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An EPD-Based Comparative Assessment of the Fossil Global Warming Potential of Wood-Based Materials Used in Furniture Production

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Makale Bilgisi

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Anahtar Kelimeler

Ahşap esaslı kompozitler
Yaşam Döngüsü Değerlendirmesi (YDD)
Çevresel Ürün Beyanı (EPD)
Sürdürülebilir malzeme seçimi
Küresel Isınma Potansiyeli (GWP)

Grafik Özet (Graphical/Tabular Abstract)

Five wood-based furniture materials were compared using harmonised EPD data. Sawn timber showed the lowest A1–A3 GWP-fossil, while processed and finished products showed higher impacts. / Beş ahşap esaslı mobilya malzemesi uyumlaştırılmış EPD verileriyle karşılaştırılmıştır. Masif kereste en düşük A1–A3 GWP-fosil değerini gösterirken işlenmiş ve yüzey bitirmeli ürünlerde daha yüksek etkiler belirlenmiştir.

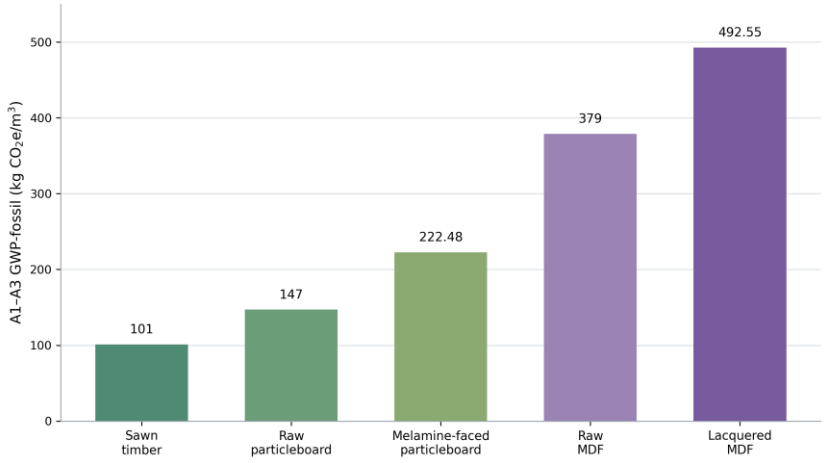

Figure A. *Comparative A1–A3 GWP-fossil values of selected wood-based products based on harmonised EPD data (kg CO_2e/m^3) /* ***Şekil A.*** *Uyumlaştırılmış EPD verilerine dayalı olarak seçilmiş ahşap esaslı ürünlerin karşılaştırmalı A1–A3 GWP-fosil değerleri (kg CO_2e/m^3)*

Highlights (Önemli noktalar)

- *Harmonised EN 15804+A2 EPD data enabled consistent comparison. / Uyumlaştırılmış EN 15804+A2 EPD verileri tutarlı karşılaştırma sağlamıştır.*
- *Sawn timber showed the lowest GWP-fossil value. / Masif kereste en düşük GWP-fosil değerini göstermiştir.*
- *Lacquered MDF showed the highest GWP-fossil value. / Lake MDF en yüksek GWP-fosil değerini göstermiştir.*
- *Surface finishing increased environmental impacts. / Yüzey işlemleri çevresel etkileri artırmıştır.*

Aim (Amaç): *To compare the A1–A3 GWP-fossil values of selected wood-based furniture materials using harmonised EPD data. / Seçilen ahşap esaslı mobilya malzemelerinin A1–A3 GWP-fosil değerlerini uyumlaştırılmış EPD verileriyle karşılaştırmak.*

Originality (Özgünlük): *The study plirovides a methodologically harmonised EPD-based comparison of wood-based materials. / Çalışma, ahşap esaslı malzemelerin metodolojik olarak uyumlaştırılmış EPD tabanlı karşılaştırmasını sunmaktadır.*

Results (Bulgular): *Sawn timber had the lowest GWP-fossil value, whereas lacquered MDF had the highest. / Masif kereste en düşük, lake MDF ise en yüksek GWP-fosil değerine sahip olmuştur.*

Conclusion (Sonuç): *Harmonised EPD data support more reliable and environmentally informed material selection. / Uyumlaştırılmış EPD verileri daha güvenilir ve çevresel açıdan bilinçli malzeme seçimini desteklemektedir.*

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An EPD-Based Comparative Assessment of the Fossil Global Warming Potential of Wood-Based Materials Used in Furniture Production

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Abstract

This study compares the cradle-to-gate (A1–A3) fossil global warming potential (GWP-fossil) of five wood-based products used in furniture production: kiln-dried and planed sawn timber, raw particleboard, melamine-faced particleboard, raw medium-density fibreboard (MDF), and lacquered MDF. To improve methodological consistency, manufacturer-specific EPDs issued in 2021 for products from the same manufacturer and compliant with EN 15804+A2 were selected. All results weret harmonised to a declared unit of 1 m³, and only the A1–A3 GWP-fossil indicator was evaluated. The values were 101.00 kg CO_2e/m³ for sawn timber, 147.00 kg CO_2e/m³ for raw particleboard, 222.48 kg CO_2e/m³ for melamine-faced particleboard, 379.00 kg CO_2e/m³ for raw MDF, and 492.55 kg CO_2e/m³ for lacquered MDF. Sawn timber had the lowest value, whereas lacquered MDF was approximately 4.88 times higher. Differences between untreated and surface-finished product pairs indicate the contribution of resin use, fibre preparation, hot pressing, and finishing processes to fossil greenhouse-gas emissions. Nevertheless, the findings are limited to one manufacturer, one impact indicator, and product-category-specific EPD/PCR conditions. The study demonstrates that sustainable material selection in the furniture sector requires verified, current, and methodologically harmonised EPD data.

Mobilya Üretiminde Kullanılan Ahşap Esaslı Malzemelerin Fosil Küresel Isınma Potansiyelinin EPD Tabanlı Karşılaştırmalı Değerlendirmesi

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Öz

Bu çalışma, mobilya üretiminde yaygın olarak kullanılan beş ahşap esaslı ürünün beşikten kapıya (A1–A3) fosil küresel ısınma potansiyelini (GWP-fosil) EPD verileri üzerinden karşılaştırmaktadır. İncelenen ürünler kurutulmuş ve planyalanmış masif kereste, ham yonga levha, melamin kaplı yonga levha, ham MDF ve lake MDF'dir. Karşılaştırılabilirliği artırmak amacıyla aynı üreticiye ait, 2021 yılında yayımlanmış ve EN 15804+A2 standardına uygun üreticiye özgü EPD'ler seçilmiş; sonuçlar 1 m³ deklarasyon birimine dönüştürülmüştür. Yalnızca A1–A3 GWP-fosil göstergesi değerlendirilmiştir. GWP-fosil değerleri masif kereste için 101,00; ham yonga levha için 147,00; melamin kaplı yonga levha için 222,48; ham MDF için 379,00 ve lake MDF için 492,55 kg CO_2e/m³ olarak belirlenmiştir. Masif kereste en düşük değeri gösterirken lake MDF'nin değeri yaklaşık 4,88 kat daha yüksektir. Ham ve yüzey işlemi görmüş ürün çiftleri arasındaki farklar, reçine kullanımı, lif hazırlama, sıcak presleme ve yüzey bitirme süreçlerinin fosil kaynaklı emisyonlarla ilişkisini ortaya koymaktadır. Bununla birlikte sonuçlar tek üretici, tek etki göstergesi ve ürün gruplarına özgü EPD/PCR koşullarıyla sınırlıdır. Bulgular, mobilya sektöründe malzeme seçiminin doğrulanmış, güncel ve metodolojik açıdan uyumlu EPD verileri üzerinden gerçekleştirilmesi gerektiğini göstermektedir.

1. INTRODUCTION (GİRİŞ)

Today, the building and furniture industries account for a significant share of global carbon emissions and natural resource consumption. The environmental performance of materials used in these sectors has become one of the key determinants of sustainable production and low-carbon economy strategies [1,2]. In this context, the use of materials based on renewable and circular resources has taken a central role within sustainable manufacturing strategies.

Wood-based composite materials stand out among sustainable material groups due to their ability to enable efficient use of natural resources and to

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valorize production residues [3, 4]. These materials are produced by combining wood components such as fibers, particles, or veneers—typically with resin or bio-based adhesives. In this way, the physical limitations of natural wood are overcome, while it becomes possible to utilize recycled or waste-derived raw materials during the production process [5]. However, despite these advantages, the environmental impacts of wood composites can vary significantly depending on production processes, resin types, and energy use patterns [6, 7].

From a sustainability perspective, accurately assessing a material's environmental impact requires focusing not only on the origin of raw materials but also on all processes occurring throughout its life cycle. To this end, the Life Cycle Assessment (LCA) method—developed in accordance with ISO 14040 and ISO 14044 standards—systematically analyzes the environmental impacts of products "from cradle to grave" [8, 9]. LCA provides a comparable assessment framework through indicators such as carbon footprint, energy consumption, and resource depletion, thereby supporting environmentally grounded design and production decisions.

Environmental Product Declarations (EPDs), which ensure the transparent dissemination of LCA-based environmental data, have emerged as an essential tool in sustainable product management [10, 11]. EPD documents, verified through independent assessment processes, provide concise summaries of environmental performance based on life cycle data, enabling objective comparison between products. Their use contributes both to the development of environmentally conscious manufacturing policies by producers and to informed material selection by designers [12].

The primary aim of this study is to compare the A1–A3 GWP-fossil values of five furniture-relevant wood products using methodologically harmonised, manufacturer-specific EPD data. The selected set comprises kiln-dried and planed sawn timber, raw and melamine-faced particleboard, and raw and lacquered MDF. This pairing enables both cross-material comparison and examination of the additional burden associated with surface finishing.

The study is limited to the product stage (A1: raw-material supply, A2: transport to the manufacturer, and A3: manufacturing) and uses 1 m³ as the common declared unit. Because EN 15804+A2 separates climate-change indicators, the analysis focuses specifically on GWP-fossil rather than an unspecified aggregate GWP value. GWP-total, GWP-biogenic, GWP-luluc, use-stage effects, service life, and end-of-life modules are outside the defined scope.

Within this framework, the main objectives of the study can be summarized in three points:

- To compare A1–A3 GWP-fossil values across selected wood-based products on a common 1 m³ basis,
- To examine how resin-intensive processing and surface finishing are reflected in differences between untreated and finished product pairs,
- To evaluate the usefulness and limitations of harmonised EPD data in supporting sustainable material selection in furniture production.

Accordingly, the study treats EPDs as a comparative decision-support source rather than as automatically interchangeable data. Standard version, declared unit, indicator definition, publication year, manufacturer, production location, and PCR context are considered before numerical comparison.

2. CONCEPTUAL FRAMEWORK
(KAVRAMSAL ÇERÇEVE)

The sustainability assessment of wood composite materials focuses not only on the renewable origin of the materials but also holistically on the environmental impacts of their production processes, service life, and disposal stages. These materials offer significant opportunities in terms of resource efficiency, carbon emission reduction, and circular economy principles; however, factors such as the type of binder used in production, energy intensity, and the proportion of recycled content play a decisive role in their environmental performance. Therefore, the sustainability of wood composites is a multidimensional phenomenon that extends beyond raw material selection and requires analysis through a life cycle approach. In this section, the environmental impacts of wood composites, innovative manufacturing approaches, resource efficiency, and sustainability trends in the sector are examined from a life cycle perspective.

2.1. Wood Composite Materials in the Furniture Industry (Mobilya Sektöründe Ahşap Kompozit Malzemeler)

Wood composite materials are increasingly preferred in the furniture industry to overcome the limitations of natural wood, promote sustainable resource use, and enable cost-effective production.

These materials are engineered products produced by combining wood fibers, particles, or veneers with polymers, resins, or bio-based adhesives [3, 13]. Consequently, composites with controllable mechanical and physical properties, varying densities, strengths, and surface qualities can be obtained.

Common wood composites used in the furniture sector include particleboard, fiberboard (MDF/HDF), plywood, oriented strand board (OSB), wood-polymer composites (WPCs), bamboo-based engineered products, and bio-based composites [3, 4, 14]. This diversity allows materials to be tailored to both functional requirements and aesthetic design criteria. The following table summarizes commonly used wood composite materials in the furniture industry, their structural properties, and typical applications.

Table 1. Common wood composite materials in the furniture industry: structural properties and typical applications (Mobilya sektöründe yaygın olarak kullanılan ahşap kompozit malzemeler: yapısal özellikleri ve tipik uygulamaları)

Composite Type	Structural Properties	Typical Furniture Applications	References
Particleboard / MDF	Wood particles or fibers + synthetic resin	Panels, shelves, cabinet carcasses	[3, 4]
Plywood / OSB	Veneer layers or wood strands + adhesive	Load-bearing surfaces, frame elements	[13]
Wood-Polymer Composite (WPC)	Wood flour or fibers + thermoplastic polymer	Indoor/outdoor furniture	[15, 16]
Engineered Bamboo	Laminated or pressed bamboo	Lightweight, high-strength furniture	[5, 13]
Bio-based Composite	Bio-resin or self-binding wood fibers	Eco-friendly furniture products	[17, 18]

One of the most significant advantages of these materials is that they offer production flexibility due to the diversity of raw materials. The use of alternative sources such as wood waste, agricultural fibers, or recycled plastics reduces production costs while contributing to waste management [5, 16].

Wood composite materials demonstrate superior performance compared to natural wood in terms of dimensional stability, resistance to moisture and pests, and homogeneous mechanical behavior [3, 17]. Additionally, the controllability of parameters such as density, fiber content, and resin type provides manufacturers with the opportunity for tailored material engineering for specific furniture types. Consequently, furniture producers can simultaneously optimize both the aesthetic and structural performance of their products [4, 14].

Currently, R&D activities in the furniture industry are focused on formaldehyde-free resins, bio-based adhesives, and high-strength hybrid structures [18, 19]. Moreover, the introduction of advanced engineered products such as Cross-Laminated Timber (CLT) in small-scale furniture designs reflects the sector's innovative orientation. An examination of research trends shows a steady increase in publications on wood composite furniture between 2014 and 2024, indicating that these materials are recognized not only as technical solutions but also as fundamental components of sustainable design [5, 14].

2.2. Life Cycle Assessment (LCA) and EPD-Based Product Comparison (Yaşam Döngüsü Değerlendirmesi (LCA) ve EPD Tabanlı Ürün Karşılaştırması)

In sustainable product design and environmental performance management processes, Life Cycle Assessment (LCA) is one of the most fundamental methods for holistically analyzing the environmental impacts of building products. Based on ISO 14040 and ISO 14044 standards, this method encompasses all stages of a product's life cycle—from raw material extraction, production, distribution, and use to maintenance and disposal [8, 9]. This approach provides a scientific foundation for material selection, design optimization, and environmental declaration systems (e.g., EPDs) in the building and furniture industries. LCA consists of four main stages (Figure 1):

- Goal and scope definition: Establishes the boundaries of the analysis, the functional unit, and assumptions.
- Life cycle inventory (LCI): Quantifies all energy, material, and emission flows entering and leaving the product system.
- Life cycle impact assessment (LCIA): Evaluates the environmental impacts of these flows across categories such as global warming potential, acidification, and resource depletion.
- Interpretation: Results are interpreted along with uncertainties and improvement recommendations [21, 22, 23].

els of variable processing parameters and the parameters kept fixed.

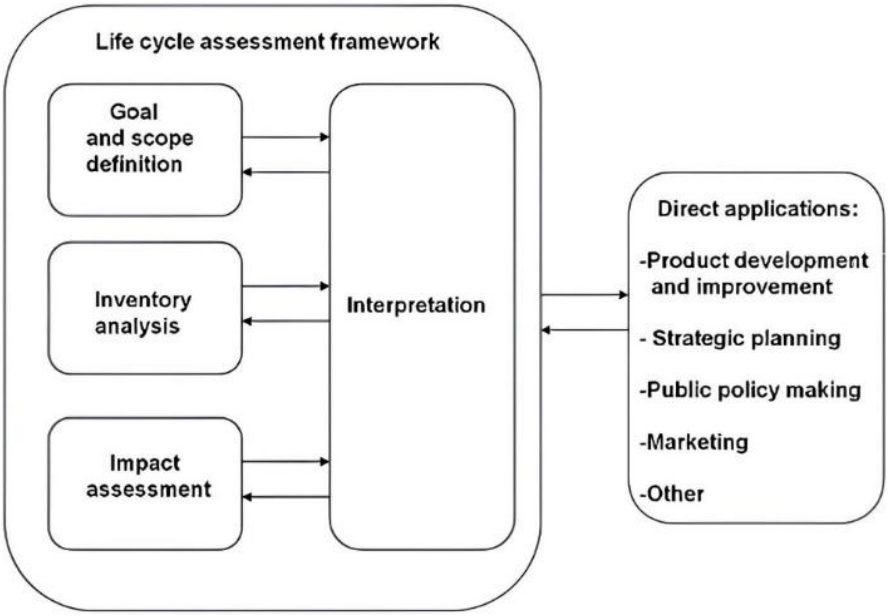

Figure 1. Phases of an LCA according to EN ISO 14040:2006 [20] (EN ISO 14040:2006 standardına göre Yaşam Döngüsü Analizinin (LCA) Aşamaları)

This framework is widely used to assess the environmental performance of building materials and furniture components, and it is also integrated into product development processes to guide material optimization and design decisions [24, 25].

In the construction sector, LCA is a critical tool for determining the embodied energy and carbon footprint of products [26, 27]. These analyses play a decisive role in material selection, particularly in the design of energy-efficient buildings. For instance, numerous studies have shown that wood-based panels or composites exhibit lower environmental impacts compared to high-emission alternatives such as concrete and steel [7, 27].

LCA also provides the essential data foundation for environmental labeling and green building certification systems (e.g., LEED, BREEAM, DGNB). Environmental Product Declarations (EPDs) used in these systems are third-party verified summaries of environmental performance derived from LCA data [10]. This ensures a comparable, transparent, and scientifically grounded decision-making mechanism in product selection and procurement processes.

Life cycle assessments conducted at the product level are directly related to product development and R&D activities in the building and furniture industries [28, 29]. These assessments analyze the environmental impact of a single product or component while also accounting for parameters such as energy inputs during production, transportation, and service life (Figure 2).

the side surfaces of the keyseat. Radius (R) measurements were obtained with circles created by touching three points, and the distance measurement between the circles and the "L" dimension were checked. Perpendicular to the ground "line" was formed from the side walls of the keyseat, and perpendicularity checks were made with the plane on the floor. All calibration and measurement processes were carried out at 21°C. The experimental setup and workflow are shown in Figure 3.

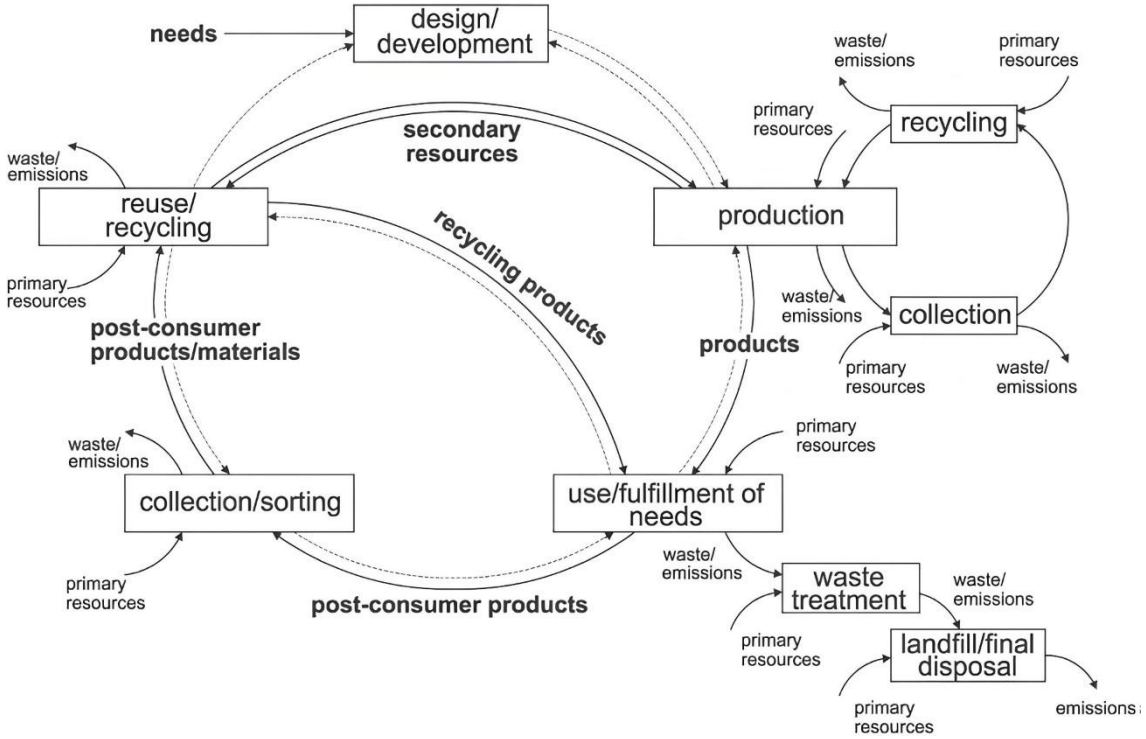

Figure 2. Schematic Representation of a Generic Life Cycle of a Product [30] (Bir Ürünün Genel Yaşam Döngüsünün Şematik Gösterimi)

Recently developed modular and parametric LCA approaches allow rapid environmental assessment, particularly in the early stages of design [22, 31]. These approaches, when integrated with digital modeling tools (e.g., BIM-based LCA systems), directly support designers in the decision-making process [32, 33].

The application of LCA in furniture production is becoming increasingly common for evaluating the environmental impacts of material selection, production technologies, and product life strategies [34]. For example, resin content and energy consumption in materials such as MDF and particleboard are significant determinants of total greenhouse gas emissions [6]. Similarly, the use of bio-based composites or self-binding fiberboards can substantially reduce carbon emissions, contributing to sustainable product development [35].

In this context, LCA has evolved from merely being an environmental performance measurement tool to a decision-support system guiding design. Its ability to quantitatively compare the environmental impacts of products, especially when integrated with EPDs, provides a fundamental tool for environmentally conscious product selection and green supply chain management.

2.3. Wood Composite Materials and Sustainability (Ahşap Kompozit Malzemeler ve Sürdürülebilirlik)

Sustainability objectives in the furniture industry are being redefined within the framework of resource efficiency, low carbon footprint, and circular economy principles. In this regard, wood composite materials occupy a central role in sustainable production systems due to their ability to reduce natural resource use and facilitate waste recovery [15, 34, 36]. Replacing traditional solid wood products with composites helps conserve forest resources, valorize production waste, and reduce environmental burdens throughout the product life cycle.

Life Cycle Assessment (LCA) is the most widely used method for quantitatively analyzing the environmental impacts of wood composites. Studies indicate that composites produced from recycled wood, agricultural residues, or bio-based polymers significantly reduce fossil fuel consumption, greenhouse gas emissions, and raw material depletion [7, 15, 37]. These advantages play a critical role in lowering the carbon footprint of the furniture industry, especially when combined with energy-efficient production technologies [38, 39].

However, not all composite types are equally environmentally friendly. Formaldehyde-based resins and energy-intensive pressing processes can

increase the total environmental impact of certain products [6, 7]. Consequently, contemporary sustainability approaches focus not only on the biological content of materials but also on production methods and emissions during the product's service life [40, 41].

Recent research aimed at reducing the environmental impacts of wood composites has focused on the development of bio-based binders and the widespread adoption of formaldehyde-free production processes. Self-bonding and adhesive-free hot-pressing methods, in particular, eliminate toxic emissions and improve indoor air quality [17, 35]. Additionally, the use of natural fibers such as flax, hemp, willow, and jute or biopolymers (e.g., PLA) reduces petrochemical dependency and enhances sustainability performance [15, 34, 42].

Another outcome of these technological innovations is an increase in material circularity. The use of recyclable or biodegradable composites provides significant benefits in terms of waste reduction and resource efficiency [41, 43]. In particular, in line with policies such as the European Union's Circular Economy Action Plan, the furniture industry is increasingly shifting toward these types of materials [7, 44].

The partial replacement of solid wood with composites has created a measurable impact on forest resource conservation. In the study by Ciupan et al. (2018), it was demonstrated that substituting a certain proportion of natural wood with fiber composites could preserve thousands of hectares of forest annually [34]. Furthermore, the utilization of low-quality wood, production residues, and recycled fibers enhances raw material efficiency and facilitates energy recovery [39, 44].

Resource efficiency is not limited to material selection; reducing energy consumption during production and revalorizing by-products are also fundamental components of sustainability [41]. Consequently, many manufacturers now aim to document their production chains in terms of environmental performance through tools such as ISO 14001 environmental management systems and EPDs.

Wood composite materials have become not only a component of the sustainable production paradigm but also a driving force for industrial transformation. Research trends indicate a rapid increase in LCA-based assessments and bio-based material studies since the early 2000s [7, 45]. This trend demonstrates that the furniture industry is shaped not only by aesthetic and functional considerations but also by environmental responsibility awareness.

2.4. EPDs in Material and Product Selection
(Malzeme ve Ürün Seçiminde EPD'ler)

An Environmental Product Declaration (EPD) is a document that transparently presents a product's environmental impact throughout its life cycle in a standardized and third-party verified manner. Based on ISO 14025, these declarations primarily rely on Life Cycle Assessment (LCA) data and render the environmental performance of products quantitatively comparable [10, 46].

In the building and furniture industries, EPDs support decision-making in sustainable product selection, green building certification systems (LEED, BREEAM, DGNB), and green procurement in public projects [11, 47]. Consequently, EPDs function not merely as environmental reporting tools but also as key information systems for implementing decarbonization strategies. They report environmental impacts during cradle-to-gate or cradle-to-grave life cycle stages—such as global warming potential, energy consumption, waste generation, and resource depletion [11]. This provides manufacturers with opportunities for performance improvement and competitive advantage while enabling informed material selection for end users [11, 48].

EPDs are issued at material or product level and may be manufacturer-specific, sectoral, or generic. Manufacturer-specific declarations are particularly useful for product comparison when their declared units, system boundaries, standard versions, indicator definitions, and PCR conditions are sufficiently aligned. In the furniture sector, EPDs for particleboard, MDF, coatings, laminates, and solid-wood products can therefore support material selection, but their numerical values should not be compared without methodological screening.

Table 2. Classification of EPD Types, Intended Uses, and Evaluation of Advantages/Limitations (EPD Türlerinin Sınıflandırılması, Amaçlanan Kullanımları ve Avantaj/Sınırlamalarının Değerlendirilmesi)

EPD Type	Intended Use	Advantages / Limitations	References
Manufacturer-specific EPD	Supply chain and product comparison	High accuracy, enables direct comparison	[10, 12]
Sectoral / Collective EPD	Early design phase, sector average	Highly representative, but not company-specific	[10, 12]
Generic / Industry-average EPD	Policy, strategic planning, research	Lowest accuracy, high uncertainty	[12, 50]

This classification directly informed the data strategy of the study. Manufacturer-specific EPDs from one producer were prioritised to reduce variation associated with company-level modelling practices. The records were then restricted to EN 15804+A2 and a common GWP-fossil indicator. These controls improve comparability, although differences between the PCRs for solid wood and wood-based panels remain a methodological limitation.

The integration of EPD data with Building Information Modeling (BIM) and LCA software enhances the effectiveness of decision-support systems in design and material selection processes [32, 51]. This allows designers to evaluate the environmental impacts of different materials in the early stages of design and identify optimal solutions. Future trends include PCR harmonization, the development of digital databases, and the global standardization of EPD data quality requirements [49, 52]. These advancements are expected to transform EPDs from mere environmental reporting tools into a strategic component for sustainable product management and carbon-neutral production policies [11, 46].

3. MATERIALS AND METHODOLOGY (MATERYAL VE YÖNTEM)

This research is an EPD-based comparative assessment rather than a new process-level LCA. Five furniture-relevant products were examined: kiln-dried and planed sawn timber, raw particleboard, melamine-faced particleboard, raw MDF, and lacquered MDF. Manufacturer-specific declarations from Fritz EGGER/EGGER Sägewerk Brilon were selected from the One Click LCA Materials Compass archive [53] and checked against the underlying IBU declarations [54–58]. The records were retrieved during 2025 and were issued in 2021.

The declared unit was harmonised to 1 m³, and the system boundary was restricted to modules A1–A3. All selected declarations comply with EN 15804+A2. Because this standard reports GWP-total and its fossil, biogenic, and land-use components separately, only GWP-fossil was used in the primary comparison. This choice is consistent with the non-biogenic values displayed in the source database but does not represent the total climate balance of wood products.

Products already declared per cubic metre were used directly. For melamine-faced particleboard and lacquered MDF, the EPD values reported per square metre were converted to 1 m³ using the relationship $GWP_{m^3} = GWP_{m^2} \times \rho/mA$, where ρ is density (kg/m³) and mA is surface mass (kg/m²). Consequently, 3.93 kg CO_2e/m² for melamine-faced particleboard was converted using 655 kg/m³ and 11.57 kg/m², while 8.87 kg CO_2e/m² for lacquered MDF was converted using 733 kg/m³ and 13.20 kg/m².

The analysis comprised four steps. First, products were selected according to relevance to furniture production. Second, EPDs were screened for manufacturer specificity, EN 15804+A2 compliance, publication year, system boundary, and availability of GWP-fossil. Third, units were harmonised to 1 m³ and values were normalised relative to sawn timber. Fourth, the ranking, relative ratios, arithmetic mean, median, minimum–maximum range, and differences between untreated and finished product pairs were calculated. Interpretation was based on process information reported in the EPDs and supporting literature; causal attribution was avoided where product-specific inventory data was unavailable.

Figure 3 presents the harmonized A1–A3 GWP-fossil values. The updated data set produces a progressive increase from sawn timber to raw

particleboard, melamine-faced particleboard, raw MDF, and lacquered MDF. Unlike the previous mixed-standard comparison, the figure uses only EN 15804+A2 declarations and the same climate-change indicator.

Table 3. Harmonised comparison of A1–A3 GWP-fossil values for selected wood-based products (Seçilen ahşap bazlı ürünler için A1–A3 GWP-fosil değerlerinin uyumlu karşılaştırması)

Product category	Product name in EPD	Country	Density (kg/m³)	EPD identifier / issue year	Basis	A1–A3 GWP-fossil (kg CO_2e/m³)
Sawn timber	EGGER Timber, kiln-dried, rough-sawn and planed	Germany	503	EPD-EGG-20200248-IBC2-EN (2021)	EN 15804+A2 GWP-fossil	101.00
Raw particleboard	EGGER Eurospan raw chipboard	Germany	655	EPD-EGG-20200249-IBC1-DE (2021)	EN 15804+A2 GWP-fossil	147.00
Melamine-faced particleboard	EGGER Eurodekor melamine-faced chipboard	Germany	655	EPD-EGG-20200251-IBC2-EN (2021)	EN 15804+A2 GWP-fossil	222.48*
Raw MDF	EGGER medium-density fibreboard	Germany	736	EPD-EGG-20200250-IBC1-DE (2021)	EN 15804+A2 GWP-fossil	379.00
Lacquered MDF	EGGER PerfectSense lacquered board	Germany	733	EPD-EGG-20200253-IBC1-DE (2021)	EN 15804+A2 GWP-fossil	492.55*

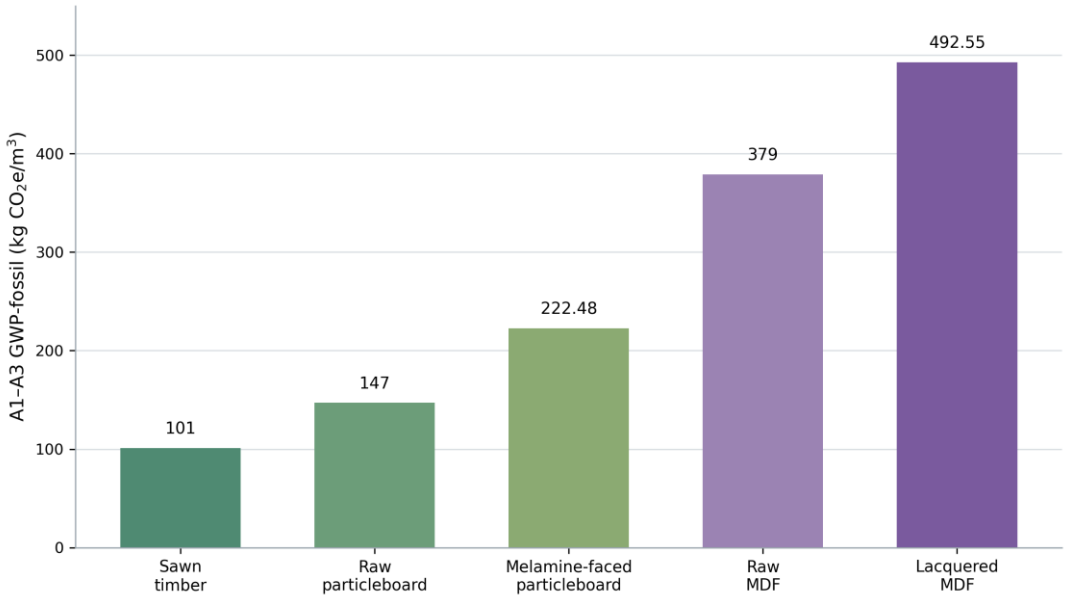

Figure 3. Comparative A1–A3 GWP-fossil values of selected wood-based products based on harmonized EPD data (kg CO_2e/m³) (Uyumlaştırılmış EPD verilerine dayalı olarak seçilmiş ahşap bazlı ürünlerin karşılaştırmalı A1–A3 GWP-fosil değerleri (kg CO_2e/m³))

The product ranking is interpreted together with EPD descriptions of raw-material preparation, adhesive systems, thermal and electrical energy, pressing, impregnation, and lacquer finishing. These parameters were not held constant; they are product-specific characteristics that may contribute to the observed differences. GWP-biogenic and GWP-total were excluded from the numerical ranking and are addressed as a scope limitation.

4. RESULTS AND DISCUSSION (BULGULAR VE TARTIŞMA)

The harmonized A1–A3 GWP-fossil values of the five products were compared using a common declared unit of 1 m³ (Table 3 and Figure 3). Values increased in the following order: sawn timber (101.00 kg CO_2e/m³), raw particleboard (147.00 kg CO_2e/m³), melamine-faced particleboard (222.48

kg CO_2e/m^3), raw MDF (379.00 kg CO_2e/m^3), and lacquered MDF (492.55 kg CO_2e/m^3).

Sawn timber showed the lowest GWP-fossil value. Its production mainly involves log processing, kiln drying, and planing and does not require the synthetic resin systems used in particleboard and MDF production. Nevertheless, its updated EN 15804+A2 value (101.00 kg CO_2e/m^3) is substantially higher than the 24 kg CO_2e/m^3 value obtained from the superseded EN 15804+A1 record, demonstrating why standard versions should not be mixed.

Raw particleboard recorded 147.00 kg CO_2e/m^3, whereas melamine-faced particleboard reached 222.48 kg CO_2e/m^3. The finishing stage was therefore associated with an increase of 75.48 kg CO_2e/m^3, or approximately 51.3% relative to the raw board. Because both records relate to the same manufacturer, production country, publication period, standard version, and indicator, the difference can be interpreted more confidently than in the previous comparison. The EPD indicates that decorative paper and melamine impregnation resin are additional relevant inputs, although the result still represents an aggregated product system.

Raw MDF recorded 379.00 kg CO_2e/m^3 and lacquered MDF 492.55 kg CO_2e/m^3. Lacquering was associated with an increase of 113.55 kg CO_2e/m^3, corresponding to approximately 30.0% relative to raw MDF. The higher values of both MDF products compared with particleboard are consistent with the additional fibre preparation, drying, resin application, and pressing requirements described in the literature [6, 7, 42].

When normalised to sawn timber (1.00), the relative ratios were 1.46 for raw particleboard, 2.20 for melamine-faced particleboard, 3.75 for raw MDF, and 4.88 for lacquered MDF. Across the five products, the arithmetic mean was 268.41 kg CO_2e/m^3, the median was 222.48 kg CO_2e/m^3, and the minimum–maximum range was 391.55 kg CO_2e/m^3.

The direction of the results is consistent with previous studies showing that resin systems, fibre preparation, thermal processing, and surface finishing can increase fossil energy demand and greenhouse-gas emissions in wood-based panels [6, 7]. However, the numerical values should not be treated as universal material constants because EPD results depend on product formulation, plant technology, electricity and thermal-energy supply, background databases, and PCR assumptions.

Overall, the harmonised comparison supports two observations. First, solid timber had the lowest GWP-fossil value within the selected product set. Second, surface-finished particleboard and MDF had higher values than their untreated counterparts. These findings support the use of EPD data in material selection while also showing that a meaningful comparison requires explicit control of standard version, indicator, declared unit, data year, manufacturer, and product definition.

4.1. Methodological Limitations (Metodolojik Sınırlamalar)

The study has five principal limitations. First, the sample is restricted to one manufacturer and primarily one production location, which improves internal consistency but limits generalizability. Second, only GWP-fossil was compared; the findings therefore do not represent GWP-total or the complete environmental profile. Third, solid timber and wood-based panels remain subject to product-category-specific PCR conditions even though all declarations comply with EN 15804+A2. Fourth, the declared unit of 1 m^3 does not establish equivalent mechanical performance, service life, or finished furniture function. Finally, the interpretation is based on aggregated EPD results and reported process descriptions rather than disaggregated inventory data. The results should therefore be used for screening and comparative interpretation, not as universal emission factors for all products in each material category.

5. CONCLUSIONS (SONUÇLAR)

This study compared five furniture-relevant wood products using manufacturer-specific EN 15804+A2 EPDs, a common 1 m^3 declared unit, and the A1–A3 GWP-fossil indicator. The methodological harmonization corrected the inconsistencies created by combining EN 15804+A1 and +A2 records and resolved the previously observed anomaly in which coated particleboard appeared to perform better than raw particleboard.

The revised ranking was sawn timber (101.00 kg CO_2e/m^3), raw particleboard (147.00 kg CO_2e/m^3), melamine-faced particleboard (222.48 kg CO_2e/m^3), raw MDF (379.00 kg CO_2e/m^3), and lacquered MDF (492.55 kg CO_2e/m^3). Accordingly, lacquered MDF had approximately 4.88 times the GWP-fossil value of sawn timber. The raw/finished comparisons also showed increases of approximately 51.3% for melamine-faced particleboard and 30.0% for lacquered MDF,

indicating that finishing processes should be considered explicitly in furniture material selection.

The results also demonstrate that EPD transparency alone does not guarantee comparability. Designers, manufacturers, and researchers should verify the standard amendment, PCR, declared unit, system boundary, indicator definition, publication year, production geography, and manufacturer before comparing products. Manufacturers should therefore publish current product-specific EPDs in accessible digital formats and clearly report the assumptions underlying energy, resin, recycled content, and finishing processes.

Within its defined scope, the study provides a reproducible framework for EPD-based material screening in the furniture sector. Future research should expand the sample to multiple manufacturers and regions, including GWP-total and GWP-biogenic alongside GWP-fossil, evaluate additional impact categories, and compare products on equivalent functional and service-life requirements. Such extensions would allow EPD-based selection to develop from a single-indicator comparison into a more comprehensive environmental decision-support approach.

DECLARATION OF ETHICAL STANDARDS (ETİK STANDARTLARIN BEYANI)

The author of this article declares that the materials and methods they use in their work do not require ethical committee approval and/or legal-specific permission.

Bu makalenin yazarı çalışmalarında kullandıkları materyal ve yöntemlerin etik kurul izni ve/veya yasal-özel bir izin gerektirmediğini beyan ederler.

AUTHORS' CONTRIBUTIONS (YAZARLARIN KATKILARI)

***Sadık AKŞAR*:** He conducted the data collection and analysis, interpreted the findings, and carried out the writing and revision of the manuscript.

Verilerin toplanması ve analizini gerçekleştirmiş, bulguları yorumlamış ve makalenin yazım ve revizyon süreçlerini yürütmüştür.

CONFLICT OF INTEREST (ÇIKAR ÇATIŞMASI)

There is no conflict of interest in this study.

Bu çalışmada herhangi bir çıkar çatışması yoktur.

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