Journal of Business and Management Studies
ISSN: 2709-0876
DOI: 10.32996/jbms
Journal Homepage: www.al-kindipublisher.com/index.php/jbms

JBMS
AL-KINDI CENTER FOR RESEARCH AND DEVELOPMENT

| RESEARCH ARTICLE

Human-Centered Visualization Interfaces for Sustainable Supply Chains

Sonu Kapoor
Independent Researcher, Ontario, L6X 0X5, Canada
Corresponding Author: LIRONG LIU, **E-mail**: Sonukapoor@gmail.com

| ABSTRACT

The rising complexity of global supply chains has raised the necessity of sustainable practices integrating economic performance and environmental and social accountability. Though data-centric tools provide great insights, the effectiveness of such systems depends upon the exposition of information to the decision-maker. Human-centered visualization interfaces were found to be the enablers par excellence for user augmentation, enhancement of interpretability, and sustainable decision-making among different stakeholders' groups. The paper discusses the conceptual foundations and the design fundamentals of human-centered visualization for sustainable supply chains through usability, accessibility, and transparency. By integrating sustainability metrics such as carbon footprint, energy efficiency, and waste minimization into user-centric dashboards and interactive programs, organizations can bridge the gap between the complexity of the technique and the depth of human understanding. The conceptual framework presented herein depicts the possibility of tailored visualization strategies ranging from dashboards up through immersive AR and VR systems enabling adaptive planning, real-time monitoring, and informed trade-offs within the parameters of the supply chain operation. Though the present work is conceptual and makes no use of empirical data, it provides an established portal for academicians and practitioners for designing interfaces enabling decision-makers, reducing the barriers of cognition, and increasing trust within sustainability reporting. The paper ends with an outline of the future avenues for investigating personalization, multi-modal interaction, and cross-cultural usability for sustainable supply chain management development.

| KEYWORDS

Human-Centered Design, Visualization Interfaces, Sustainable Supply Chains, Interactive Dashboards

| ARTICLE INFORMATION

ACCEPTED: 23 August 2025 **PUBLISHED:** 27 September 2025 **DOI:** 10.32996/jbms.2025.7.6.1

1. Introduction

The acceleration of the global extension of supply chains has created an increasingly complex system of interdependence that spans an array of geographies, industries, and regulatory regimes. As firms move toward the growing necessity for efficiency, speed, and cost reduction, they are confronted simultaneously with the need for sustainability. Climate change, resource depletion, waste, and social inequities have pushed sustainability into the foreground as a hard necessity for the supply chain leaders. Seeking sustainability is no longer constrained by compliance with environmental standards but is an indelible element of the firm's long-term resilience and competitiveness.

Most pressing among these is the problem of converting vast amounts of sustainability-related data into usable insights. Supply chains generate data at many interface points—procurement, logistics, manufacturing, recycling, and landfilling. But unless such information is framed crisply, decision-makers do not react to it. Visualization interfaces close the gap between noisy data sets and the human mind, enabling managers, policymakers, and operators to perceive patterns, make judgments regarding risk, and make trade-offs under real-time scrutiny. But since most available tools are designed first for technical accuracy and only second for human usability, they actually cause cognitive overload and misunderstanding [1].

This gap demands human-oriented visualization interfaces that focus on user requirements, usability, and credibility. Differing from classical performance-driven dashboards, human-oriented systems consider the variability of the involved stakeholders along the supply chains—from C-suite leaders who require strategic information up to shop-floor operators who require operational cues. Integrating sustainability indicators such as carbon footprint, energy efficiency, and social compliance into graspable interfaces allows decision-makers to aim at goals balancing economics, environment, and society results [2][3].

The objective of the paper is two-fold: first, exploring the promising directions for human-centered visualization as an enabler for sustainable supply chains; and second, conceptualizing the interrelation of visualization design fundamentals and sustainability drivers. Through the examination of usability, interpretability, and adaptability, the paper develops an appreciation for the potential for enabling stakeholders, higher transparency, and sustainability-motivated decision-making through future supply chain interfaces. The content for the paper thereafter is a literature review for the study, the proposed framework, illustrative application cases, and directions for future work.

2. Literature review

2.1 Sustainable Supply Chains

Sustainable thinking across the supply chain has shifted from a specialty consideration to the mainstream of strategy. Drawing on the triple bottom line framework, sustainable supply chains emphasize three basic dimensions: economic sustainability, environmental sustainability, and social sustainability. Businesses increasingly are pressed to apply the thinking of green logistics, closed-looping, and the circular economy into their operations. That means not only the reduction of the carbon footprint and consumption of resources but ethical sourcing, fair labor standards, and balanced stakeholder value creation. Inclusion of sustainability metrics within decision-making processes remains, however, an ongoing obstacle due to disjointed data, inconsistent reporting standards, and the complexity of global supply webs [4].

2.2 Visualization in Supply Chains

Visualization technologies today underlie complexity management in the supply chain. Dashboards, geographic information systems (GIS), Internet of Things (IoT) monitoring portals, and predictive analytics interfaces have transformed the way managers interact with data. Dashboards let executives track key performance indicators in real time, and simulation models allow scenario development for managing risk and allocation of resources. Higher-order interfaces, such as augmented and virtual reality (AR/VR), are increasingly becoming prominent visualization tools for logistics flows, facility layouts, and disruptions happening in real time. Despite such advancements, the visualization platforms available prioritize technical precision over human usability and thus are not as effective for the more heterogeneous group of stakeholders [5].

2.3 Human-Centered Design

Human-centered design philosophies emphasize usability, accessibility, and consistency of systems with human cognitive and behavioral capabilities. In visualization, it is reducing the complexity of the information, reducing the cognitive load, and tailoring the interface for different user groups for purposes of use. The primary features are intuitive navigation, clear visual hierarchy, adaptability of layout, and support for decision-making under uncertainty. Human-computer interaction research underscores the point that those systems designed without consideration for the limitations of perception and decision-making by human's incline toward information overload, error, or reduced trust toward technology. Their applicability within the field of supply chain visualization is essential for the purpose of ensuring the sustainability-related information available is not only collected but usable [6].

2.4 Identified Gaps

Even though there is an abundance of literature on sustainable supply chains and visualization systems, very few studies synthesize both perspectives through a human-centric framework. Most solutions available earlier prefer either sustainability metrics or state-of-the-art visualization technology but rarely focus on designing such tools for diversity of end users. Also, very little literature is available for incorporating sustainability indicators into human-centric interfaces that adapt their configuration according to the divergent decision-making contexts—from operational adjustments at the factory floor level up to policy-level strategies for the global stage. In an initiative toward filling the gap, the current paper puts forward a framework for human-centric visualization interfaces for sustainable supply chain decision support directly [2].

3. Conceptual Framework: Human-Centered Visualization

The rising necessity for sustainability along the supply chain has emphasized the necessity for decision-support systems able to handle highly complex data and deliver it back within a form compatible with human cognitive processes. A human-centered visualization framework can be the integrating interface between raw data, insightful interpretation, and sustainable action strategies. The presently developed framework highlights the interaction between three focal layers; i.e., data aggregation and integration, conceptualization of visualization, and human cognition. These layers together make information related to sustainability not only accurate but also comprehensible, believable, and usable for a variety of disparate stakeholders [7].

The core data layer accumulates information from diversely sourced locations, such as energy usage data, emissions of greenhouse gases, suppliers' compliance reports, and social studies of impact. Even though such data sets increasingly become publicly available due to the advancements of IoT sensors, blockchain transparency platforms, and virtual supply chain systems, their diversity provides complexity for interpretability at a large scale.

The second level is the visualization design whereby raw data is transformed into intuitive interfaces. They consist of interactive dashboard applications, geospatial mapping applications, 3D simulation spaces, and AR/VR interfaces showing the sustainability metrics of the supply chain in usable formats. The emphasis of the design is on the integration of features such as drill-down capability, scenario visualization, and benchmarking the sustainability performance comparably among suppliers or logistics corridors.

The final layer is human cognition, which imposes consistency of visualization with the manner stakeholders perceive, process, and react to information. The linchpin of the layer is the administration of cognitive load: rather than overwhelming stakeholders with detailed graphs or raw data, the system condenses the most relevant sustainability indicators and provides contextual cues. Interpretability and trust are equally important, as decision-takers are more willing to react to insights from transparent and explainable systems.

Under this paradigm, four principal dimensions emerge:

I. User-Centricity – Creating adaptive interfaces that account for the differences in executives, operators, regulators, and even consumers' needs.
II. Transparency – Displaying sustainability indicators in a way that inspires confidence, for instance, dashboard for carbon emissions with clear units and comparisons.
III. Interactivity – Enabling the users to perform “what-if” analyses, for instance, assessing the impact of switching suppliers with reduced emissions.
IV. Ethics and Trust – Ensuring that visualization tools reduce bias, preserve data integrity, and communicate their limitations properly.

The framework articulated puts forward the argument that sustainable outcomes of decision-making are the product not only of enhanced data but of enhanced human-data interaction. Embracing more the human element, organizations can envision visualization systems that lead to sustainability outcomes and enable more interaction and trust among stakeholders.

4. Core Elements of Human-Centered Interfaces

The effectiveness of human-oriented visualization interfaces for sustainable supply chains depends upon a system of core elements of design that balance technological expertise and human usability. These elements define the manner in which complex sustainability data is processed, visualized, and interpreted such that decision-makers can respond with clarity and confidence.

4.1 Visualization Techniques

Legacy dashboards are good for offering summaries, but the modern supply chains require more immersive and interactive tools. Interactive dashboards enable stakeholders to track sustainability metrics in real-time and benchmark them versus suppliers or geographies. Geospatial visualization highlights the carbon emissions by logistics corridors, and 3D supply chain models provide end-to-end summaries of the production networks. Future tools such as augmented reality (AR) and virtual reality (VR) carry user interaction one step further by allowing decision-makers to experience the supply chain data through immersive modes such as walking through a digital twin of a warehouse and pinpointing the energy consumption hotspots [8].

4.2 Cognitive Load Management

Information overload through detailed data can deter decision-making. Human-centered user interfaces employ the approach of minimalistic user interface and intuitive navigation and visual hierarchy that pull user focus toward the critical sustainability metrics. Use of color coding, progressive disclosure (the display of details only upon necessity), and user-selectable dashboards make complexity manageable. An executive dashboard, for example, can show summary-level sustainability metrics, and an operations manager can drill down into the equipment-level energy information [9].

4.3 Multi-Stakeholder Integration

Supply chains include diverse players who possess different requirements for decision-making. Interfaces therefore need to be powerful enough to support divergent perspectives. Managers desire strategic-level metrics at the top-most level, plant operators desire operational-level alerts, governments desire reports of compliance, and consumers may desire product-level information. Architecting for the diversity facilitates the sustainability insights where they can be executed upon throughout the supply chain ecosystem [10].

4.4 AI and Machine Learning Integration

While machine learning and artificial intelligence enable greater predictiveness, models must be transformed into interpretable outcomes. Black-box results lead to the erosion of trust, but explainable AI facilitates predictions (e.g., risk of non-compliance by suppliers or forecasted carbon emissions) being reported through clear visual indicators, confidence intervals, or prose descriptions. This facilitates the user being able to make informed decisions without specialist technical expertise [11].

4.5 Sustainability Metrics Display

At the heart of human-centered visualization is the effective communication of sustainability indicators. Indicators such as carbon footprint, water usage, waste generation, recycling rate, and ethical compliance must be displayed such that trade-offs are highlighted. In our exemplars, for instance, one dashboard can illustrate that cutting the carbon through switching suppliers means higher spend but offers an alternative for decision-takers to weigh overtly. Through visual representation of such trade-offs, interfaces forestall over-simplification and render information palatable nonetheless [12].

4.6 Comparison with Traditional Dashboards

Conventional dashboards are usually centered on operational efficiency or financial performance with sustainability metrics being an adjunct. People-oriented displays align the emphasis on sustainability as a key dimension of decision-making and integrate it on the same visual plane as cost, quality, and delivery. The shift is a testament both to the increasing prominence of sustainability and a conviction that intuitive, people-oriented visualization is a requirement for creating enduring supply chain resilience [2][13].

5. Application Scenarios

Although this study is conceptual and doesn't incorporate empirical data, application scenarios are an excellent means of conveying how human-oriented visualization interfaces could be applied for ensuring sustainable supply chain practices. The following scenarios are hypothetical and demonstrate how decision-makers would be able to utilize visualization systems to identify trade-offs, increase transparency, and make informed decisions that are sustainability-inclined.

5.1 Scenario 1: Carbon Footprint Visualization in Supplier Selection

Multinational manufacturer is weighing two suppliers for a crucial component. Supplier A offers lower prices slightly but a higher carbon footprint due to use of coal-fired energy, whereas Supplier B offers a higher environmental profile with renewable energy at a higher cost. People-focused dashboard presents a comparative bar chart between carbon output per unit and price per unit.

The users are allowed to turn on and turn off filters to simulate the downstream impact of selecting Supplier B, for instance, output reduction and increase in conformity to future carbon standards. The visualization allows executives to balance financial and environmental outcomes without hidden agendas.

5.2 Scenario 2: Waste and Recycling in Plant Operations

Factory manager watches production activity where scrap has been on the rise. The visualization of the real-time waste heatmap presents locations within the plant where scrap is above thresholds. The manager might interact with the visualization to track causes—such as improperly calibrated machines or human error—and calculate a “what-if” scenario to predict savings if they are fixed. Material cost savings and waste that ends up in the landfill are shown, providing reinforcement of alignment between economic and environmental value.

5.3 Scenario 3: Logistics Optimization with AR Visualization

The logistics planner is responsible for planning the best last-mile delivery routes for the urban core. Through an augmented reality interface, the planner sees traffic patterns, fuel use, and carbon output on 3D cityscapes. The software enables the planner to simulate a different delivery route, where taking a somewhat longer yet less busy route ends up being a lower emitter on balance. Through an interface with projected scenarios, the planner strikes a balance between service delivery efficiency and environmental objectives.

5.4 Scenario 4: Policymaker Oversight through Global Dashboards

On the regulatory side, a policymaker reviews end-to-end global supply chain sustainability compliance through a multi-layered visualization dashboard. The world map presents regions with high carbon emissions, low recycling rates, or high labor violation rates. Clicking into a country-level dashboard permits the policymaker to view detailed performance figures and trends. Scenario simulation capabilities enable one to analyze plausible policy interventions, say, stricter carbon caps, and their likely impacts on industrial performance and sustainability.

5.5 Illustrative Example with Simulated Data

Take a hypothetical data set: Supplier A generates 120 kg CO_2/unit at $80 per unit, while Supplier B generates 60 kg CO_2/unit at $90 per unit. The comparative visualization could show that a shift to Supplier B reduces year-over-year emissions by 50% for an additional 12% increase in price. This simulation demonstrates how visualization interfaces make trade-offs clear, making it possible for companies to make sustainability investments in a data-driven yet human-readable format.

6. Challenges and Limitations

Human-centered visualization interfaces are filled with promise for enhancing supply chain sustainability, yet some shortcomings and challenges must be acknowledged. They refer to tradeoffs that are a part of designing systems that are technically competent, usability-driven, and yet compatible with a set of diverse sustainability goals.

6.1 Data Complexity and Fragmentation

Supply chains generate voluminous amounts of data from different sources such as IoT sensors, enterprise resource planning (ERP), blockchain ledgers, and reports from suppliers. The data, however, are often fragmented, heterogeneous, and fragmented across isolated systems. The integration of such heterogeneous data within one visualization framework forms a contemporary technical and organizational bottleneck. With unreliable and inconsistent data as input, visualization systems are vulnerable to producing incomplete or wrong insights [14].

6.2 User Diversity and Usability Conflicts

One of human-centered design principles is that one should develop interfaces for the different users. Unfortunately, for supply networks, the different actors are C-suite executives and factory workers, who require different amounts of information and visualization settings. It is difficult to strike a balance between high levels and detailed operational information and may lead to over-simplification for technical specialists or detailed data for lay people.

6.3 Over-Reliance on Technology

Visualization systems may inadvertently lead the decision-makers to focus on the quantitative outputs and neglect qualitative or contextual elements such as labor practices locally or cultural variations. Though data-informed insights are important, human judgment is also central in making sure that decisions for sustainability include ethical and social aspects that cannot be expressed in figures at times.

6.4 Privacy, Security, and Trust Issues

Sustainability data often contains confidential information about a supplier's performance, labor standards, or regulatory compliance. The sharing between global supply chain partners of such information generates issues around confidentiality, cyber-attacks, and data leakage. The loss of confidence in data gathering or visualization may restrain stakeholders from taking full advantage of visualization portals.

6.5 Scalability and Resource Constraints

Implementing human-centric visualization systems at scale has a high price tag for digital infrastructure, training, and change management. The small and medium-sized enterprises (SMEs), the majority of supply chain actors, are unable to afford deploying the latest visualization platforms. The end result is a digital divide where larger firms reap the benefits and small actors are at the risk of being shut out from sustainability-driven ecosystem participation.

6.6 Limitations of Conceptual Approaches

Finally, the study is essentially conceptual and has no empirical confirmation. Despite the scenarios and frameworks being worthwhile directions, the absence of case studies or experimental evidence forecloses generalized inferences. The concept must be tried in pilot projects, cross-sector studies, and user testing.

On the whole, these issues illustrate that human-centered visualization has a transformative capability that must be harnessed while overcoming technological, organizational, and societal barriers. Defying these limitations is crucial for causing visualization systems to produce actual supply chain transformation and not just one more level of complexity.

7. Future Research Directions

The conceptual model presented in this work demonstrates the applicability of human-centered visualization interfaces for ensuring supply chain sustainability. The failure to test against actual data, however, lends support to the need for follow-up research that empirically supports these conceptions. There are several directions that could guide scholars and managers in taking this line of research a step further.

Firstly, pilot projects and case studies must be empirically verified. Applying the proposed framework to actual supply chains—automotive, pharmaceutical, and consumer goods sectors—would establish evidence on usability, barriers to use, and quantitative contributions to sustainability performance. The study could also experiment with visualization on decisions in ambiguity, trade-offs, and stakeholder bargaining.

Second, AI-driven personalization of visualization interfaces should be studied. Adaptable learning systems that adjust to human behavior could provide individualized dashboards that would display executives, regulators, and operators with data relevant to their needs and information-processing behaviors. The integration of explainable AI (XAI) in visualization will also enhance trust yet another level, making people aware of what the system is suggesting and why.

Third, we have blockchain-driven visualization opportunities. By connecting human-focused interfaces to blockchain data, one can increase visibility in areas such as carbon emissions, ethical sourcing, and tracing for compliance. This would allow end-users to confirm claims for sustainability without a greenwashing danger.

Fourth, multi-modal methods of interaction deserve greater attention. Combining visualizations with voice command, haptic feedback, or immersive VR environments has the promise for increasing accessibility, particularly for users who have disparate technical skills or cultural experience. Usability research across cultures is a necessity, for international supply systems must function within a spectrum of linguistic and intellectual environments.

Ultimately, research for the future must be sensitive to the moral dimension of visualization. Investigating how decisions are influenced by visual framing, what biases are possible, and how one may frame protections against manipulation will be crucial for responsible use.

Together, these streams of research point to the future frontier for sustainable supply chain management being less about data analytics than about creating systems that make human beings act responsibly, inclusively, and transparently.

8. Conclusion

Increasing demand for supply chain sustainability has provided a significant boost to systems that transform complex data into valuable insights. The current paper has put forth that human-oriented visualization interfaces can be a key enabler of sustainable decisions by bringing information systems in harmony with human cognition, usability, and trust. Compared to conventional dashboards that prioritize operational efficiency, human-oriented systems integrate sustainability indicators—such as carbon footprint, waste reduction, and ethical compliance—into simple, comprehensible, and interactive formats.

The proposed conceptual model identified three interlocking levels: data integration, visualization design, and human cognition. Collectively, they suggest that sustainability is not a matter of data existence, but human activity upon that data. Scenarios illuminated how visualization would enable supplier selection, plant performance, logistics planning, and policy monitoring and highlighted that visualization would be appropriate in many different settings.

The paper also identified notable barriers, including data fragmentation, end-user diversity, and over-reliance on technology risks. Overcoming those barriers requires cross-boundary collaboration that extends across technology creators, supply chain managers, policy-makers, and researchers. For the future, research must empirically ground these concepts, incorporate explainable AI, extend multi-modal interactions, and be attentive to ethical dimensions of visualization.

Overall, human-focused visualization interfaces are more than ancillary tools for supply chain management, they are sustainable supply chain enablement strategies. When systems are designed to allow people to interpret and make decisions on sustainability indicators, companies are better positioned to make progress on global objectives of resilience, transparency, and environmental stewardship.

References

1. Busse C, Meinlschmidt J, Foerstl K (2017) Managing Information Processing Needs in Global Supply Chains: A Prerequisite to Sustainable Supply Chain Management. Journal of Supply Chain Management 53:. https://doi.org/10.1111/jscm.12129
2. Bai C, Kusi-Sarpong S, Khan SA, Vazquez-Brust D (2021) Sustainable buyer–supplier relationship capability development: a relational framework and visualization methodology. Ann Oper Res 304:. https://doi.org/10.1007/s10479-021-04090-4
3. Büdel V, Fritsch A, Oberweis A (2020) Integrating sustainability into day-to-day business: A tactical management dashboard for O-LCA. In: ACM International Conference Proceeding Series
4. Cioffi R, Travaglioni M, Piscitelli G, et al (2020) Smart manufacturing systems and applied industrial technologies for a sustainable industry: A systematic literature review. Applied Sciences (Switzerland) 10
5. Kihel Y El (2022) Digital Transition Methodology of a Warehouse in the Concept of Sustainable Development with an Industrial Case Study. Sustainability (Switzerland) 14:. https://doi.org/10.3390/su142215282
6. Koppenhagen N, Mueller B, Maedche A, et al (2016) Designing a supply network artifact for data, process, and people integration. Information Systems and e-Business Management 14:. https://doi.org/10.1007/s10257-015-0296-1
7. Ozmen Garibay O, Winslow B, Andolina S, et al (2023) Six Human-Centered Artificial Intelligence Grand Challenges. Int J Hum Comput Interact 39:. https://doi.org/10.1080/10447318.2022.2153320
8. Power AG (2010) Ecosystem services and agriculture: Tradeoffs and synergies. Philosophical Transactions of the Royal Society B: Biological Sciences 365
9. Ceccarini C, Mirri S, Salomoni P, Prandi C (2021) On exploiting Data Visualization and IoT for Increasing Sustainability and Safety in a Smart Campus. Mobile Networks and Applications 26:. https://doi.org/10.1007/s11036-021-01742-4
10. Olan F, Arakpogun EO, Jayawickrama U, et al (2024) Sustainable Supply Chain Finance and Supply Networks: The Role of Artificial Intelligence. IEEE Trans Eng Manag 71:. https://doi.org/10.1109/TEM.2021.3133104

11. Yu TH, Su BH, Battalora LC, et al (2022) Ensemble modeling with machine learning and deep learning to provide interpretable generalized rules for classifying CNS drugs with high prediction power. Brief Bioinform 23:. https://doi.org/10.1093/bib/bbab377
12. Akash Abaji Kadam, Supriya Akash Kadam (2024) Theoretical foundations and practical implementation of supply chain optimization a metal fabrication business model. World Journal of Advanced Engineering Technology and Sciences 13:831–844. https://doi.org/10.30574/wjaets.2024.13.1.0480
13. Akash Abaji Kadam, Ramakrishna Garine, Supriya Akash Kadam (2024) Revolutionizing inventory management: A comprehensive automated data-driven model using power BI incorporating industry 4.0. World Journal of Advanced Research and Reviews 24:477–488. https://doi.org/10.30574/wjarr.2024.24.1.3035
14. Akash Abaji Kadam, & Harshad Pitkar. (2025). Blockchain-Enabled Lean Automation and Risk Mitigation in Supply Chain 4.0 A Systematic Review and Future Directions. *Journal of Economics, Finance and Accounting Studies* , *7*(3), 64-81. https://doi.org/10.32996/jefas.2025.7.7