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Sustainable Choices in Leather: Contrasting the Environmental Aspects of Animal and Alternative Leathers

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In a time when environmental consciousness has begun to influence consumer choices, the leather industry presents a complex case where product demand continues to grow despite challenges with environmental impact. The industry's narrative of leather as a sustainable byproduct of meat production is called into question as data shows cowhide leather generates 110 kg of CO_2 equivalent per square meter and 17,100 liters of water per kilogram produced (Circumfauna, 2024; WWF, 2024). This conflict between market demand and environmental awareness has driven companies to develop alternative leather materials, which creates a situation where sustainability claims must be carefully evaluated against actual environmental performance. This research examines environmental aspects and trade-offs of traditional animal leather and alternative materials by analyzing the categories, manufacturing methods, and environmental pros and cons of each to inform stakeholders and consumers who navigate the complex world of leather and sustainability.

Animal Leathers

Types of Animal Leather

The leather industry has long relied on cowhide as its primary raw material, but growing environmental and ethical concerns have prompted discussions about alternative animal leathers. Cowhide leather production is intrinsically linked to the meat and dairy industries, as hides are a byproduct of cattle raised for food. While this reduces waste, the environmental costs of cattle farming are substantial. Cattle are major emitters of methane, a potent greenhouse gas, and require vast amounts of land and water. Deforestation, particularly in critical regions like the Amazon, is driven by the expansion of grazing land and feed crops (World Wildlife Fund, 2024). Additionally, traditional chrome tanning, used for 80-90% of leather, involves toxic chemicals like hexavalent chromium, which can contaminate soil and water, posing health risks to workers and nearby communities (PETA, 2010a). Vegetable tanning, though less toxic, is slower, more expensive, and still resource-intensive (Peck, 2025). Despite these drawbacks, cowhide leather has sustainability advantages. Its durability and biodegradability make it a long-lasting material, reducing the frequency of replacement compared to synthetic alternatives. However, the ethical concerns of industrial animal farming and the hazardous conditions in tanneries cannot be overlooked (Achabou, 2021).

Alternative animal leathers, such as sheepskin, goatskin, and pigskin, offer unique properties but face significant limitations. Sheepskin is lightweight and insulating but less durable and prone to moisture damage. Goatskin is flexible and water-resistant, but thinner and more expensive. Pigskin is cost-effective and breathable but has visible pores and a stiffer feel, limiting its aesthetic appeal (Neo, 2023). Exotic leathers, like alligator or ostrich, are niche products due to their high cost, limited supply, and regulatory restrictions under CITES (Convention on International Trade in Endangered Species) (Baptiste Pesanti, 2023).

The economic and infrastructure challenges of processing alternative hides further complicate their adoption. Tanneries are optimized for cowhide, and adapting equipment and chemical treatments for other hides is costly and inefficient. Smaller hides from animals like goats or sheep result in inconsistent sizes and higher defect rates, complicating manufacturing (Kennedy, 2024). Additionally, the supply chains for alternative leathers are fragile, often relying on byproducts from other industries, such as fisheries for fish leather (Molinari, 2025). The leather industry is a $400 billion market dominated by cowhide, which accounts for 40% of production (Verified Market Reports, 2024). Transitioning to alternative leathers would require massive investments in new infrastructure and training, which small and medium enterprises—the backbone of the industry in many countries—cannot afford (Kral, 2017). Furthermore, regulatory hurdles, such as CITES permits for exotic leathers and tightening import/export restrictions, limit market access (Deepwear, 2025). Consumer demand also plays a critical role. While some buyers seek sustainable or exotic options, the majority prefer cowhide for its affordability, consistency, and familiarity. The higher cost of alternatives, driven by limited supply and specialized processing, makes them unviable for mass production (PW Consulting, 2024).

Manufacturing Animal Leathers

The leather production process begins with beamhouse operations, which prepare raw hides for tanning by removing impurities and stabilizing the material. Fresh hides are typically preserved with salt to prevent decay during transport (Mastrotto, 2024). Upon arrival at tanneries, the hides undergo desalting, where rotating drums remove excess salt and rehydrate the material (Leather Naturally, 2023). Subsequent steps include soaking, where hides are treated with water and surfactants for 8–16 hours to eliminate dirt and blood residues (Process Flow Sheets, 2011). Liming and unhairing follow, using lime and sodium sulfide to dissolve hair and epidermis while softening the collagen structure (Keleen Leathers, 2024). This step is critical for ensuring the hide's permeability to tanning agents. Fleshing then mechanically removes subcutaneous fat and tissue, while splitting divides thick hides into layers—the grain layer for premium leather and the lower layer for suede (Ahlstrom, 2025). The final preparatory steps, deliming and bating, involve enzymatic treatments to neutralize alkalinity and further soften the hide (Nera, 2023).

Tanning is the cornerstone of leather production, converting perishable hides into stable, non-decaying material. Chrome tanning dominates the industry, accounting for 80–90% of global production due to its speed and versatility (Cisco et al., 2023). This method involves immersing hides in chromium sulfate solutions for 8–12 hours, followed by basification with sodium bicarbonate to fix the chromium (Ludvik, 2000). The result is "wet blue" leather, characterized by its blue hue and high moisture content (BestLeather, 2017). For traditional or eco-conscious products, vegetable tanning employs natural tannins from tree bark, requiring weeks to months in pits or 2–30 days in modern drums (Lanius, 2025). Though environmentally friendlier, vegetable-tanned leather is costlier and less pliable. Emerging alternatives like chrome-free tanning and DyTan technology —which combines tanning and dyeing—are gaining traction to reduce reliance on heavy metals (Hakimi Leather, 2024). The final phase, finishing, determines the leather's appearance and performance. Drying methods like vacuum drying or toggling remove moisture, while mechanical treatments enhance suppleness and surface smoothness (UDEC, 2025). Chemical finishing involves applying ground, base, and top coats to achieve desired colors, textures, and protective qualities (Superior, 2020). Advanced techniques like embossing or polyurethane coating add decorative or functional elements, such as water repellency.

Modern tanneries leverage technology to improve efficiency and reduce environmental impact. IoT-enabled drums monitor real-time parameters like temperature and pH, optimizing chemical use (GER, 2023). Automated cutting systems minimize waste through precision laser cutting, while water recycling technologies achieve 90% reuse rates in advanced facilities (Enigma2040, 2024). Sustainability initiatives are reshaping the industry. DriTan technology, pioneered by ECCO Leather, saves 20 liters of water per hide by utilizing the hide's natural moisture (Siegman, 2022). Chrome recycling systems recover and reuse chromium, reducing toxic waste (UNIDO, 2000). Bio-fabricated leather, such as Modern Meadow's lab-grown collagen, offers animal-free alternatives (Siegman, 2022). These innovations align with global demands for eco-friendly production without compromising quality.

Environmental Pros and Cons

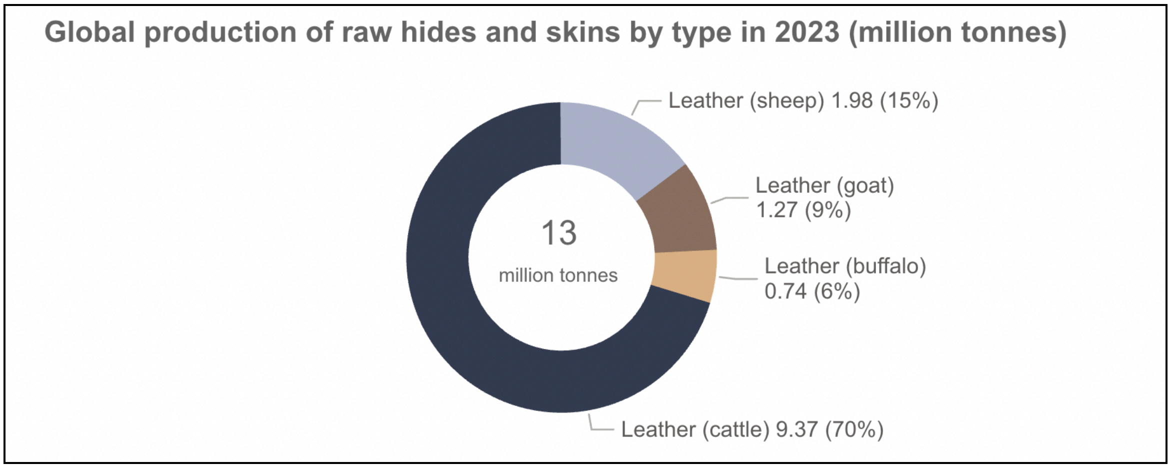
Cow leather dominates the market but carries severe environmental costs. Cattle farming accounts for 14–18% of agricultural greenhouse gas (GHG) emissions, primarily due to methane production and feed cultivation (PETA, 2010b). The production of cow leather generates approximately 110 kg of CO_2 equivalent per square meter, with deforestation for cattle ranching—particularly in the Amazon—exacerbating biodiversity loss and carbon sink destruction (WWF, 2024). Water consumption is equally staggering, requiring 17,100 liters per kilogram of leather, equivalent to 104,000 liters per hide (Circumfauna, 2024). Chemical pollution from chrome tanning, which releases chromium and sulfides, further contaminates waterways (Hirsh, 2022).

Despite these drawbacks, cow leather offers durability advantages. Its longevity—often spanning decades—reduces replacement frequency and waste generation (Yiannari, 2024). Additionally, cowhide utilization as a byproduct of the meat and dairy industries minimizes resource waste, though some argue it functions as a co-product due to its economic value (Hirsh, 2022). Vegetable-tanned cow leather also holds biodegradability potential, though chemical treatments often hinder decomposition (Brownlee, 2023). Horse leather, while less common, has a smaller environmental footprint due to limited production scale. Horse farming emits methane and nitrous oxide, but its specialized, low-volume nature reduces cumulative impact (Carmichael, 2024). Horsehide is prized for exceptional durability, often outperforming cow leather in lifespan, which mitigates long-term resource use (Carmichael, 2024). Most horse leather derives from animals not raised primarily for hides, reinforcing its byproduct status.

Sheep and goat leathers benefit from smaller animal sizes, which reduce per-unit resource demands. However, sheep farming contributes significantly to methane emissions, with New Zealand's sheep population alone responsible for 90% of national methane output (PETA, 2010b). Overgrazing has also led to soil erosion, particularly in regions like Patagonia, where 93% of the land has faced desertification (Meek, 2019). Tanning processes for these hides mirror cow leather's chemical intensity, releasing chromium and sulfides (Dota et al., 2016). On the positive side, sheep and goats require less water and feed than cattle, and their ability to graze on marginal lands can support sustainable land use when managed properly (Jones Family Farm, 2023). Their hides are typically byproducts of the wool and meat industries, aligning with circular economy principles.

Deer leather's environmental impact varies by sourcing method. Wild deer harvesting can disrupt ecosystems if unregulated, but when integrated with population control programs, it provides a sustainable use for culled animals (Klein et al., 2002). Unlike farmed livestock, wild deer require no additional land or feed, reducing their carbon footprint. However, tanning deer hides remain chemically intensive, mirroring other leathers' pollution challenges. Pigskin leather leverages the pork industry's byproducts, minimizing waste. In regions with high pork consumption, such as East Asia, domestic processing reduces transportation emissions (Fukushima Chemical Industry, 2025). However, pigskin tanning is notoriously polluting, with wastewater containing sulfides, chromium, and ammonia nitrogen at levels comparable to a small city's sewage output. Nearly 30% of pigskin tanneries discharge untreated wastewater, exacerbating environmental harm.

Fig 1: Market shares of different types of animal leathers (Vandepaer, 2025).



Alternative Leathers

Types of Alternative Leather

The first category of alternative leather is synthetic leather. Synthetic leathers are composed of a base textile and coated with a layer of polyurethane or polyvinyl chloride. Base materials can include, but are not limited to, cotton, nylon, polyester, and rayon ("Leather & Leather Alternatives | Understand Leather Labelling," 2023; Tewari, Reshamwala, Bhatt, & Kale, 2023; Tonti, 2023). Polyurethane leather, or PU, is prepared by selecting one fiber out of a combination of different synthetic fibers to pick the one that most resembles animal leather. PU is more breathable than polyvinyl chloride, or PVC, so it is often used in clothing (Tewari et al., 2023). PU is also considered to be safer than PVC, as the latter is more difficult to degrade and utilizes more carbon (Tewari et al., 2023; Tonti, 2023). PVC leather is made by adding plastic and dye to vinyl. This polymer is a thermoplastic that is composed of 42% carbon and 57% chlorine. PVC also has additional plasticizers that are added to make the material more flexible and softer (Tewari et al., 2023; Tonti, 2023). In addition to the use of plastic polymers in synthetic leathers, the next category of leathers also often uses plastic polymers in its coatings

("Leather & Leather Alternatives | Understand Leather Labelling," 2023; Tewari et al., 2023; Tonti, 2023).

The second category of alternative leather is vegan leather. Vegan leathers are leathers derived from things in nature such as bacteria, fruit, fiber, fungi, and leaves. For leathers that use bacteria, companies typically grow bacterial cellulose, a biomaterial, and fibers which contribute to the composition of the leather (Tewari et al., 2023; Tonti, 2023). Fruit leathers can be made of different fruits, such as apple, mango, and grape. Often leather made from fruit uses fruit juice, pulp, or peels from agricultural waste to make the leathers. Leathers that use fiber include leather derived from tree bark, tree rubber, and bananas (Collective Fashion Justice, 2024; Tewari et al., 2023; Tonti, 2023). The brands that make leather from tree materials often claim to sustainably source their wood and sap as well (Collective Fashion Justice, 2024; Tewari et al., 2023). Additionally, fungi-derived leathers are typically made by growing mycelium, which are root-like structures of fungi. Mycelium can be grown in vertical farms as well as directly on fabric backing (Tewari et al., 2023; Tonti, 2023). Lastly, there are leathers derived from leaves, which include leaves from pineapples, cacti, and olive plants. These leathers are created by extracting the leaves of the plants and then converting the leaves into a mesh or paper-like structure (Collective Fashion Justice, 2024; Tewari et al., 2023; Tonti, 2023).

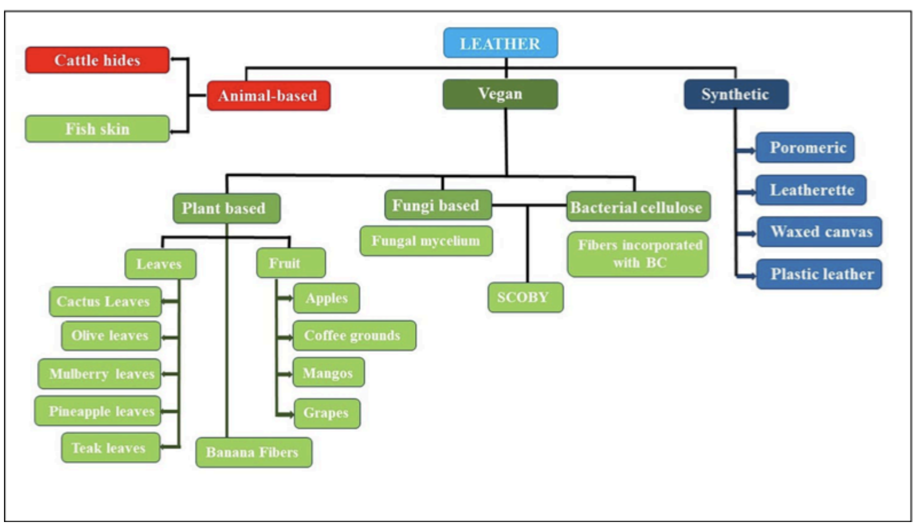


Fig. 2: Categories of leather (Tewari et al., 2023, p. 3364).

Manufacturing Vegan Leathers

While understanding the basic categories of alternative leather provides important context, examining specific manufacturing processes reveals how these materials are actually produced and their relative advantages. Some of the most well-known brands in the vegan leather industry include Appleskin, Desserto, Mirum, Mylo, and Piñatex. Each brand's leather has different characteristics when it comes to textures, durability, and environmental costs, which affects what the leather can be used for and what buyers may purchase. This section will cover how two different vegan leather brands, one made from fruit and another from leaves, manufacture their products.

Appleskin is a vegan leather created from the pomace and peels of apples that are considered waste from the beverage industry, like cider, compote, and juice. Since the brand uses agricultural waste, it can be considered more sustainable than other brands that do not, and it also reduces the demand for virgin resources in their products (Akkan, 2023; "IMPACT | VEGATEX," 2016; Muthu & Ramchandani, 2024). The use of agricultural waste also helps reduce the amount of petroleum-based components that would have been used instead (Akkan, 2023). To make the leather, the company first collects the byproduct that is the apple pomace. Next, the pomace is cleaned, sterilized, and dried. After the pomace is dried, it is converted into nano-sized particles that are blended into water-based PU. The blend is then coated onto a recycled textile base and finished with textures and colors ("IMPACT | VEGATEX," 2016; Muthu & Ramchandani, 2024). The use of PU or PVC in the product allows the product to be more similar in flexibility and texture to animal leather, and the thickness of the leather is close to other natural-based leathers that are used in apparel goods, gloves, and shoes (Akkan, 2023; Muthu & Ramchandani, 2024).

In contrast to apple-based leather, Desserto represents another approach to plant-based alternatives. Desserto is a vegan leather created from the leaves of cacti. From three leaves picked off a cactus, which allows the cactus to keep growing, a linear meter of leather can be created. The cactus used in Desserto leather, the Nopal cactus, also does not require fertilizers, irrigation, or pesticides to grow. Additionally, for eight years one plantation of the cacti can be consistently harvested (Akkan, 2023; Muthu & Ramchandani, 2024). After the leaves are harvested, they go through a process of repeated milling and sun drying to make the cactus leather (Desserto, 2024; Muthu & Ramchandani, 2024). Moreover, although Desserto markets their products as having a 65% biobased content, a study in 2021 on alternative leathers found that Desserto does have a coating that contains PU layers, which give materials similar flexibility and durability characteristics to animal leather (Akkan, 2023, pp. 18-19; Desserto, 2024). Furthermore, similar to Appleskin, the thickness of Desserto is close to the material used in apparel goods, shoes, and gloves (Akkan, 2023). However, Desserto leather can also be used for home furnishings and car interiors (Muthu & Ramchandani, 2024; "Desserto Catalogue 2025," 2025).

Environmental Pros and Cons

While the manufacturing processes of brands like Appleskin and Desserto illustrate how some alternative leathers are produced, evaluating their environmental impact requires a look at how these production methods affect carbon emissions, water consumption, and waste generation. While production methods of alternative leather may be better than animal leather when it comes to carbon emissions, energy usage, water consumption, and agricultural waste, there are issues with microplastics, toxic chemicals, and biodegradability.

One of the positive aspects of utilizing alternative leather is that it emits less carbon dioxide than animal leathers. In comparison to the carbon impact of bovine leather, which is 60 kg CO_2 equivalent per square meter, vegan leather has an average carbon impact of 5.6 kg CO_2eq/m^2 (Akkan, 2023, p. 35; Muthu & Ramchandani, 2024, Figure 3.14). Additionally, many vegan leathers make their products with sustainable forms of energy. For instance, Piñatex, a vegan leather derived from pineapple leaves, utilizes a natural fertilizer and biofuel in their production process (Akkan, 2023). Moreover, Mylo, a vegan leather derived from mycelium, powers their farming with 100% renewable electricity (Akkan, 2023, p. 16; Bolt Threads, 2023). In addition to carbon and energy, alternative leathers typically consume less water than animal leathers in production. A big reason for this is that 95% of water consumption of leather is from feed production. Additionally, animal leathers use tanning processes that occur in water-based baths, unlike some vegan leather. For example, a life cycle analysis found that compared to animal leather, cactus leather has a 164,650% reduction in water consumption (Akkan, 2023, pp. 31-33). There are also many vegan leathers that utilize agricultural waste. In addition to Appleskin, other companies like Vegea and Fruitleather also use byproducts. Vegea, a grape leather company, utilizes grape waste from wineries to make their leather (Muthu & Ramchandani, 2024; Tewari et al., 2023). Fruitleather, a mango leather company, uses waste mangoes to create leather for bags (Tewari et al., 2023).

Although the use of agricultural waste helps make products more sustainable, one of the concerns with alternative leathers is the spread of microplastics. Like mentioned previously, alternative leathers use PU or PVC in their coatings. The shedding of these microfibers contributes to the spread of microplastics, which end up in food chains and in human bodies (Muthu & Ramchandani, 2024; Tewari et al., 2023; Tonti, 2023). Additionally, there is a concern about the release of toxic chemicals related to alternative leathers. For instance, the plasticizers that are added to PVC that make the leather more flexible and softer are derived from phthalic acid, which is often prone to leaching. The leaching releases harmful chemical gases, like dioxin and organochlorine, that make their way into the environment and human bodies. Organochlorine is especially harmful as it cannot be expelled from bodies easily and is neurologically toxic, a hormone disruptor, and a carcinogen (Chiu, 2024; Tewari et al., 2023). Another concern with alternative leathers is biodegradability. Since most alternative leathers utilize some form of plastic, as well as synthetic dyes, their products are non-biodegradable (Ramos, 2023; Tewari et al., 2023; Tonti, 2023). This can contribute to landfill overflow, which can lead to the contamination of groundwater, the destruction of habitats, and an increase in methane emissions (Muthu & Ramchandani, 2024).

Fig. 3: Leather comparisons (Akkan, 2023, p. 22).

Company Name	Product Name	Product Structure	Material Description	Biodegarable
Various	GENUINE LEATHER	Animal hide	Full-grain bovine leather finished with thin topcoat	✓
Ananas Anam	PIÑATEX by ananas anam	Fabric with water-based polyurethane finish	Polyurethane mixed with pineapple leaf fibers	✗
Bolt Threads	MYLO	Fabric with water-based polyurethane finish	Lyocell embedded with mycelium fibers and coated with polyurethane	✗
Adriano Di Marti	DESSERTO	Fabric with water-based polyurethane finish	Polyurethane mixed with cactus fibers	✗
Mabel SRL	appleskin	Fabric with water-based polyurethane finish	Polyurethane mixed with apple fibers	✗
Natural Fiber Welding	MIRUM®	Rubber (biodegradable)	Rubber cured with plant-based chemistry	✓

Conclusion

The comparison between traditional animal leather and alternative leathers reveals a complex landscape of environmental trade-offs. Animal leather, particularly cowhide, is resource-intensive, contributing significantly to greenhouse gas emissions, water consumption, and chemical pollution. However, its durability and biodegradability offer long-term benefits, reducing waste frequency. Alternative leathers, such as those derived from plants, fungi, or agricultural waste, present lower carbon footprints and water usage but often rely on synthetic coatings like polyurethane or PVC, which introduce microplastics and toxic chemicals into ecosystems. While innovations like mycelium-based or fruit-derived leathers show promise, challenges in scalability, biodegradability, and chemical use remain unresolved.

For consumers and stakeholders, the choice between leather types hinges on prioritizing specific environmental impacts—whether reducing immediate resource use or mitigating long-term pollution. The industry must continue advancing sustainable practices, such as chrome-free tanning for animal leather and bio-based polymers for alternatives, to minimize ecological harm. Ultimately, a shift toward circular economy principles, including recycling and waste reduction, will be critical in aligning leather production with global sustainability goals. Informed decision-making, supported by transparent data and innovation, is essential to navigate this evolving market responsibly.

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