

From cultural heritage to sustainability: Evaluating green economy in the Gringsing weaving industry using the MULTIMOORA approach

I Dewa Ayu Made Natasah Dewani; Ida Ayu Nyoman Saskara*

Magister Economics, Faculty of Economics and Business, Udayana University, Indonesia

**To whom correspondence should be addressed. Email: saskara@unud.ac.id*

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Abstract.

The green economy, as a dimension of sustainable development, offers a comprehensive framework for achieving sustainability goals. The Gringsing textile industry in Bali presents a unique opportunity to integrate traditional crafts with principles of a green economy. This study examines the opportunities and challenges of sustainable Gringsing textile production in Tenganan through the lens of green economy principles. The MULTIMOORA (Multi-Objective Optimization by Ratio Analysis plus Full Multiplicative Form) method was employed to evaluate the environmental, economic, and social impacts of production alternatives. The findings reveal that Alternatives A1 and A3 achieved identical aggregate values of 0.84, with distinct strengths. A1 excels in economic viability and social contribution, making it a balanced option for stakeholders seeking comprehensive benefits. In contrast, A3 demonstrates superior environmental performance, making it the preferred choice for initiatives prioritizing ecological sustainability. Opportunities for sustainable Gringsing textile production include market expansion, innovation, and policy support, while challenges encompass high production costs, market competition, and resource constraints.

Keywords: *Gringsing textile, Green economy, MULTIMOORA, Sustainability*

JEL Classification: L67, O13, Q56

INTRODUCTION

Research on the green economy is closely linked to sustainable development. According to the United Nations Environment Programme (UNEP), a green economy enhances human welfare and social equity while significantly reducing environmental risks and ecological scarcity (UNEP, 2011). Consequently, implementing a green economy emphasizes economic improvement alongside environmental preservation. The concept integrates economic growth with environmental sustainability, aiming to minimize ecological risks while promoting social equity. This approach has gained global traction in response to challenges such as climate change and resource depletion (Li, 2024). Over the past decade, the green economy has become increasingly appealing to

policymakers. Sustainable development and green economic growth are mutually reinforcing. As Hu et al. (2019) highlight, policies supporting the green economy must account for spatial and temporal dynamics and the factors influencing them. The green economy is regarded as a long-term strategy for environmentally friendly economic growth, employing fiscal policies and climate change financing instruments that facilitate economic recovery (Mohsin et al., 2023). It also presents a viable alternative for increasing income, particularly by developing various sectors such as tourism, creative industries, and industrial activities grounded in environmental sustainability.

Bali Province exemplifies a region rich in textile diversity. The textile industry in Bali has undergone a long and sustainable evolution (Achwan, 2015). The introduction of progressive provincial policies, such as Bali Governor Regulation Number 79 of 2018, which mandates the use of traditional attire for civil servants within the Bali Provincial Government, regency/city government and encourages adoption in the private sector, has further stimulated the growth of Bali's textile industry. Karangasem, a district in Bali, is notable for its culture-based textile industries, including *endek*, *songket*, and *gringsing*. The village of Tenganan Pegringsingan, located in Karangasem, is renowned for its Gringsing weaving, a centuries-old heritage that represents a blend of traditional artistry and technology admired internationally. This woven fabric has become a cornerstone of the textile industry, showcasing the creativity of the Tenganan community.

The unique traditions and cultural heritage of Tenganan Pegringsingan Village significantly contribute to its tourism development, forming a vital economic resource. The interplay between cultural preservation and tourism offers a sustainable model for community development (Duha & Listyorini, 2023). Tourism growth has been further supported by the designation of Tenganan Pegringsingan as a Tourism Village in 2014 through Karangasem Regent Decree Number 658/HK/2014 on the Determination of Tourism Villages in Karangasem Regency. This designation introduces both internal and external factors that influence the lives of local communities, particularly in sustaining the tradition of Gringsing ikat weaving.

Gringsing woven fabrics, produced by the Bali-Aga community in Tenganan Pegringsingan Traditional Village, Karangasem, are recognized as a valuable form of intangible cultural heritage. Historically, this weaving craft has undergone a long evolution as an ancestral legacy and a reflection of the local wisdom of the Balinese people (Telagawathi et al., 2021). The term "Gringsing" is derived from the Balinese words *gering* (sick) and *sing* (not), which together mean "not sick." Symbolically, Gringsing represents the rejection of misfortune or bad luck (Sumunar et al., 2017). Gringsing fabric is created through the interweaving of warp and weft yarns that undergo a dyeing process using the double ikat technique (Dunlop, 2023). This distinctive technique, unique in Indonesia, has brought international recognition to the Gringsing fabrics crafted by the Tenganan community. The fabric holds significant cultural importance in traditional rituals, including tooth-filing ceremonies (*metatah/mesangih*), weddings, and various religious ceremonies.

The uniqueness of Gringsing woven fabric also lies in its entirely natural dyeing process, which is exceptionally time-intensive and can take two to three years to complete (Sukawati, 2020). The fabric typically features primary colors such as red, yellow, black, and blue, derived from natural dyes sourced from plants using traditional methods (Darmawati et al., 2016). In Tenganan Village, the yellow, red, and black threads are dyed

locally, while the blue threads are dyed in Sidemen Village. Yellow dye is extracted from candlenut oil, red from morinda root, and black from indigo (*tarum*) leaves, which are re-dyed red. This intricate dyeing and weaving process reflects the deep cultural and historical significance of Gringsing fabric as an ancestral legacy and a manifestation of Balinese local wisdom. The Tenganan weaving community believes that marketing their local products, mainly double ikat Gringsing woven fabrics, is the most effective way to enhance their economic welfare.

The global demand for Gringsing woven products has increased significantly, highlighting the importance of integrating green economy practices into Gringsing textile production to improve sustainability and economic viability (Sakrianti & Saskara, 2024). The creation of Gringsing fabric is a collaborative effort involving multiple stages, from preparing tools and obtaining raw materials to the manufacturing process. Female artisans within a household play a central role as primary supervisors, overseeing the entire production chain, including yarn preparation, dyeing, and tying yarns into woven fabric. Each stage of production involves the expertise of skilled individuals, such as toolmakers, dye specialists, binding experts, and weavers, depending on the needs identified by the primary supervisor (Sukmadewi et al., 2022).

The Gringsing textile industry in Bali, particularly in Tenganan Pegringsingan Village, has been chosen as a case study due to its deep historical roots, which span centuries and reflect the enduring cultural legacy of the Bali-Aga people. Its cultural significance is evident in its integral role in traditional ceremonies and its representation of communal identity and heritage. Additionally, the industry's reliance on sustainable practices, such as the use of natural dyes and labor-intensive production methods, exemplifies a harmonious integration of tradition and environmental responsibility. These attributes position the Gringsing textile industry as an exemplary model for examining how traditional crafts can align with green economy principles, offering valuable insights for both local and global sustainable development initiatives. The Gringsing weaving tradition uniquely combines cultural heritage with sustainable production practices, making it a compelling subject for exploring the intersection of traditional industries and green economic models.

While Bali is celebrated for its rich array of creative and cultural industries, the Gringsing textile industry stands out for its adherence to environmentally sustainable practices, mainly through the use of natural dyes and labor-intensive techniques. These practices align closely with the principles of environmental sustainability and community-based economic development.

From an economic perspective, this research will evaluate the Gringsing weaving industry's contributions to the local economy, particularly its role in job creation, income generation, and competitiveness in the global market. The broader implications of aligning traditional crafts with green economy principles are significant. Gringsing weaving serves as a concrete example of how traditional industries can adopt sustainable practices while preserving their cultural identity. This alignment addresses critical environmental challenges by employing eco-friendly production methods, such as the use of natural dyes and renewable resources, which substantially lower the environmental impact compared to synthetic alternatives.

Moreover, the Gringsing industry enhances local economies by generating employment opportunities and supporting community-based production systems, thereby

improving economic resilience. Socially, it fosters community cohesion and preserves cultural heritage, as the craft's techniques and symbolic meanings are transmitted across generations. On a global scale, the Gringsing weaving tradition demonstrates the potential for traditional crafts to contribute to sustainability goals, offering a replicable model for other regions and industries seeking to balance economic, environmental, and cultural priorities.

By integrating traditional knowledge with modern sustainability principles, Gringsing weaving underscores the critical role of cultural industries in achieving a green economy. This research will investigate how green economy practices can support cultural preservation and how traditional values can be harmonized with modern economic innovations.

The sustainability of Gringsing weaving presents significant potential for further development, particularly in efforts to regenerate artisans, enhance its economic value, and implement policies supporting the craft's long-term sustainability. This research seeks to explore the concept of a green economy within the context of Gringsing woven fabrics, focusing on three primary aspects: economic, environmental, and social. As a cultural heritage product with high economic value, Gringsing fabric serves as a local-level example of green economy implementation. In addressing the challenges faced by the Gringsing weaving industry in Bali, this study aims to formulate a comprehensive strategic approach by evaluating the opportunities and challenges of sustainability. The analysis is grounded in the MULTIMOORA (Multi-Objective Optimization by Ratio Analysis plus Full Multiplicative Form) method, which provides a robust framework for assessing the industry's environmental, economic, and social impacts.

This study makes unique contributions by adopting an interdisciplinary approach to examining the Gringsing textile industry within the framework of the green economy. First, it bridges the gap between traditional craft industries and contemporary sustainability objectives, offering a nuanced understanding of how cultural heritage can be leveraged to promote economic, environmental, and social sustainability. Second, the research highlights the potential of traditional crafts, such as Gringsing weaving, to serve as models for integrating cultural preservation with green economic principles. By employing the MULTIMOORA method, the study delivers a systematic and innovative analysis of sustainability challenges and opportunities, distinguishing itself as a methodological contribution to the evaluation of traditional industries. Finally, this research enriches the literature on sustainable creative industries by demonstrating how traditional practices can adapt to global market dynamics while preserving their ecological and cultural integrity.

METHODS

This research was conducted in Tenganan Pegringsingan Village, one of the Bali-Aga villages that has maintained its sustainability. The data collected in this study is categorized into primary and secondary data. Primary data was obtained directly from respondents through questionnaires, interviews, and observation methods. Secondary data was sourced from relevant agencies, such as the Department of Industry and Trade and other government institutions. The population of this research consists of 150 artisans, with a sample size of 100 artisans selected to address the sustainability goals of Gringsing weaving from the perspective of the green economy. The sample of Gringsing

weaving artisans was determined using a non-probability sampling technique, specifically accidental sampling, combined with snowball sampling. This approach was deemed appropriate for identifying respondents, particularly artisans who utilize dyeing services in Bugbug Village. The MULTIMOORA (Multi-Objective Optimization by Ratio Analysis plus Full Multiplicative Form) data analysis technique is employed in this study to achieve the research objectives.

The MULTIMOORA method is a valuable decision-making tool for multi-criteria assessments (Wang et al., 2021). It is used to evaluate and rank alternatives based on multiple criteria (Alkan & Albayrak, 2020). The MULTIMOORA approach integrates three ranking methods: the Ratio System, the Reference Point Approach, and the Full Multiplicative Form (Brauers et al., 2015).

- Ratio System Approach: This method calculates the performance ratio of each alternative for every criterion. The ratios are used to rank the alternatives, with the highest ratio indicating the best alternative.
- Reference Point Approach: This technique establishes a target or reference value for each criterion and calculates the distance of each alternative from that reference point. Alternatives with the shortest distance to the reference point are deemed the best (Baležentis & Zeng, 2013).
- Full Multiplicative Form Approach: This approach involves multiplying the performance values for all criteria of each alternative. The alternative with the highest multiplicative value is considered the most favorable.

By combining these three methods, the MULTIMOORA approach offers a comprehensive framework for evaluating alternatives and supports robust decision-making.

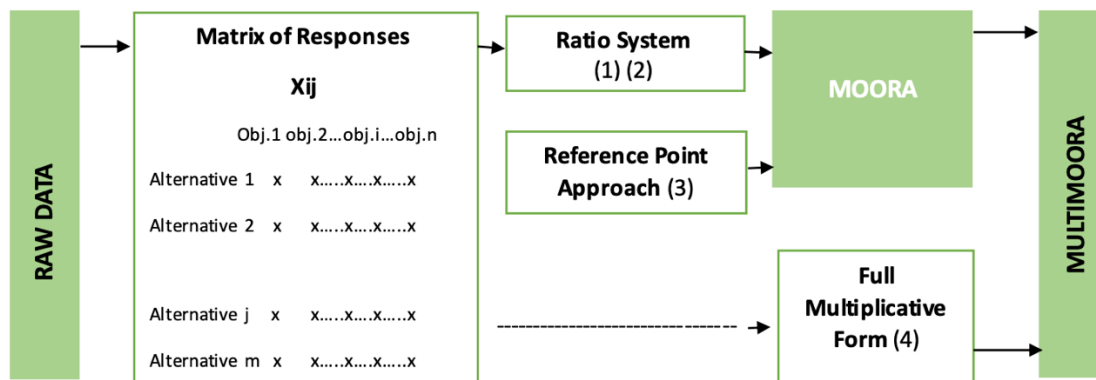


Figure 1. The general overview of the MULTIMOORA method

Raw data refers to unprocessed information that has been collected, which is subsequently organized into a Matrix of Responses. This matrix represents the placement of each data point, assessed against a set of predefined weighted criteria (Chaaben et al., 2024). Once the data is structured into a matrix, the Ratio System calculation is performed, followed by the Reference Point Approach. The results of the Ratio System and the Reference Point Approach are then processed using the MOORA (Multi-Objective Optimization by Ratio Analysis) method (Zhang et al., 2023). Additionally, the data in the Matrix of Responses undergoes calculation using the Full Multiplicative Form. The outcomes of the Full Multiplicative Form and the MOORA method are integrated

using the MULTIMOORA (Multi-Objective Optimization by Ratio Analysis plus Full Multiplicative Form) approach to yield the final results (Liu et al., 2014).

The strength of the MULTIMOORA method lies in its ability to incorporate three distinct methodologies—Ratio System, Reference Point Approach, and Full Multiplicative Form—ensuring a comprehensive and robust analysis. This integration allows for cross-verification of results, reducing bias and enhancing decision-making accuracy. Furthermore, MULTIMOORA does not require the pre-determination of weights, as it utilizes intrinsic weights derived directly from the data, making it less prone to subjectivity compared to methods such as AHP (Analytical Hierarchy Process) or TOPSIS (Technique for Order Preference by Similarity to Ideal Solution). Its adaptability across diverse decision-making contexts makes it particularly suited for evaluating the sustainability of Gringsing textile production, which involves complex and varied criteria.

The MULTIMOORA method offers several notable advantages in multi-criteria decision-making (Tian et al., 2017). Its three-pronged structure—Ratio System, Reference Point Approach, and Full Multiplicative Form—enables researchers to analyze and integrate results from each method. This integrated approach enhances the precision of the final outcomes (Yang & Zhang, 2023). As a result, MULTIMOORA is a preferred choice for multi-criteria decision-making due to its simplicity, efficiency, robustness, and adaptability across various applications.

In this research, the MULTIMOORA method is applied to evaluate the sustainability of Gringsing textile production, focusing on three primary criteria: environmental impact, economic viability, and social contribution. Environmental impact assesses the ecological footprint of the Gringsing textile production process, ensuring minimal environmental harm. Economic viability evaluates the financial sustainability and profitability of artisans, which is essential for the continued production of Gringsing textiles. Social contribution examines the cultural and societal benefits of the weaving tradition, ensuring alignment with local values and community well-being. These criteria comprehensively address the pillars of sustainability while ensuring relevance to stakeholders and policymakers.

Stakeholder input was gathered through a combination of observation methods, in-depth interviews, and Focus Group Discussions (FGDs). Observations were conducted to examine the activities of Gringsing weavers in Tenganan Village and in Bugbug Village, where dyeing processes occur in areas affected by pollution. FGDs with Gringsing weavers were instrumental in establishing a decision matrix (raw data) and identifying the most appropriate criteria for evaluating the sustainability of Gringsing weaving. This input was critical for weighting each criterion, ensuring the evaluation framework reflected the priorities of the artisans and the broader community.

RESULTS AND DISCUSSION

Implementation of the green economy in the Gringsing woven textile industry

The implementation of green economy principles in the Gringsing woven textile industry in Tenganan Pegringsingan Village represents a highly relevant strategy for preserving cultural heritage while enhancing environmental sustainability. The Gringsing weaving industry is renowned for its use of natural materials and traditional dyeing techniques. Gringsing woven fabrics are crafted using a distinctive double-ikat technique, and their production involves natural dyes derived from sources such as wood sap and

hazelnut seeds, resulting in the characteristic dominant red color (Wijana et al., 2022). The use of natural materials and traditional dyeing methods not only ensures high-quality coloration but also mitigates the environmental impact associated with synthetic chemicals (Sukawati, 2020).

Natural dyes used in the Gringsing weaving process are derived from renewable sources, including plants, insects, and minerals, which significantly reduce environmental pollution compared to synthetic alternatives. These dyes are biodegradable, naturally decomposing without releasing harmful chemicals into the environment. Furthermore, the production of natural dyes requires less energy and water compared to synthetic dye manufacturing, thereby minimizing resource exploitation and reducing the ecological footprint of the textile industry.

The authenticity of Gringsing woven products is critical for preserving the cultural values and heritage passed down from ancestors. These fabrics hold immense cultural significance due to their complex and time-intensive manufacturing process, as well as the specialized skills inherited through generations (Sudarmanto, 2022). The community of Tenganan Village has adopted customary laws to govern their forest resources, ensuring sustainable environmental management through participatory governance systems. These systems involve various stakeholders in resource management, promoting equitable access and long-term sustainability.

By integrating traditional practices with green economy principles, the Gringsing weaving industry exemplifies a model where cultural preservation aligns with ecological and economic objectives, offering valuable insights into sustainable development practices.

MULTIMOORA (Multi-Objective Optimization by Ratio Analysis plus Full Multiplicative Form)

Research on the implementation of the green economy concept in the Gringsing woven textile industry employs MULTIMOORA analysis to identify the most effective criteria and alternatives for integrating green economy principles into the Gringsing weaving business.

Results 1: Determine evaluation criteria

To comprehensively assess the sustainability of the Gringsing textile industry, researchers conducted an in-depth evaluation using key criteria identified through surveys and in-depth interviews with Gringsing weaving artisans in Tenganan Pegringsingan Village. Three primary criteria were selected to guide the evaluation: Environmental Impact (C1), Economic Viability (C2), and Social Contribution (C3).

1. Environmental impact (C1)

Environmental impact is a critical factor in evaluating sustainability, particularly in textile production. Within the context of the Gringsing woven textile industry in Tenganan Pegringsingan Village, the environmental impact is assessed through the following three alternatives:

A. Environmentally Friendly Raw Materials Usage (A1)

This alternative evaluates the use of raw materials sourced from renewable natural resources that are safe for the environment. In the textile industry, this includes the application of natural fibers, such as organic cotton, and natural dyes that avoid harmful chemicals. The objective is to reduce carbon footprints,

minimize pollution, and promote ecosystem sustainability (Tummino et al., 2023).

B. Resource Usage Efficiency (A2)

Resource usage efficiency focuses on maximizing the use of energy, water, and raw materials during production. This includes minimizing waste generation and optimizing water and energy utilization. Resource usage efficiency can be assessed by calculating ratios such as energy consumption per unit of product and monitoring waste levels in the production process. The goal is to enhance productivity while reducing the industry's environmental impact (Yaxyaeva, 2020).

C. Responsible Waste Management (A3)

This alternative examines the implementation of waste management practices that aim to minimize environmental harm caused by production-related waste. Effective waste management strategies include waste reduction at the source, waste segregation for recycling, and the adoption of methods to create added value from waste. These practices not only contribute to environmental preservation but also enhance the industry's sustainability and profitability (Ponnambalam et al., 2023).

2. **Economic viability (C2)**

Economic viability assesses an industry's capacity to generate profits and ensure business continuity. For the Gringsing woven textile industry, economic viability is evaluated through the following three alternatives:

A. Local community income (A1)

Local community income represents the total assets received by individuals or households in Tenganan Pegringsingan Village from various sources, such as sales of woven products, earnings from tourism activities, and other income streams. This income is measured in Rupiah and serves as an indicator of the economic well-being of the local community. Metrics used to assess local community income include average per capita income and household earnings (Bachok et al., 2019).

B. Production cost (A2)

Production cost encompasses all expenditures incurred by the Gringsing woven textile industry in the creation of woven fabrics. These costs include raw materials, labor, energy, and overhead expenses associated with production. The evaluation of production costs involves calculating total expenditure over a specified period and comparing it with the volume of products produced. Key indicators include cost per unit of product, the ratio of fixed to variable costs, and profitability analyses, such as gross profit margins (Bantelay et al., 2020).

C. Market demand (A3)

Market demand reflects the consumer need and preference for Gringsing woven fabric products in both local and global markets. This alternative is assessed through factors such as sales volume, consumer purchasing trends, and market analyses that identify target consumer segments. Indicators of market demand include the quantity of products sold during a given period, sales growth rates, and changes in consumer behavior over time (Grosu et al., 2020).

3. Social contribution (C3)

Social contribution evaluates the impact of the industry on local communities, including its role in community empowerment, cultural heritage preservation, and improvements to quality of life. In the context of the Gringsing woven textile industry, social contribution is assessed through the following three alternatives:

A. Local community empowerment (A1)

Local community empowerment refers to efforts by the industry to enhance the capacity and capabilities of individuals to participate actively in economic and social activities. This includes providing skills training, facilitating market access, and supporting local entrepreneurial initiatives. Indicators for measuring community empowerment include the number of training sessions conducted, the number of individuals engaged in Gringsing weaving production, and the increase in community income resulting from involvement in the industry (Nadiwa et al., 2024).

B. Cultural heritage protection (A2)

Cultural heritage protection encompasses the industry's efforts to safeguard the traditions and cultural values associated with the production of Gringsing woven fabrics. This involves preserving traditional weaving techniques, using natural dyes, and maintaining motifs and symbols of cultural significance. Indicators of cultural heritage protection include the number of educational or training programs organized for younger generations to learn traditional weaving techniques and the level of community participation in traditional ceremonies involving Gringsing textiles. Such efforts ensure the continued appreciation and transmission of cultural heritage to future generations (Inanna et al., 2020).

C. Quality of life of local communities (A3)

The quality of life of local communities pertains to the social and economic benefits derived from the Gringsing weaving industry. These benefits include improved access to essential services such as education, healthcare, and infrastructure, as well as increased income and overall well-being. Indicators for assessing the quality of life include education levels within the community, access to healthcare facilities, and welfare metrics such as the per capita income or well-being index of the local population (Roy & Chouhan, 2017).

Results 2: Data and develop a decision matrix

The next step in evaluating the sustainability and viability of the Gringsing woven textile industry involves developing a comprehensive decision matrix. This analysis provides a clear representation of the sustainability potential of each alternative in the Gringsing weaving industry. The decision matrix results are expected to assist stakeholders in making informed and sustainable decisions for the industry's future development.

The data presented in the matrix was obtained through surveys and in-depth interviews with Gringsing weaving artisans in Tenganan Pegringsingan Village. The matrix includes information about three primary criteria—Environmental Impact (C1), Economic Viability (C2), and Social Contribution (C3)—and their corresponding alternatives (A1, A2, and A3). The decision matrix is presented in Table 1.

Table 1. Decision matrix

Alternative/Criteria	A1	A2	A3	Total
Environmental Impact (C1)	8	7.5	9	24.5
Economic Viability (C2)	9	6.5	7	22.5
Social Contribution (C3)	9	8	8	27
Total	26	22	24	

The scores for each criterion in Table 1 were determined through a combination of survey responses and qualitative insights gained from interviews. Artisans evaluated each alternative against the criteria using a standardized scoring system ranging from 1 to 10, where higher scores represent better performance. The scores reflect the perceived sustainability potential of each alternative in terms of environmental impact, economic viability, and social contribution.

Based on the data in Table 1, it is evident that each alternative exhibits unique strengths and areas for improvement:

- Alternative 1 (A1) achieved the highest total score of 26, reflecting strong performance across all three criteria. A1 excelled particularly in Economic Viability (9) and Social Contribution (9), indicating its balance between profitability and positive social impacts. This positions A1 as a strong candidate for sustainable development initiatives.
- Alternative 2 (A2) received a total score of 22, the lowest among the alternatives. Its primary weakness lies in Economic Viability (6.5), which could stem from higher production costs or limited market demand. Despite this, A2 showed moderate performance in Environmental Impact (7.5) and Social Contribution (8), suggesting its potential contribution to sustainability goals in specific areas.
- Alternative 3 (A3) achieved a total score of 24, with its highest performance in Environmental Impact (9), underscoring its alignment with environmentally sustainable practices. However, its relatively lower score in Economic Viability (7) indicates room for improvement in profitability, which may need to be addressed to enhance its overall sustainability potential.

The decision matrix underscores the importance of evaluating all three criteria—environmental, economic, and social—in determining the sustainability and viability of the Gringsing textile industry. While A1 appears to be the most balanced and sustainable option, A3 demonstrates significant potential for environmentally focused strategies, and A2 offers insights into areas requiring targeted interventions for improvement.

Results 3: Normalization of the decision matrix

Normalization of the decision matrix is a crucial step in the MULTIMOORA method, as it transforms raw data into a standardized format, enabling effective aggregation and ranking of alternatives. In multi-criteria decision-making, each criterion may have a different unit or scale, requiring normalization to ensure comparability (Kariani & Saskara, 2024).

Based on Table 1, the initial decision matrix is expressed as follows:

$$x = \begin{bmatrix} 8 & 7.5 & 9 \\ 9 & 6.5 & 7 \\ 9 & 8 & 8 \end{bmatrix} \dots\dots\dots (1)$$

In this research, the vector normalization method is applied to process the data obtained from the multi-criteria analysis using the MULTIMOORA approach. The normalization process is carried out using the formula:

$$\bar{x}_{ij} = \frac{x_{ij}}{\sqrt{\sum_{i=1}^m x_{ij}^2}} \dots\dots\dots (2)$$

Where,

\bar{x}_{ij} = normalization value for alternative i in criterion j

x_{ij} = original value for alternative i in criterion j

m = number of alternatives

Normalization calculation of environmental impact criteria (C1)

$$\begin{aligned} \text{A1: } \bar{x}_{11} &= \frac{x_{11}}{\sqrt{\sum_{i=1}^m x_{ij}^2}} = \frac{8}{\sqrt{8^2+7.5^2+9^2}} = \frac{8}{\sqrt{64+56.25+81}} = \frac{8}{14.18} = 0.56 \\ \text{A2: } \bar{x}_{12} &= \frac{x_{12}}{\sqrt{\sum_{i=1}^m x_{ij}^2}} = \frac{7.5}{\sqrt{8^2+7.5^2+9^2}} = \frac{7.5}{\sqrt{64+56.25+81}} = \frac{7.5}{14.18} = 0.53 \\ \text{A3: } \bar{x}_{13} &= \frac{x_{13}}{\sqrt{\sum_{i=1}^m x_{ij}^2}} = \frac{9}{\sqrt{8^2+7.5^2+9^2}} = \frac{9}{\sqrt{64+56.25+81}} = \frac{9}{14.18} = 0.63 \end{aligned}$$

Normalization calculation of economic viability criteria (C2)

$$\begin{aligned} \text{A1: } \bar{x}_{21} &= \frac{x_{21}}{\sqrt{\sum_{i=1}^m x_{ij}^2}} = \frac{9}{\sqrt{9^2+6.5^2+7^2}} = \frac{9}{\sqrt{81+42.25+49}} = \frac{9}{13.13} = 0.69 \\ \text{A2: } \bar{x}_{22} &= \frac{x_{22}}{\sqrt{\sum_{i=1}^m x_{ij}^2}} = \frac{6.5}{\sqrt{9^2+6.5^2+7^2}} = \frac{6.5}{\sqrt{81+42.25+49}} = \frac{6.5}{13.13} = 0.50 \\ \text{A3: } \bar{x}_{23} &= \frac{x_{23}}{\sqrt{\sum_{i=1}^m x_{ij}^2}} = \frac{7}{\sqrt{9^2+6.5^2+7^2}} = \frac{7}{\sqrt{81+42.25+49}} = \frac{7}{13.13} = 0.53 \end{aligned}$$

Normalization calculation of social contribution criteria (C3)

$$\begin{aligned} \text{A1: } \bar{x}_{31} &= \frac{x_{31}}{\sqrt{\sum_{i=1}^m x_{ij}^2}} = \frac{9}{\sqrt{9^2+8^2+8^2}} = \frac{9}{\sqrt{81+64+64}} = \frac{9}{14.46} = 0.62 \\ \text{A2: } \bar{x}_{32} &= \frac{x_{32}}{\sqrt{\sum_{i=1}^m x_{ij}^2}} = \frac{8}{\sqrt{9^2+8^2+8^2}} = \frac{8}{\sqrt{81+64+64}} = \frac{8}{14.46} = 0.55 \\ \text{A3: } \bar{x}_{33} &= \frac{x_{33}}{\sqrt{\sum_{i=1}^m x_{ij}^2}} = \frac{8}{\sqrt{9^2+8^2+8^2}} = \frac{8}{\sqrt{81+64+64}} = \frac{8}{14.46} = 0.55 \end{aligned}$$

The normalization process results in a normalized decision matrix, which identifies the best-performing alternatives and significantly contributes to the decision analysis in this research. The outcomes of the MULTIMOORA calculation at the normalization matrix stage are presented in Table 2.

Table 2. Normalization of the decision matrix

Alternative/Criteria	A1	A2	A3
Environmental Impact (C1)	0.56	0.53	0.63
Economic Viability (C2)	0.69	0.50	0.53
Social Contribution (C3)	0.62	0.55	0.55

Results 4: Calculating ratio values for the ratio system (MOORA)

The ratio values for the Ratio System are calculated using the following formula:

$$R_{ij} = \frac{X_{ij}}{X_{ij,max}} \dots\dots\dots(3)$$

Where,

- R_{ij} = ratio value for alternative i in criterion j
- X_{ij} = original value for alternative i in criterion j
- $X_{ij,max}$ = maximum value of criterion j

Maximum value on each criterion

- Maximum Environmental Impact Value (C1) = max(8, 7.5, 9) = 9
- Maximum Economic Viability Value (C2) = max(9, 6.5, 7) = 9
- Maximum Social Contribution Value (C3) = max (9, 8, 8) = 9

Calculation of the environmental impact criteria ratio value (C1)

- A1: $R_{11} = \frac{X_{ij}}{X_{ij,max}} = \frac{8}{9} = 0.89$
- A2: $R_{12} = \frac{X_{ij}}{X_{ij,max}} = \frac{7.5}{9} = 0.83$
- A3: $R_{13} = \frac{X_{ij}}{X_{ij,max}} = \frac{9}{9} = 1$

Calculation of the economic viability criteria ratio value (C2)

- A1: $R_{21} = \frac{X_{ij}}{X_{ij,max}} = \frac{9}{9} = 1$
- A2: $R_{22} = \frac{X_{ij}}{X_{ij,max}} = \frac{6.5}{9} = 0.72$
- A3: $R_{23} = \frac{X_{ij}}{X_{ij,max}} = \frac{7}{9} = 0.76$

Calculation of the social contribution criteria ratio value (C3)

- A1: $R_{31} = \frac{X_{ij}}{X_{ij,max}} = \frac{9}{9} = 1$
- A2: $R_{32} = \frac{X_{ij}}{X_{ij,max}} = \frac{8}{9} = 0.89$
- A3: $R_{33} = \frac{X_{ij}}{X_{ij,max}} = \frac{8}{9} = 0.89$

Table 3. Ratio Value

Alternative/Criteria	A1	A2	A3	Number of Ratios
Environmental Impact (C1)	0.89	0.83	1	2.72
Economic Viability (C2)	1	0.72	0.76	2.48
Social Contribution (C3)	1	0.89	0.89	2.78

Based on Table 3, the results of the Ratio System calculation for alternatives A1, A2, and A3, evaluated against the criteria of Environmental Impact (C1), Economic Viability (C2), and Social Contribution (C3), provide a clear picture of the performance

of each alternative in supporting the sustainability of the Gringsing weaving industry and its alignment with green economy principles.

Social Contribution (C3) achieved the highest number of ratios score, totaling 2.78, highlighting its significant impact on the quality of life in local communities. This high score reflects the importance of social contributions, including community empowerment, cultural heritage preservation, and quality-of-life improvement. Empowering local communities involves enhancing individual skills through training and education, enabling greater participation in economic and social activities. Additionally, the protection of cultural heritage is vital for maintaining local identity and traditions, ensuring that future generations can benefit from this legacy (Purnamawati, 2016). Social contributions also improve access to essential public services and create job opportunities, leading to enhanced community welfare.

From a theoretical perspective, the high ratio value for social contribution underscores its critical role in achieving a green economy. By fostering local community well-being and safeguarding cultural heritage, the Gringsing weaving industry establishes a solid foundation for responsible and sustainable economic growth. The principles of a green economy, which emphasize sustainability and inclusivity in economic development, are reinforced by initiatives that prioritize community welfare.

Environmental Impact (C1) received the second-highest Number of Ratios score, totaling 2.72, indicating the industry's effective efforts to reduce environmental harm. This score reflects the industry's commitment to sustainable practices, including the responsible use of natural resources, carbon emissions reduction, and proper waste management. These practices align with the UNEP (United Nations Environment Programme) definition of a green economy as a system that is low-carbon, resource-efficient, and socially inclusive. High performance in this criterion also demonstrates the industry's contribution to sustainable development goals, particularly by adopting environmentally friendly practices (Pryanka & Saskara, 2023).

The use of natural raw materials, such as organic fibers and natural dyes, remains a key factor in supporting the sustainability of the Gringsing weaving industry. This commitment to environmental preservation enhances the quality and appeal of Gringsing products while aligning with green growth theories that advocate for sustainable resource utilization and pollution prevention. The consistent use of environmentally friendly materials ensures that the Gringsing weaving industry not only generates economic benefits but also improves local community welfare through increased income and empowerment opportunities.

Economic Viability (C2), with a Number of Ratios score of 2.48, ranks third among the criteria. While the Gringsing weaving industry has positively contributed to local income and market demand, challenges such as high production costs and market competitiveness affect its overall performance. The manual production process, reliant on natural materials, often results in elevated production costs.

Several strategies can be implemented to address these challenges. For example, government subsidies could help reduce costs for artisans employing sustainable practices by lowering expenses related to raw materials, labor, and energy. This would enable producers to offer competitive prices without compromising product quality. Additionally, partnerships with the tourism sector could further support economic viability. Tourists visiting Tenganan Pegringsingan Village could be encouraged to

purchase woven products directly from artisans, enhancing local income and expanding market exposure. Establishing dedicated shops within the village to market community-produced goods would also help boost sales and promote the unique cultural heritage of the area.

In the context of a green economy, focusing on economic benefits while addressing social and environmental impacts is critical. By balancing these priorities, the Gringsing weaving industry can maintain its cultural significance, environmental sustainability, and economic resilience, contributing to a more sustainable and inclusive economic model (Sudarmanto, 2022).

The government plays a pivotal role in supporting environmentally friendly practices within the textile industry, as exemplified in Tenganan Pegringsingan Village. One significant step the government can take is establishing regulations that promote the use of sustainable raw materials and environmentally responsible production methods. By setting clear standards for utilizing natural and eco-friendly materials, the government can ensure that the textile industry prioritizes not only economic profits but also its environmental impacts.

Additionally, providing subsidies to artisans who adopt sustainable practices can help mitigate production costs and enhance product competitiveness. These subsidies could include direct financial assistance or access to low-interest financing, enabling artisans to invest in sustainable production processes. Training programs are equally important for equipping artisans with the skills needed to implement sustainable techniques and modern technologies. Enhanced skills will enable artisans in Tenganan to produce high-quality goods that meet international standards, further improving their market potential.

An illustrative example of government intervention in the textile sector is the Partnership for Cleaner Textile (PaCT) project in Bangladesh, which highlights the positive outcomes of fostering sustainability in the industry. The project aims to promote responsible consumption and production in the textile sector and facilitate its transition toward a greener future. The initiative has achieved remarkable results, including reducing greenhouse gas (GHG) emissions by over half a million tons, equivalent to removing 900,000 cars from the road and saving approximately 29 billion liters of water. These achievements underscore how targeted government support can reduce the industry's carbon footprint while improving resource efficiency.

Applying similar principles to Tenganan Pegringsingan Village could ensure that the Gringsing weaving industry becomes economically sustainable while delivering significant social and environmental benefits to the local community. In this context, government involvement is critical in creating a supportive framework for sustainability in the textile industry. An integrated approach, combining regulations, financial incentives, and capacity-building programs, can help drive local economic growth while safeguarding the environment and preserving cultural heritage.

Such initiatives will ensure that the eco-friendly textile industry not only thrives but also generates long-term benefits for all stakeholders involved. By aligning with sustainability principles, the Gringsing weaving industry can serve as a model for balancing economic growth with environmental responsibility and cultural preservation.

Results 5: Calculating values in full multiplicative form

In the multi-criteria evaluation process, the calculation of the Full Multiplicative

Form is a crucial step. This stage incorporates the assigned weights for each criterion, reflecting their relative importance in the decision-making process. Assigning appropriate weights ensures that more significant criteria exert a greater influence on the analysis outcome.

In this research, the weights of the criteria were determined based on direct assessments from stakeholders and Gringsing weaving artisans in Tenganan Pegringsingan Village. The criteria weights are as follows:

- Weight of environmental impact criteria (C1) : 0,4
- Weight of economic viability criteria (C2) : 0,3
- Weight of social contribution criteria (C3) : 0.3

Once the criteria weights are established, the aggregate value for each alternative is calculated using the following formula:

$$M_{ij} = \prod_{j=1}^n X_{ij}^{w_j} \dots\dots\dots(4)$$

Where,

M_{ij} = aggregate value for alternative i in criterion j

X_{ij} = ratio value for alternative i in criterion j

w_j = weight value of criterion j

n = number of criteria

Calculation of A1 alternative aggregate value

$$M_{A1} = X_{A1,C1}^{w_1} \cdot X_{A1,C2}^{w_2} \cdot X_{A1,C3}^{w_3}$$

$$M_{A1} = (0.89^{0.4}) \cdot (1^{0.3}) \cdot (1^{0.3})$$

$$M_{A1} = 0.89^{0.4} = 0.84$$

Calculation of A2 alternative aggregate value

$$M_{A2} = X_{A2,C1}^{w_1} \cdot X_{A2,C2}^{w_2} \cdot X_{A2,C3}^{w_3}$$

$$M_{A2} = (0.84^{0.4}) \cdot (0.72^{0.3}) \cdot (0.89^{0.3})$$

$$M_{A2} = 0.83$$

Calculation of A3 alternative aggregate value

$$M_{A3} = X_{A3,C1}^{w_1} \cdot X_{A3,C2}^{w_2} \cdot X_{A3,C3}^{w_3}$$

$$M_{A3} = (1^{0.4}) \cdot (0.77^{0.3}) \cdot (0.89^{0.3})$$

$$M_{A3} = 0.84$$

Table 4. Values in full multiplicative form

Alternative	Aggregate Value
A1	0.84
A2	0.83
A3	0.84

The aggregate value calculations for alternatives A1, A2, and A3 reveal that both A1 and A3 achieved high aggregate values of 0.84, reflecting their strong overall performance across the evaluated criteria. These equal scores indicate their balanced sustainability potential, yet practical distinctions differentiate their strengths. A1 excels

in Economic Viability and Social Contribution, making it a well-rounded option for stakeholders seeking comprehensive benefits. Conversely, A3 demonstrates superior performance in Environmental Impact, positioning it as the preferred choice for initiatives prioritizing ecological sustainability. While the equal aggregate values highlight their shared strengths, they also emphasize the importance of prioritizing specific goals and considering trade-offs in practical decision-making.

A1 focuses on environmentally friendly raw material usage, local community income, and community empowerment, encapsulating the principles of a green economy that emphasizes the interconnection of economic development and sustainability. According to green economy theory, an alternative's success is not solely measured by economic benefits but also by its social and environmental contributions. By employing environmentally friendly raw materials, A1 reduces its negative environmental impact while enhancing the quality of life for local communities through increased income and empowerment.

In contrast, A3 excels in responsible waste management, market demand, and quality of life for local communities. Effective waste management preserves the environment by reducing pollution and improving public health, thereby elevating the quality of life. Additionally, by successfully meeting market demand, A3 contributes to local economic growth (ELdesoky, 2024). Both alternatives also demonstrate a significant positive impact on community empowerment and cultural heritage protection, aligning with social contribution theory. This theory posits that alternatives enhancing societal welfare garner stronger stakeholder support (Rahmadani et al., 2024).

The high aggregate scores for A1 and A3 underscore their outstanding performance in meeting the evaluation criteria, reflecting adherence to the principles of the green economy and social contribution. Both alternatives prioritize not only economic benefits but also consider their social and environmental impacts. This highlights their sustainability potential and their capacity to uphold social responsibility, making them exemplary models for initiatives seeking a balance between ecological preservation, economic growth, and community well-being.

When comparing the performance of the three alternatives, it is important to examine the specific practices each implements. For instance, Alternative A1 emphasizes the use of sustainable raw materials, such as organic fibers and natural dyes. This approach not only minimizes environmental damage but also supports local agriculture by sourcing materials from local farmers. In contrast, Alternative A2 prioritizes resource efficiency by optimizing energy and water consumption during the production process. This may involve adopting energy-efficient technologies or recycling water used in the dyeing process to minimize overall resource usage. Meanwhile, Alternative A3 distinguishes itself through its commitment to responsible waste management, incorporating practices such as separating waste at the source for recycling and composting organic waste. These waste management efforts not only reduce pollution but also create additional income opportunities through recycling initiatives.

The high Number of Ratios score for social contribution (C3) at 2.78 highlights the significant impact of the evaluated alternatives on the quality of life of local communities. Social contribution encompasses key aspects such as empowering local communities, preserving cultural heritage, and improving overall quality of life. Empowerment involves enhancing individuals' skills and capabilities through training and education,

enabling them to participate more actively in social and economic activities. Simultaneously, preserving cultural heritage maintains local identity and wisdom, ensuring that traditions are safeguarded for future generations.

Although Alternatives A1 and A3 achieve equally high aggregate scores, they achieve this through distinct yet complementary approaches aligned with green economy principles. A1 emphasizes sustainability directly through the use of environmentally friendly raw materials, fostering eco-conscious production choices. Conversely, A3 enhances sustainability through robust waste management practices, focusing on reducing pollution and utilizing waste as a resource. Together, these alternatives illustrate how diverse strategies can be effectively implemented in the Gringsing weaving industry to promote economic sustainability while ensuring social responsibility and environmental protection.

In the broader context of sustainability within the creative and textile industries, the findings from this research underscore how the Gringsing weaving industry serves as a model for implementing sustainable practices. By focusing on the use of environmentally friendly raw materials and empowering local communities, the industry not only generates economic benefits but also contributes positively to environmental and societal well-being. This aligns with global trends that increasingly prioritize sustainability as a cornerstone of creative industry development. The sustainable practices adopted in the Gringsing weaving industry can inspire other textile sectors to transition toward more eco-friendly and socially responsible business models.

With growing consumer awareness of the importance of environmentally friendly and ethical products, there is a significant opportunity for the textile industry to embrace sustainability. The results of this study are not only pertinent to the Gringsing weaving industry but also offer valuable insights for shaping sustainability policies and practices in the creative sector at large.

Lessons from the Gringsing weaving industry can be applied to other industries or regions by emphasizing several key strategies. First, community engagement is crucial. As demonstrated by Gringsing weaving, involving local artisans and stakeholders in the production process ensures that cultural heritage and traditional practices are respected and preserved. Second, implementing educational programs focused on skill enhancement and character development for artisans can foster sustainability across sectors. These programs should include training in both technical skills and an understanding of the cultural significance of crafts, nurturing a sense of responsibility toward sustainability. Finally, government support through policies that protect cultural heritage while promoting sustainable practices can create an enabling environment for these industries to thrive. Such policies ensure that the lessons learned from Gringsing weaving contribute meaningfully to the sustainability of similar crafts in diverse contexts.

CONCLUSION AND RECOMMENDATIONS

Conclusion

The Gringsing textile industry showcases considerable potential for promoting a green economy through the implementation of sustainable practices, as demonstrated by the MULTIMOORA analysis. This study highlights the industry's ability to balance environmental, economic, and social criteria, offering a viable model for sustainable development. The high cultural value of Gringsing textiles underscores their importance

in preserving Indonesia's heritage while addressing contemporary challenges in sustainability.

By adopting environmentally friendly production techniques and prioritizing the well-being of local communities, the Gringsing weaving industry aligns with the growing consumer demand for sustainable and ethical products. However, challenges such as high production costs and market competition must be addressed to ensure the long-term viability of these practices. Through innovation, collaboration, and policy support, the Gringsing textile industry can emerge as a leading example of sustainable development in Indonesia, benefiting both local communities and the environment.

Recommendations

Several strategic measures should be adopted to strengthen the sustainability and global competitiveness of the Gringsing textile industry. Policy support is essential, including the establishment of subsidies for eco-friendly raw materials to reduce production costs and the provision of financial assistance to encourage innovation in production methods and technologies. Export incentives could further bolster the industry's presence in international markets. Collaborations with international stakeholders, such as eco-tourism operators, cultural preservation organizations, and sustainable fashion brands, would enhance the global visibility and reach of Gringsing textiles. The integration of the textile industry with cultural tourism in Tenganan Village could also attract more visitors, creating new economic opportunities for local communities.

Capacity building is equally important. Training programs should be implemented to improve artisans' technical skills in sustainable practices and modern production technologies while fostering awareness of the cultural significance of Gringsing weaving to ensure its preservation for future generations. Expanding market access through online platforms and participation in global trade exhibitions can diversify the industry's customer base, promoting the unique combination of cultural heritage and sustainability in Gringsing textiles. Additionally, monitoring global trade dynamics and raw material price fluctuations will help the industry anticipate and respond to market changes, while mechanisms to mitigate the effects of international competition could protect local artisans' livelihoods.

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