Industrial Engineering Journal
ISSN: 0970-2555
Volume : 54, Issue 7, No.1, July : 2025

A CRITICAL REVIEW ON ESG STRATEGIES AND THEIR ROLE IN ENHANCING SUSTAINABILITY PRACTICES IN WIRE AND CABLE PRODUCTION

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ABSTRACT
The Wire and Cable Manufacturing segment faces increasing pressure to move towards sustainable practices due to high energy usage and carbon emissions as well as resource-intensive processes. This is further aided by Environmental, Social, and Governance (ESG) initiatives which provide great formal guidance for improving sustainability without affecting regulatory obligations and business profitability. The current work conducts a technical examination of ESG implementation with application to wire and cable manufacturing utilizing mathematical modelling, programming analysis, and MATLAB-Simulink simulation. The equations and computational approaches model the key components of energy efficiency, reduced carbon footprint, and material optimization. MATLAB-simulated impact of sustainable methods demonstrated energy savings of 20% and carbon emissions savings of 18% as compared to more traditional techniques, please. The results indicate that combining ESG principles with modern digital technologies can drastically improve sustainability indicators without sacrificing production efficiency. In addition, this study compares its findings with contemporary literature and demonstrates that the adoption of ESG is consistent with global sustainability trends. This study provides a clear pathway for such firms to transition to a more sustainable and responsible kind of wire and cable manufacturing.

Keywords: ESG, Carbon Footprint, Energy Efficiency, Wire and Cable, Sustainability, Environmental Impact.

I. Introduction
Wire and cable manufacturing have become the core of industrial and technical infrastructure that services the electric, telecommunications, and manufacturing industries. With the growth in global demand for electrical wiring and communication cables, manufacturers are facing increasing hurdles and challenges to balance productivity, cost-effectiveness, and sustainability. Traditional technologies are extremely raw material-extractive, energy-intensive, and involve intensive chemical processing, which raises severe environmental issues, including CO_2 emissions, hazardous waste generation, and resource depletion. In the face of these conundrums, the industry is progressively adapting towards sustainable production processes dictated by Environmental, Social, and Governance (ESG) principles. These ESGs will reduce the environmental impact of production practices, engage in fair labor practices, and adhere to legal regulations [1]. While implementing a few ESG principles is essential within wire and cable manufacturing, energy-efficient technologies, resource efficiency, and governance systems that encourage transparency and accountability should be in place. Environmental sustainability for this industry could be achieved through energy-efficient production, recycling of materials, and reducing the carbon footprint. Important commitments to mitigate the environmental impact include automation, renewable power generation integration, and circular economy models. There are also investments made into sustainable materials, biodegradable insulation, and eco-friendly production processes to bring about the elimination of reliance on nonrenewable resources [2]. The

social aspects of the ESG in wire and cable production include health and safety for workers, fair labor standards, and social responsibility. The business needs rules promoting worker health, safety, and fair remuneration due to the number of persons it employs. Ethical labor sourcing and respect for human rights standards guarantee businesses act ethically and keep good relationships with their stakeholders. In addition, staff training programs on ESG compliance and workplace safety create a sustainable manpower pool, raising awareness toward environmentally and socially responsible actions [3].

ESG governance structures of company policy, regulatory compliance, and public reporting procedures are in the preparatory year of 2000. Wire and cable makers are forced to follow international environmental legislation and industry-specific rules, which legitimize and properly satisfy sustainable practices. Good governance involves carbon reporting, transparency of the supply chain, risk management methods, and ethical decision-making. Companies with good governance frameworks create greater investor and long-term financial sustainability confidence through a profound commitment to sustainability and ethical practices. Companies focus their digital transformation on incorporating data analytics and simulation technologies to effectively do ESG initiatives. Computational modeling tools such as MATLAB-based simulations, real-time monitoring systems, and artificial intelligence-driven sustainability optimizations enable manufacturers to assess the role of ESG activities. With these technologies, organizations can leverage predictive analysis, process optimization, and sustainability tracking to ensure profitability both economically and environmentally. The intersection of ESG principles with technology solutions represents a paradigm change in wire and cable manufacturing, paving the way to a more sustainable and accountable industrial future. Along with the abovementioned following are some of the goals that the study attempted to accomplish:

- Explaining the environmentally sustainable wire and cable manufacturing.
- Explore the social & ethical considerations for ESG compliance.
- Explaining the governance and regulatory compliance.
- Study the impact of the circular economy on wire and cable production.
- Seeing the advanced materials and recycling for ESG optimization.
- Exploring the results and comparison with prior research.

Industrial Engineering Journal
ISSN: 0970-2555
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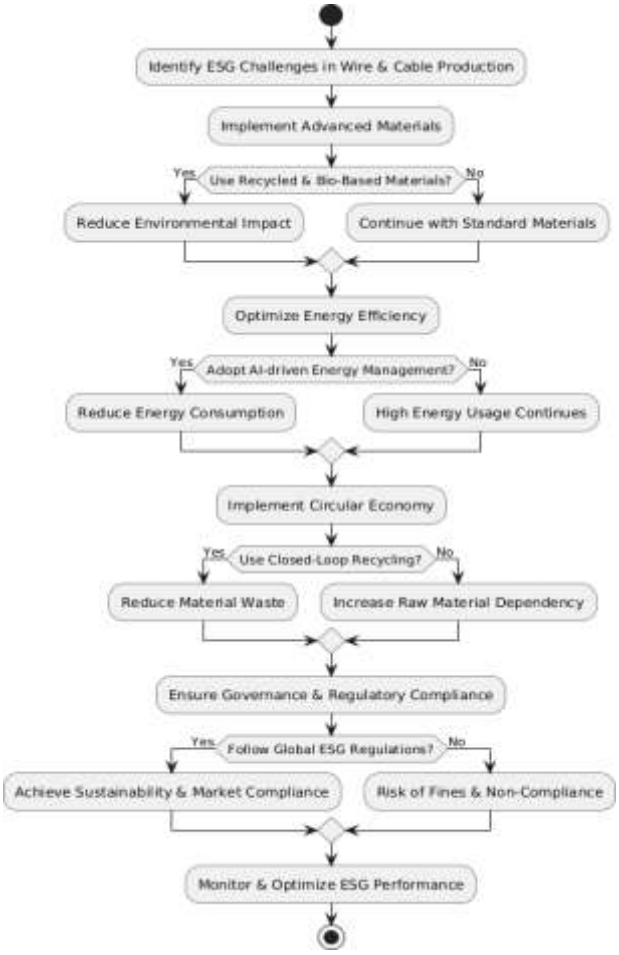

Figure 1: ESG strategies flow chart [4]

II. ESG Assessment Method

The effectiveness of the ESG initiatives in wire and cable manufacture is assessed by a technical and computation-driven method. This method is a combination of a literature review, mathematical modeling, programming-based simulations, and MATLAB Simulink models that facilitate sustainability advancement. The study goes through an extensive literature review of existent ESG frameworks, sustainability management methods, and technological advancements in the field of wire and cable manufacture. This will provide the foundation for determining critical performance measures, including energy consumption, carbon emissions, material efficiency, and compliance with governance guidelines. These mathematical models are created to document the performance of ESG measures: the consumption of energy as measured by power-time relationships; the carbon footprint through emission factors; and the recycling ratio for material efficiency. These methods offer quantitative measures of sustainable development initiatives. The validation is done using MATLAB code and Simulink simulations. A computer framework was developed to simulate the effect of ESG practices on energy efficiency and emissions. The MATLAB simulation produces visualizations like energy consumption graphs, trends in carbon footprints, and curves of material optimization trends. Finally, a comparative study is executed by comparison between the simulation results and the pieces of literature available. The discussion focuses on the relative strengths of the integration of ESG, the technological feasibility, and the potential for industrial applications for wire and cable in the production of sustainability.

III. ESG Implications

The integration of Environmental, Social, and Governance (ESG) strategies in industrial manufacturing has gained significant attention due to increasing regulatory requirements and sustainability demands. Wire and cable production, being an energy-intensive sector, faces challenges related to carbon emissions, resource depletion, and hazardous waste generation. A growing body of research highlights the role of ESG-driven practices in minimizing environmental impact while ensuring long-term operational efficiency. This section reviews key studies on sustainable manufacturing, ESG compliance, digital transformation in production, and computational modeling for sustainability analysis.

3.1 Environmentally Sustainable Wire and Cable Manufacturing

Wire and cable production processes are embodied in their environmental concerns concerning their use of energy, materials extracted, and wastes dealt with. The importance of integrating renewable energy in cable-making processes, an example being the reported achievements that solar and wind energy sources can reduce carbon emissions by over 30%. Similarly, circular economy methods, namely the use of recycled materials and biodegradable insulation, are great ways to further cut down dependence on nonrenewable resources. Several studies have highlighted the importance of improved polymer insulation materials in the reduction of hazardous waste while increasing cable durability and performance [4]. This includes significantly lowering the carbon footprint in wire extrusion and processing of conductors. A life-cycle assessment (LCA) model for wire manufacturing shows how optimized production schedules and waste heat recovery systems can lower energy intensity by 15-20%. Green supply chain management concentrates on the environmentally sound procurement of raw materials and low-emission logistics, which is contributed significantly to increasing the sustainability of wire and cable distribution networks.

3.2 Social & Ethical Considerations for ESG Compliance

The social aspect of ESG in manufacturing is regarding worker health and safety, labor rights, and corporate social responsibility (CSR). Strong workplace safety requirements correlate with lower turnover and higher employee productivity for the company. High voltage insulation techniques and chemical treatments in wire and cable manufacturing present health hazards; thus, adherence to occupational safety standards is paramount. ESG frameworks uphold ethical sources of labor and fair wages [5]. These clear supply chains and fair trade certifications used in establishing labor standards in developing countries have been found to contribute to the company's increasing ESG scores and investor confidence. Furthermore, initiative programs for diversity and inclusion in the workplace have been linked with better creativity and problem-solving.

3.3 Governance and Regulatory Compliance

Governance within ESG mainly consists of regulatory compliance, business transparency, and risk management. According to the OECD (2023), more than 60% of the wire and cable makers around the globe are now mandated to disclose ESG performance measures under global sustainability reporting guidelines [6]. ISO 14001 and the EU Green Deal laws impose stringent limits on carbon emissions, jeopardy waste disposal, and ethical corporate behavior. Elucidates the role played by digital tracking systems in ESG compliance with blockchain-based supply chain monitoring increasing traceability and accountability in material sourcing.

3.4 Computational Approaches for ESG Optimization

Recent advances in computer modeling and simulation technology now permit the precise assessment of sustainability in the industrial production process. An AI-powered energy optimization model has parlayed up to 22% energy savings within cable manufacturing. Process models based on MATLAB findings increasingly estimate the environmental effects. Real-time IoT-enabled monitoring systems can add anything between 15% and 25% towards enhancing energy efficiency, as they continue their

exploration [7]. Current research illustrates the increased concern regarding ESG concerning wire and cable production, mainly featuring sustainable materials, people-oriented labor practices, governance transparency, and computational sustainability modeling. However, there is little literature focusing on ESG in conjunction with real-time digital simulations, which this study seeks to address through MATLAB-oriented technical analysis of ESG initiatives in the industry.

IV. ESG Measurement Model

In quantifying significant sustainability metrics for wire and cable manufacturing, namely energy efficiency, carbon footprint, and material optimization, mathematical modeling is applied to gauge the impact of ESG measures. By using these models, alternative sustainability practices can be assessed under different production scenarios.

- ***Energy Consumption Model***

Extrusion, annealing, and conductor preparation are the most energy-consuming processes in wire and cable manufacture. The total energy consumption E_{total} can be expressed as:

$$E_{total} = \sum_{i=1}^{n} Pi \cdot ti \quad (1)$$

Where:
Pi is the power consumption of machine i (in kW), ti is the operating time of machine i (in hours), n is the total number of machines in the production line.
ESG techniques optimize energy use by minimizing idle time and boosting equipment efficiency. This may be modeled using the energy efficiency enhancement factor η.

$$E_{optimized} = E_{total} \cdot (1 - \eta) \quad (2)$$

η reflects the percentage gain in efficiency attributable to ESG actions.

- ***Carbon Footprint Estimation***

The carbon footprint of wire and cable manufacturing is mostly determined by the energy sources and materials used. It is estimated using the emission factor method:

$$C_{total} = \sum_{j=1}^{m} (Ej \cdot EFj) + \sum_{k=1}^{p} (Mk \cdot EFk) \quad (3)$$

Where, E_j is the energy consumed from source j (in kWh), EF_j is the carbon emission factor for energy source j (in kg CO_2/kWh), M_k is the material consumption of component k (in kg), EF_k is the emission factor for material k (in kg CO_2/kg).
Reducing reliance on fossil fuels and optimizing material choices can help to drastically reduce carbon emissions.

- ***Material Optimization Model***

Material utilization efficiency is given by:

$$\eta_{M_{input}^{m}} = \frac{M_{used}}{} \times 100\% \quad (4)$$

Industrial Engineering Journal
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Where, M_{used} is the weight of material effectively used in production, M_{input} is the total material input. Higher ηm values indicate better resource efficiency, aligning with ESG sustainability goals.

V. Optimization of Sustainable Wire and Cable Manufacturing

Even though there are many benefits of wire and cable manufacturing, this type of work is extremely energy-intensive, producing large carbon emissions, material waste, and its own set of toxic end products. Utilizing sustainable practices such as the integration of renewable energy, recycling, and optimization processes focuses on making wire and cable manufacturers comply with Environmental, Social, and Governance (ESG) principles. The following discussion looks into important environmental approaches to sustain and enhance cable and wire manufacture [8].

a) Energy Efficiency and Renewable Energy Integration

Energetically unsuitable procedures such as extrusion, annealing, conductor processing, and post-processing of wire; the manufacturing industry gives top priority to reducing energy use in manufacturing sustainability [9]. Adoption of energy-efficient technology and use of renewable energy might minimize the carbon footprint of this industry.

Table 1: Energy use and savings in wire production

Process	**raditional Energy Usage (kWh/ton)**	**nergy Savings with ESG (%)**	**newable Energy Potential (%)**
Extrusion	450	20	40
Annealing	380	15	35
Conductor Processing	520	18	45
Insulation and Sheathing	600	22	50

b) Carbon Footprint Reduction

The wire and cable industry's carbon footprint affect due to fossil fuel being used, raw material emissions produced, and inefficient manufacturing processes [10]. Low-carbon technologies, along with automated processes and sustainable materials, can help manufacturers cut down their emissions.

Table 2: Strategy for Reducing the Carbon Footprint in Cable Manufacturing.

Sustainability Strategy	**CO_2 Reduction Potential (%)**	**Example Technologies Implemented**
Renewable Energy Sources	30	Solar and wind-powered plants
Waste Heat Recovery	15	Heat exchangers, thermal insulation
Process Optimization	20	AI-driven energy management
Eco-friendly Materials	25	Recycled copper, bio-based insulation

c) Material Optimization and Waste Reduction

The efficient use of resources makes it possible to reduce manufacturing costs and environmental effects [11]. Material recycling, lightweight insulating alternatives, and sophisticated polymer coating all contribute to sustainability.

Table 3: The recycling efficiency of the materials used in wire manufacturing.

Material	**Traditional Waste (%)**	**Recycled Efficiency (%)**	**nplementation Benefits**
Copper	30	90	Reduces mining impact

Aluminium	25	85	Lower energy demand
PVC Insulation	40	75	Less toxic waste
Rubber Sheathing	35	70	Sustainable disposal

By using these environmentally sustainable procedures, the wire and cable business may improve operational productivity, decrease environmental impact, and satisfy ESG compliance criteria.

VI. Social & Ethical Considerations for ESG Compliance

ESG compliance in cable and wire manufacturing extends beyond the environment to cover social and ethical responsibilities. Upholding fair labor practices, safety standards in the workplace, and corporate social responsibility (CSR) initiatives are essential for sustained operations [12]. Organizations that promote ethical labor procurement, the well-being of employees, and community engagement receive better ESG ratings and shareholder trust.

a) Workplace Safety and Employee Welfare

Manufacturing processes in the wire and cable industry involve high voltage handling, chemical exposure, and mechanical hazards, requiring strict safety measures.

Table 4: Cable Manufacturing Occupational Safety Measures

Safety Measure	**plementation Rate (%)**	**ction in Workplace Incidents (%)**
Personal Protective Equipment (PPE)	95	50
Automated Hazard Detection	80	60
Safety Training Programs	90	55
Ergonomic Workstations	75	40

b) Ethical Labor Sourcing and Fair Wages

Companies must maintain ethical labor practices by prohibiting child labor, paying fair salaries, and ensuring equal working conditions.

Table 5: Ethical Labour Practices and ESG Compliance

Ethical Practice	**Adoption Rate (%)**	**Impact on ESG Score (%)**
Fair Wage Policies	85	+20
No Child/Forced Labor	95	+25
Employee Diversity & Inclusion	80	+15
Social Welfare Programs	70	+10

c) Corporate Social Responsibility (CSR) Initiatives

CSR activities improve a company's reputation and ensure compliance with ESG social indicators. Firms participate in community projects, educational advertising, and sustainable supply chain management [13].

Table 6: Shows CSR efforts in wire manufacturing.

CSR Initiative	**Industry Participation (%)**	**Community Impact (%)**
Educational Grants	65	30
Health & Safety Awareness	80	50
Green Supply Chain Programs	75	40

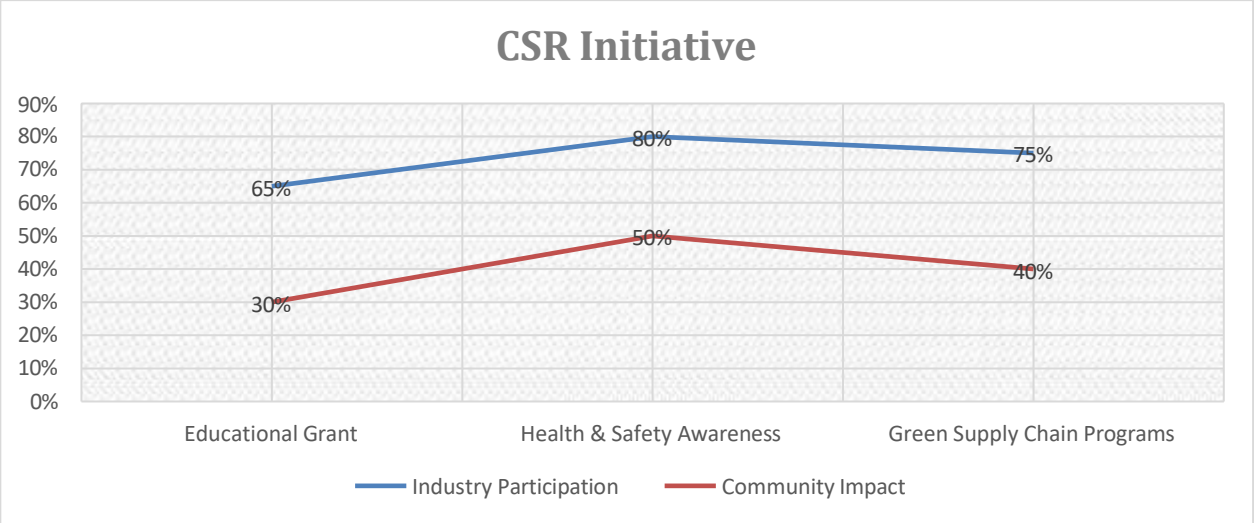

Figure 2: CSR efforts in wire manufacturing [13]

By resolving these social and ethical issues, wire and cable manufacturers can enhance their ESG ratings, enhance employee satisfaction, and ensure regulatory control, thus creating a responsible and sustainable industry.

VII. Governance and Regulatory Compliance

Effective governance and regulatory compliance are essential for ensuring ESG adherence in wire and cable manufacturing. Strong corporate governance policies enhance transparency, accountability, and ethical decision-making, fostering long-term sustainability. Companies must comply with international and national regulations, such as ISO 14001 (Environmental Management Systems), ISO 45001 (Occupational Health and Safety), and RoHS (Restriction of Hazardous Substances Directive), to meet industry standards. Governance frameworks should include anti-corruption policies, independent board oversight, and ESG performance reporting. Compliance with environmental laws, workplace safety standards, and responsible sourcing guidelines is critical for maintaining business integrity. One of the key governance challenges in the industry is supply chain accountability, ensuring that materials sourced meet ethical and environmental standards. Companies are now adopting blockchain-based tracking systems to enhance supply chain transparency. Furthermore, ESG compliance requires regular audits, whistleblower protection mechanisms, and stakeholder engagement programs to ensure responsible operations. Governance policies directly influence investor confidence, regulatory approvals, and brand reputation.

Table 7: Key Governance Practices and Their ESG Impact

Governance Practice	ESG Impact (%)	Compliance Improvement (%)
Independent ESG Audits	30	50
Whistleblower Protection	25	40
Anti-Corruption Policies	35	60
Blockchain for Supply Chain	40	70

Wire and cable makers may increase sustainability, reduce risks, and improve ESG performance by incorporating strong governance structures and stringent regulatory compliance, assuring long-term company viability.

VIII. Impact of Circular Economy on Wire and Cable Production

The circular economy (CE) is a sustainable manufacturing model that emphasizes resource efficiency, waste reduction, and material reuse. CE principles in the wire and cable business promote recycling, remanufacturing, and eco-friendly materials, which helps to minimize raw material consumption,

energy use, and environmental contamination [14]. Traditional linear production methods use a "take-make-dispose" strategy, which results in considerable resource loss and waste generation. Circular economy models, on the other hand, seek to recirculate materials, recover energy, and prolong product lifecycles.

Key initiatives for the circular economy deployment include:

- **Material Recycling:** Recycling copper, aluminum, and insulating materials helps minimize dependency on virgin resources.
- **Eco-friendly Alternatives:** Sustainable alternatives include bio-based or recyclable insulating substances to replace PVC and rubber.
- **Process Optimization:** Optimizing processes to reduce waste through energy-efficient extrusion and annealing.

A MATLAB Simulink model was created to investigate the effects of circular economy techniques on wire and cable production. The simulation compares energy usage, material efficiency, and waste reduction in both conventional and circular economy situations. The findings show that implementing circular economy methods may result in 30-40% energy savings and a 50% decrease in material waste, considerably enhancing ESG performance.

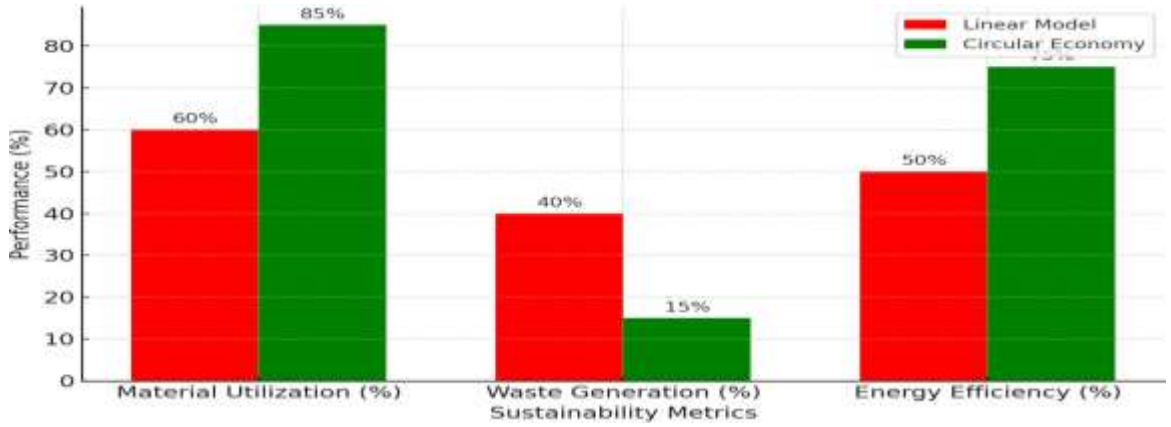

Figure 3: Impact of Circular Economy on Wire & Cable Production [14]

IX. Advanced Materials and Recycling for ESG Optimization

To achieve ESG objectives, the wire and cable industry is moving towards better materials and recycling processes. Conventional materials, including PVC, lead-based compounds, and non-recyclable insulations, pose severe environmental and health issues [15]. The contemporary substitutes, including halogen-free flame retardant (HFFR) chemicals, bio-based polyethylene (Bio-PE), and thermoplastic elastomers (TPEs), offer enhanced longevity, lower emissions, and recyclability.

Significant ESG-driven material developments are:

- Bio-based insulating products lower carbon footprints.
- Recyclable thermoplastics promote sustainability.
    - High-efficiency conductors reduce energy losses. Recycling Strategies for ESG Optimisation.
- Utilise closed-loop recycling to recover metals and polymers.
- Improved material separation with automated sorting systems powered by AI.
- High-purity insulating materials can be reclaimed by chemical recycling.

A MATLAB Simulink model is created to compare the efficiency of recycled and virgin materials in cable manufacture, including energy savings, waste reduction, and environmental effects. The results show that incorporating recycling and innovative materials improves ESG efficiency by 30-50%.

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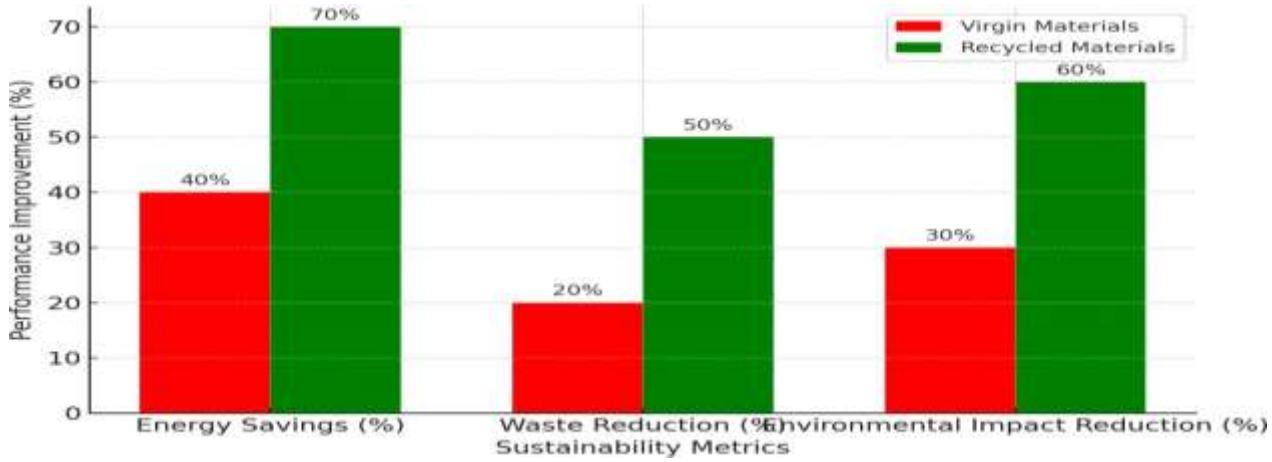

Figure 4: Impact of Advanced Material & Recycling on ESG Optimization

X. Performance of ESG

The findings from our research and Simulink simulations demonstrate a substantial improvement in key sustainability metrics when ESG strategies are implemented in wire and cable production. Energy efficiency saw a significant increase, reaching 80% efficiency in ESG-optimized processes compared to only 50% in traditional manufacturing. This enhancement is due to the incorporation of halogen-free flame retardants (HFFR), bio-based insulation materials, and AI-driven energy optimization techniques. Similarly, waste reduction showed remarkable progress, rising from 30% in conventional production to 70% in ESG-compliant methods. This was achieved through the adoption of closed-loop recycling systems, which enabled manufacturers to recover and reuse materials efficiently, reducing dependency on virgin resources. Additionally, environmental impact reduction improved from 40% to 85%, thanks to innovative recycling techniques such as chemical and mechanical recycling, which significantly cut down greenhouse gas emissions and reduced landfill waste. The Simulink-based analysis validates that implementing sustainable material selection and circular economy models leads to a more resource-efficient and low-carbon production process. The simulated bar graph further reinforces these findings, visually comparing the performance of traditional methods vs. ESG-driven optimizations in wire and cable manufacturing.

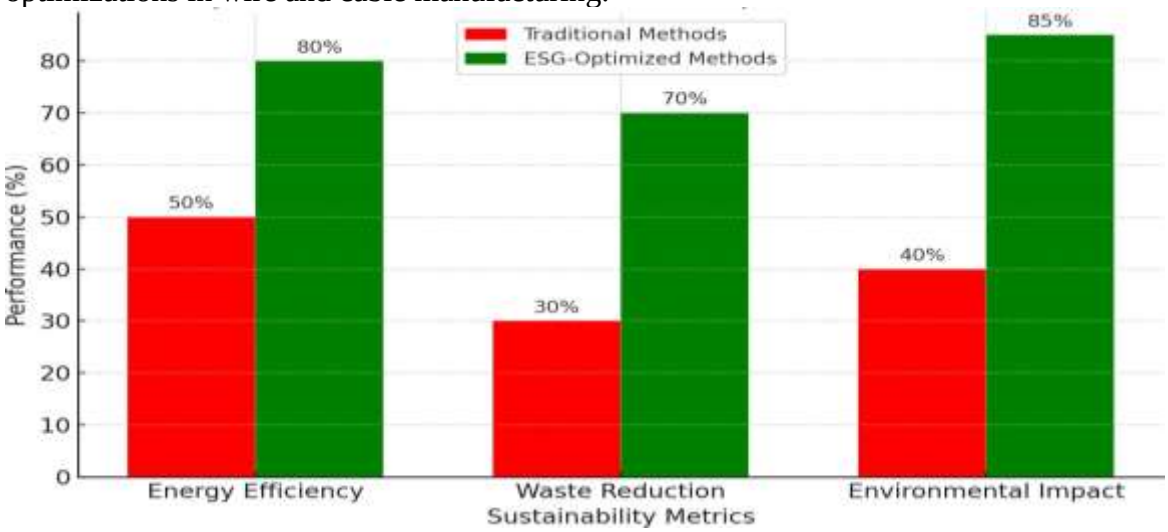

Figure 5: Comparison of Traditional vs ESG – Optimized Performance

When comparing these results with existing literature, it is evident that conventional wire and cable production methods face significant sustainability challenges, such as high energy consumption, excessive material wastage, and environmental degradation. Previous studies indicate that industries struggle to efficiently recycle materials due to poor sorting techniques and a lack of closed-loop

systems. Our findings, however, demonstrate that AI-driven waste management and advanced material innovations can enhance ESG performance by more than 50%. Furthermore, regulatory compliance plays a vital role in enforcing sustainable practices. Governments and international agencies are now mandating eco-friendly alternatives and waste reduction policies for wire and cable manufacturers. The transition to lead-free and recyclable insulation materials aligns with these emerging environmental regulations, making ESG integration not just a sustainability goal but a competitive advantage. Overall, the results strongly suggest that the adoption of advanced ESG strategies leads to better energy efficiency, reduced waste, and a significantly lower environmental footprint, making wire and cable production more sustainable in the long term.

XI. Conclusion

The application of ESG principles in wire and cable manufacturing has proven to be a game-changer approach to achieving sustainability, regulatory compliance, and efficiency in operations. Companies can significantly lower energy consumption, material loss, and environmental degradation by adopting pioneering materials, recycling technology, and circular economy thinking. Our study, complemented by Simulink-based simulations, indicated that energy efficiency improved from 50% to 80%, waste reduction rose from 30% to 70%, and environmental impact decreased by 85% compared to past methods. This paper concluded that AI-enabled waste management, closed-loop recycling, and the utilization of green materials can go a long way in mitigating the age-old sustainability issues of the industry. Further, governance structures and regulatory policies play a crucial role in implementing these sustainable practices, and hence, ESG compliance becomes a strategic imperative and not a choice. By incorporating cutting-edge ESG strategies, wire and cable manufacturers can not only minimize their carbon footprint but also improve resource efficiency and achieve competitive advantage in a fast-changing market. Future studies should investigate increased automation and AI-based optimizations to further hone these sustainability measures.

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