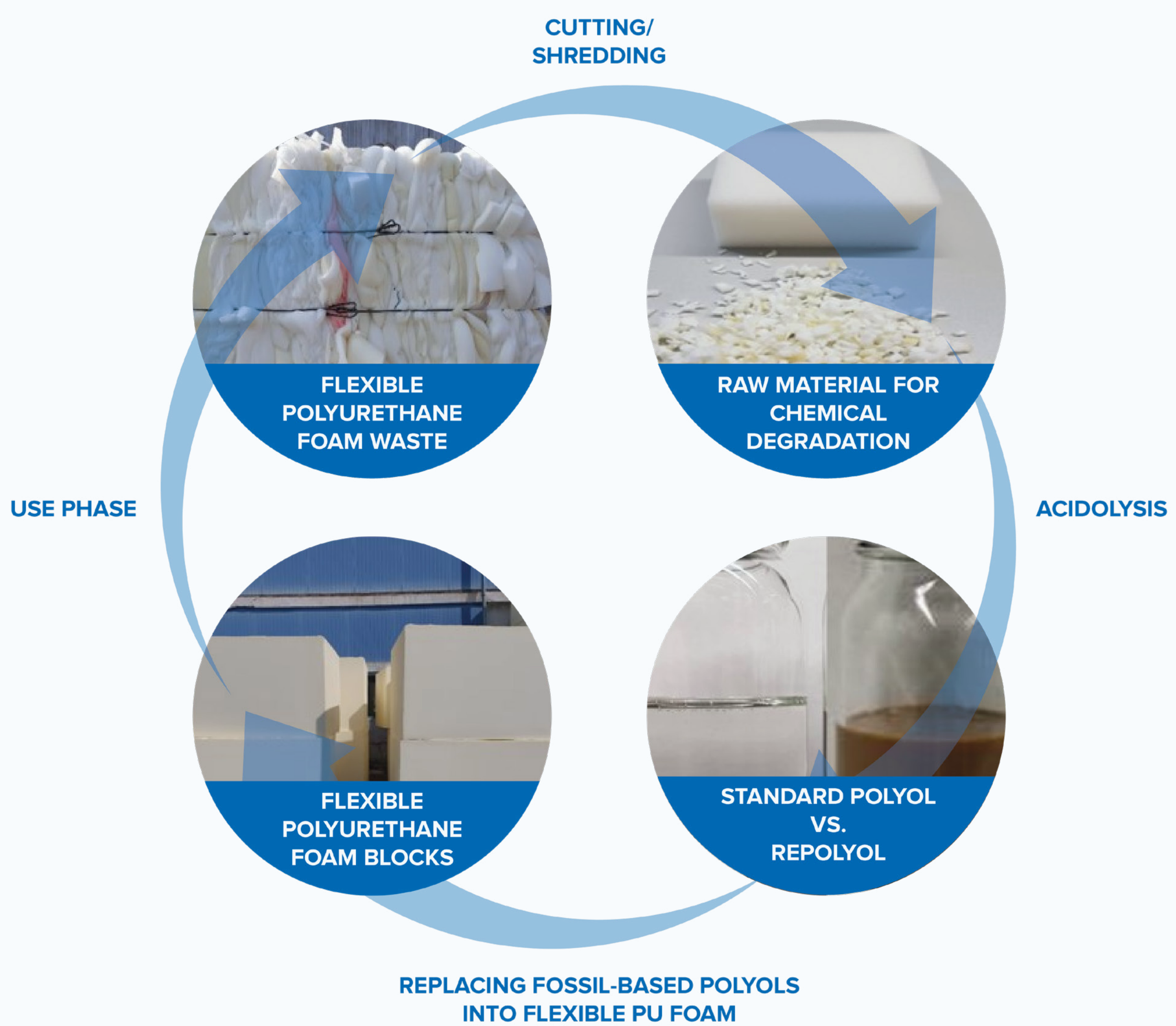
https://doi.org/10.1016/j.progpolymsci.2024.101805

[4] Sheel, A., Pant, D. (2018). Chemical depolymerization of polyurethane foams via glycolysis and hydrolysis. In Recycling of polyurethane foams (pp. 67–75). https://doi.org/10.1016/B978-0-323-51133-9.00006-1

Figure 3. Process of mattresses production with chemically recycled polyols (schematically)



However, challenges remain – most notably the need to scale up production to meet industrial demand, which requires significant investment. Between 2020 and 2023, leading chemical corporations such as Repsol, Evonik, Covestro, BASF announced that they had successfully completed the research and development phase and are now moving towards the construction of production facilites for producing recycled polyols from old mattresses. Still, the construction of industrial plants is expected to take several years and entails significant capital investment.

To date, only Dow has announced the operationalization of a facility able to recycling old mattresses into polyols with an annual production capacity of appoximately 2000 tonnes. Another important consideration is the geographic distribution capacity. As of now, all recycling plants listed in Table 3 are located in Europe.

Importantly, chemical recycling is particularly relevant for used mattresses, as these products are often in poor condition at end of life. They typically carry dust, dirt, and other contaminants, making them unsuitable for direct reuse or mechanical recycling. As a result, many companies are unwilling to take them back without a process that ensures proper sanitization and material recovery.

In summary, while chemically recycled polyols have limited availability in the market, their presence is expected to grow significantly in the European region over the next few years.

Table 2. Companies dealing with chemical recycling of old mattresses

Company	Country (recycling plant)	Project description	Expected production capacity	Expected year for starting building an industrial recycling facility
Repsol[5]	Puertollano, Spain	The first plant in Spain (Puertollano Industrial Complex) to chemically recycle PU foam with a capacity to treat 2,000 tonnes of this type of waste per year. This is equal to 200 000 mattresses.	2,000 tonnes/year	In 2024 the pilot plant for chemical recycling of polyols was launched
Evonik and REMONDIS[6]	Hanau, Germany	Evonik's new hydrolysis recycling process	Not known	2023
Consortium under Horizon 2020 funding (9 partners including Covestro)[7]	Leverkusen, Germany	PUReSmart project (2019-2022)	N/a	Research project
Dow[8]	France	Renuva	~2 000 tonnes/ year	2020

The recommended proportion of chemically recycled polyol in the polyol blend is between 30 and 80%, which corresponds to approximately 18% to 48% of the total composition of the PU mattress.

1.3.2 Option 2: Use of bio-based polyols

Bio-based polyols[9], derived from renewable resources, offer several advantages over their conventional petroleum-based counterparts, including reduced reliance on non-renewable fossil resources and a smaller carbon footprint[10]. The primary sources of bio-based polyols include biomass from various origins (soybean, palm, castor, corn, etc.). However, the availability of suitable renewable feedstocks can be limited and subject to seasonal fluctuations, and the cultivation of certain feedstocks may compete with food production or raise concerns about land use and biodiversity. Moreover, some studies indicate that bio-based polymers may have higher impacts on eutrophication[11] and stratospheric ozone depletion[12] compared to their petroleum-based counterparts[13]. However, considering all the above points and compared to chemically recycled polyols, bio-based polyols appear to be more readily available for mattress production and are supported by standards such as CertiPUR, which may help drive market competition.

5 Repsol. (n.d.). Chemical recycling of polyurethane foam. Repsol. Retrieved June 12, 2025, from https://www.repsol.com/en/sustainability/sustainability-pillars/environment/circular-economy/our-projects/chemical-recycling-of-polyurethane-foam/index.cshtml

6 Evonik Industries AG. (n.d.). Hydrolysis: Chemically recycling mattresses. Evonik. Retrieved June 12, 2025, from https://www.evonik.com/en/company/we-go-beyond/hydrolysis.html

7 PUReSmart. (n.d.). PolyUrethane Recycling towards a Smart Circular Economy. Retrieved June 12, 2025, from https://www.puresmart.eu/

8 Dow. (n.d.). Converting PU foams to polyols. Dow. Retrieved June 12, 2025, from https://corporate.dow.com/en-us/seek-together/converting-pu-foams-to-polyols.html

9 Campana, F., Brufani, G., Mauriello, F., Luque, R., & Vaccaro, L. (2024). Green polyurethanes from bio-based building blocks: Recent advances and applications. Green Synthesis and Catalysis. https://doi.org/10.1016/j.gresc.2024.08.001

10 Silva, R., Barros-Timmons, A., & Quinteiro, P. (2023). Life cycle assessment of fossil- and bio-based polyurethane foams: A review. Journal of Cleaner Production, 430, 139697. https://doi.org/10.1016/j.jclepro.2023.139697

11 Eutrophication -- the gradual increase in the concentration of phosphorus, nitrogen and other plant nutrients in an aging aquatic ecosystem.

12 Stratospheric ozone depletion – is the gradual thinning or reduction of the ozone layer in the Earth's stratosphere, particularly in the region known as the ozone layer.

13 Weiss, M., Haufe, J., Carus, M., Brandão, M., Bringezu, S., Hermann, B., & Patel, M. K. (2012). A review of the environmental impacts of biobased materials. Journal of Industrial Ecology, 16(S1), S169–S181. https://doi.org/10.1111/j.1530-9290.2012.00468.x

1.3.3 Option 3: polyethercarbonate polyols from carbon dioxide

Carbon dioxide is an abundant, low-cost, non-flammable, and renewable feedstock that can be captured directly from the air or through point-source carbon capture (for fuels, chemicals, and polymers). Once purified, CO_2 can serve as a carbon source in various applications, including polyols. These polyols can then be processed into polyurethanes, enabling CO_2 to be used in large amounts. The motivation for using CO_2 in polyol production lies in its potential to reduce greenhouse gas (GHG) emissions and fossil resource depletion[14].

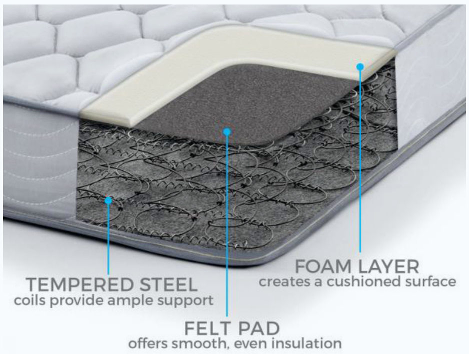
In 2016, CO_2-based polyols entered industrial-scale production[15] with Covestro's launch of the Cardyon® product line, which includes up to 20% CO_2 content in polyols in polyols, desiged for use in flexible PU foam[16] such as mattresses and upholsters. By 2022, the production capacity expanded up to 5 000 tonnes, demonstrating scalable manufacturing capabilities.

Despite the potential, scaling up production of CO_2-based polyol faces several challenges. A major limitation is the lack of supporting infrastructure, which is further hindered by technical and logistical constraints[17]. A key bottleneck is the limited availability of high-purity CO_2; polyol yields can fall by up to 18% if CO_2 purity falls below 99.7%. Currently, most of the CO_2 used in this process is sourced from coal-fired power plants or cement plants, which often fail to supply sufficiently pure CO_2. Purifying CO_2 is energy-intensive, and when required, can increase the overall carbon footprint of the resulting material. Additionally, CO_2-based polyols are more temperature-sensitive than traditional polyols. To remain stable, they must be stored at 15-25°C, which makes transport and storage more challenging and costly (shipping costs can be almost 50% higher than conventional shipping). These combined issues currently limit the ability to scale-up this technology.

1.3.4 Option 4: Mattresses made of metal springs and fibers

Spring mattresses are widely used and consist of a cushion base supported by a system of metal springs, typically enclosed in a cover made of a mixture of fibers (Figure 4). In this variant, both steel springs and fibers can be of secondary origin. The spring systems often use steel, frequently recycled, or other metals, which may be sourced from discarded mattresses, automotive parts, or industrial scrap.

FIGURE 4. AN EXAMPLE OF A SPRING MATTRESS STRUCTURE[18]



These mattresses offer several advantages: they are widely available on the market, can be manufactured quickly, and contain metal components that are relatively easy to recycle. However, they also have notable disadvantages. Spring mattresses tend to be heavier, more expensive, and more difficult to stack and transport efficiently. Additionally, they consist of multiple material types (metal and fiber) that are more complex to separate during the recycling process, which can limit their overall recyclability.

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[14] von der Assen, N., & Bardow, A. (2014). Life cycle assessment of polyols for polyurethane production using CO_2 as feedstock: Insights from an industrial case study. Green Chemistry, 16(6), 3272–3280. https://doi.org/10.1039/C4GC00513A

[15] Willams, D. (2016, June 22). Covestro inaugurates CO_2-to-polyols plant. CHEManager. https://www.chemanager-online.com/en/news/covestro-inaugurates-co2-polyols-plant

[16] Plastics le Mag. (2021, October 12). Mattresses made from CO_2. Plastics le Mag. https://plastics-themag.com/Mattresses-made-from-CO2

[17] PW Consulting. (2025, January 25). Carbon dioxide polyether polyol market. PW Consulting. Retrieved June 12, 2025, from https://pmarketresearch.com/it/carbon-dioxide-polyether-polyol-market/

[18] GoodBed. (n.d.). Mattress cushioning guide. Retrieved June 12, 2025, from https://www.goodbed.com/guides/mattress-types/innerspring-mattresses/cushioning-types/

1.3.5 Option 5: Mattresses made of recycled textile waste

The textile and apparel industry is widely acknowledged as one of the most environmentally damaging industries globally[19]. According to Textile Exchange's annual Materials Market Report[20], global fibre production for clothing, home textiles, and other applications reached 124 million tonnes in 2023 and is projected to rise to 160 million tonnes by 2030. As a result, the textile industry accounts for approximately 6-8% of global carbon dioxide emissions[21], making it one of the largest environmental polluters[22].

At the same time, less than 1% of the global market consists of pre-, and post-consumer recycled textiles. The vast majority of textile waste is either incinerated or sent to landfills, contributing to land degradation and air pollution. To mitigate the negative environmental impact of the textile industry, it is crucial to enhance textile waste recycling efforts and extend the useful lifespan of these materials.

One promising application for post-consumer recycled textiles is in the production of bedding products, including mattresses[23] (Figure 5). For this purpose, waste textiles must be collected, sorted, cleaned, and processed through several recycling stages before being formed into new products. These include mattresses[24], insulation blocks[25], building materials[26], nonwoven textiles, and textiles for use in the automotive sector[27], etc.

Advantages of using recycled textile waste in mattresses include the potential to divert large volumes of waste from landfills, reduce the environmental footprint of the textile industry, and utilize materials that are often abundantly available. This approach also supports circular economy principles and can promote innovation in mattress design.

Disadvantages include challenges related to the collection and sorting of diverse textile waste streams, potential contamination issues, and the variability in quality and composition of recycled fibres.

FIGURE 5. EXAMPLES OF MATTRESSES MADE OF RECYCLED TEXTILES

(A), (B) – NOVAFIBER MATTRESSES[28] ; (C) NATURALMAT X COTTON LIVES ON™ MATTRESSES[29]

[19] Huang, X., Tan, Y., Huang, J., Zhu, G., Yin, R., Tao, X., & Tian, X. (2024). Industrialization of open- and closed-loop waste textile recycling towards sustainability: A review. Journal of Cleaner Production, 436, 140676. https://doi.org/10.1016/j.jclepro.2024.140676

[20] https://textileexchange.org/knowledge-center/reports/materials-market-report-2024/

[21] Imran, S., Mujtaba, M. A., Zafar, M. M., Hussain, A., Mehmood, A., Farwa, U. E., Korakianitis, T., Kalam, M. A., Fayaz, H., & Saleel, C. A. (2023). Assessing the potential of GHG emissions for the textile sector: A baseline study. Heliyon, 9(11), e22404. https://doi.org/10.1016/j.heliyon.2023.e22404

[22] https://www.cbsnews.com/news/earth-day-2019-fashion-industrys-carbon-impact-is-bigger-than-airline-industrys/

[23] Nayak, R., Houshyar, S., Patnaik, A., Nguyen, L. T. V., Shanks, R. A., Padhye, R., & Fegusson, M. (2020). Sustainable reuse of fashion waste as flame-retardant mattress filling with ecofriendly chemicals. Journal of Cleaner Production, 251, 119620. https://doi.org/10.1016/j.jclepro.2019.119620

[24] Novafiber. (n.d.). Productos. Novafiber. Retrieved June 12, 2025, from https://novafiber.com.gt/productos/

[25] ANDRITZ. (2025, March 20). Sustainable insulation: ANDRITZ tearing line to enhance recycling capabilities at Buitex. Texdata International. Retrieved June 12, 2025, from https://www.texdata.com/news/Nonwovens-TechnicalTextiles/21463.html

[26] Innovation in Textiles. (2025, February 3). New Andritz lines commissioned in Spain and Sweden. Retrieved June 12, 2025, from https://www.innovationintextiles.com/new-andritz-lines-commissioned-in-spain-and-sweden/

[27] World of Technical Textile. (2022, May 23). Andritz to present innovative nonwovens production and textile solutions at Techtextil. Retrieved June 12, 2025, from https://worldoftechnicaltextile.com/andritz-to-present-innovative-nonwovens-production-textile-solutions-at-techtextil/

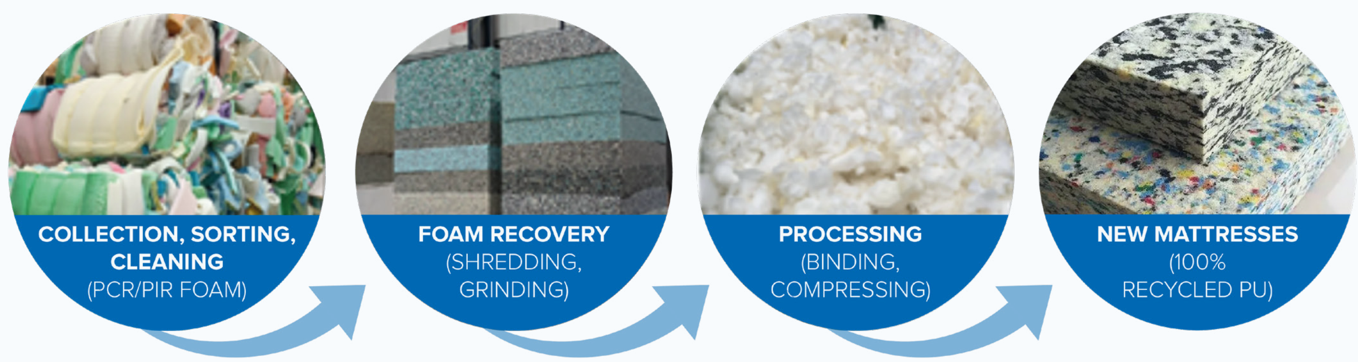
[28] Novafiber. (n.d.). Colchonero. Novafiber. Retrieved June 12, 2025, from https://novafiber.com.gt/colchonero/

[29] Naturalmat. (n.d.). Cotton Lives On x Naturalmat. Retrieved June 12, 2025, from https://naturalmat.co.uk/pages/cotton-lives-on

1.3.6 Option 6: Mechanically recycled PU foams: PCR (post-consumer recycled) and/or PIR (post-industrial recycled) PU

Mechanical recycling of PU foam involves the reuse of PU foam scraps which may originate from post-consumer or post-industrial processes. In this method, PU foam scraps are typically shredded or crushed into small particles, then bonded and compressed into blocks. These blocks can subsequently be processed into new foam slabs (Figure 6).

Figure 6. Process of mattresses production from mechanically recycled (PCR and/or PIR) foam



This approach offers several benefits: it reduces the volume of waste sent to landfill, conserves raw materials by reusing existing resources, and generally has a lower environmental impact compared to other recycling methods. Mechanical recycling is also considered a more affordable and less technically complex option compared to chemical recycling, making it more accessible in low- and middle-income regions.

Mechanical recycling of PU foams appears as a cost-effective and widely available method, especially for post-industrial waste. It reduces landfill waste and conserves resources by repurposing foam scraps into new products. While post-consumer foam recycling presents additional considerations, such as the need for proper sanitization to address dust, contaminants, or allergens.

Chapter 2

Summary of Product Carbon Footprint Evaluation of different materials options for mattresses

2.1 Goal of the assessment

The purpose of this Chapter is to assess and compare the potential environmental impacts of producing 1 unit of mattress with different materials:

- Option 0: PU made of 100% virgin fossil-based polyol;
- Option 1: PU made with the inclusion of chemically recycled polyol;
- Option 2: PU made with the inclusion of bio-based polyol
- Option 3: PU made with the inclusion of CO2-based polyol
- Option 4: Mattress made of metal springs and fibers
- Option 5: Mattress made of recycled textile.
- The study doesn't cover and include Option 6 (Mechanically recycled PU foams) due to the lack of available production data from manufacturers.

This assessment is compliant with the requirements of EN ISO 14040/14044[30,31], EN ISO 14067[32], GHG Product Standard[33].

2.2 Declared unit

- One piece of mattress (3.496 kg) with a density of at least 23 kg/m3 and dimensions of 1.9 x 0.8 x 0.1 m.
- In the case of the pocket spring mattress and the recycled textile mattress, the weight and the dimensions of the mattresses are different as follows:
  - Pocket spring mattress weighs 21.3 kg with the dimensions of 2.0 x 1.0 x 0.2 m.
  - Recycled textile mattress weighs 6.2 kg with the dimensions of 1.9 x0.95x0.1 m.

[30] **EN ISO 14040:** International Organization for Standardization. (2006). Environmental management – Life cycle assessment – Principles and framework (EN ISO 14040:2006). European Committee for Standardization.

[31] **EN ISO 14044:** International Organization for Standardization. (2006). Environmental management – Life cycle assessment – Requirements and guidelines (EN ISO 14044:2006). European Committee for Standardization.

[32] **EN ISO 14067:** International Organization for Standardization. (2018). Greenhouse gases — Carbon footprint of products – Requirements and guidelines for quantification (EN ISO 14067:2018). European Committee for Standardization (CEN).

[33] GHG protocol product life cycle accounting and reporting standard. (2011). World Resources Institute. https://ghgprotocol.org/product-standard

2.3 System Boundaries

This study follows a “cradle-to-gate” approach for an average product, covering the following product life-cycle stages:

- Extraction and processing of virgin raw materials.
- Generation of secondary energy carriers (e.g. electricity).
- All relevant transport to the plant gate and at the manufacturing site; transport of waste to the respective recycling facilities.
- Production process.
- Waste and wastewater generated as outputs from the production phase.

The **foreground system** encompasses site-specific processes occurring directly at the production facility, using specific information from that location. These include energy consumption, raw material processing, product manufacturing, on-site transport, packaging, and waste management, all based on data specific to the plant’s production.

In contrast, the **background system** comprises upstream and downstream processes generally not directly controlled by the manufacturer. These include raw material extraction and the external transportation of materials or waste, typically modeled using secondary or average data from suppliers and databases.

Although the products assessed are manufactured at a single production site, average global values are used for selected background data where specific data is unavailable.

2.4 Criteria for the Exclusion of Inputs and Outputs (Cut-off)

According to ISO 14044, cut-off criteria define the thresholds for including or excluding material, energy flows, or environmental impact in a Life Cycle Assessment (LCA) study. Criteria such as mass, energy use, and environmental relevance are typically applied to determine which inputs and outputs should be considered.

In this study, all input and output data related to factory processes are fully included in the model. Input and Output are considered without the application of any cut-off criteria, even when the mass or energy flows account for less than 1% of the whole energy and mass employed in the process. For post-production stages, scenarios are developed based on geographical context and current practices, such as waste treatment methods. When specific data from the production site is unavailable, reliable generic data sources are used and subsites.

The construction of buildings, manufacturing equipment, and office-related activities are excluded from the system boundaries, as they are not directly associated with the core production process.

2.5 Inventory Analysis

Secondary data representative of the specific production processes is sourced from relevant research[34], while primary data is provided directly by the manufacturer in the case of the recycled textile mattress. The data collected covers all inputs and outputs within the defined system boundary.

Detailed inventory data for each mattress type assessed in this study was compiled through a comprehensive internal LC. As this data includes proprietary inputs and secondary datasets provided by a consultant using the Ecoinvent database without a UNHCR formal license agreement, it is not publicly available.

[34] Lanoë, T., Simões, C. L., & Simoes, R. (2013). Improving the environmental performance of bedding products by using life cycle assessment at the design stage. Journal of Cleaner Production, 52, 155–164. https://doi.org/10.1016/j.jclepro.2013.03.013

2.6 Unit Processes

2.6.1 Raw Materials and pre-products supply

Raw materials for the PU foam products are pre-produced ingredients delivered by external suppliers. The manufacturing and grid energy residual mix are considered global averages. Manufacturing of packaging is included. For spring mattresses, it is assumed that materials are originated from primary (virgin) sources.

2.6.2 Transportation

Transportation of all input materials is fully included. Data is taken from the following research[34]; in the case of the recycled textile mattress, data is provided by the manufacturer.

2.6.3 Manufacturing process

The PU foam mattress manufacturing process starts with a moulded PU foam block, based on the mixture of two liquids, Polyol and Isocyanate. The foam block is taken out of the mould and passes through a cylinder to explode the cells and enable the polymerization reaction. It is necessary to cut the top and lateral sides in order to remove from the block any marks left by the mould. Simultaneously, the removable cover is manufactured. This process starts with quilting, where three components are sewed together: the mesh fabric, the polyester fibre and the jersey fabric. After this step, the quilted material will be transformed into the outside cover of the mattress. Also, the inside cover is manufactured from jersey fabric and equipped with a zipper. After all these components are ready, the PU foam block is inserted into the inside cover and finally the outside cover is applied. The mattresses are placed in a packaging machine that automatically wraps the mattress in a low-density polyethylene (LDPE) film[34]. The manufacturing steps for PU mattresses that incorporate bio-based, recycled, or CO_2-based polyol are essentially the same as described above.

The pocket spring mattress manufacturing process starts with metal wires formed into tempered springs, which are inserted into ultrasound-welded non-woven fabric to create a continuous line. This line is shaped into the mattress core using an assembling machine and joined with hotmelt glue. The spring core is placed into a PUR foam box, forming the nucleus. Covers made of mesh fabric, polyester fibre, and PUR foam add comfort and aesthetics. Borders with various fabrics and accessories enhance design and durability. The mattress is sewn closed with a top-edge sewing machine and wrapped in LDPE film for delivery[34]. Transportation of all input materials is fully included. Data is taken from the following research[34].

The manufacturing steps of the recycled textile mattress is as follows:

- Scrap collection: Scraps are collected from clothing factories treating used fabrics in central Americas region.
- De-linting: Scraps are processed with spiked rollers into fibres, which are then stored.
- Thermo-bonding and cutting: The fibres are mixed to form a batt with a specific weight per m^2, which is passed through an oven and cold calenders to achieve the required height by means of thermal shock. The panels are then cut to the defined dimensions.
- Finish: The panels are lined with the chosen type of fabric and packaged for sale.

2.7 Life cycle impact assessment

The calculation and categorization of life cycle emissions were conducted in alignment with ISO 14040 principles. The impact assessment focuses on mid-point impact categories deemed most relevant to the objectives of this study (Table 3).

LCA impacts were calculated using an Excel-based model, where each input or output was multiplied by the corresponding impact factor. For energy use, values in natural units were converted to the corresponding energy units using country-specific or generic net calorific values, as appropriate. The environmental impact from electricity consumption was assessed applying the global average specific factor

TABLE 3. CORE ENVIRONMENTAL INDICATOR ASSESSED

Category	Indicator	Unit
Climate change-GHG	Global warming potential-greenhouse gas (GWP-GHG)	kg CO_2-eq.

2.8 Carbon footprint of different mattresses

Figure 7 indicates the relevant carbon footprint of the assessed mattresses under the same functional unit. Table 5 indicates the relative CO_2-eq. change in comparison with the reference mattress (PU, 100% virgin fossil-based polyol). The weights and dimensions of each of the investigated mattresses are given in Table 4.

TABLE 4. SIZES AND WEIGHTS OF THE ANALYSED MATTRESSES

Characteristic	Option 0	Option 1	Option 2	Option 3	Option 1	Option 5
Material	PU, 100% virgin fossil-based polyol	PU with the inclusion of chemically recycled polyol	PU with the inclusion of bio-based polyol	PU with the inclusion of CO_2-based polyol	Metal spring mattress	Recycled textile mattress
Sizes	1.9 x 0.8 x 0.1 m				2.0 x 1.0 x 0.2 m	1.9 x 0.95 x 0.1 m
Weight of 1 mattress, kg	3.5 kg				21.3 kg	6.2 kg

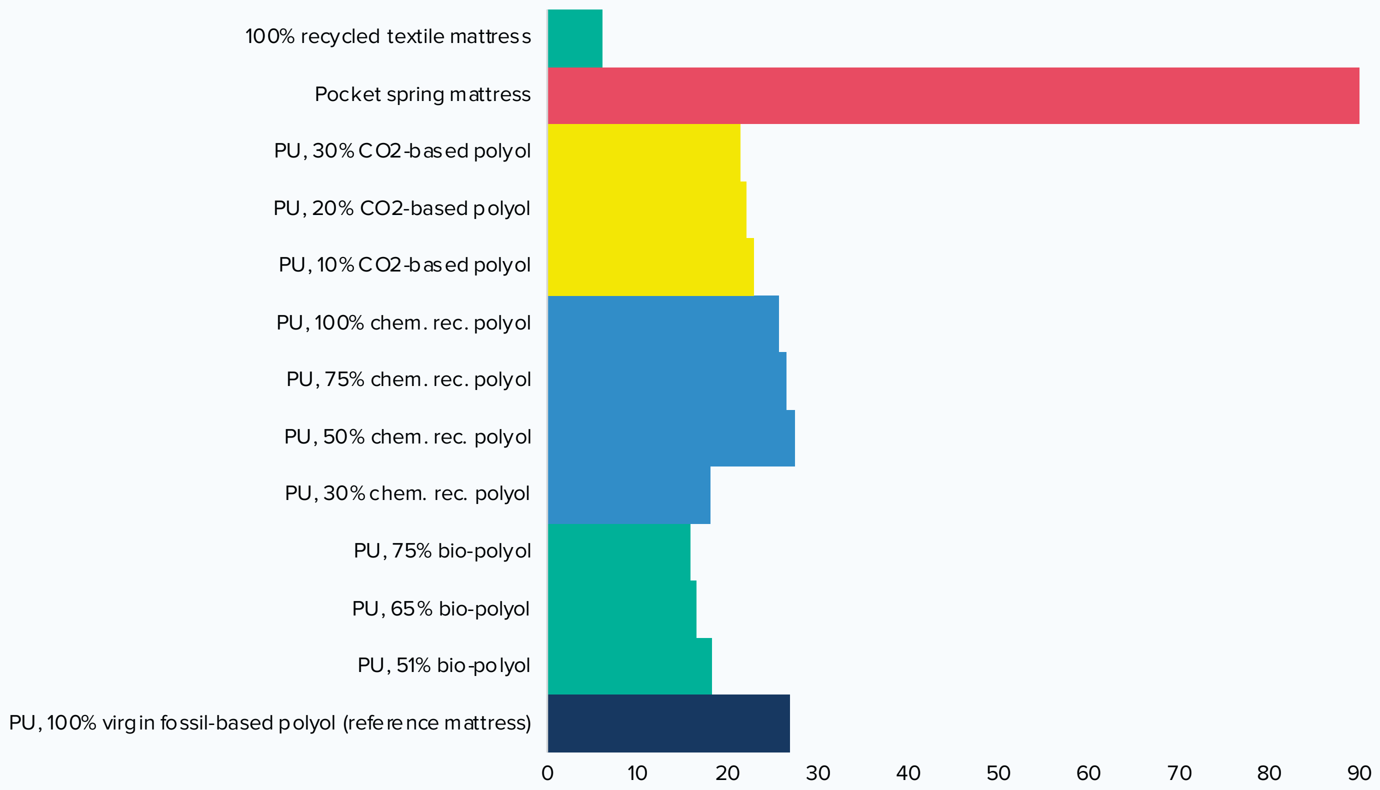


FIGURE 7. COMPARISON OF CARBON FOOTPRINT OF DIFFERENT MATERIAL OPTIONS FOR MATTRESS (KG CO_2 PER MATTRESS)

TABLE 5. SUMMARY OF THE CARBON FOOTPRINT OF THE MATTRESSES AND THE RELATIVE CHANGE OF THEIR CARBON FOOTPRINT IN COMPARISON TO THE STATUS QUO

Name of the mattress	kg CO_2-eq./piece	Change of CO_2-eq. in comparison to status quo
PU, 100% virgin fossil-based polyol (reference mattress)	26.92	0.0%
PU foam mattress, 51% bio polyol	18.23	-32.3%
PU foam mattress, 66% bio polyol	16.43	-39.0%
PU foam mattress, 74% bio polyol	15.78	-41.4%
PU foam mattress, 30% chemically recycled PU	28.13	4.5%
PU foam mattress, 50% chemically recycled PU	27.42	1.9%
PU foam mattress, 75% chemically recycled PU	26.55	-1.4%
PU foam mattress, 100% chemically recycled polyol	25.70	-4.5%
PU foam mattress, 10% CO_2-based polyol	22.81	-15.3%
PU foam mattress, 20% CO_2-based polyol	22.01	-18.2%
PU foam mattress, 30% CO_2-based polyol	21.41	-20.5%
Pocket spring mattress	89.95	234.2%
Recycled textile mattress from manufacturer w/ washing	6.13	-77.2%

Conclusions

Polyurethane (PU) foam mattresses containing bio-based polyol have a significantly lower carbon footprint than the reference mattress. This is primarily due to the emission factor[35] used for bio-based polyols in the study, which accounts for the carbon sequestration effect[36] of the biomass materials.

Among the chemically recycled PU foam mattress scenarios assessed, only those with 75% and 100% chemically recycled polyol content (two cases) demonstrate a lower carbon footprint than the reference mattress.

A relatively new approach to reducing the carbon footprint of PU foam mattresses involves using CO_2-based polyol. In this study, PU foam mattresses containing 10%, 20%, and 30% CO_2-based polyol exhibited a moderately lower carbon footprint than the reference mattress. These scenarios outperformed those using chemically recycled polyol but did not perform as well as the bio-based polyol scenarios.

The pocket spring mattress shows a significantly higher carbon footprint compared to the PU foam reference mattress, mainly due to the weight of its components - particularly the use of over 13 kg of steel wires. Although using recycled steel could potentially reduce its footprint, at present it is not recommended to replace PU foam mattresses with pocket spring alternatives.

The recycled textile mattress has a substantially lower carbon footprint than the reference mattress. This advantage is largely due to its lower energy requirements – especially the consumption of electricity – and the much lower specific carbon footprint of its recycled textile components. Despite requiring more material inputs (6.2 kg for textile mattress vs. 3.4 kg for PU mattress), the environmental benefit outweighs the impact of the increased volume. Overall, the procurement of recycled textile mattress is recommended for further consideration and study.

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[35] Polylabs. (n.d.). Product list. Polylabs. Retrieved June 12, 2025, from https://www.polylabs.eu/product-list/

[36] Sequestration effect for bio-based plastics refers to the ability of these materials to capture and store carbon dioxide from the atmosphere during their lifecycle, particularly during the biomass growth phase. This effect is reflected in the related emission factors of bioplastics through the reduction in the carbon footprint associated with the material's lifecycle, particularly in the raw material acquisition phase.


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Annex - List of Acronyms

Acronym	Full Form
CO_2	Carbon Dioxide
CRIs	Core Relief Items
EN	European Norm (standard)
EU	European Union
GHG	Greenhouse Gas
GWP	Global Warming Potential
ISO	International Organization for Standardization
LCA	Life Cycle Assessment
LDPE	Low-Density Polyethylene
PCR	Post-Consumer Recycled
PIR	Post-Industrial Recycled
PU	Polyurethane
PUR	Polyurethane (alternate abbreviation)

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