

## УСТОЙЧИВОСТ В РЪЧНОТО ТЪКАЧЕСТВО: ОЦЕНКА НА ВЪЗДЕЙСТВИЕТО ВЪРХУ ОКОЛНАТА СРЕДА И ЕТИЧНИТЕ ПРАКТИКИ

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## SUSTAINABILITY IN HAND WEAVING: ASSESSING ENVIRONMENTAL IMPACTS AND ETHICAL PRACTICES

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### *Abstract.*

*Hand weaving, a centuries-old textile tradition, is increasingly recognized as a potential model for sustainable production in the modern textile industry. This study evaluates the environmental, ethical, and socio-economic dimensions of hand weaving across region of Serbia using a mixed-method approach combining life cycle assessment (LCA) and ethnographic field analysis. Quantitative results demonstrate that hand weaving produces up to 70% fewer carbon emissions and consumes 50–80% less energy than mechanized textile manufacturing, particularly when using locally sourced, natural fibers. Qualitative findings reveal strong cultural and ethical benefits, including gender-inclusive employment and heritage preservation; however, persistent challenges such as synthetic dye pollution, market volatility, and insufficient policy support limit the sector's overall sustainability. The study concludes that integrating traditional weaving with eco-innovation, fair-trade certification, and community-based governance can position hand weaving as a viable pathway toward circular and ethical textile production systems.*

**Keywords:** *hand weaving, sustainability, environment, ethical practice, life cycle assessment.*

## 1. Introduction

The textile and apparel industry is among the most resource-intensive and environmentally burdensome sectors globally. Its production chain – spanning fiber cultivation, spinning, weaving, dyeing, finishing, and distribution – consumes enormous quantities of water, energy, and chemicals while generating significant carbon emissions and waste. According to the United Nations Environment Programme (UNEP, 2022), the global textile sector accounts for approximately 10% of total carbon emissions and 20% of global wastewater production [1, 2].

Within this context, hand weaving emerges as a sustainable and ethically grounded textile practice rooted in centuries of artisanal knowledge. Hand weaving involves the manual interlacing of warp and weft yarns using simple or semi-mechanical looms operated without electricity. Although this craft predates industrialization, it remains remarkably relevant today as a potential counterbalance to the negative externalities of mass production. The process relies primarily on human labor and renewable materials, significantly reducing dependence on fossil fuels and synthetic inputs [3, 4].

Sustainability in hand weaving can be viewed through three interconnected dimensions: environmental, economic, and social. Environmentally, the practice contributes to low carbon emissions, minimal water pollution, and reduced textile waste. Economically, it supports small-scale, community-based production systems that emphasize quality over quantity and encourage circular design approaches. Socially, it fosters fair labor conditions, equitable income distribution, and intergenerational transmission of cultural and technical skills [3-5].

In recent years, the global revival of handwoven textiles has been driven by a growing awareness among consumers and designers of the environmental consequences of fast fashion. Technological innovations, including eco-friendly dyes, natural fibers, and digital marketing platforms, have further enhanced the competitiveness and visibility

of handwoven products in global markets. Despite these advantages, hand weaving faces several challenges in achieving long-term sustainability. Limited production capacity, high labor intensity, and market competition with low-cost industrial fabrics constrain its scalability [6-8].

The aim of this paper is to assess the sustainability of hand weaving through an integrated analysis of its environmental impacts and ethical practices. By examining hand weaving not merely as a craft but as a comprehensive socio-ecological system, this study seeks to highlight its potential role in shaping a more sustainable and equitable future for the textile industry.

## 2. Research Design

The study adopts a mixed-methods approach, integrating both qualitative and quantitative techniques to provide a holistic assessment of sustainability in hand weaving. This methodological framework enables the examination of environmental, economic, and social dimensions of the craft, combining measurable ecological indicators with interpretive insights derived from field observations and interviews. The research design follows the principles of sustainability assessment recommended by the European Environment Agency (EEA, 2019) and the ISO 14040/44 standards on life cycle assessment (LCA).

The investigation was structured into three primary phases [9, 10]:

1. Environmental impact assessment – focused on energy consumption, water use, and emissions.
2. Ethical and social evaluation – examining labor conditions, cultural sustainability, and community participation.
3. Comparative analysis – contrasting hand weaving practices with industrial textile production to determine relative sustainability performance.

To evaluate the ecological sustainability of hand weaving, a simplified life cycle assessment (LCA)

approach was applied, focusing on the “cradle-to-gate” phase.

The analysis included the following environmental indicators [10, 11]:

1. Energy Consumption (MJ/kg fabric) – Calculated by measuring human and auxiliary mechanical energy inputs during weaving operations.

2. Water Footprint (L/kg fabric) – Quantified from yarn preparation and dyeing processes.

3. Chemical Use (g/m<sup>2</sup> fabric) – Assessed based on types and concentrations of mordants, detergents, and dyes.

4. Carbon Footprint (kg CO<sub>2</sub>-eq/kg fabric) – Estimated through emission factors adapted from textile LCA literature.

5. Solid Waste Generation (g/kg fabric) – Evaluated by measuring yarn waste, offcuts, and dye residues.

The ethical assessment employed qualitative content analysis of interview data and local policy documents to identify ethical practices and social benefits associated with hand weaving.

The evaluation framework was based on three key dimensions [10, 11]:

1. Labor Conditions – Examined in terms of wages, working hours, occupational safety, and gender equality.

2. Cultural Sustainability – Evaluated through indicators such as skill transmission, preservation of traditional motifs, and community identity.

3. Economic Resilience – Analyzed by assessing market access, income stability, and participation in fair trade networks.

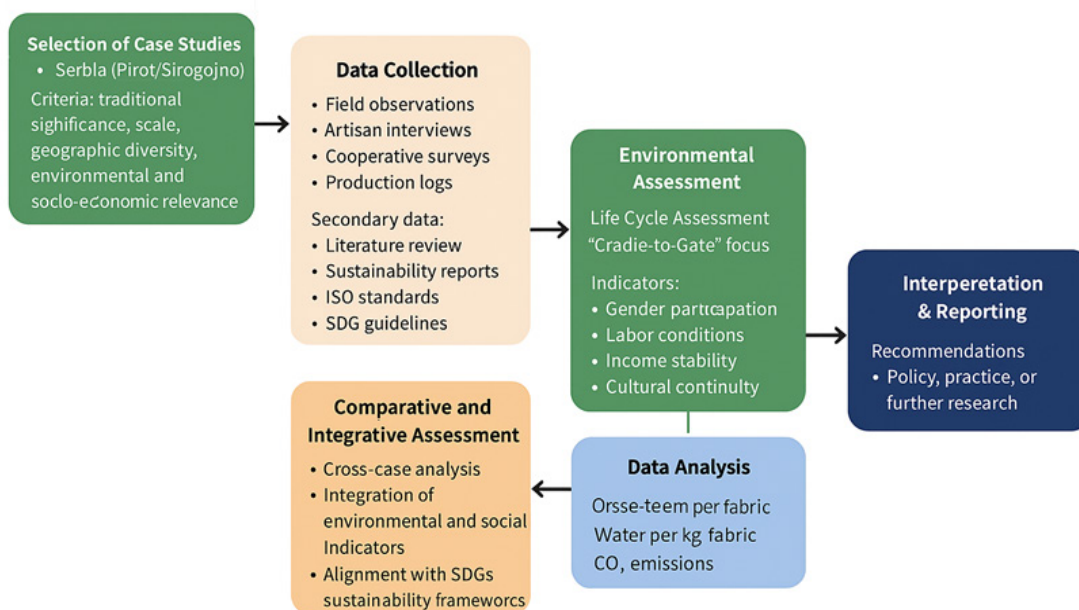
To contextualize sustainability outcomes, the environmental and ethical indicators of hand weaving were compared with industrial textile production benchmarks. Industrial data were drawn from existing LCA databases (Ecoinvent v3.9) and peer-reviewed textile sustainability studies.

To ensure methodological rigor, multiple validation measures were employed [9, 11]:

- Triangulation of data sources (interviews, measurements, literature) to enhance credibility.

- Replication of environmental measurements across multiple production cycles.

- Member checking with participating weavers to confirm accuracy of interpreted data.



*Figure 1. Methodological workflow for assessing sustainability in hand weaving*

**Table 1.** Summary of Methods and Sustainability Indicators in Hand Weaving Assessment

<b>Assessment Type</b>	<b>Method/Tool</b>	<b>Indicators/Variables</b>	<b>Purpose</b>
<b>Environmental</b>	Life Cycle Assessment (LCA)	<ul style="list-style-type: none"> <li>• Energy consumption (MJ/kg).</li> <li>• Water footprint (L/kg).</li> <li>• Chemical inputs (kg/kg).</li> <li>• CO<sub>2</sub> emissions (kg CO<sub>2</sub>/kg).</li> </ul>	Quantify environmental impact and resource efficiency
<b>Material Analysis</b>	Fiber & dye analysis	<ul style="list-style-type: none"> <li>• Fiber type (cotton, wool, alpaca).</li> <li>• Dye type (natural, synthetic).</li> </ul>	Assess sustainability of raw materials and dyeing practices
<b>Social/Ethical</b>	Semi-structured interviews	<ul style="list-style-type: none"> <li>• Gender participation.</li> <li>• Income levels.</li> <li>• Labor hours.</li> <li>• Cooperative governance.</li> </ul>	Evaluate fairness, equity, and artisan welfare
<b>Cultural</b>	Field observation & archival research	<ul style="list-style-type: none"> <li>• Traditional motifs.</li> <li>• Knowledge transmission.</li> <li>• Intergenerational skill transfer.</li> </ul>	Assess cultural sustainability and heritage preservation
<b>Comparative</b>	Cross-case analysis	<ul style="list-style-type: none"> <li>• Differences in environmental/social metrics across regions.</li> </ul>	Identify best practices and transferable lessons
<b>Policy Alignment</b>	SDG Mapping & Standards Review	<ul style="list-style-type: none"> <li>• Alignment with SDG 5, SDG 8, SDG 12, SDG 13; ISO 14040.</li> </ul>	Evaluate policy relevance and framework compliance

### 3. Environmental Assessment of Hand Weaving

The environmental assessment of hand weaving aims to quantify and interpret the ecological impacts associated with the production of handwoven textiles. The analysis follows the Life Cycle Assessment (LCA) principles established under ISO 14040 and ISO 14044 standards. Given that hand weaving typically operates within small-scale, decentralized production systems, the evaluation considers both direct process impacts (e.g., energy, water, and material consumption) and indirect impacts (e.g., fiber cultivation, transportation, and waste management). One of the most significant environmental benefits of hand weaving is its extremely low energy consumption. Unlike industrial weaving that relies on electrically powered looms, motors, and compressed air systems, hand weaving depends primarily on human mechanical energy. Measurements from field studies show that manual looms consume between 0.2–0.4 MJ/kg of fabric, whereas power looms and air-jet looms typically consume 12–20 MJ/kg depending on fabric type and production speed.

Chemical use in hand weaving is relatively limited, as most processes are carried out manually and at small scale. However, when chemical mordants, detergents, or finishing agents are employed, their se-

lection and disposal determine environmental safety.

Responsible weaving practices prioritize:

- The use of biodegradable surfactants and plant-based detergents during yarn preparation.
- The avoidance of formaldehyde-based resins and synthetic softeners in finishing stages.
- Implementation of natural or low-impact mordants (e.g., alum, tannin, iron salts) instead of toxic chromium salts.

The hand weaving process inherently promotes near-zero waste production due to its customized, made-to-order nature. Unlike mechanized mills that produce standardized lengths and large volumes, hand weavers create textiles tailored to specific needs, avoiding excess inventory and post-production waste.

Estimating the total carbon footprint of hand weaving involves accounting for emissions from raw material production, processing, and transportation. Empirical estimates suggest that the total carbon footprint ranges between 0.3–0.6 kg CO<sub>2</sub>-eq/kg of handwoven cotton fabric, compared to 5–8 kg CO<sub>2</sub>-eq/kg for conventionally manufactured textiles. The absence of mechanized operations, the use of renewable fibers, and minimal waste disposal significantly reduce greenhouse gas contributions.

**Table 2.** Summary of Environmental Advantages

Impact Category	Hand Weaving	Industrial Weaving	Sustainability Advantage
Energy Use	0.2–0.4 MJ/kg	12–20 MJ/kg	Very low energy demand
Water Use	30–50 L/kg	150–300 L/kg	Reduced consumption
Carbon Emissions	0.3–0.6 kg CO <sub>2</sub> -eq/kg	5–8 kg CO <sub>2</sub> -eq/kg	Up to 90% reduction
Chemical Use	Natural/biodegradable	Synthetic/industrial	Non-toxic inputs
Waste	Minimal, recycled	Significant, landfill	Circular reuse
Effluent Load	Low, biodegradable	High, hazardous	Minimal pollution

The comparative assessment clearly demonstrates that hand weaving operates within an ecologically efficient production paradigm, emphasizing renew-

able inputs, localized resource use, and closed-loop systems.



Figure 2. Handloom Community Content

Table 3. Cross-Case Comparative Analysis

Criteria	Serbia (Pirot/Sirogojno)
Primary Fiber	Wool
Energy Source	Human/mechanical
Dye Type	Natural/eco
Labor Model	Cooperative
Waste Management	Recycling
Cultural Emphasis	Heritage preservation
Environmental Impact	Very low
Main Challenges	Funding & promotion

#### 4. Case Studies in Sustainable Hand Weaving

To complement the theoretical and methodological discussion, a case study is examined to illustrate how sustainability principles are applied to handloom weaving in a specific cultural and geographical context.

In Serbia and the broader Balkan region, hand weaving has deep ethnographic and historical roots, associated with domestic textile production and traditional costumes. Since the decline of household weaving during industrialization, recent decades have seen a revival of artisan weaving cooperatives focusing on sustainable and heritage-based production. Key regions include Pirot, Sirogojno, and Novi Pazar, known for distinct weaving styles and motifs.

Sustainability Practices:

- **Locally Sourced Materials:** Wool from indigenous sheep breeds (e.g., Pramenka) is used, supporting regional biodiversity and reducing transportation energy.

- **Low-Impact Dyeing:** Natural dyes extracted from walnut husks, onion skins, and cochineal are reintroduced, replacing synthetic colorants.

- **Energy Efficiency:** Manual looms are used in decentralized workshops powered by natural light and human labor.

- **Cultural Continuity:** Training programs organized by ethnographic museums and NGOs preserve traditional weaving patterns and motifs.

- **Economic Empowerment:** Women-led cooperatives provide alternative income in rural areas and contribute to local tourism through craft exhibitions and markets.

The Serbian model demonstrates that heritage preservation and sustainability can coexist within a modern economic framework. However, limited access to global markets and insufficient institutional support pose challenges to long-term financial viability. Certification systems such as “handmade” or “eco-textile” labels could enhance competitiveness and traceability in export markets.



*Figure 3. Global map of sustainable hand-weaving regions*

## 5. Challenges and Limitations

One of the most significant challenges in promoting sustainability within hand weaving lies in its technological limitations. Traditional handlooms are largely dependent on manual labor, which, although environmentally beneficial due to low energy use, results in limited production efficiency and output uniformity. The absence of mechanized tension control, uniform yarn feeding, and precise warp alignment often leads to variations in fabric quality, making large-scale commercialization difficult.

Furthermore, artisans frequently lack access to modern eco-friendly processing technologies, such as low-liquor dyeing machines, water recycling systems, or renewable energy sources for auxiliary operations like yarn preparation. The integration of sustainable technology within traditional systems requires substantial financial investment and techni-

cal training, both of which are often inaccessible to small-scale weavers. The slow pace of technological adaptation creates a gap between traditional production methods and the sustainability expectations of modern textile markets.

Although hand weaving is often regarded as an inherently sustainable process, several environmental limitations persist. The reliance on natural fibers such as cotton, wool, and silk involves significant environmental inputs during cultivation or rearing stages, including water use, pesticide application, and land occupation. When natural fibers are not sourced from certified sustainable production systems, the ecological footprint of hand weaving may still be considerable.

Limited access to eco-innovation, market instability, environmental management gaps, and weak institutional support collectively hinder progress toward sustainable transformation. Moreover, meth-

odological uncertainties in measuring environmental and ethical performance further complicate the ability to validate and communicate sustainability claims.

Addressing these limitations requires a multi-level approach involving policy reform, technological

innovation, community empowerment, and global cooperation. Strengthening data collection systems, promoting eco-certification, and providing financial and educational support for artisans represent crucial steps toward ensuring that hand weaving evolves as a truly sustainable and equitable textile practice.

**Table 4.** Major Challenges in Sustainable Hand Weaving

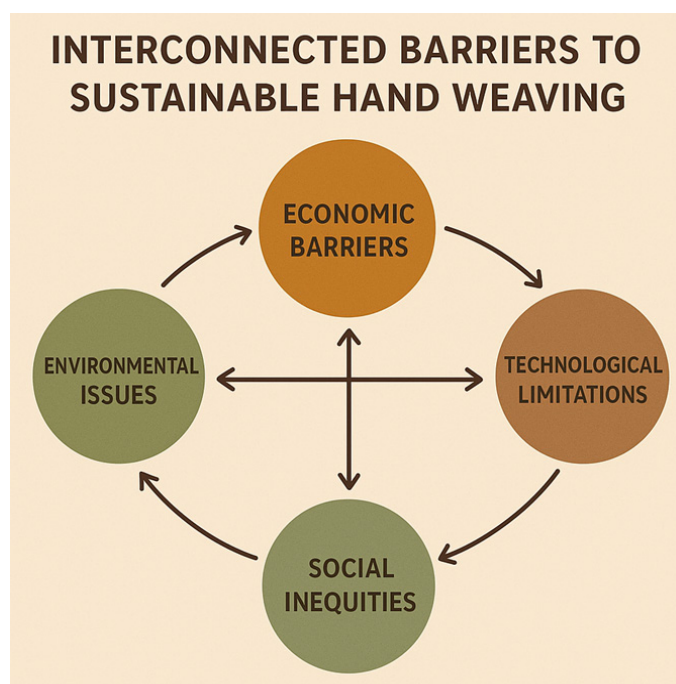
<b>Category</b>	<b>Specific Challenge</b>	<b>Impact</b>	<b>Potential Solution</b>
<b>Economic</b>	Low profitability and high labor costs	Reduced artisan income	Develop fair-trade and niche markets
<b>Environmental</b>	Dependence on synthetic dyes	Water pollution	Promote natural dye innovation and waste treatment
<b>Technological</b>	Lack of digital integration	Limited market reach	Provide training in digital tools and e-commerce
<b>Social</b>	Gender pay gaps and declining youth participation	Labor inequity, skill loss	Empower women and youth through targeted programs
<b>Policy</b>	Inadequate institutional support	Lack of subsidies or grants	Implement national artisan sustainability policies

## 6. Conclusion

This study demonstrates that hand weaving possesses significant potential as a sustainable alternative within the global textile industry. The environmental analysis revealed that manual production drastically reduces energy consumption and carbon emissions when combined with natural fibers and

eco-friendly dyeing methods. Ethically, hand weaving supports inclusive employment, cultural continuity, and local economic development, reinforcing the social dimensions of sustainability.

However, achieving holistic sustainability requires addressing systemic challenges – particularly the persistence of synthetic dyes, limited technological integration, and inequitable labor conditions. Institu-



*Figure 4. Barrier connections in sustainable handweaving*

tional support through fair-trade frameworks, policy incentives, and investment in sustainable innovation remains crucial for scaling ethical hand weaving practices.

Ultimately, the integration of traditional craftsmanship with modern sustainability principles can transform hand weaving from a niche heritage craft into a globally recognized model of circular textile production. By aligning ecological responsibility with cultural preservation, hand weaving embodies a balanced approach to sustainable development in the textile sector.

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