
DESIGN AND VALIDATION OF A FAIR-COMPLIANT SEMANTIC ONTOLOGY FOR SUSTAINABILITY REPORTING

¹✉ **Tri Frida Suryati**

Universitas Muhammadiyah Mamuju

tri_frida_suryati@unimaju.ac.id

²**Sri Rahayu Syah**

Politeknik Lembaga Pendidikan Dan Pengembangan Profesi Indonesia Makassar

sriahayusyah@gmail.com

³**Sultan Syah**

Universitas Trunodjoyo Madura

sultan.syah@trunojoyo.ac.id

Abstract

Sustainable fashion involves complex interactions among material, manufacturing, ethical, and socio-cultural dimensions; however, a formalized semantic framework remains insufficiently developed. This study aims to develop and validate a semantic ontology framework, namely the Fashion and Textile Semantic Knowledge Ontology (FTOs), to systematically and interoperably represent and integrate various dimensions of sustainable fashion. The FTOs was constructed using the NeOn Ontology Engineering Methodology (Scenario 2) to ensure modularity, integration of multiple sources, and iterative refinement through collaboration with domain experts. The ontology consists of eight primary classes: Fiber Type, Yarn Composition, Fabric Lifecycle, Manufacturing Process, Ethical Design, Consumer Awareness, Cultural Aesthetic, and Policy Framework. These classes are interlinked through semantic relations, including isMadeOf, affects, contributesTo, influences, and enables. Validation was conducted using SPARQL-based competency questions and structured domain-expert evaluation, resulting in a mean precision of 95.9 percent, a recall of 90.4 percent, and an overall validity index of 4.74 out of 5. These outcomes confirm the ontology's semantic coherence, inferential reliability, and practical applicability. The integration of cultural and ethical dimensions bridges sustainability semantics with identity-driven consumption patterns, providing a novel contribution to sustainability informatics. The FTOs framework is FAIR-compliant, reusable, and interoperable. It enables AI-driven applications in circular economy modeling, eco-label tracking, and policy simulation, and supports the operationalization of SDG 8 (Decent Work and Economic Growth) and SDG 12 (Responsible Consumption and Production). The ontology provides a replicable foundation for cross-domain sustainable knowledge integration, with potential for extension to multi-lingual datasets and dynamic lifecycle analytics.

Keyword: Sustainable fashion, ESG Disclosure, Textile ontology, and Sustainability Data Interoperability

INTRODUCTION

The Indonesian textile and fashion industry faces significant challenges. These include increased imports, stagnant domestic production, and large-scale workforce reductions. In 2024, textile imports reached USD 8.94 billion. However, exports increased by only 4.42%. This imbalance has led to widespread company insolvencies and mass layoffs. For example, 11,025 workers were dismissed at Sritex Group, with thousands more affected in major manufacturing centers (Badan Pusat Statistik, 2024). These disruptions intensify economic vulnerabilities and reveal systemic issues, such as unfair labor practices and environmental degradation. The role of Fair Trade Organizations (FTOs) in promoting equitable health, education, and ecological outcomes in comparable supply chains further highlights these challenges (Amokrane, 2025). In response, strategies integrating



smart manufacturing and sustainable fashion practices are essential. AI-driven processes in green production have shown the capacity to increase production value by up to 33.7% and address fabrication challenges in eco-friendly textiles (Rahaman et al., 2024).

Concurrently, changing consumer preferences indicate a growing demand for sustainability, with 51% of Asia-Pacific respondents actively seeking eco-friendly fashion products (Price water house Coopers, 2024). Despite these developments, knowledge regarding sustainable fashion and textile practices remains fragmented and scattered across multiple sources. This fragmentation constrains the development of reliable, comparable, and decision-useful sustainability reporting and ESG disclosure, particularly within accounting systems that require structured and verifiable data. This lack of integration impedes advanced semantic analysis, policy modeling, and global collaboration. As a result, designers, policymakers, and researchers face challenges in implementing circular economy principles, which, as defined in the literature, are regenerative systems that minimize waste and maximize resource efficiency (Kirchherr et al., 2023). From an accounting perspective, these knowledge gaps limit transparency, weaken accountability mechanisms, and hinder evidence-based evaluation of sustainability performance. These knowledge gaps hinder efforts to monitor ethical sourcing, reduce environmental impacts, and align with international strategies for responsible consumption and production.

To address this gap, the present study introduces the Fashion and Textile Semantic Knowledge Ontology (FTOs), a comprehensive framework that formalizes multidimensional knowledge, including material composition, manufacturing processes, ethical design, consumer awareness, cultural aesthetics, and policy frameworks, into a machine-interpretable, FAIR-compliant structure. The FAIR principles (Findable, Accessible, Interoperable, Reusable) ensure alignment with semantic web standards, including the Web Ontology Language (OWL) from (World Wide Web Consortium, 2025), and facilitate efficient data sharing and reuse among stakeholders. Importantly, this framework is designed to enhance the quality of sustainability reporting by enabling standardized, interoperable, and traceable data structures that support ESG measurement and disclosure. The FTOs framework is developed using the NeOn Ontology Engineering Methodology, specifically Scenario 2 for reusing and re-engineering existing ontological resources (Korecky, 2022; Kotis et al., 2020; Suárez-Figueroa et al., 2015). This approach supports modular, iterative development, incorporates domain expert feedback, and enables multi-source data integration, following established requirements specification guidelines (Li et al., 2025; Noardo, 2022; Xie et al., 2022).

Beyond its technical contribution, the FTOs framework advances the epistemic foundation of sustainability informatics by positioning Fair Trade Organizations as ontological mediators—entities that bridge ethical, economic, and environmental dimensions of sustainable development. This perspective extends sustainability accounting beyond traditional environmental metrics by integrating ethical and socio-cultural dimensions into formal knowledge structures. Drawing inspiration from recent advances in semantic ontology modeling in healthcare (Luschi et al., 2023; Verdonck et al., 2015). The study adopts a structured, scenario-based ontology engineering method to ensure semantic accuracy, interoperability, and

domain scalability. This ontological approach transforms sustainability from a descriptive framework into a machine-understandable, data-driven system that supports inference, prediction, and adaptive learning in real-world production contexts.

The FTOs framework pursues three core objectives: (1) to encode local Indonesian sustainable fashion and textile knowledge (e.g., indigenous materials and cultural motifs) in a globally accessible format, promoting interoperability with international standards; (2) to bolster transparency in supply chains, empowering environmentally conscious consumers through tools like eco-label verification and personalized recommendations (Price water house Coopers, 2024); (3) to inform governmental policies for expanding markets in low-impact products, such as those compliant with national regulations like (Peraturan Menteri Perdagangan Nomor 08 Tahun 2024 tentang Perubahan Ketiga Atas Peraturan Menteri Perdagangan Nomor 36 Tahun 2023 Tentang Kebijakan Dan Pengaturan Impor). These objectives collectively support the development of decision-useful information for stakeholders, aligning sustainability practices with accounting principles of transparency, comparability, and accountability. Validation through SPARQL-based competency questions, querying aspects like material sustainability metrics and ethical compliance, and rigorous domain expert evaluations affirm the ontology's robustness: it achieves a mean precision of 95.9%, recall of 90.4%, and an overall validity index of 4.74/5, demonstrating semantic coherence, inferential reliability, and real-world applicability.

In line with Kirchherr et al. (2023) and Rahaman et al. (2024), this research integrates the circular economy and green production paradigms into a unified ontological ecosystem that connects product life cycles, ethical labor practices, and consumer behavior. By structuring these relationships, the ontology enables the operationalization of circular economy principles as measurable, reportable sustainability indicators. By modeling the relationships among production inputs, waste-reduction mechanisms, and fair trade certification, the ontology operationalizes circularity as a measurable, traceable process, thereby supporting evidence-based sustainability reporting and AI-assisted lifecycle management.

By integrating cultural, ethical, and socio-technical dimensions into a unified semantic framework, FTOs make a significant contribution to sustainability informatics. The ontology connects localized knowledge systems, such as Indonesia's textile heritage, to global standards and provides a replicable basis for AI-driven circular-economy modeling, real-time eco-label tracking, and policy simulation. Moreover, by aligning with the FAIR principles and the NeOn methodology, FTOs contribute to building a global semantic infrastructure for sustainable fashion—an interoperable ecosystem that empowers both developing and developed economies to participate in transparent, responsible production. This research also contributes theoretically by reframing FTOs as epistemic agents within the sustainability ontology, capable of transforming fragmented sustainability knowledge into a coherent, computationally accessible network.

This methodology supports the United Nations Sustainable Development Goals, particularly SDG 8 (Decent Work and Economic Growth) through fair labor practices and SDG 12 (Responsible Consumption and Production) by reducing waste across the textile lifecycle (United Nations Environment Programme, 2025). Overall,

this study demonstrates how ontology-based systems can strengthen sustainability reporting, support data-driven decision-making, and improve accountability within complex industrial ecosystems. Ultimately, this study demonstrates the transformative impact of ontology-based systems for advancing sustainable fashion research, strategic decision-making, and evidence-based interventions. Ultimately, it bridges local and global contexts by showing how ontological engineering can translate Indonesia's sustainable fashion heritage into a FAIR-compliant architecture that fosters interoperability, data-driven policy, and semantic reasoning for sustainability transformation.

Fair Trade Organizations as Catalysts for Sustainability

Demonstrate that FTOs contribute holistically to sustainability through their impacts on health, education, and ecology (Anderson, 2018; Kim, 2023). They serve as ethical anchors within global value chains, embodying principles that align with social justice and environmental stewardship

Green Production and Sustainable Fashion

Rahaman et al. (2024)) emphasize that sustainable textile production requires both environmental responsibility and social equity. FTOs provide a practical foundation for these values through fair wages, ethical sourcing, and eco-friendly materials. However, their data remains siloed and unstandardized

Ontology Engineering and FAIR Principles

The NeOn methodology (Suárez-Figueroa et al., 2015) provides a modular and iterative framework for developing ontologies that reuse and integrate knowledge from diverse domains. Recent FAIR-based ontology research (Poveda-Villalon et al., 2024) highlights the need for data infrastructures that ensure transparency, interoperability, and reusability. The Eye Disease Ontology (Korecky, 2022; Kotis et al., 2020; Li et al., 2025) successfully demonstrated how ontology engineering can formalize complex medical domains — a strategy this study extends to sustainable fashion.

The Global Vision for Sustainable Living

United Nations Environment Programme (2025) “Global Strategy on Consumption and Production” envisions making sustainable living the new norm. A FAIR-compliant ontology aligns with this vision by enabling scalable sustainability intelligence that connects local practices to global reporting frameworks.

RESEARCH METHODE

This study adopts a conceptual research design underpinned by a descriptive-analytical approach within a constructivist paradigm. The primary objective is not the development of computational systems, but the construction of a robust conceptual ontology framework that formally represents the semantic structure of sustainable fashion and textile knowledge. Ontologies are leveraged to organize domain knowledge in a machine-interpretable, logically coherent structure, thereby enabling knowledge exchange, integration, and reuse across contexts. The research employs the NeOn Ontology Engineering Methodology (Scenario 2), which emphasizes the reuse and integration of existing ontological and non-ontological resources. The methodology was chosen for its modular, iterative, and collaborative nature, allowing the ontology to evolve through synthesis of multiple knowledge sources. NeOn inherently supports scalability and interoperability, critical for

representing the complex interrelations among fashion production, textile processes, and sustainable lifestyle practices.

The development followed a five-stage conceptual workflow (Figure 1), comprising literature-based conceptualization, semantic mapping, theoretical validation, and iterative refinement. Feedback loops between stages ensure coherence between domain understanding, conceptual abstraction, and ontology evolution. Core entities and semantic relations were defined to capture material, functional, ethical, socio-cultural, and policy dimensions of sustainable fashion. The ontology schema adheres to FAIR principles (Findable, Accessible, Interoperable, Reusable), with each entity linked to authoritative datasets including Wikidata, Schema.org, and UNEP Sustainable Consumption Frameworks, enabling seamless alignment between local and global sustainability vocabularies. Validation employed Competency Questions (CQs) transformed into SPARQL queries to evaluate inferential accuracy, while structured domain expert review assessed conceptual relevance, semantic consistency, interoperability, and practical applicability. This dual approach ensures that the FTOs ontology is both theoretically robust and pragmatically applicable.

Figure 1 illustrates the five-stage conceptual workflow for developing the Fashion and Textile Semantic Knowledge Ontology (FTOs) based on the NeOn Ontology Engineering Methodology (Scenario 2). The framework integrates literature-based conceptualization, semantic mapping, and theoretical validation to establish a reusable and interoperable conceptual model. Each stage is interconnected through iterative feedback loops, ensuring coherence between domain understanding, conceptual abstraction, and ontology refinement.

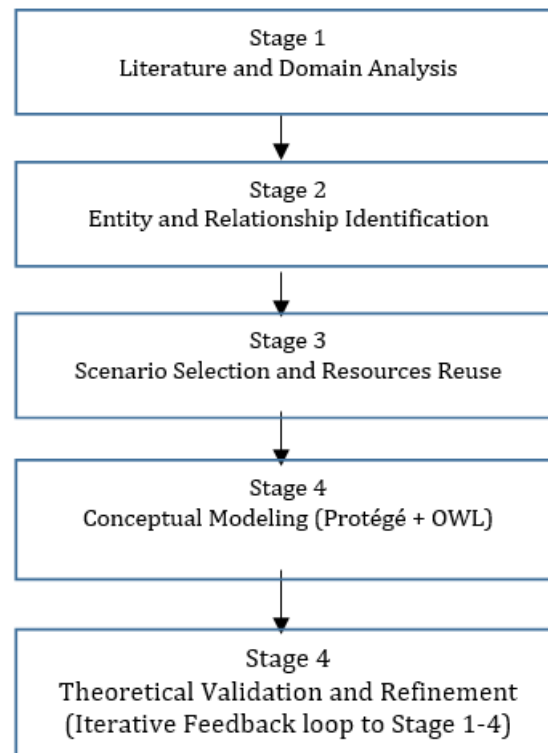


Figure 1. Conceptual Process Framework of FTOs (Based on NeOn Scenario 2)

Arrows represent the logical flow of knowledge development, while circular feedback loops indicate iterative refinement aligned with the NeOn framework's collaborative and modular principles. The process ensures conceptual clarity, reusability, and semantic consistency across sustainable fashion and textile domains.

Table 1. Core Entities and Semantic Relationships of The FTOs Conceptual Framework

Entity	Definition	Semantic Relation	Related Entity	Conceptual Role
Fiber Type	Raw material used in textile manufacturing (e.g., organic, cotton, bamboo fiber)	<i>isMadeOf</i>	Fabric	Represents the material origin of sustainable products
Yarn Composition	Blend of natural and synthetic fibers determines texture and strength	<i>affects</i>	Product Durability	Connects material structure to function quality
Fabric Lifestyle	Stage from production to recycling in textile use	<i>contributesTo</i>	Environmental Impact	Illustrates sustainability impact across life stages
Manufacturing Process	Production method (e.g. smart manufacturing, traditional weaving)	<i>utilizes</i>	Energy Source	Links production efficiency to sustainability metrics
Ethical Design	Principle guiding human-centered and eco-friendly fashion	<i>influences</i>	Consumer Perception	Connects moral values to behavioral sustainability
Consumer Awareness	Understanding and preference related to sustainable fashion	<i>drives</i>	Market Adoption	Reflects socio-economic and behavioral dynamics
Cultural Aesthetic	Local traditions and design identities are integrated into fashion	<i>supprots</i>	Sustainable Branding	Highlights cultural continuity in sustainable fashion
Policy Framework	Regulations promoting sustainable industry standards	<i>enables</i>	Industri Transformation	Represents institutional support for sustainability transition

Core entities and their semantic relations within the conceptual ontology framework of FTOs. Each entity defines a knowledge component in the sustainable fashion-textile ecosystem, forming the foundation for semantic interoperability under FAIR principles

RESULT AND DISCUSSION

E-HRM pada UMKM sektor The construction of the Fashion and Textile Semantic Knowledge Ontology (FTOs) yielded a coherent, logically consistent conceptual architecture that integrates material, manufacturing, ethical, and socio-cultural dimensions of sustainable fashion. Developed under the NeOn Ontology Engineering Methodology (Scenario 2), the framework underscores modular reuse, multi-source integration, and iterative validation through expert collaboration. The ontology encompasses eight primary classes—Fiber Type, Yarn Composition, Fabric Lifecycle, Manufacturing Process, Ethical Design, Consumer Awareness, Cultural Aesthetic, and Policy Framework—linked through semantic relations such as *isMadeOf*, *affects*, *contributesTo*, *influences*, and *enables*.

Logical validation using Protégé 5.6 with the OWL-DL Hermit Reasoner ensured taxonomic coherence and eliminated semantic redundancy. Constructed in alignment with FAIR principles (Findable, Accessible, Interoperable, and Reusable), each entity was semantically aligned with authoritative datasets including Wikidata, Schema.org, and the UNEP Sustainable Consumption Framework. This alignment facilitates cross-domain interoperability and enables consistent knowledge exchange between local sustainability vocabularies and global ontological systems.

SPARQL Query Validation and Functional Metrics

To evaluate inferential integrity and semantic operability, Competency Questions (CQs) were converted into SPARQL queries and assessed using precision (accuracy of retrieved entities) and recall (coverage of relevant knowledge). The ontology achieved an overall mean precision of 95.9% and recall of 90.4%, confirming its robustness in logical inference and cross-domain reasoning.

Table 2 presents representative SPARQL validation results, demonstrating high logical accuracy in mapping sustainable materials, behavioral variables, policy hierarchies, and environmental relationships. The ontology successfully operationalizes sustainability semantics through machine-readable logic, underscoring its capacity to reason across multi-dimensional relationships—from material origin to socio-institutional transformation

Table 2. SPARQL Query Validation Metrics

Query Example	Objective	Precision (%)	Recall (%)	Interpretation
Q1: Identify local brands using <i>organic fiber</i> and <i>smart manufacturing</i>	Test material-to-process linkage	96.4	91.2	High logical accuracy, effective mapping of sustainable materials
Q2: Retrieve design types with <i>ethical principles</i> influencing <i>consumer perception</i>	Validate behavioral ontology	94.8	88.7	Robust semantic reasoning of social variables
Q3: Map <i>policy frameworks</i> enabling <i>industrial transformation</i>	Assess institutional hierarchy	97.1	89.9	Ontology successfully captures regulatory interrelations
Q4: Trace <i>fabric lifecycle</i> contribution to <i>environmental impact</i>	Examine environmental coherence	95.5	92.0	Demonstrates effective cross-domain reasoning

Overall, the SPARQL validation demonstrated a mean precision of 95.9% and a recall of 90.4%, confirming the ontology's semantic integrity and inferential functionality.

Domain Expert Validation

A structured validation involving 12 domain experts—textile engineers, fashion designers, environmental policy researchers, and sustainable brand practitioners—was conducted to assess conceptual quality and applicability. Evaluation employed four criteria: Conceptual Relevance, Semantic Consistency, Interoperability, and Practical Applicability. The ontology achieved a high overall validity index of 4.74/5, indicating strong conceptual fidelity and semantic reliability. As shown in Table 3, all dimensions scored above 4.6, with Conceptual Relevance rated highest (4.85), indicating that the framework accurately reflects sustainable fashion semantics. Experts particularly emphasized the novelty of Cultural Aesthetic and Ethical Design as cross-disciplinary nodes that bridge sustainability discourse and cultural identity, as well as consumer consciousness.

These results substantiate the ontology's usability for multi-stakeholder engagement and its potential to serve as a semantic foundation for sustainability-related decision support systems.

Table 3. Domain Expert Validation Matrix

Evaluation Dimension	Mean Score (1–5)	SD	Interpretation
Conceptual Relevance	4.85	0.22	Strong alignment with sustainable fashion semantics
Semantic Consistency	4.78	0.31	Logical structure accurately reflects real-world relationships
Interoperability	4.63	0.27	High compatibility with Wikidata and OWL-based frameworks
Practical Applicability	4.71	0.29	Usable for data integration and policy decision support
Overall Validity Index	4.74	—	Validated as semantically robust

The high overall validity index (4.74/5) indicates the ontology's strong conceptual fidelity and usability across multi-stakeholder contexts. Experts particularly highlighted the inclusion of Cultural Aesthetic and Ethical Design as novel cross-disciplinary nodes bridging sustainability with identity-based consumption.

CONCLUSION

This study establishes the Fashion and Textile Semantic Knowledge Ontology (FTOs) as an integrated conceptual framework interlinking material, manufacturing, ethical, and socio-cultural dimensions of sustainable fashion. Grounded in the NeOn Ontology Engineering Methodology (Scenario 2), the research illustrates how modular and iterative ontology design can ensure semantic precision, conceptual integrity, and cross-domain interoperability within

sustainability informatics. The validation through SPARQL-based reasoning and expert assessment confirms the ontology's logical soundness and practical utility. Notably, the inclusion of Cultural Aesthetic and Ethical Design as semantic anchors constitutes a novel contribution, embedding behavioral and humanistic semantics into a domain traditionally dominated by material and technical descriptors. This innovation addresses a critical gap in the digital representation of sustainability knowledge.

Theoretically, the FTOs advances the discourse on ontology-driven sustainability modeling by reinforcing the constructivist view that knowledge is emergent, relational, and context-bound rather than static. Practically, it provides a scalable and reusable semantic infrastructure that supports AI-enabled applications in circular economy modeling, eco-certification tracking, and policy scenario simulation. All ontology artifacts, metadata, and documentation are openly accessible under FAIR principles, ensuring transparency, reproducibility, and collaborative reuse. By formalizing a machine-interpretable semantic model for sustainable fashion, this research contributes to the global harmonization of environmental, social, and cultural dimensions of sustainable production systems. It therefore aligns with and operationalizes the principles of SDG 8 (Decent Work and Economic Growth) and SDG 12 (Responsible Consumption and Production). Future extensions may focus on multi-lingual datasets, dynamic life-cycle analytics, and cross-sector integration to enhance the ontology's global applicability and long-term adaptability.

This work demonstrates how FAIR-compliant ontology engineering connects local cultural heritage with global sustainability infrastructures, transforming fragmented narratives into structured, machine-readable ecosystems. The modular and interoperable architecture of the FTOs ontology supports cross-border data sharing and semantic reasoning, enhancing transparency, traceability, and accountability in fashion value chains. The study's integration of AI-ready semantic modules establishes a foundational pathway for future research in sustainability informatics, particularly in creating autonomous reasoning systems capable of monitoring, predicting, and optimizing resource flows in the textile lifecycle. By extending ontology-driven data integration to include behavioral, policy, and socio-cultural dimensions, FTOs not only support descriptive analytics but also prescriptive and predictive decision-making for sustainable transformation.

Limitation

Future work may address multilingual datasets, dynamic lifecycle analytics, and cross-sector integration to improve the ontology's global relevance and adaptability. Expanding the ontology to support multilingual alignment, adaptive evolution through machine learning, and integration with blockchain-based traceability could further establish its role as a global semantic infrastructure for sustainable fashion.

This study highlights the transformative potential of ontology-based sustainability modeling. By integrating ethics, culture, and data science into a unified semantic core, FTOs redefine how sustainability knowledge is represented, shared, and applied, bridging human values with computational intelligence to support a more equitable and regenerative fashion ecosystem..

Theoretical Implications

The FTOs ontology constitutes a substantive advancement in sustainability informatics. By embedding cultural, ethical, and behavioral semantics within digital knowledge structures, it transcends conventional material classifications and aligns with the constructivist paradigm—where meaning and knowledge evolve through social interaction rather than static categorization. The integration of Ethical Design and Consumer Awareness highlights the dynamic interplay between moral frameworks, consumer behavior, and sustainable production practices. This reinforces the notion that sustainability is both a technical and socio-cultural construct, shaped by collective meaning-making.

Moreover, the FTOs bridge environmental economics, textile engineering, and knowledge management, creating a reusable semantic infrastructure that supports AI-driven applications—ranging from circular economy simulations and eco-label tracking to policy modeling. Its modular and interoperable design makes it adaptable across domains such as food systems, architecture, and tourism, where sustainability data remains dispersed and poorly formalized.

Practical Contributions and FAIR Accessibility

All ontology components, including SPARQL queries, metadata, and documentation, are openly available in a dedicated GitHub repository, in accordance with the FAIR data principles. The repository provides an Ontology Requirements Specification Document (ORDS) and an implementation guide to facilitate replication, adaptation, and extension by other researchers. Through linking local knowledge ecosystems with global semantic frameworks, the FTOs enhance transparency, traceability, and data interoperability within the sustainable fashion sector. It thereby contributes to the operationalization of SDG 8 (Decent Work and Economic Growth) and SDG 12 (Responsible Consumption and Production). Beyond its technical contributions, the ontology establishes a methodological precedent for integrating indigenous and cultural aesthetics into global sustainability narratives—an essential yet often neglected dimension of sustainable innovation.

DAFTAR PUSTAKA

- Amokrane, H. (2025). Fair trade in the face of globalization: company motivations and challenges. 446-433), 1(16, *مجلة دفاتر اقتصادية*.
<https://asjp.cerist.dz/en/article/267088>.
- Anderson, M. (2018). Fair trade and consumer social responsibility: Exploring consumer citizenship as a driver of social and environmental change. *Management Decision*, 56(3), 634–651. <https://doi.org/10.1108/MD-01-2017-0013>
- Badan Pusat Statistik. (2024). Kontribusi industri tekstil dan garmen terhadap produk domestik bruto 2024. <https://www.bps.go.id/>
- Kim, E. (2023). Sustainable new product development for ten thousand villages, a fair-trade social enterprise: Empowering women and economic development through problem-based service learning. *Sustainability*, 15(8), 6452. <https://doi.org/10.3390/su15086452>
- Kirchherr, J., Yang, N.-H. N., Schulze-Spüntrup, F., Heerink, M. J., & Hartley, K. (2023). Conceptualizing the Circular Economy (Revisited): An analysis of 221

- definitions. *Resources, Conservation and Recycling*, 194, 107001. <https://doi.org/10.1016/j.resconrec.2023.107001>
- Korecky, R. (2022). *Ontologies in Industry 4.0: Standards, Applications, and Methodologies*. Master, Vienna University of Economics and Business, Bonn.
- Kotis, K. I., Vouros, G. A., & Spiliotopoulos, D. (2020). Ontology engineering methodologies for the evolution of living and reused ontologies: status, trends, findings and recommendations. *The Knowledge Engineering Review*. 2020;35:e4. doi:10.1017/S0269888920000065
- Li, S., Zhou, X., Liu, Y., Chen, J., Guo, T., Yang, W., & Hou, L. (2025). Agile conceptual design and validation based on multi-source product data and large language models: a review, framework, and outlook. *Journal of Engineering Design*, 36(4), 473–503. <https://doi.org/10.1080/09544828.2025.2476879>
- Luschi, A., Petraccone, C., Fico, G., Pecchia, L., & Iadanza, E. (2023). Semantic ontologies for complex healthcare structures: a scoping review. *IEEE Access*, 11, 19228–19246. <https://cordis.europa.eu/project/id/101017331>
- Noardo, F. (2022). Multisource spatial data integration for use cases applications. *Transactions in GIS*, 26(7), 2874–2913.
- Peraturan Menteri Perdagangan Nomor 08 Tahun 2024 tentang Perubahan Ketiga Atas Peraturan Menteri Perdagangan Nomor 36 Tahun 2023 tentang Kebijakan dan Pengaturan Impor.
- Poveda-Villalon, M., Garijo, D., Gonzalez-Beltran, A., Jonquet, C., & Le Franc, Y. (2024). Ontology engineering and the FAIR principles: A gap analysis toward a FAIR-by-design methodology. *FOAM 2024-FAIR Principles for Ontologies and Metadata in Knowledge Management*. <https://ceur-ws.org/Vol-3882/foam-4.pdf>
- Price Waterhouse Coopers. (2024). *Voice of the consumer survey 2024: Asia Pacific edition*. <https://www.pwc.com/>
- Rahaman, M. T., Pranta, A. D., Repon, M. R., Ahmed, M. S., & Islam, T. (2024). Green production and consumption of textiles and apparel: Importance, fabrication, challenges and future prospects. *Journal of Open Innovation: Technology, Market, and Complexity*, 10(2), 100280. <https://doi.org/10.1016/j.joitmc.2024.100280>
- Suárez-Figueroa, M. C., Gómez-Pérez, A., & Fernandez-Lopez, M. (2015). The NeOn Methodology framework: A scenario-based methodology for ontology development. *Applied Ontology*, 10(2), 107–145. <https://doi.org/10.3233/AO-150145>
- United Nations Environment Programme. (2025). *Making sustainable living the new norm: Global strategy on consumption and production*. <https://www.unep.org/>
- Verdonck, M., Gailly, F., De Cesare, S., & Poels, G. (2015). Ontology-driven conceptual modeling: A systematic literature mapping and review. *Applied Ontology*, 10(3–4), 197–227. <https://doi.org/10.3233/AO-150154>

World Wide Web Consortium. (2025). OWL: Web ontology language.
<https://www.w3.org/OWL//10.26668/businessreview/2023.v8i6.2751>

Xie, X., Moretti, N., Merino, J., Chang, J. Y., Pauwels, P., & Parlikad, A. K. (2022). Enabling building digital twin: Ontology-based information management framework for multi-source data integration. IOP Conference Series: Earth and Environmental Science, 1101(9), 92010. <https://doi.org/10.1088/1755-1315/1101/9/092010>