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Operational Restructuring For Energy Efficiency And Best Esg Practices For Business Sustainability: A Global Analysis Of Leather Working Group Certified Tanneries

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ABSTRACT

Leather industry is a major contributor to the global economy, more importantly in the developing countries with significant impact on foreign exchange and employment opportunities. While the limiting factors of the tanneries are its contribution to carbon footprints, sludge from water waste treatment and effluent from process, the purpose of this study is to bring out the operational restructuring benefits for Energy efficiency for reduced carbon footprints and notable ESG practices in leather tanneries in Uganda, Russia Nigeria, Syria, Turkey, India, and Bangladesh. Last 6 years secondary data was collected from 46 tanneries from these countries, during the LWG audits for certification. Results were obtained through qualitative and quantitative analysis of various parameters directly related to the United Nations' Sustainability Development Goals.

The contributions from restructuring basically evolve from reduction of energy and water consumption in production, better air and noise emission control, effluent treatment to acceptable levels, hazardous and non-hazardous waste recycling and reuse, workplace safety, and decent working conditions. Important findings demonstrate that high-level operational transformation and Environmental governance have resulted in significantly minimising manufacturing costs, has secured businesses from environmental conscious markets, promotes responsible raw material and chemical consumption ensuring employees and consumer safety, eliminating environmental degradation, thus saving lives on land and under water...

Keywords : Operational Restructuring, Energy efficiency, ESG, Business Sustainability.

1. INTRODUCTION:

The leather industry was chosen for this study due to its dual significance: first, its economic role in foreign exchange earnings and employment generation—especially for women; second, the need to challenge the perception that leather manufacturing is inherently toxic and that tanneries fail to mitigate environmental harm. Contrary to popular belief, leather industry contributes to the circular economy and many tanneries have adopted sustainability measures to reduce carbon footprints and treat effluents effectively.

Leather is an integral part of various industries, from fashion and footwear to furniture and automotive interiors. Valued at over $400 billion annually, the industry is projected to grow to $708.7 billion by 2030 (Acumen Research and Consulting). Given this scale, ensuring sustainable practices within tanneries is crucial for long-term viability and environmental responsibility.

The Leather Working Group (LWG) plays a key role in advancing sustainability in leather production. As a global multi-stakeholder organization, LWG promotes best practices and drives positive social and environmental change in the industry. With a vision of a fully sustainable leather supply chain, the organization works towards a transparent value chain aligned with the United Nations' 2030 Sustainable Development Goals (SDGs).

As industries worldwide align with ESG principles, tanneries have undertaken measures to enhance energy efficiency, optimize water usage, and effectively treat wastewater and sludge. While past research has explored various social and environmental aspects of leather production such as studies conducted in Kenya (Evaline, 2020), the Netherlands (Brindha Prakash, 2020), Peru (Yesenia Avila, 2023), Bangladesh (Md. Mahfujul Haq, 2023), Latin America (Benjamin Carril, 2023), Colombia (Nicholas), and Italy (Leather Industry Park Case Study, Sauro di Sandro, 2017)there has been limited focus on the role of energy efficiency in reducing carbon footprints.

Thus, this study aims to:

Analyse operational restructuring for energy-efficient production in tanneries worldwide.

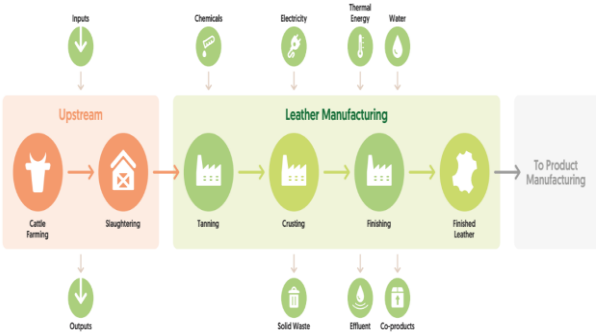
Examine the adoption of alternative and renewable energy sources in leather manufacturing.

Evaluate environmental governance measures concerning air and noise pollution, effluent treatment, solid waste management, water consumption

2. LITERATURE REVIEW

Leather is often perceived as a sustainable material, primarily because it upcycles waste hides and skins from the meat and dairy industries, reducing landfill burdens. However, the leather tanning industry faces significant scrutiny for its environmental and social impacts, particularly due to its reliance on chemicals, water, and energy-intensive processes. The improper management of waste exacerbates these concerns, driving the need for operational restructuring aimed at enhancing sustainability.

Value Chain of Leather production



Operational restructuring in tanneries aligns operations with ESG principles, reducing waste, energy use, and environmental impact while boosting resource efficiency. It fosters innovation, enhances brand reputation, and meets consumer demand for sustainable leather products. The rising emphasis on Environmental, Social, and Governance (ESG) compliance has prompted tanneries to integrate sustainable practices that align with the United Nations' Sustainable Development Goals (SDGs), providing a framework for responsible consumption, resource efficiency, and reduced environmental footprints. By addressing employee safety and community well-being, operational restructuring also contributes to better working conditions and stronger community relations.

Energy Management

Tanning is the most essential step in leather manufacture (Xiao et al., 2023) and represents the primary source of CO2 emissions during the transformation of pickled hides into crust leather (Shi et al., 2016; Yu et al., 2021). The energy-intensive processes involved in tanning, such as heating, drying, and machinery operation, contribute significantly to greenhouse gas emissions and resource depletion. Addressing these challenges requires prioritizing energy efficiency, which aligns with **SDG 7 (Affordable and Clean Energy)** and **SDG 13 (Climate Action),** emphasizing renewable energy adoption and carbon neutrality. For Leather Working Group (LWG)-certified tanneries, optimizing energy consumption is a key criterion reflecting their commitment to sustainability, as it enhances resource efficiency, lowers production costs, and supports compliance with international standards.

The urgency of reducing global warming to no more than 1.5°C, as outlined in the Paris Agreement, necessitates a 43% reduction in emissions by 2030 and achieving net-zero emissions by 2050. To address this, replacing fossil fuel-based leather chemicals has gained attention. For instance, novel biomass-based tanning agents have demonstrated effectiveness in reducing CO2 emissions, as shown through life cycle assessments (Shi et al., 2016; Yu et al., 2021). Presently, chrome tanning remains the most widely used method globally due to its advantages (Xiao et al., 2023; Zhang et al., 2018).

Advances in artificial intelligence (AI) technologies, such as machine learning algorithms and intelligent optimization tools, offer unique advantages in addressing complex industrial challenges (Al Aani et al., 2019). AI-assisted methods have been proposed to optimize the chrome tanning process, achieving energy savings and carbon reduction (Jin et al., 2023). For example, AI-driven strategies like backpropagation-artificial neural networks (BP-ANN) integrated with genetic algorithms (GA) have been successfully applied to optimize industrial parameters, resulting in improved energy efficiency (Soepangkat et al., 2019).

Water Consumption & Effluent Management

The tanning process generates wastewater containing pollutants such as salts, sulphides, and chromium, which, if untreated, can pose serious environmental and health risks. Effective wastewater treatment systems are necessary to align with the United Nations' Sustainable Development Goals, particularly **Goal 6 (Clean Water and Sanitation)** and Goal **16 (Life Under water)**, by promoting sustainable water use and reducing pollution (Zhang et al., 2017).

For Leather Working Group (LWG)-certified tanneries, implementing advanced wastewater treatment systems and recycling technologies is crucial for meeting international standards and minimizing environmental impact. The adoption of Zero Liquid Discharge (ZLD) systems helps conserve water and meet regulatory requirements, supporting sustainable business practices (Sundar et al., 2011). Ongoing research is focused on improving the efficiency and cost-effectiveness of these systems, as noted by Chauhan et al. (2015), who emphasize the need for sustainable technologies in the leather industry. Chromium, a major pollutant in tannery effluent, can be treated effectively using methods like precipitation, which removes over 90% of chromium (Atif Husain et al., 2024; Karmakar et al., 2015). These methods allow for its reuse in additional tanning operations, contributing to both environmental protection and cost savings.

Additionally, the leather industry is a significant consumer of water, with approximately 30 billion litres used annually (Kandasamy et al., 2020). To reduce water consumption, the Central Leather Research Institute (CLRI) has developed strategies that optimize water use and promote recycling and reuse (Victor John et al., 2021; Gandhi et al., 2021). New equipment such as hides processors and compartmental drums are used to minimize water usage, and these practices have been successfully implemented in tanneries in India and Sri Lanka, improving overall water management in the leather industry.

Effective treatment methods, including coagulation/flocculation, membrane separation processes, advanced oxidation processes (AOPs), adsorption, biological treatments, and hybrid technologies, have been shown to effectively address tannery wastewater (Aksu et al., 2005; Zhang et al., 2018). While these techniques have demonstrated promise, further innovation and refinement are necessary to meet increasingly stringent environmental standards. Additionally, emerging methods such as enzymatic treatments, fungal processes, and the use of microalgae offer potential for improving effluent quality (Singh et al., 2020). The application of membrane separation processes facilitates the reuse of treated wastewater in the tanning process, supporting the development of sustainable, closed-loop systems that reduce water consumption and waste generation (Zhou et al., 2016). Although the reuse of treated leather effluent as a raw material is not yet widespread, it presents an opportunity for future advancements in waste reduction and resource conservation within the industry.

Solid Waste Management and Recycling

The leather industry generates considerable solid and liquid waste, including leather shavings, trimmings, and chemical residues. Approximately 40–50% of untreated hides and skins are discarded as waste, contributing to an estimated 8.5 million tons of tannery solid waste (TSW) annually. Effective waste management and recycling are essential to mitigate environmental and health risks while promoting a circular economy. Vaporization techniques, such as thermochemical conversion, biological treatment, and phytoremediation, have demonstrated potential in transforming TSW into value-added products. Recycling initiatives align with **SDG 12 (Responsible Consumption and Production)** and **SDG 15 (Life on Land),** supporting resource recovery and reduced landfill dependency. LWG-certified tanneries emphasize innovative waste management practices, integrating resource-efficient technologies to enhance sustainability and economic performance.

Air and noise emissions

Air and noise emissions from leather tanning industries pose significant challenges to environmental health and human well-being, emphasizing the need for effective mitigation strategies. Air pollutants, including volatile organic compounds (VOCs), ammonia, hydrogen sulphide, and particulate matter, degrade air quality, contribute to smog, and cause respiratory health issues. Additionally, machinery noise creates occupational hazards, such as hearing loss and stress among workers.

Innovative approaches, such as enzymatic treatments and the use of microalgae, also show promise in reducing pollutants. Integrating these technologies and practices is essential for achieving regulatory compliance, protecting the environment, and enhancing the sustainability of leather tanning operations (Gautam et al., 2021; Suthar & Bishnoi, 2022; Rana et al., 2023).

Data and Research Methods

This study evaluates the sustainable practices of Leather Working Group (LWG)-certified tanneries worldwide, with a focus on key metrics including energy consumption, water usage, air and noise emissions, waste management, and effluent treatment. Primary and Secondary data were drawn from audits conducted across 46 tanneries, predominantly in India, with additional samples from Bangladesh, Nigeria, Russia, Syria, Turkey, and Uganda. This research investigates operational changes, energy efficiency improvements, and best practices in environmental, social, and governance (ESG) domains.

This study focuses on key metrics including energy consumption, water usage, air and noise emissions, waste management, and effluent treatment and aims to provide actionable insights for enhancing sustainability in the leather industry, thereby improving environmental, social, and economic outcomes globally.

LWG certification is granted based on adherence to rigorous sustainability standards, categorizing tanneries as Gold, Silver, or Bronze. Certification spans multiple processes, such as raw hide/skin processing to finished leather, tanned hide/skin to finished leather, and crust hide/skin to finished leather, among others. Also, ABCDEFG categorisation of tanneries are done depending on the process involved in processing leather.

Category A - Raw hide to tanned leather

B- Raw Hide to crust leather

C- Raw Hide to Finished Leather

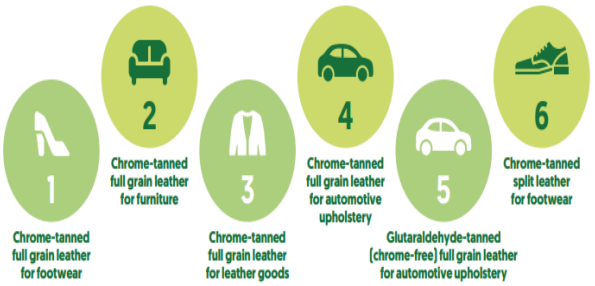
D- Tanned Hide to finished leather

E- Crust hide to finished leather

F- Tanned Hide to Crust leather

G-raw hide to pre-tanned leather.

The various applications of leather is also mentioned below.



RESULTS AND DISCUSSION

Analysis on Energy Consumption

Energy consumption encompasses the total energy used across leather production stages, including material preparation, tanning, drying, finishing, heating, ventilation, and wastewater treatment. Tanneries rely on electricity and thermal energy, making energy efficiency

critical to sustainability by reducing both operational costs and carbon emissions. The following is benchmark level for each kind of tannery for gold rating.

Table 1

A	B	C	D	E	F
8.5 MJ/m 2	18.5 MJ/m 2	33.5 MJ/m 2	28 MJ/m 2	15 MJ/m 2	14 MJ/m 2

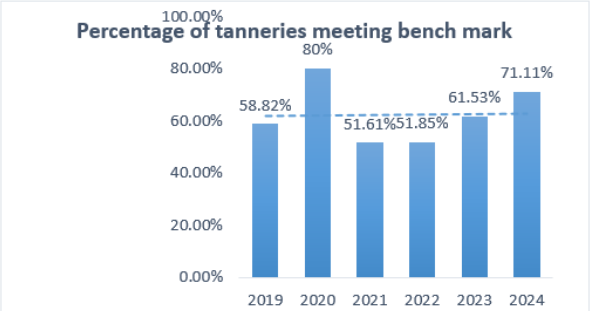


Figure 1

From 2019 to 2024, significant improvements in energy efficiency were observed, with the proportion of tanneries meeting the benchmark levels rising to 71.11% by 2024 from 58.82% in 2019. Approximately 26% of tanneries (12 out of 46) demonstrated notable reductions, including Calico Impex (India), Dabbagh Deri Ve Tekstill San Ve Tic Ltd Sti (Turkey), Mamuda Industries (Nigeria), Unique Leather Finishing (India), VMR (India), and Flamingo SSI Unit 1 (India). Renewable energy adoption was particularly notable among tanneries like Dabbagh Deri Overseas & Prime International Calico Impex, further underscoring advancements in sustainable energy practices.

Process optimization, energy-saving devices, adaption of alternative energy sources and advanced machinery were instrumental in achieving these reductions, showcasing the importance of targeted interventions in energy management.

Analysis on water consumption

Water consumption is another critical metric in sustainable tannery operations. The benchmark levels for water consumption for different type tanneries for gold rating are as follows.

Table 2

A	B	C	D	E	F
90 ltr/m 2	150 ltr /m2	165 ltr/m 2	74.5 ltr/m 2	6 ltr/m 2	35 ltr/m 2

Figure 2

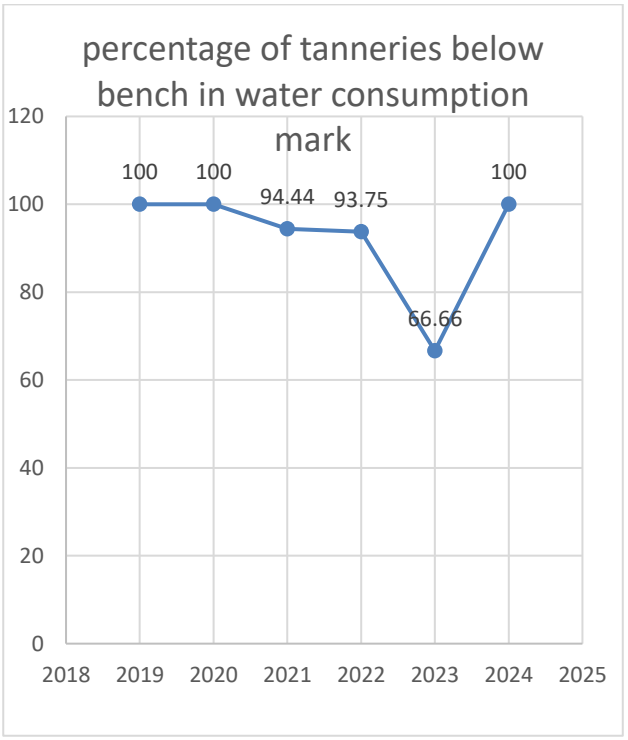
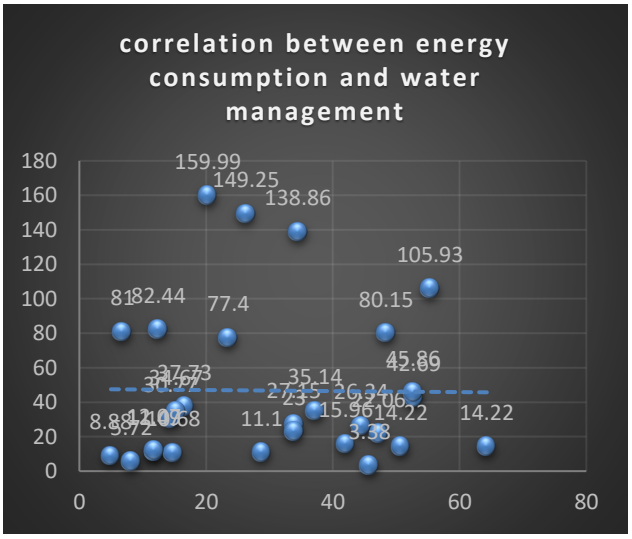


Figure 3



The following were the trends and observations of the study.

Compliance with water consumption benchmarks remained above 94% from 2019 to 2021 but dipped to 66.66% in 2023 due to external factors and operational inefficiencies **(figure 2).** However, compliance rebounded to 100% by 2024, indicating improved water management practices.

While tanneries such as Meenal Leather Exports and S K Leather Corporation (India) achieved significant reductions in water consumption through water-saving technologies through use of recycled water, and water flow controller system. Others such as Florence Shoe Company (Tannery Division), and Alina India Ltd., increased their use of recycled water.

71% of the gold rated tanneries met the benchmark in energy consumption and 100% met the benchmark in water consumption, including Flamingo SSI Unit 1,

Simona Tanning Inc. (Bangladesh), BAB Leather products, and Annai Fathima Leathers (India), illustrating the potential for synergistic sustainability improvements.

To understand if there was a relationship between energy consumption and water consumption pattern **(figure 3)** a correlation was drawn and the following was the observation made.

A weak negative correlation of -0.01146 suggests that energy and water efficiency strategies were implemented independently, avoiding unintended trade-offs.

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Analysis of Solid waste management and Air Emission

Figure 4

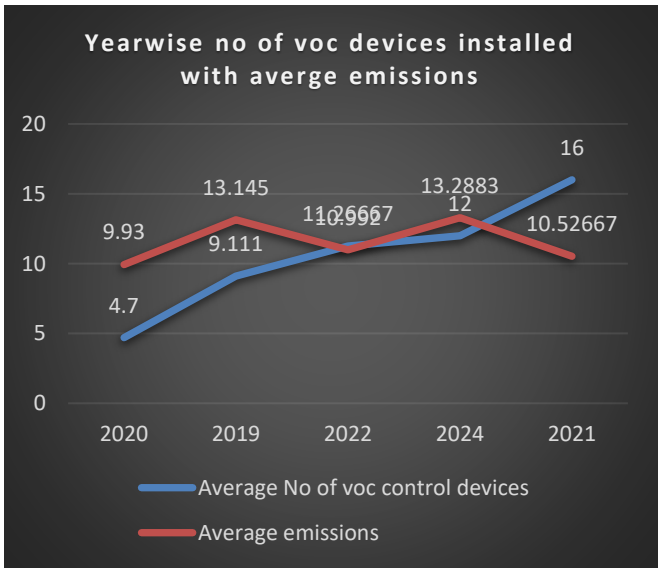


Figure 5

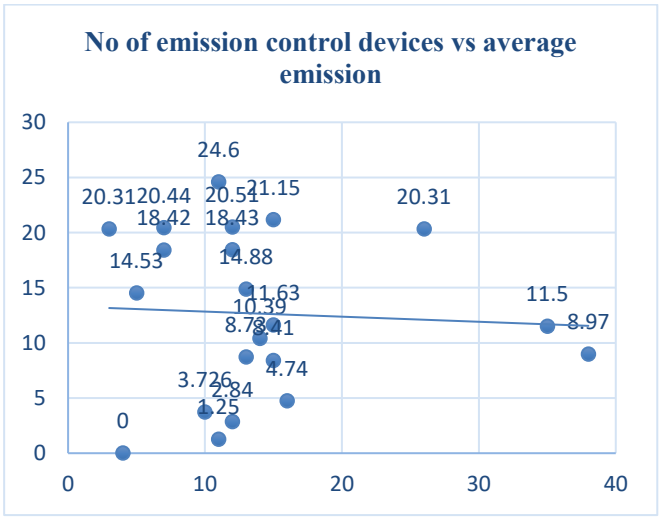


Figure 6

Effective waste management and emissions control were integral to the sustainable practices observed. The visualizations reinforce the strong correlation (0.94) and highlights the positive impact of audits on emission control measures.

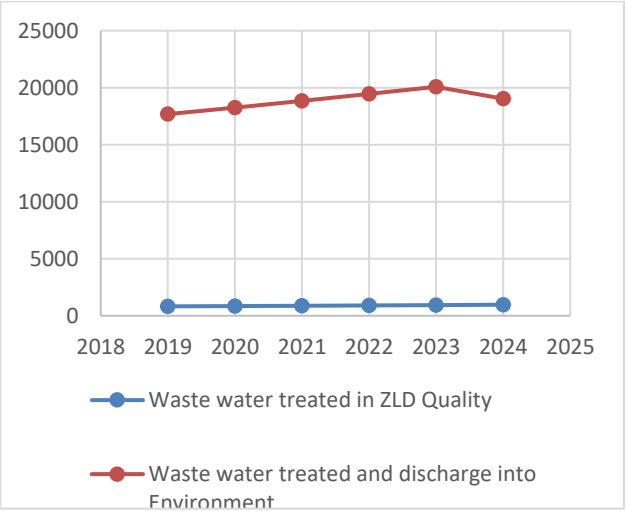
Tanneries such as Avanti Leathers Limited (India) and Dabbagh Deri Ve Tekstill San Ve Tic Ltd Sti (Turkey) significantly reduced volatile organic compound (VOC) emissions by deploying advanced VOC control devices.

Tanneries including Calico Impex, Flamingo SSI Unit 1, and Annai Fathima Leathers adopted waste segregation, recycling, and hazardous material treatment, demonstrating robust commitment to environmental protection.

These measures reduced pollution while improving operational efficiency, exemplifying the benefits of systematic waste and emissions management.

Figure 7

Analysis of Effluent Treatment and Zero Liquid Discharge (ZLD)



Effluent treatment is crucial for minimizing the environmental impact of wastewater generated during the leather manufacturing process. The study notes a steady

increase in the treatment of wastewater through Zero Liquid Discharge (ZLD) systems, which ensures that no liquid waste is discharged into the environment.

Trends in ZLD Implementation: Tanneries have shown significant progress in treating wastewater through ZLD systems, with the quantity of average wastewater treated into ZLD rising from 825.48 in 2019 to 967.49 in 2024. This indicates a growing focus on sustainable wastewater management practices.

Variability in Wastewater Discharge: While wastewater treated and discharged into the environment increased from 2019 to 2023, a noticeable decline occurred in 2024. This reduction could reflect increased adoption of ZLD systems and a more stringent approach to managing environmental impact.

Exemplary Tanneries: Dabbagh Deri Ve Tekstill San Ve Tic Ltd Sti (Turkey), Unique Leather Finishing Company Limited (India), and Mamuda Industries Nigeria Ltd. (Nigeria) were among the top performers in wastewater treatment.

Tanneries such as Florence Shoe Company Pvt. Ltd. Flamingo SSI Unit 1, Dabbagh Deri Ve Tekstill San Ve Tic Ltd Sti, Calico Impex, Unique Leather Finishing Company Limited, Gemini Enterprises C/o Pranaam Leather Pvt. Ltd. have excelled in multiple sustainability categories, demonstrating a comprehensive approach to reducing their environmental footprint. Their success in energy and water efficiency, waste management, and effluent treatment serves as a model for the broader leather industry, offering valuable insights into how tanneries can enhance their sustainability efforts and contribute to a greener future.

KEY FINDINGS AND PRACTICAL IMPLICATIONS

The analysis of operational restructuring and ESG-aligned practices in Leather Working Group-certified tanneries reveals significant advancements in energy efficiency, water management, waste management, air and noise emissions, and effluent treatment. These efforts collectively demonstrate how strategic interventions can promote sustainability, reduce environmental impact, and enhance operational efficiency in the leather industry.

In the realm of **energy efficiency**,

tanneries like Calico Impex, Prime international, Overseas Leather use alternate technologies like solar air heating system much suited for countries in tropical zone. Solar heating can provide renewable energy for the entire tanning process while energy-efficient drying, solar thermal energy, and heat recovery units can optimize specific stages of production for maximum energy savings and reduced greenhouse gas emission.

Florence shoe company-based tannery implemented a Kaizen-driven process optimization, which reduced the dyeing time per drum from 14 hours to 10 hours. This change not only lowered energy consumption by 60 EB units per drum but also resulted in substantial cost savings of INR 2,70,000 over five months, showcasing the direct financial benefits of operational improvements.

Simona tannery tackled inefficiencies related to excessive noise generated by diesel generators, installing acoustic enclosures that reduced noise levels from 100–105 dBA to legal limits. Such measures not only mitigate environmental noise pollution but also contribute to improved energy utilization, demonstrating how targeted interventions can optimize both performance and sustainability.

Water management improvements were equally significant.

Vaigai Leathers have introduced solar and sprinkler evaporation systems for soak and pickle liquor, increasing evaporation rates from 4.5 mm/day to 8–10 mm/day. This innovation significantly reduced water usage and enhanced the efficiency of effluent concentration.

Florence tannery optimized its dyeing process, reducing water consumption by 0.5 Liters per square foot and achieving up to 300% water efficiency.

KAR tannery improved solution preparation systems by developing processes that minimized water contamination and facilitated the reuse of settled myrobalan. These advancements emphasize the role of advanced water management techniques in reducing resource dependency and aligning with environmental sustainability goals.

In **Solid Waste management**,

Leather Land Limited made substantial improvements by constructing cemented storage areas for dusted salt and raw hide trimmings, addressing the risks of land contamination.

KAR tannery further optimized its waste handling practices by introducing efficient chemical storage systems, preventing spillage and reducing the potential for land pollution.

Flammingo SSI adopted enzyme-based waterproofing treatments, replacing hazardous surfactants, and improving waste biodegradability, while BBT installed concrete waste storage sheds with spillage containment systems. These actions underline the importance of systematic solid waste management practices in minimizing environmental hazards and supporting sustainable production.

Addressing **air and noise emissions**,

Dabbagh Deri tannery installed air curtains, dust extraction systems, and suction pipes in shaving and crust operations to capture airborne particles, ensuring compliance with ambient air quality standards.

SIMONA tackled excessive noise pollution from diesel generators by installing acoustic enclosures, successfully reducing noise levels to meet legal requirements. Similarly, BBT tannery implemented dust extractors and chemical mist control systems to improve air quality and reduce the risk of chemical exposure. These interventions demonstrate a strong commitment to reducing

environmental pollution, enhancing workplace safety, and ensuring regulatory compliance.

Significant innovations were also made in **effluent treatment**, with tanneries implementing advanced practices to manage hazardous discharges effectively.

Vaigai Leathers introduced solar evaporation pans for soak and pickle liquor, complying with Tamil Nadu Pollution Control Board regulations and reducing environmental impact.

Santa Maria tannery optimized its re-tanning process by reducing basic chrome sulphate usage, eliminating rechroming, and adopting safer alternatives, resulting in better effluent quality, and reduced chemical waste.

Flammingo SSI lowered COD levels in effluent by adopting chrome-free vegetable tanning methods and improved water conditioning processes, while Gemini tannery transitioned to wet green tanning, reducing BOD levels, and ensuring zero hazardous discharge.

Through Zero Liquid Discharge technology effluent is treated and water is reused for purpose tanning in 27 tanneries (59%) out of 46 tanneries in 2024

These practices exemplify how targeted innovations in effluent management can meet regulatory requirements while supporting eco-friendly leather production. Largely, the findings highlight the transformative impact of operational restructuring in the leather industry, aligning with best ESG practices to promote energy efficiency, conserve water, reduce waste, and minimize emissions. By adopting these innovative practices, certified tanneries not only enhance their environmental performance but also position themselves as leaders in sustainable manufacturing, meeting global demands for eco-conscious production while ensuring long-term business viability.

This research underscores the importance of continued investment in sustainable technologies, process improvements, and adherence to best practices in achieving long-term sustainability in the leather industry.

Social measures – Training on the benefits of the ESG initiatives were offered to 425 employees in 2024.

SUGGESTIONS

1.Beyond compliance and LWG certification other tanneries too can adapt to benchmark practices for significant cost savings and for attracting environment conscious customers & markets

2.Social aspect can be adapted more rigorously covering 100% employees for training on ESG measures and health benefits

3.Working conditions can be improved and automation can be introduced in process that are potentially toxic and delicate to handle.

4.Possibility of using wind energy as an alternate energy source, to be explored

CONCLUSION

This study highlights the remarkable strides made by Leather Working Group (LWG)-certified tanneries in advancing sustainability through energy efficiency, water conservation, waste management, emissions control, and effective effluent treatment practices. The findings demonstrate that through operational restructuring, process optimization, and the adoption of innovative technologies, tanneries can significantly reduce their environmental footprint while maintaining economic viability. The benchmark ESG practices has resulted in significant savings in the manufacturing costs, has secured businesses from environmental conscious markets, promotes responsible raw material and chemical consumption ensuring employees and consumer safety, eliminating environmental degradation, thus saving lives on land and under water.

The social measures not only benefit the employees in terms of better occupational health and safety it also contributes to the wellbeing to all the stakeholders in the value chain and the society at large in terms of providing a cleaner and a safer environment to thrive.

As global industries continue to emphasize sustainability, the insights from this study provide a valuable roadmap for further innovation, policy development, and industry-wide adoption of greener technologies. The leather sector's commitment to sustainability will not only enhance its global reputation but also contribute significantly to a more responsible and environmentally resilient future as envisioned by United Nation's SDGs.

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