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Review

Discarded Mattresses: From Environmental Problem to Recoverable Resource

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Abstract

Mattresses represent one of the most widespread and problematic bulky waste streams worldwide, due to their unavoidable daily use, their high presence in municipal solid waste flows, and the complexity of their end-of-life management. Their heterogeneous composition—combining polyurethane foams, textiles, metal springs, and adhesives—makes separation and recovery difficult, leading many discarded mattresses to end up in landfills or incinerators, with associated greenhouse gas emissions and the loss of valuable secondary resources. Within this context, recycling emerges as a priority alternative under the circular economy framework, enabling material recovery and reducing reliance on traditional disposal methods. Among current options, mechanical recycling is especially promising, as it provides energy savings and lower emissions compared to thermal treatments. However, its large-scale implementation requires improvements in product design, collection logistics, and regulatory frameworks to address existing challenges. This article provides a critical review of the current state of mattress recycling and valorization, examining technological advances, environmental impacts, and systemic barriers. It also highlights successful initiatives in the hospitality and healthcare sectors, which illustrate the potential of circular strategies to transform bulky waste management and promote sustainable material flows.

Keywords: mattress recycling; circular economy; bulky waste valorization; environmental sustainability; technological innovation

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1. Introduction: The Mattress as Waste

The management of municipal solid waste constitutes one of the main challenges for sustainability in contemporary urban environments. In this context, bulky waste—particularly end-of-life household mattresses—represents a significant burden from both a logistical and environmental perspective. Their complex nature, derived from their heterogeneous composition and large volume, hinders their treatment within conventional waste management systems. At the same time, their replacement frequency—estimated between eight and twelve years in both residential and hospitality contexts—generates a continuous flow of units requiring efficient and sustainable solutions. In the hospitality sector, additional preventive and maintenance measures are implemented, such as steam cleaning of mattresses every six months and the use of two mattress protectors per unit, which are washed more frequently to extend product lifespan and ensure higher hygiene standards.

Currently, the main end-of-life treatment pathways for mattresses are landfilling, incineration, and, to a lesser extent, recycling. In Southern Europe, landfilling remains the predominant option due to its low immediate cost and the lack of specialized infrastructure, although it entails severe environmental impacts such as greenhouse gas emissions and the risk of soil and groundwater contamination [1].

In Northern Europe, incineration with energy recovery is more widely employed, enabling partial exploitation of the calorific value of mattresses; however, this process involves high energy consumption, the release of atmospheric pollutants, and the irreversible loss of valuable materials.

In light of these limitations, recycling—particularly mechanical recycling—emerges as the most sustainable alternative, as it enables the recovery of significant fractions of foams, metals, and textiles; reduces the volume of waste sent for disposal; and promotes material circularity. Although its development still faces technical and economic challenges, scientific evidence and industrial experience demonstrate that recycling constitutes the best available option to minimize environmental impact and advance toward a waste management model more consistent with the principles of the circular economy [2].

In Europe, it is estimated that between 30 and 40 million mattresses are discarded annually—considering both residential use and those employed in the hospitality sector—representing several million tons of bulky waste each year, with a significant impact in terms of management, emissions, and the loss of recoverable materials [3]. Each mattress occupies an average volume of between 0.6 and 0.75 cubic meters and has an estimated weight of 18 to 35 kg, depending on its typology (spring, foam, hybrid, latex, etc.) [4]. These wastes not only require specific collection and transport systems but also create challenges at treatment facilities due to their low compactability, structural resistance, and the presence of potentially contaminating materials such as flame retardants, industrial adhesives, or petroleum-derived synthetic foams.

The widespread disposal of mattresses in landfills represents a potential source of soil and groundwater contamination, in addition to contributing to the emission of greenhouse gases during their anaerobic decomposition (Figure 1). To this is added the problem of their abandonment in public spaces, with the consequent sanitary, visual, and economic implications for municipalities. However, the valorization of end-of-life mattresses as a resource for the construction industry represents an innovative pathway with high replicability potential.

Several studies [5] have demonstrated that mattresses contain significant fractions of materials with high recovery and valorization potential, particularly polyurethane foams, steel springs, and nonwoven textiles [6]. This recognition has driven research lines focused on the life cycle analysis of mattresses, the detailed characterization of their components, and the evaluation of their suitability as inputs for low-environmental-impact applications.

Among the most promising uses of materials recovered from end-of-life mattresses is their application in the construction sector, where recycled foams are employed in thermal and acoustic insulation systems, textiles are incorporated into technical roofing layers, and various fractions are integrated into non-structural prefabricated elements. Furthermore, these materials have stimulated increasing interest in the furniture industry, where they can be used as padding and filling for sofas or chairs, and in the automotive sector, where they are applied in seat bases, technical upholstery, or soundproofing panels. These applications significantly expand the valorization opportunities of discarded mattresses, reinforcing their role within a multisectoral circular economy model [7–9].

Figure 1. Abandoned mattress on a street (edited in black and white). Original photo by jaimecin, via Flickr [10]. Licensed under CC BY-SA 2.0.

2. The Mattress: History and Evolution

Rest has been, and will continue to be, a fundamental pillar in the development and well-being of humankind. Its impact extends beyond health and physiological balance, being closely linked to productivity, cognitive performance, and the ability to carry out daily activities. The importance of rest has been recognized since the earliest stages of human evolution, becoming a key factor for both survival and societal progress [11].

Beyond the duration and quality of sleep, the posture adopted during rest is a decisive factor in ensuring its effectiveness. The need to lie in a comfortable position responds to biomechanical principles that promote muscle relaxation, spinal alignment, and uniform weight distribution. An inadequate posture can generate excessive pressure points in specific areas of the body, potentially leading to musculoskeletal discomfort and disturbances in sleep quality [12].

It is for this reason that human beings have continually sought to optimize their sleeping conditions by making use of materials available in their immediate environment. Early nomadic and sedentary groups already employed leaves, animal hides, and other natural resources to create more comfortable surfaces while simultaneously reducing the risks associated with sleeping directly on the ground [13]. These risks included not only exposure to humidity and low temperatures, which could compromise health and well-being, but also increased vulnerability to predators and parasites.

With the advent of early civilizations, more sophisticated sleeping structures emerged. In Egypt, for instance, a specific bed design was developed, consisting of a rectangular wooden or metal frame with an integrated headrest that incorporated a curved support for the head, thereby facilitating ergonomic posture and proper spinal alignment. This base was complemented with soft materials such as wool or straw, covered by breathable fabrics that enabled adequate thermal regulation in the Egyptian climate. Beyond its practical function, this system was restricted to pharaohs and the elite, becoming a clear symbol of social status [14].

Subsequently, the Greek civilization introduced key improvements to the concept of the mattress by employing fabric sacks filled with straw, wool, or feathers. This innovation provided greater adaptability to the human body and ensured a more even distribution of weight, in contrast to the rigid surfaces used previously [15]. The system also reflected social distinctions, as the choice of materials and finishes varied according to class, thereby consolidating the mattress as an object associated with both comfort and prestige. This

Greek innovation had a decisive influence on later cultures, laying the foundations for what would eventually become the modern mattress [16].

The evolution of materials used in mattress manufacturing has been closely linked to technological progress and the changing needs of society. With the Industrial Revolution and the mechanization of production, significant advances enabled the transition from rudimentary sleeping systems to more sophisticated structures [17]. One of the most relevant milestones in this transformation was the invention of the Bonnell spring system by Heinrich Westphal in Berlin in 1875 [18]. This mechanism, based on the incorporation of metal wires inspired by the suspension systems used in horse-drawn carriages, endowed the mattress with an industrial identity and facilitated its large-scale production.

The original design of spring mattresses consisted of a block of interconnected coils covered by an outer fabric layer, which provided greater durability and a more uniform sleeping experience compared to the materials used up to that time [19] (Figure 2). Owing to these features, spring mattresses became the predominant option on the market, maintaining their dominance until the 1920s. However, despite their popularity, these mattresses exhibited a significant drawback: motion transfer caused by the interconnection of the springs. This disadvantage was particularly problematic for couples, leading engineer James Marshall to develop a more efficient alternative. In 1899, Marshall designed the first pocketed springs, characterized by the independence of each coil enclosed in a fabric casing, thereby eliminating motion transfer [20]. This system established a new standard in mattress manufacturing, enabling a more personalized and ergonomic sleeping experience.

The twentieth century brought significant advances in the diversification of materials used in the mattress industry (Figure 3). In the 1920s, research on natural rubber led to the development of a material with exceptionally elastic and durable properties: latex foam. Through a chemical process that combined rubber milk with non-toxic compounds, a highly adaptive and breathable material was obtained. The first commercial production of latex mattresses was carried out by the Dunlop company, whose name became permanently associated with this innovative material [21].

In 1931, the use of latex for sleep applications began, especially in mattresses. Its popularity expanded rapidly, establishing it as a preferred option within the luxury hotel sector. Over time, the mattress industry developed different variants of latex, including natural, synthetic, blended, and styrene-butadiene rubber (SBR), whose performance and quality depended on the proportion of natural rubber milk incorporated into the composition. Currently, the production of natural latex foam using advanced technology maintains a rubber milk content close to 97%, which provides optimal properties for sleep [22].

The next major milestone in the mattress industry occurred in the 1940s with the rise of polyurethane foam. This material, derived from petrochemical compounds, offered a more economical and versatile alternative compared to latex. Its ease of production and adaptability enabled its integration into a wide range of applications, from springless mattresses to support layers in hybrid sleep systems. Over time, polyurethane foam became the most widely used material in the mattress industry, driven by its low production cost and comfort properties [23].

During the 1960s, at the height of the space exploration era, NASA conducted research aimed at reducing the pressure exerted on astronauts during space shuttle launches [24]. In 1966, these studies led to the development of viscoelastic foam, a material with a molecular structure capable of absorbing and evenly distributing pressure. Unlike other support materials, viscoelastic foam responded to body temperature and gradually adapted to body contours, making it a revolutionary material for sleep applications.

Figure 2. Boys assembling metal bed-springs in a U.S. factory, circa 1910. Source: Lewis W. Hine/Library of Congress, via Wikimedia Commons [25].

Figure 3. Typical scene at the Newberry County Mattress Project Center, South Carolina (1942) (U.S. National Archives, via Wikimedia Commons) [26].

In a distinct way, it is important to highlight Asian traditions related to sleep, which differ significantly from those developed in the Mediterranean. In Japan, the use of the traditional futon—a lightweight mattress made of cotton or other biodegradable materials—remains widespread, with estimates indicating that around 34% of Japanese people still use it as their usual sleeping system [27,28]. In India, although industrial mattresses now dominate the market, traditional systems persist in rural regions, relying on cotton or plant-based fibers such as coir, which continue to be used as sustainable alternatives.

In China and Korea, the use of biodegradable fibers and fillings predominated in past times, significantly reducing the generation of persistent waste compared to modern industrialized mattresses. Although these traditional practices have largely been displaced by industrialization and the globalization of the sector, they still persist in rural contexts or in initiatives linked to artisanal and sustainable production. While in decline, these strategies represent early examples of circular economy principles, where simple design and the use of renewable materials extended product lifespans and facilitated more environmentally responsible end-of-life management [29].

3. The Mattress in the 21st Century

In the context of the 21st century, the main challenge is no longer limited to improving ergonomics or sleep quality but extends to the incorporation of sustainability, energy efficiency, and circularity criteria in design and production. The sector faces the need to innovate with materials that reduce environmental footprints and facilitate end-of-life management, without compromising comfort or durability. Within this framework, the development of more sustainable foams, recyclable textiles, and modular structures opens a field of research and industrial application aimed at reconciling human well-being with environmental responsibility. This transition marks a paradigm shift, in which the mattress is conceived not merely as a mass-consumption product, but as a key element within the value chain of the circular economy.

In the contemporary context, mattresses can be classified into different typologies according to the materials and technologies employed, with the two main categories being foam mattresses and spring mattresses, complemented by hybrid variants that combine features of both.

Foam mattresses represent one of the most widespread options in today's market, accounting for approximately 45% of global sales [30,31]. Their success is largely attributed to their versatility, adaptability, and cost competitiveness. This typology includes polyurethane foams of varying densities, viscoelastic foams with memory properties, and technical formulations incorporating additives to enhance breathability, thermal conductivity, or fire resistance. Foam is particularly valued for its ability to distribute pressure evenly, reduce localized load points on the body, and improve ergonomic comfort. Nevertheless, it presents significant challenges from an environmental perspective, as most foams are derived from fossil-based synthetic polymers, which are difficult to separate and recycle at the end of their life cycle.

Spring mattresses, by contrast, constitute another traditional and widely used typology, representing nearly 33% of the global market [32]. Variants range from classic Bonnell or biconic springs to the latest pocket spring systems (Figure 4). Their main advantages lie in their structural durability, enhanced internal ventilation, and the progressive firmness they provide. Moreover, the steel used in the springs is a highly recyclable material, offering an environmental benefit compared to other components. However, the combination of metals with foam and textile layers complicates the dismantling process and limits the efficient recovery of materials.

In parallel, hybrid mattresses combine a spring core with upper layers of high-density or viscoelastic foam, seeking to integrate the firmness and ventilation of springs with the adaptability of foam. This category, which accounts for approximately 20% of the global market, represents the fastest-growing segment in recent years [33]. Although these models are gaining increasing popularity, their structural complexity significantly raises barriers to recycling, positioning them as an additional challenge in the transition toward more sustainable sleep systems.

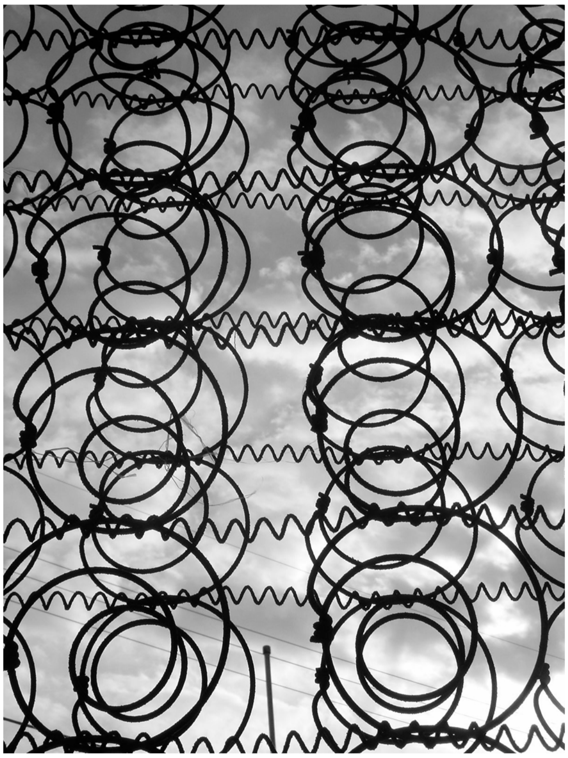

Figure 4. Mattress springs detail. Original image by Angie de Sawara, modified to black and white by the author (Wikimedia Commons) [34].

3.1. Technical Characterization of the Modern Mattress

From a technical perspective, the mattress is a durable consumer product with a complex composition, resulting from the integration of multiple functional layers designed to provide support, comfort, ventilation, thermal insulation, and mechanical resistance (Table 1). These materials, bonded through industrial adhesives, stitching, or thermal sealing systems, form a unit that is difficult to dismantle, whether manually or mechanically, thereby complicating end-of-life management. The most common typologies—spring mattresses, polyurethane foam mattresses, hybrid mattresses, and latex mattresses—share a basic stratified structure, which, although varying in material proportions and quality, follows a generalized pattern within the sleep industry [35].

Flexible polyurethane (PU) foams, which account for approximately 30% to 60% of the total weight of a mattress, constitute its primary volumetric component. With densities ranging from 20 to 100 kg/m^3, they are characterized by compressibility, acoustic and thermal insulation, and impact absorption capacity, making them suitable for sleep systems and construction applications, yet difficult to manage as waste [36]. Their thermoset reticulated structure prevents thermal reprocessing, and their formulation includes additives that can further hinder recycling. In addition, their low density and high elasticity complicate transport and storage. Although recycling is challenging, several valorization routes are possible, including mechanical recycling (e.g., as filling material or in composites), chemical recycling (polyol recovery through glycolysis), and energy recovery.

Metal springs, accounting for 10–20% of the total mattress weight, are typically made of carbon steel and are highly recyclable through magnetic separation. However, pocket spring systems require specific processes due to the presence of textile casings [37].

Textiles, which represent up to 25% of the weight, encompass both natural and synthetic fibers. Although many of these are theoretically recyclable, their effective recovery is hindered by lamination with other materials as well as the presence of additives and contaminants.

Other materials include latex (5–15%), viscoelastic gels, thermo-activated adhesives, and fire-retardant layers. Perimeter reinforcements, MDF boards, or stabilizing tapes may also be incorporated to increase structural rigidity, but they further contribute to the heterogeneity of the waste stream. Components such as MDF or particleboard pose additional challenges due to their synthetic resins, which hinder valorization and may generate pollutant emissions during treatment [38].

This structural complexity adds further layers of technical difficulty to the dismantling and end-of-life treatment of mattresses, resulting in higher unit recycling costs and lower efficiency in facilities lacking advanced sorting systems. Therefore, a detailed analysis of mattress composition and the identification of models with reduced heterogeneity are essential for designing effective and economically viable recycling strategies within the framework of the circular economy.

Table 1. Typical mattress composition and recycling potential [39–41].

Component	Approx. Mass %	Common Material	Recyclability	Potential Valorization
Polyurethane foam (PU)	30–60%	Flexible PU, HR, viscoelastic, gel	Medium	Thermal and acoustic insulation, filler in concrete, composite panels
Springs (steel)	15–25%	Carbon steel (pocketed or continuous springs)	High	Ferrous recycling (scrap metal), remelting for new steel, remanufacturing of components
Cover fabrics	10–25%	Polyester, viscose, cotton, linen, hemp	Low to medium	Acoustic insulation, recycled textiles, furniture filler, geotextiles
Natural or synthetic latex	0–20%	Dunlop or Talalay latex	Medium	Shock-absorbing layers, cushioned bases, eco-friendly insulation
Adhesives/glues	1–3%	Hot-melt, PU-based, solvent-based	Very low	Hinder recycling processes; typically discarded
Natural fiber fillings	0–10%	Wool, cotton, hemp, coconut fiber	Medium	Sustainable insulation, recycled cushioning, composting in some cases
Miscellaneous plastics	1–3%	Zippers, edges, labels, rigid polyester	Low	Recyclable only if properly separated; otherwise, sent to disposal

3.2. Environmental Impacts Associated with the Mattress Life Cycle

During their service life, mattresses do not generally present highly significant direct environmental impacts, apart from their potential contribution to indoor air quality deterioration through the emission of volatile organic compounds (VOCs) [42,43]. This phenomenon is particularly evident in newly manufactured mattresses that incorporate polyurethane foams or textiles treated with chemical additives. Among the most common VOCs are formaldehyde, residual isocyanates, and certain volatile plasticizers. Although typically released at low concentrations, these compounds may adversely affect respiratory health, especially in poorly ventilated environments.

However, it is at the end-of-life stage where the environmental impact of mattresses becomes most critical. In Europe, despite regulatory progress in the field of circular economies, a large proportion of discarded mattresses are still sent to landfills, due to the complexity of their recycling, the high cost of dismantling, and the lack of specialized infrastructure for comprehensive treatment. It is estimated that currently, between 60% and 80% of used mattresses are not effectively recycled [44].

In landfill conditions, mattresses display particularly problematic environmental behavior. Their multilayered structure, composed of diverse materials (foams, springs, textiles, adhesives, polymers, etc.), not only hinders compaction and increases the occupied volume but also drastically slows down decomposition processes. Depending on their composition, a mattress may take between 80 and 120 years to fully degrade, during which time both gaseous emissions and contaminated leachates are generated. The main environmental impacts associated with landfilling are discussed below.

Among the main environmental impacts associated with the landfilling of mattresses are the emissions of greenhouse gases, primarily methane (CH_4) and carbon dioxide (CO_2), resulting from the anaerobic degradation of natural fibers such as cotton, linen, or hemp, with a high global warming potential in the absence of biogas control. In addition, the release of volatile organic compounds (VOCs) originating from solvents, resins, and flame retardants contributes to the generation of toxic and persistent vapors in the landfill environment [45,46]. Another relevant impact is the formation of contaminated leachates, which carry additives, plasticizers, dyes, and heavy metals, posing risks of infiltration into aquifers if adequate sealing systems are not in place. Finally, the persistence of polyurethane foams, which are highly resistant to biodegradation, promotes their fragmentation into microplastics that can disperse into the environment and enter food chains.

In the field of energy recovery, discarded mattresses are primarily managed as feedstock in the production of Refuse-Derived Fuel (RDF) or Solid Recovered Fuel (SRF), together with other bulky waste streams. The polyurethane (PU) foam fraction is particularly relevant due to its high lower heating value (LHV), ranging between 22 and 28 MJ/kg, which is comparable to that of fossil fuels such as coal and significantly higher than that of the organic fraction of municipal solid waste (MSW), which rarely exceeds 10 MJ/kg [47]. This characteristic makes mattress foam a high-value energy input in RDF blends, supporting its co-combustion or application in cement kilns and gasification plants. However, the heterogeneity of mattresses and the presence of metals, textiles, and adhesives require intensive pretreatment processes (shredding, separation, and classification), which increase operational costs and hinder their direct integration into the energy recovery chain.

The recovery of mattresses through incineration or their use as a component of RDF/SRF, while providing immediate energy output, entails significant environmental externalities. The combustion of polyurethane foams and textiles treated with additives can release nitrogen oxides (NO_x), halogenated compounds, and ultrafine particles, requiring advanced flue gas cleaning systems. In addition, the process generates bottom ash and fly ash equivalent to 20–30% of the incinerated weight, with substantial concentrations of heavy metals, which must be managed in hazardous waste landfills or subjected to stabilization processes [48].

In recent years, beyond traditional materials, the market has seen the emergence of mattresses equipped with advanced functions such as heating, cooling, or active temperature regulation through integrated electrical components, internal fluid circulation, or phase-change technologies. While these innovations aim to optimize thermal comfort and the overall sleeping experience, they introduce new challenges from an environmental perspective. On the one hand, they entail higher energy consumption during their use phase, thereby increasing their carbon footprint compared to conventional mattresses. On the other hand, the incorporation of electrical circuits, sensors, batteries, or specialized composite materials adds further complexity to their end-of-life management, complicating disassembly and recycling processes. These hybrid systems bring mattresses closer to the category of Waste Electrical and Electronic Equipment (WEEE), subject to stricter regulations and differentiated treatment streams. Consequently, the trend towards "smart" mattresses or those with additional functionalities, if not accompanied by circular design principles, risks exacerbating existing barriers to material recovery and generating additional impacts in the post-consumer phase.

4. Materials and Recycling Pathways for Mattresses

The end-of-life management of mattresses represents a significant economic burden for municipal collection and treatment systems, due to the physical characteristics of this waste stream and the complexity of its recycling. This burden is distributed across a series of direct and indirect costs, the magnitude of which underscores the need to establish specific, sustainable, and tailored management models adapted to this type of waste.

Among the direct costs, those associated with specialized transportation stand out as particularly relevant. Due to their large volume and low density, mattresses hinder efficient space management in collection vehicles, which increases the number of trips required and, consequently, fuel consumption and associated emissions. In addition, their handling often requires adapted vehicles or differentiated services within bulky waste collection systems.

Another critical element is the labor cost associated with manual handling. Mattresses require intensive intervention in terms of dismantling, material separation, and component classification—including metal springs, polyurethane foams, and textiles, among others—since they cannot be processed mechanically in the same way as other household wastes. This demand for specialized labor significantly increases the operational costs of recycling [49].

Furthermore, the costs associated with providing adequate spaces for intermediate storage must also be considered, as these are essential for the logistical management of mattress waste. Such storage areas require specific safety conditions, proper ventilation, and fire protection measures, as well as appropriate planning of material inflows and outflows. These requirements entail substantial investments in infrastructure or the rental of industrial facilities.

Regarding indirect costs, these include collateral effects arising from inadequate or insufficient management. On the one hand, the saturation of recycling centers and civic amenity sites negatively affects the efficiency of public services and undermines citizens' perception of urban environmental quality. On the other hand, there has been an observable increase in the illegal dumping of mattresses in public spaces, which not only generates a negative visual impact but also compromises urban health and safety in certain neighborhoods, thus requiring corrective interventions by municipal services.

In addition to these factors, the average cost of treating a discarded mattress ranges between EUR 15 and EUR 40 per unit, according to various comparative technical studies. This cost variation depends on multiple variables [50]. The first is the typology of the mattress: spring-based models, for instance, contain metallic components, which, although valuable in recycling markets, require manual separation processes; viscoelastic or polyurethane foam mattresses, in turn, pose greater challenges for recovery due to their chemical composition and the presence of additives that complicate recycling; hybrid mattresses, combining different materials (springs, foams, latex), demand more complex and time-consuming dismantling procedures, which substantially increase treatment costs.

Secondly, the regulatory and fiscal context plays a decisive role in determining overall costs. The presence of regulations promoting eco-design or imposing extended producer responsibility (EPR) schemes can help reduce the direct financial burden on local administrations. Likewise, the possibility of applying tax incentives or exemptions for operators integrating mattress recycling processes can create a more favorable environment for cost optimization.

Another relevant factor is the proximity to specialized recycling facilities. The availability of adequate infrastructure in the immediate geographical area reduces logistical costs, whereas its absence necessitates long-distance transportation of waste, directly impacting the final treatment cost. In many cases, the lack of nearby valorization plants constitutes a structural barrier to the development of effective circular models.

Finally, the maturity of the local waste management system and the level of technological development of treatment facilities determine process efficiency. Plants equipped with advanced technologies for automated dismantling, selective shredding, and material sorting are able to reduce processing times and improve the economic performance of recycling. In less developed contexts, where these operations must be performed manually and without advanced technical means, the cost per treated unit increases substantially.

In comparative terms, these costs are significantly higher than those associated with other household waste streams, underscoring the urgent need to develop specific valorization strategies that not only mitigate the environmental and social impacts of this waste but also facilitate its integration into productive value chains such as construction, automotive manufacturing, and the furniture industry. In this regard, the transition toward circular economy models requires not only technological solutions but also public policies that incentivize separate collection, applied research, and the creation of markets for recycled materials derived from discarded mattresses.

4.1. Recycling of Foams (Polyurethane, Memory Foam, Latex)

Polyurethane (PU) foams constitute the largest component of mattresses, representing between 30% and 60% of their total mass. Their widespread use is linked to key properties such as elasticity, resilience, and pressure distribution capacity, which make them the most prevalent material in the bedding industry. However, these same characteristics, derived from their polymeric origin and the presence of chemical additives, pose significant challenges at the end of their life cycle. The high heterogeneity of formulations—including flexible, high-resilience, and viscoelastic foams—together with the use of petroleum-derived isocyanates and polyols, complicates separation and recycling processes. Despite these barriers, the valorization of PU foams is considered a priority within the framework of the circular economy, as they represent a significant stream of bulky waste with high recovery potential in sectors such as construction, thermal and acoustic insulation, or the production of secondary raw materials. In this context, different recycling routes—mainly mechanical and chemical—have been developed to transform this waste into useful resources, thereby reducing its environmental impact and dependence on fossil-based materials [51].

The chemical recycling of polyurethane (PU) foams derived from end-of-life mattresses is emerging as a strategic alternative to incineration or mechanical recycling. Among the most relevant processes are pyrolysis and gasification, both based on the thermochemical decomposition of polymers to recover either energy or chemical feedstocks.

Pyrolysis is conducted in the absence of oxygen at temperatures ranging between 400 and 700 °C, producing three main fractions: light gases, liquid oils, and a solid carbonaceous residue (char). In the case of PU, the resulting oils are rich in aromatic compounds and polyol fractions, which can be reintroduced into the chemical industry for the synthesis of new polyurethanes. A life cycle assessment (LCA) conducted in the Netherlands demonstrated that pyrolysis can save up to 802 kg CO_2-eq per ton of mattresses treated compared with incineration while reducing cumulative energy demand by 24% (≈5.1 GJ/ton) [52]. These findings highlight the potential of pyrolysis not only as a waste management method but also as a pathway towards a circular economy, generating high-value chemical products rather than mere energy carriers.

Gasification, in contrast, is carried out at higher temperatures (700–1000 °C) in the presence of an oxidizing agent (air, oxygen, or steam). The main product is synthesis gas (syngas), composed primarily of carbon monoxide (CO) and hydrogen (H_2), which has applications in energy generation as well as serving as a precursor for chemical synthesis. Recent studies indicate that PU gasification achieves high conversion rates, with efficiencies exceeding 80% in syngas production and a more comprehensive energy recovery compared to pyrolysis. However, this process requires higher energy inputs and advanced gas-cleaning systems to control emissions of nitrogen oxides (NO_x) and isocyanate-derived compounds [53].

Taken together, both processes offer clear advantages over landfilling or incineration, as they reduce greenhouse gas emissions and promote resource recovery. Nevertheless, economic and technical barriers remain: pyrolysis requires improvements in the separation and valorization of the oils produced, while gasification demands large-scale infrastructure and advanced environmental control systems. Despite these limitations, pilot-scale trials and life cycle assessments converge in highlighting chemical recycling of foams—particularly via pyrolysis—as a viable pathway to integrate mattresses into circular economy strategies and reduce dependence on fossil-based resources.

Mechanical recycling of polyurethane (PU) foams is currently the most widespread valorization pathway, primarily due to its relative technological simplicity and lower operational costs compared to chemical alternatives. The process involves the shredding and granulation of flexible or viscoelastic foam, followed by agglomeration using adhesives to produce so-called bonded foam. This recycled material is widely applied in low- to medium-value applications, including upholstery fillings, carpet underlays, acoustic insulation panels, and sports surfaces [54].

There are also variants of mechanical recycling aimed at producing fine PU powders that can be reincorporated as a polyol fraction in the synthesis of new foams, achieving substitution rates of up to 20% without significantly compromising the mechanical properties of the final product. However, this improvement entails higher energy consumption during advanced milling stages—such as the use of two-roll mills—which increases the environmental footprint of the process. From a sustainability perspective, life cycle assessments indicate that mechanical recycling can yield savings of up to 1749 kg CO_2-eq per ton of mattresses recycled compared to incineration [55]. Nevertheless, its limitations are notable: the quality of the recovered material is strongly dependent on foam purity, and the incorporation of new adhesives during agglomeration hinders subsequent recycling cycles, positioning it closer to downcycling than to fully circular valorization.

In contrast, chemical recycling via pyrolysis or gasification offers greater potential for recovering high-value compounds—such as polyols or aromatic precursors—but these technologies remain at the pilot stage, require significant investments and complex infrastructures, and face uncertainties related to emission management and product separation efficiency. For these reasons, mechanical recycling continues to be the most viable and consolidated option for mattress foam treatment today while awaiting technological advances that could make chemical routes competitive at an industrial scale.

4.2. Textile Recycling (Synthetic and Natural Fibers)

The external cover of a mattress is composed of blended fabrics, typically combining synthetic fibers such as polyester or polypropylene with natural fibers such as cotton, wool, or linen, in proportions that vary according to product type (Figure 5). These fabrics often also incorporate reinforcing layers, intermediate padding, and chemical surface treatments—such as flame retardants, waterproofing agents, or finishing resins—which complicate their recovery at the end of life [56].

In terms of valorization, mechanical recycling is the most widely used pathway for these fractions. After manual or automated separation of the outer covers, textiles can undergo shredding or tearing processes, yielding secondary fibers that are reused in different applications. From this material, it is possible to produce geotextiles for civil engineering, insulating felts for construction and automotive applications, thermal blankets for roofing or interior partitions, and even new fibers for spinning, although in the latter case, the process is limited by quality and strength losses inherent to recycling [57].

The viability of this process largely depends on the condition of the fibers and the presence of contaminants. When textiles are heavily impregnated with adhesives, residual foams, or flame-retardant treatments, the recovery yield decreases significantly, increasing the need for additional pretreatment steps. Nevertheless, advances in optical and mechanical sorting technologies are improving the efficiency of fiber separation, thereby opening new opportunities to increase recovery rates and reduce the volume destined for disposal.

Figure 5. Pile of discarded mattresses in an urban setting (edited in black and white). Original photo by Alan Hughes, Geograph project. Licensed under CC BY-SA 2.0, (Wikimedia Commons) [58].

4.3. Steel Recycling (Springs and Internal Structures)

In traditional spring mattresses, metallic structural elements account for between 10% and 25% of the total weight, typically consisting of carbon steel or high-strength tempered steel designed to provide durability and structural support throughout the product's lifespan [59].

The metallurgical recycling of these components follows a well-established chain within the steel industry. First, springs and metallic parts are recovered either manually or, more commonly, through magnetic separation techniques after mattress disassembly or shredding. Subsequently, the material is subjected to pressing and classification by typology, which facilitates its integration as ferrous scrap in steelmaking furnaces. There, the springs are melted and transformed into new metallic products, ensuring the circularity of the material.

One of the main advantages of this process is that recycled steel fully retains its mechanical properties, which enables its reintegration into high-performance sectors such as automotive, construction, or machinery manufacturing. Moreover, steel recycling offers significant environmental and energy benefits: it avoids iron ore extraction and reduces energy consumption by approximately 74% compared to primary production, while substantially decreasing CO_2 emissions associated with conventional steelmaking [60].

5. Action Environments

Aware of the existing recycling processes and equally concerned with identifying new research pathways to address alternative treatments for these materials, as well as novel applications for recycled products, various institutional, business, and scientific actors worldwide are driving research efforts, technical analyses, and experimental projects. These initiatives aim to circumvent the obstacles of conventional technologies and explore more efficient, sustainable, and scalable solutions, thereby contributing to a circular transformation of the sector.

5.1. United States: The Mattress Recycling Council

The most prominent institutional reference in the U.S. context is the Mattress Recycling Council (MRC), a nonprofit organization established in 2013 by the International Sleep Products Association (ISPA), with the aim of managing, coordinating, and overseeing mattress recycling in states that have adopted specific legislation on this matter [61,62]. Through its program Bye Bye Mattress, operational since 2015, the MRC has implemented a collection, treatment, and recovery system in three states: California, Connecticut, and Rhode Island. These states have established, through legislation, the mandatory recycling of mattresses under Extended Producer Responsibility (EPR) policies, whereby manufacturers and retailers assume, directly or indirectly, the costs associated with waste management. The system is financed through an eco-fee applied at the time of purchase of new mattresses, ranging between USD 9 and USD 16 per unit [63], which sustains an operational infrastructure covering the entire chain from collection points to recycling facilities.

Since the launch of the Bye Bye Mattress program, more than twelve million mattresses have been recycled across the three participating states, thereby preventing the landfilling of millions of cubic meters of waste and recovering over 75% of the materials contained in each unit. In California alone—the state with the highest operational volume—over nine million mattresses have been processed, generating more than 250 direct jobs associated with recycling and material recovery. The cumulative estimate of greenhouse gas emissions avoided since 2015 exceeds 600,000 metric tons of CO_2-equivalent, underscoring the positive environmental impact of this strategy [64].

The recycling process in the United States is characterized by a pragmatic and highly systematized approach. The first stage involves the collection of mattresses at authorized drop-off points, which may include both municipal facilities and retail outlets. Subsequently, the mattresses are transported to specialized facilities where they undergo manual or semi-automated dismantling. This process allows for the effective separation of the main material fractions: metal springs, generally made of carbon steel, are extracted using mechanical and magnetic techniques and sent for metallurgical recycling; flexible and viscoelastic polyurethane foams are shredded and repurposed as filler in industrial products (such as carpets, acoustic panels, and pillows); while textile layers, although more challenging to recover, are directed toward the production of technical felts or employed as low-value components in sectors such as automotive manufacturing or civil engineering.

Among the most relevant operators within this ecosystem is DR3 Recycling (California, USA), founded in 1999 and currently considered the largest mattress recycler in the United States. This non-profit, socially oriented entity belongs to The Society of St. Vincent de Paul of Lane County, an organization widely recognized for its work in labor reintegration programs and support for vulnerable groups. DR3 manages a network of more than ten facilities along the West Coast, particularly in California, where it works in close collaboration with the MRC. With an annual processing capacity of over 400,000 mattresses and material recovery rates reaching up to 85% in some facilities, DR3 Recycling stands as a benchmark model in terms of operational efficiency, process innovation, and inclusive employment generation [65]. Its social mission is particularly noteworthy, as it actively integrates individuals at risk of exclusion into training and paid employment programs, thereby linking environmental sustainability with social equity. Dismantling times range between five and ten minutes per unit, depending on mattress type, condition, and the degree of automation implemented.

The success of the U.S. mattress recycling model can be largely attributed to the convergence of several structural factors: first, the existence of a specific legal framework mandating the recycling of this type of waste and establishing funding mechanisms through eco-fees; second, a well-structured and geographically distributed logistics network, with more than 300 collection points in California alone; third, effective cooperation between public, private, and third-sector actors, which enables cost-sharing and enhances efficiency; and finally, the establishment of technical standards and operational manuals developed by the MRC has facilitated worker training, process standardization, and model replicability [66].

Nevertheless, despite the progress achieved, the system still faces significant limitations. In particular, the management of mattresses contaminated with biological fluids or pests, as well as those manufactured with hybrid technologies that integrate multiple layers of materials bonded with technical foams, poses a considerable challenge for dismantling and sorting processes. Likewise, the recycling of technical textiles used in external or comfort layers is less efficient due to the presence of chemical treatments and the reduced quality of fibers after use. Moreover, the expansion of the model to other U.S. states has been constrained by the absence of equivalent legislative frameworks, generating territorial inequalities in access to sustainable solutions.

Beyond these limitations, however, the U.S. case constitutes an international benchmark for best practices in the valorization of complex waste streams. Unlike the still incipient approaches prevailing in many European regions, the North American system has demonstrated that it is possible to establish a fully structured mattress recycling chain that is financially viable, environmentally efficient, and socially inclusive. This model, primarily focused on the mechanical recycling of components, is further complemented by ongoing research on chemical recycling, controlled energy recovery, and mattress redesign for enhanced dismantling.

Since its inception, the MRC has adopted a distinctly technical–scientific perspective, investing resources in the continuous improvement of its procedures and in the promotion of research lines oriented toward recycling innovation. To this end, it regularly collaborates with universities, technological centers, and third-sector entities, both in the United States and internationally. Its priority areas of action include the optimization of dismantling processes, the enhancement of material recovery from complex fractions, the design of new products from recycled materials, and the life cycle assessment (LCA) of implemented processes. The MRC's research activity is structured through various experimental projects, financed partly by funds collected from the eco-fee and partly through external collaborations. These projects address topics such as advanced polyurethane recovery, the development of machinery for automated dismantling, and comparative environmental analyses between recycling and final disposal routes.

The MRC has also spearheaded a series of innovative initiatives to explore new applications for waste streams derived from end-of-life mattresses. Among these, particular attention has been given to the energy valorization of "mattress fluff"—a fraction composed of shredded foams and textile fibers—whose higher heating value reaches 29,700 kJ/kg, comparable to certain solid biofuels. According to [67], this material presents a low moisture content and a high carbon fraction, making it suitable for processes such as co-incineration, pyrolysis, or gasification, with additional potential in the production of biochar and biogas.

Another study examined the use of shoddy, a low-value nonwoven textile material, as a filter in stormwater drainage systems and as an erosion-control barrier [68]. Despite promising laboratory results, the presence of perfluoroalkyl substances (PFASs) and the high variability in the material prevented its advancement toward full-scale applications. Nevertheless, future opportunities were identified through advanced decontamination technologies or encapsulated uses.

In the field of mechanical recycling, the MRC promoted the development of a prototype machine for the automatic dismantling of pocket coil units. This system enables efficient separation of steel and textiles from encased springs, achieving an estimated processing time of 4.5 min per unit in its optimized version. The prototype stands out for its compact design, industrial scalability, and contribution to reducing non-recyclable waste.

At the chemical level, aqueous polyurethane dispersions (WPUDs) were synthesized using recycled polyols obtained via glycolysis. These products exhibited properties comparable to virgin-derived counterparts in terms of thermal stability and particle size, validating their potential application in adhesives, coatings, and industrial membranes. In parallel, enzymatic depolymerization of shoddy pad textiles was investigated to recover PET monomers and cellulose through a sequential enzymatic protocol. Although PET conversion was limited, the approach provides a promising foundation for future biotechnological applications [69].

Energy valorization was also addressed from an electrochemical perspective, through the development of porous carbonaceous materials derived from residues such as cotton, shoddy, and coconut fiber, which were successfully employed in electrodes for supercapacitors and lithium–sulfur batteries. The results demonstrated high cycling stability, elevated coulombic efficiency, and energy capacities competitive with commercial materials, positioning these waste streams as strategic inputs for energy storage technologies. (Figure 6)

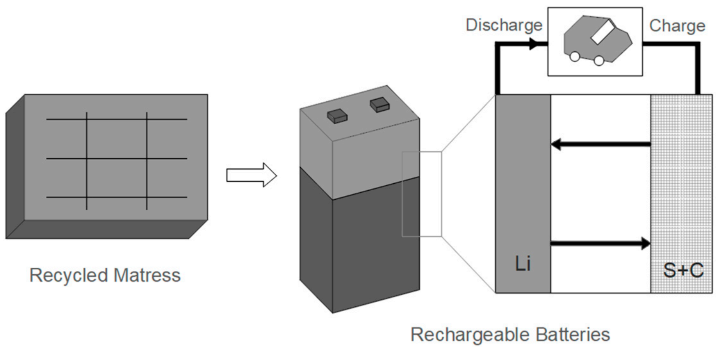

Figure 6. Conceptual scheme of recycled mattress components applied in rechargeable batteries. Source: Authors' own elaboration within the Circular Ecosystems project (City of Valladolid—University of Valladolid Foundation, 2024–2025).

In parallel, the industrial composting of mottled cotton and coconut fiber was validated as organic amendments, after being mixed with plant residues and treated for 22 weeks. The final compost analysis revealed parameters suitable for agricultural and horticultural applications, with no presence of heavy metals or relevant pathogens. This alternative is particularly relevant in contexts with landfill reduction legislation [70].

A highly innovative approach has also been the vitrimerization of polyurethane (PU) foams (Figure 7). Through covalent adaptive networks (CANs), it was possible to reconfigure the structure of thermoset foams, enabling their reprocessing into moldable plastics without loss of mechanical properties. The project demonstrated the industrial feasibility of the process, which is compatible with injection molding and capable of producing functional components such as shoe soles, technical rubbers, and sports casings, while reducing waste volume by up to 90% [71].

Figure 7. Wood pellets (edited in black and white). Original photo by Benutzer: Kallerna, Licensed under CC BY-SA 3.0 (Wikimedia Commons) [72].

Finally, the surface functionalization of recycled PU foams has been explored for their use as oil sorbents. Through simple chemical modifications, these foams exhibited more than a 300% improvement in oil absorption and a 75% reduction in water uptake, outperforming current commercial materials [73]. Potential applications extend to environmental remediation and advanced filtration systems.

These initiatives reflect a broad spectrum of scientific and technological strategies promoted by the MRC, which integrate mattress-derived waste into circular value chains spanning energy, construction, agriculture, electrochemistry, and environmental decontamination.

5.2. Europe

Mattress recycling in Europe has undergone a substantial transformation in recent years, driven by the development of advanced technologies, the implementation of extended producer responsibility (EPR) policies, and the consolidation of circular business models. In France, for instance, the RENUVA program, led by Dow, focuses on the chemical recycling of polyurethane (PU) foams, converting waste into high-quality polyols. This technology is applied at the Semoy plant, operated by Orrion Chemicals Orgaform, which has the capacity to process up to 200,000 mattresses per year. The program, awarded by the European Chemical Industry Council, has demonstrated through life cycle assessment (LCA) reductions of up to 54% in CO_2 emissions compared to conventional polyol production [74].

At the same time, Recyc-Matelas Europe has established a comprehensive mechanical recycling model with a strong social impact, operating several facilities in France and Belgium and achieving recovery rates of up to 93% [75]. Recognized as an Entreprise d'Insertion, the company integrates socially vulnerable individuals into the workforce, combining environmental sustainability with social responsibility.

In the Netherlands, RetourMatras leads mattress recycling with six plants capable of processing up to 2.5 million units annually. The company has developed automated processes to efficiently separate foam, metal, and textiles and has implemented PU chemical recycling at its Lelystad facility. Its collaborations with IKEA and Renewi have further strengthened its capacity for international expansion.

In Germany, BASF and NEVEON have developed a prototype mattress containing 80% recycled content, using chemical decomposition processes to obtain reusable polyols. The REMATTRESS project, launched in Berlin, exemplifies the industrial feasibility of recycling combined with an eco-design approach, eliminating adhesives to facilitate future material recovery [76].

The United Kingdom presents notable cases such as JBS Fibre Recovery, which processes more than 800,000 mattresses annually, and TFR Group, which has recycled over

3.5 million units since 2012. The latter has introduced technology for the automated recycling of pocket springs as well as mattress refurbishment programs, reintroducing returned products to the market under certified quality standards. The environmental impact of its operations has been independently assessed, showing reductions of more than 36,000 tons of CO_2 equivalent in a single year [77].

Spain also demonstrates remarkable progress with initiatives such as the plant projected by ACTECO in Alcorcón, supported by ESMASA and Repsol, which focuses on the recycling of mattresses, furniture, and textiles. The project integrates R&D lines to improve process efficiency and explore new applications for recovered materials, positioning itself as a circular economy hub within the Community of Madrid [78].

Among the most representative examples of the commercial valorization of mattress-derived materials in Europe are Purman and Recypur, whose business models illustrate the feasibility of combining technological innovation, environmental sustainability, and industrial competitiveness. Purman specializes in the recovery of recycled polyurethane foams through shredding, agglomeration, and reformulation processes, resulting in products such as insulation panels, technical padding, and components for the automotive and furniture industries. By ensuring compliance with stringent quality and certification standards, these products have successfully penetrated demanding markets, contributing to the reduction of dependence on virgin raw materials. Furthermore, Purman has explored applications in the field of sustainable construction, using recycled foams as acoustic and thermal insulators, thereby reinforcing the connection between mattress recycling and energy efficiency in the built environment [79].

For its part, Recypur, based in Valencia, is a benchmark in the large-scale mechanical recycling of PUR foams. Its facility, considered the most advanced in Spain in this field, achieves an estimated annual output of 250,000 recycled cores, which are reintroduced as secondary raw materials in the manufacture of new mattresses and sleep products. This model not only enables the closure of the mattress life cycle but also contributes to fostering the circular economy within the bedding sector, preventing thousands of tons of waste from ending up in landfills or incinerators. Recypur's experience demonstrates that mechanical recycling can achieve industrial and commercial viability, delivering competitive products that meet durability and comfort standards [80].

Both Purman and Recypur demonstrate that mattress recycling has evolved beyond mere waste management to become a strategy of innovation and value creation. These cases reinforce the notion that the valorization of polyurethane foams is not only environmentally necessary but also economically attractive, by integrating principles of circularity into key sectors such as construction, furniture, and automotive. In this way, they are consolidated as replicable examples for the development of new European initiatives aimed at closing material loops within the sleep products industry.

These experiences reflect an evolution toward integrated recycling models that combine technological innovation, positive environmental impact, social inclusion, and economic viability. The diversification of technologies (mechanical, chemical, and refurbishment) and the collaboration among companies, municipalities, academic institutions, and public bodies strengthen the replicability of these models.

This European landscape provides valuable lessons for the design of local policies, the development of infrastructure, and the articulation of sustainable value chains around mattress recycling. Its analysis makes it possible to identify synergies with the construction sector, where recovered materials can be employed as aggregates, insulation, or technical fillers, thereby aligning waste management objectives with those of energy efficiency and decarbonization of the built environment.

6. Conclusions

The analysis conducted highlights that mattresses, due to their structural complexity and heterogeneous composition, represent a considerable challenge within waste management systems. In contrast to conventional options such as landfilling or incineration—which generate significant environmental impacts in the form of emissions and resource loss—recycling emerges as the alternative most consistent with the principles of the circular economy. Both mechanical recycling, currently the most widespread and viable option, and chemical or energy recovery pathways, still under development, not only reduce the environmental burden associated with mattress waste but also reintroduce high-value materials into the production chain, thereby decreasing dependence on fossil-based and virgin resources.

In this regard, mattress recycling should be understood not as a residual treatment, but rather, as a priority strategy for sustainable valorization, capable of integrating environmental, economic, and social benefits. The promotion of dedicated regulatory frameworks; strengthened collaboration among public administrations, industry, and research centers; and innovation in separation and transformation technologies are all key to consolidating this approach. Ultimately, ensuring that every mattress at the end of its service life can be reintegrated into the production cycle represents a fundamental step toward ecological transition and the development of truly responsible and circular sleep systems.

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