Pakistan Journal of Life and Social Sciences
www.pjlss.edu.pk

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Scopus

https://doi.org/10.57239/PJLSS-2024-22.2.00722

RESEARCH ARTICLE

Sustainability as a Mediator of Artificial Intelligence's Impact on Reverse Logistics: Insights from the Energy Sector

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ARTICLE INFO

Received: Jul 28, 2024

Accepted: Oct 19, 2024

Keywords

Predictive Analytics for Returns

Decision Support Systems

Optimizing Resource Usage

reverse logistics, sustainability

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ABSTRACT

This study aims to understand how the nexus of sustainability mediates between reverse logistics and AI in the energy sector and what kind of impact can be expected on RL from AI. The study, rooted in Resource-Based View (RBV) and Dynamic Capabilities Theory (DCT) examines the integration between AI-enabled processes and recycling sustainability on one hand and significant improvement of reverse logistics operations performance. The study employs structured questionnaires to collect primary data from industry leaders and professionals of key stakeholders in the energy sector. A Partial Least Squares Structural Equation Modeling (PLS-SEM) method is utilized to measure the influence of AI on sustainability performance and reverse logistics. The results show that AI, given the reverse logistics process, constitutes a substantial improvement in sustainability performance as an empirical outcome. The role supports the idea of incorporating sustainability into AI logistics, which is essential in creating sustainable, efficient logistics solutions. The report emphasized that AI technologies should be flexible to sustainability objectives, providing companies in the energy sector with a more complex and eco-sensitive market edge. The current study is also considered important due to the contribution of empirical evidence on sustainability as a mediator between AI and reverse logistics literature. The insights will benefit industry practitioners and policymakers who intend to utilize AI for sustainable logistics in the energy sphere.

INTRODUCTION

The energy industry is the most resource-intensive sector but at the same time, has one of the most complex supply chain operations and significant environmental burden as well(Ali, 2022).The energy sector is caught between a rock and a hard place trade profit margins for sustainability or optimize resource usage with more immediate operational needs(Salhab et al., 2023). From its beginnings, Artificial Intelligence (AI) has identified itself as a tool capable of acting disruptively on supply chains; and through efficiency gains and sustainability improvements this can be transferred to different industries, including energy management services (Rehman et al., 2023).The use of artificial intelligence-driven predictive analytics and advice system has been trending in specific areas of reverse logistics such as material management production waste, and return processing which all together plays a strategic role in the sustainability of supply chains (Hatamlah, Allan, et al., 2023).AI can alleviate the burden of reverse logistics processes by creating more accurate return predictions, making faster decisions, and eliminating waste. Nevertheless, the role of technology is not everything for AI efficiency since the sustainability issues also have a significant mediator effect in explaining how AI affects reverse logistics (Daoud, Taha, et al., 2024). Through the sustainability mediation lens, this research addresses how AI technologies alleviate reverse logistics inefficiencies and cycle time losses by offering better resource conservation and environmental performance possibilities. While the penetration of AI in supply chains has deepened, existing literature has largely emphasized its initial implications for operational excellence. There is a significant gap in sustainability mediation, specifically within the energy efficiency sector, to handle AI and reverse logistics(Hatamlah, Allahham, Abu-AlSondos, Al-junaidi, et al., 2023). To fill this gap, this research focuses on exploring the impact of AI and sustainability through reverse logistics and how sustainability can increase the performance of implementing artificial intelligence-based logistic initiatives(Hatamlah, Allahham, Abu-AlSondos, Al-junaidi, et al., 2023). This is an intriguing study as it will give the energy sector some insights into how, in the longer run, these AI-powered predictive analytics and decision support systems by that crucial sustainable mindset can optimize resource utilization to enhance reverse logistics operations(Hatamlah, Allahham, Abu-AlSondos, Mushtaha, et al., 2023). The findings of this research can guide industry practitioners and policymakers on the need to capitalize on AI technologies in line with sustainability goals, thereby improving reverse logistics performance. Also, this study adds to academic research by offering input on sustainability being one of the main facilitators for AI to be fully exploited in reverse logistics(Jawabreh et al., 2023). With the energy spectrum in flux, these findings are a guidepost for firms looking to navigate operational efficiency with environmental responsibility in an increasingly cost-conscious and eco-friendly economy. Based on this problem statement, the following research questions are formulated:

RQ1: How does AI impact the efficiency and effectiveness of reverse logistics processes in the energy sector?
RQ2: What role does sustainability play in mediating the relationship between AI and reverse logistics in the energy sector?
RQ3: How do AI-driven sustainability practices contribute to overall organizational performance in the energy sector through the improvement of reverse logistics?

This research is organized as follows. Section 2 provided an extensive Background on the literature about sustainability as a mediator between AI and reverse logistics. The methodology: a way of collecting data and verifying the hypothesis is set forth in section 3 Findings were presented in Section 4, and an extensive discussion of the implications for theory and practice was provided in Section 5 which explores the implications for both theory and practice.

2. LITERATURE REVIEW

2.1 Reverse Logistics

Reverse logistics is the process of managing the return of goods, materials, or equipment from the end customer back through the supply chain for reuse recycling, repair or proper disposal(Allahham & Ahmad, 2024). In the energy sector, reverse logistics can help promote sustainability because it helps to offer better recovery and reuse of resources in an efficient way. It is one of the most important activities within a firm or between different consumers and companies, as reverse logistics may dramatically decrease one of the harmful factors for both environmental and operational goals (Almustafa, n.d.). Studies have shown that combining conventional reverse logistics with innovative technologies such as artificial intelligence supports resource recovery operations, promoting sustainability in the supply chain (Allahham, Sharabati, Al-Sager, et al., 2024). AI predictive analysis can also improve reverse logistics and make it more efficient by predicting returns and smoothing the way for the flow of goods back to the system(Allahham et al., 2023).

2.2 Sustainability

AI and reverse logistics in the energy sector: A case study of a growing symbiotic relationship with sustainability incentivization Reverse logistics is responsible for sustainable practices that attempt to reduce the undesirable effects on the environment through resource conservation, waste reduction, and, more importantly, reuse of materials(Alkhazaleh, n.d.). On the other hand, sustainability steers towards making reverse logistics processes effective in terms of economic and other environmental objectives (Atieh Ali, Sharabati, Allahham, et al., 2024). Some previous research findings also argue that incorporating sustainability into reverse logistics could improve the overall efficiency of supply chains, notably in resource-intensive sectors such as energy (Shehadeh et al., 2024). This sustainability integration helps companies to secure sustainable environmental results while driving operational efficiency(Alrjoub et al., 2021).

2.3 Predictive Analytics for Returns

Further, AI-enabled predictive analytics are being employed to predict returns and plan the reverse logistics (Allahham, Sharabati, Almazaydeh, et al., 2024). Based on previous performance and upcoming developments, by figuring out when to expect returns and how they will come through AI offers firms a practical solution even for resource allocation. In the energy field, predictive analytics optimizes the use of resources, including returned goods and materials that are sent to be either reused or recycled (Atieh Ali, Sharabati, Alqurashi, et al., 2024). This practice can lower waste and hence raise the sustainability of reverse logistics service. There are opportunities for increased operational efficiency and improved environmental sustainability when using AI-driven predictive analytics to inform return management strategies by supporting more effective decision-making around resource allocation (View of EFFECTS OF ARTIFICIAL INTEGRATION AND BIG DATA ANALYSIS ON ECONOMIC VIABILITY OF SOLAR MICROGRIDS_ MEDIATING ROLE OF COST BENEFIT ANALYSIS.Pdf, n.d.).

2.4 Decision Support Systems

Developing an AI-powered Decision Support System (DSS) is fundamental to improving reverse logistics in resource-dependent industries like energy (Sharabati, Awawdeh, et al., 2024). DSS leverages AI to analyze data and output more confidently motivated decisions; One area of reverse logistics, where AI-based DSS can be highly relevant is in stepping in to offer alternatives for organizations who are determined to work towards claiming returns management processes which makes the best possible use of returned things or materials and hinges on material value-added options providing them with a business opportunity(Daoud, Sharabati, et al., 2024). Companies that integrate AI-powered after-sales DSS with reverse logistics operations are better equipped to achieve their sustainability targets without compromising operational efficiency(Sharabati, Rehman, et al., 2024).

2.5 Optimizing Resource Usage

The use of AI helps in reducing the cost of bringing new applications to being able to calculate profit potential. In the energy industry, which is so integral to resource preservation, AI can also help companies reduce waste (Atta et al., 2023), By spotting opportunities for materials recycling or reuse. Based on all data collected with respect to resource consumption, AI algorithms can learn and isolate patterns that result in inefficiencies that require a company´s process adjustment and the correct use of resources. It helps in achieving the sustainability of reverse logistics operations by reducing waste and improving resource utilization(Bataineh, A. Q., Abu-AlSondos, I. A., Almazaydeh, L., El Mokdad, S. S., & Allahham, M. (2023). Enhancing Natural Language Processing with Machine Learning for Conversational AI., 2023). Combining this with the utilization of AI in resource optimization makes reverse logistics accomplish operational goals as well as broader sustainability objectives(Demirbag et al., 2006).

2.6 Sustainability as a Mediator

Sustainability is a mediator between AI and reverse logistics in this industry, even in the energy industry, where environmental issues are integrated into the standard business environment (Deb et al., 2024). Therefore, sustainability is a mediator in the AI and reverse logistics relationship to ensure technological advancements result in positive environmental impacts. Reverse Logistics processes can be improved by AI-driven initiatives with predictive analytics and DSS, however when sustainability is added to these strategies, its power-usability reach at peak (Rodríguez-Espíndola et al., 2020). This means that integrating AI with sustainability goals can help companies achieve economic and environmental gains to enhance their overall performance. The AI-based introduction to reverse logistics processes can help streamline reverse logistic efforts like changes in the energy sector by making it much more sustainable and cost-effective. Predictive analytics, decision support systems, and resource optimization tools form the foundations for these organizations to operate efficiently in reverse logistics without sacrificing environmental sustainability. Sustainability is also an essential mediator in this relationship, guaranteeing AI-based innovations deliver more than just higher efficiency straightforwardly to their respective environmental and organizational strategies in the long term. The results of this literature review indicate that without considering sustainability policies, executives may not be able to fully benefit from the holistic potential of AI and strategic reverse logistics solutions in the energy industry.

3. Hypothesis Development

3.1 Predictive Analytics for Returns and Reverse Logistics

In the energy sector, predictive analytics, which is facilitated by AI, is now indispensable in reverse logistics as it enables organizations to predict returns and, hence, plan for their logistics strategy (Aparecida et al., 2020). Knowing when and from where the returns will happen helps to optimize reverse logistics by reusing those resources that can be reused, thereby minimizing waste. Through predictive analytics, companies will have real-time efficient reverse logistics management and thus help them to support sustainability objectives in ensuring re-utilized, re-engineered, or environmentally sound goods are returned (Barrera et al., 2024). The research also showed substantial scope for predictive analytics to improve reverse logistics effectiveness, indicating its potential as an important part of sustainability performance improvement in the sector. Therefore, the study posits the following hypotheses:

H1: Predictive analytics has a significantly positive effect on reverse logistics.

H2: Predictive analytics has a significantly positive effect on sustainability performance.

H3: Predictive analytics has a significantly positive effect on reverse logistics, mediated by sustainability performance.

3.2 Decision Support Systems and Reverse Logistics

AI-based Decision Support Systems (DSS) are used for the optimization of the reverse logistics process, which performs real-time analysis and provides actionable information(William et al., 2024)AI-supported DSS facilitates reverse logistics planning for energy companies, by helping them make informed decisions on resource utilization inventory management, and logistics planning which is the cornerstone of reverse logistics in the energy sector. DSS for reverse logistics can help to improve decision-making processes in order to have higher sustainability content in opportunities and waste less and use resources (Marei et al., 2024). Many studies established that AI-based DSS can significantly reverse logistics efficiency and sustainability performance, thus constituting a critical agent of sustainable logistics strategies. Consequently, the following hypotheses are proposed:

H4: Decision Support Systems have a significantly positive effect on reverse logistics.

H5: Decision Support Systems have a significantly positive effect on sustainability performance.

H6: Decision Support Systems have a significantly positive effect on reverse logistics, mediated by sustainability performance.

3.3 Optimizing Resource Usage and Reverse Logistics

For reverse logistics, which is the core nature of energy sector resource conservation (Goczek et al., 2021)and consequently efficient usage of resources are the most important points. We can design AI-powered systems that identify waste and pollution sources in real-time, doing everything from redirecting essentially-useful materials to other use-cases recycling, or figuring out how materials can be utilized more efficiently. Reduced Environmental Impact: Improved resource utilization reduces environmental footprint by applying less waste, which is commonly found in operational and reverse logistics processes (Saleheen et al., 2014). Reverse logistics processes benefit quite nicely from AI as resource allocation can be highly optimized thanks to it. Thus, the following hypotheses are developed:

H7: Optimizing resource usage has a significantly positive effect on reverse logistics.

H8: Optimizing resource usage has a significantly positive effect on sustainability performance.

H9: Optimizing resource usage has a significantly positive effect on reverse logistics, mediated by sustainability performance.

3.4 Sustainability and Reverse Logistics

Within the energy sector, sustainability has become an important aspect in reverse logistics, resulting from the increasing demand for reduction of environmental impact and enhancement of resource efficiency (Lerman et al., 2022). Reverse logistics sustainability focuses on the reduction of waste, emissions, and environmental impacts with increasing reuse of materials. Integrating sustainability with reverse logistics operations can increase the level of a firm's environmental performance and improve operational efficiency(Reynolds, 2024). They point out the success in terms of long-term performance that companies can achieve when considering sustainability while implementing actions related to reverse logistics, which benefits the sustainability of supply chains at higher levels. Based on these insights, the following hypothesis is proposed:

H10: There is a positive relationship between sustainability performance and reverse logistics.

This hypothesis-building further provides insight into the role of sustainability as a moderator between AI-driven processes and reverse logistics in the energy sector. Improved reverse logistics via predictive analytics, decision support systems, and resource optimization can significantly enhance both operational efficiency and sustainability, ushering in a new era in the way we use and reuse energy.

3.5 Integrating Theoretical Perspectives: Dynamic Capabilities and Resource-Based View in the Energy Sector

This study brings together the two paradigms of Dynamic Capabilities Theory (DCT) and Resource-Based View (RBV) to present a unique theoretical framework for realizing the potential of AI-driven systems in enabling organizations within the energy sector to achieve sustainability objectives by improving reverse logistics fulfillment. Firms must adapt, combine, and recombine internal and external resources to meet the demands of shifting environments (Teece et al., 1997) as DCT holds. AI-based Predictive Analytics, Decision Support Systems (DSS), and Resource Optimization Tools are dynamic capabilities in reverse logistics that help firms streamline operations and enhance sustainability performance (Dubey et al., 2018). The literature review shows that AI technologies make reverse logistics more adaptable, enhance resource allocation, and support sustainability requirements as the most important factors. This is in accordance with the DCT perspective that development lies in the re-configuration of resources and capabilities to match environmental threats and opportunities. Reverse logistics processes in the energy sector are resource-intensive, and therefore their optimization through AI-driven systems is indispensable for both sustainability and profitability (Mansour et al., 2022). Using AI means firms can predict returns, use resources to their best potential, and minimize waste, which in turn empowers them to meet sustainability aims. The Resource-Based View (RBV) expands this perspective on the role of AI-driven systems and sustainable reverse logistics in line with their potential to be valuable, rare, inimitable, and non-substitutable (VRIN) resources (Barney, 1991). Under the RBV perspective, AI technologies and green logistics practices are considered strategic resources that enable organizations to achieve a competitive edge. Artificial intelligence (AI) is another way organizations can improve the efficiency of reverse logistics as well as initiate activities that incorporate sustainability into their practice, which also allows for an enhanced company reputation and compliance with various regulations, including those being implemented in the energy sector that focuses mainly on environmental issues (Khan et al., 2023). Incorporating DCT and RBV offers a powerful theoretical grounding to unpack how AI-powered systems moderate the linkage between reverse logistics and sustainability. For the DCT, in particular, employing AI frameworks that can be reconfigured over time to adhere to evolving environmental regulations and sustainability commitments is a key area of focus when it comes to keeping its operations lean. These AI-driven processes, from an RBV perspective, represent strategic resources that grant sustainable competitive advantages in the longer term by reducing waste, using resources, and enhancing performance sustainability (Madhani, 2021). Thus, this study integrates dynamic capabilities and resource-based views and posits that AI-driven systems are dynamic capabilities and strategic resources interacting with reverse logistics to achieve sustainability performance in the energy sector. This dual-theoretical lens explains how firms can develop sustainability-oriented capabilities and achieve a competitive advantage by incorporating AI technology into reverse logistics operations(Shahparvari et al., 2021).

3.6 Research Framework

The study highlights the benefit of AI-based technologies and sustainability approaches in boosting reverse logistics and reducing energy companies' organizational performance(Yu et al., 2020). The proposed research model can contribute rich insights to researchers and practitioners, helping them make strategic decisions to improve operational efficiency and sustainability outcomes. Sustainable was used to demonstrate how AI-driven strategies can affect reverse logistics processes and, ultimately, organizational performance, then impacting both lower-cost and higher-level service(Schlüter et al., 2021).

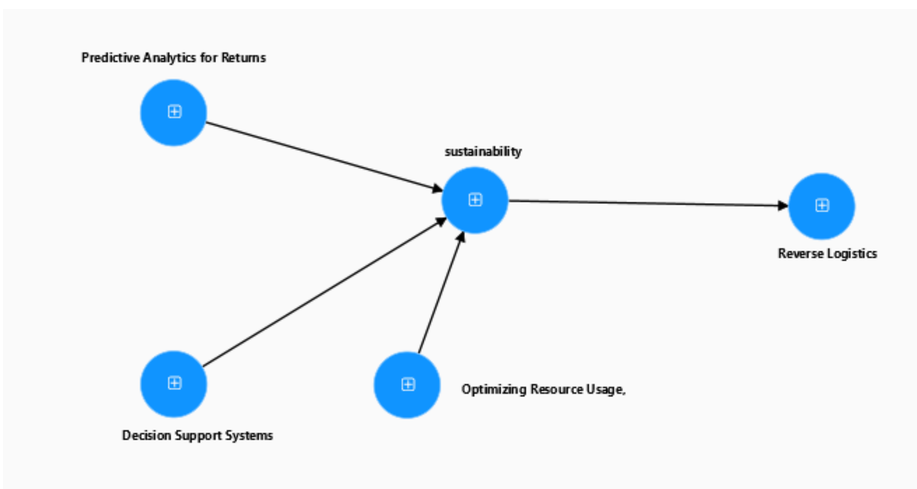

Figure 1. Research model

4. RESEARCH METHODOLOGY

4.1. Questionnaire and Pre-Testing

Eight adapted items from previous research measured supply chain visibility. Furthermore, AI-based DSSs were evaluated via eight measurement items based on the extant literature. Based on the previous study, reverse logistics were measured with 12 items, but sustainable performance was measured using fewer focused items(Aparecida et al., 2020). We had a content validity meeting to get a consultation with expert academicians and professionals with rich experience in the energy sector and reverse logistics. To test the survey, a pre-test was administered by three academic experts and two energy industry engineers who were capable in subjects of AI application, reverse logistics, and sustainability practices. A pre-test was designed to evaluate the questionnaire items' clarity, relevance, and applicability. The response suggested that the items were valid and no revisions were needed, confirming that the questionnaire was ready for a wider range of data collection.

4.2 Sample Design and Data Collection

The targeted population was the energy sector's key managers or decision makers, mainly those involved in supply chain management and reverse logistics. We chose this population because there is increased attention to sustainability within the sector and a trend toward using AI technologies to streamline operations(Zarbakhshnia et al., 2020). We gathered 150 complete responses from energy project managers, supply chain workers, and logistics coordinators who have had experience applying AI to reverse logistics performance across their firms' value chains. A structured survey was carried out for data collection to obtain the most important information to determine the mediating impact of Sustainability Performance on the relationship between AI and Reverse Logistics Effectiveness in the energy sector.

4.3. Data Analysis

Data analysis was performed on answers to select relevant parts of the survey posed to key decision-makers and industry professionals in the energy sector, providing insights directly applicable to supply chain management, reverse logistics, and sustainability(Lechner & Reimann, 2020). The sample consisted of 150 robust responses from individuals with seasoned context in AI applications to enhance reverse logistics and sustainability performances. The structured survey served as the foundation to examine the mediating effect of sustainability performance on AI technologies and reverse logistics within energy sectors. Using advanced statistical techniques Partial Least Squares Structural Equation Modeling (PLS-SEM) data analysis, we tested the hypotheses.

4.4 Assessment of the Measurement Model

Table 1. Measurement items and reliability.

Constructs	Items	Factor loadings	Cronbach's Alpha	C.R.	(AVE)
Decision Support Systems	DSS1	0.808	0.89	0.919	0.695
	DSS2	0.824			
	DSS3	0.855			
	DSS4	0.854			
	DSS5	0.825			
Optimizing Resource Usage	ORS1	0.805	0.882	0.914	0.679
	ORS2	0.835			
	ORS3	0.807			
	ORS4	0.851			

	ORS5	0.822			
Predictive Analytics for Returns	PAR1	0.861	0.899	0.922	0.665
	PAR2	0.794			
	PAR3	0.823			
	PAR4	0.751			
	PAR5	0.863			
	PAR6	0.797			
Reverse Logistics	RL1	0.821	0.852	0.892	0.624
	RL2	0.81			
	RL3	0.768			
	RL4	0.793			
	RL5	0.756			
Sustainability	SUS1	0.847	0.841	0.894	0.68
	SUS2	0.874			
	SUS3	0.839			
	SUS4	0.732			
	SUS1	0.847			

Table 1: The assessment of the constructs Decision Support Systems (DSS), Optimizing Resource Usage (ORS), Predictive Analytics for Returns (PAR), Reverse logistics (RL), and Sustainability (SUS) provides evidence of the reliability, validity, and a priori measurement models used in this study. The measurement model was proofed based on factor loadings, Cronbach's Alpha, Composite Reliability (C.R.), and Average Variance Extracted (AVE). Strong factor loadings were identified in all constructs, which implies that every measurement item well represents a construct. The items under DSS, ORS, PAR, RL, and SUS loaded well (Table 4), suggesting that these items captured their respective concepts appropriately. In addition to meeting all threshold criteria, reliability had been further validated across all constructs. The Cronbach's Alpha values for DSS, ORS, PAR, RL, and SUS were over the widely accepted threshold of 0.7, indicating a high degree of internal consistency among the items within each construct. This means the items indeed reliably measure each of our constructs. Likewise, the C.R values of all constructs are greater than 0.8, indicating the high consistency and reliability nature of the measurement instruments used. That is items representing every construct consistently measure the same underlying idea. The AVE of all constructs was above 0.5, indicating good convergent validity. It indicates that the construct on which the items are designed only captures a substantial part of the variance in those items. The AVE values of DSS, ORS, PAR, RL, and SUS also suggest that the construct items can accurately represent the intended latent constructs for the concepts proposed by the theoretical framework. The analysis of DSS proves that AI tools and algorithms are very useful for making decisions in reverse logistics. Those insights are actionable, helping to optimize and align operations for efficiency. ORS concentrates on efficient resource consumption, which is vital to reverse logistics in the energy business. ORS helps prevent waste and supports sustainable activities by enabling optimal use of resources. On top of that, the Predictive Analytics for Returns (PAR) underlying also showed great reliability and validity, supporting its usefulness as a predictive tool for return forecasts and proper reverse logistics planning. Accurately predicting returns is also a key requirement for optimizing reverse logistics, reducing inefficiencies, and supporting sustainability goals. The(Wang et al., 2021) construct of Reverse Logistics was well showcased, suggesting the recognition RL receives in managing the return flow of goods and materials for reuse, recycling, and sustainability, all essential to enable the Energy sector to meet its operational and environmental goals. This finding supports the plausible mediating role of sustainability between AI-driven interventions and reverse logistics performance(Wang et al., 2021). With strong loadings and high reliability, the sustainability construct has emerged as one of the most critical leverages in delivering supply chain operational efficiencies and environmental upshots

derived from AI-enabled applications in reverse logistics. Sustainability also coexists as a measure to ensure that AI-driven efficiencies align with environmental objectives, essentially bridging operational performance with sustainability goals in the process. Overall, the results established reliability and validity for these constructs, laying a foundation for future endeavors to investigate how AI-driven technologies contribute to reverse logistics processes. These findings highlight the importance of AI integration that combines sustainability with performance in optimizing RL in the energy sector to balance organizational dedication and eco-friendliness.

Table 2. HTMT

	Decision Support Systems	**Optimizing Resource Usage,**	**Predictive Analytics for Returns**	**Reverse Logistics**	**sustainability**
Decision Support Systems					
Optimizing Resource Usage,	0.625				
Predictive Analytics for Returns	0.673	0.856			
Reverse Logistics	0.474	0.734	0.648		
sustainability	0.51	0.616	0.581	0.424	

Table 2 In our study, the HTMT (Heterotrait-Monotrait Ratio) analysis for constructs shows that DSS with ORS, PAR, RL, and SUS have discriminant validity. A discriminant validity must be performed to ensure that each construct (both independent and dependent) is separately conceptualized and contributes uniquely to the overall research model. Compared with other constructs, the HTMT values of all DSS are below the commonly accepted LV threshold of below 0.85, proving enough Discrimination ability from each other. The factor loading of this variable indicates that DSS reflects other facets relative to the constructs from reverse logistics. Similarly, ORS is not similar to RL and SUS confirmed in HTMT values below the threshold; however, some overlap with PAR at a lower level may suggest an association between resource optimization and predictive analytics. The PAR, RL, and SUS values also indicate that all constructs maintain their distinct identity, indicating a proper understanding of their position in reverse logistics and sustainability(Sun et al., 2022). HTMT analysis indicates good discriminant validity among all the constructs. It illuminates that each has a unique purpose in measuring the effect of AI on Reverse Logistics & Sustainability in the energy domain. The results guarantee that every construct holds a distinct part of the theoretical model, thereby bolting an overall scope in AI-driven implementations to ameliorate reverse logistics practices and sustainability performance.

Table 3: Fornell-Larcker

	Decision Support Systems	**Optimizing Resource Usage,**	**Predictive Analytics for Returns**	**Reverse Logistics**	**sustainability**
Decision Support Systems	0.833				
Optimizing Resource Usage,	0.555	0.824			

Predictive Analytics for Returns	0.604	0.763	0.816		
Reverse Logistics	0.404	0.618	0.554	0.79	
sustainability	0.443	0.533	0.509	0.373	0.825

Table 3: Fornell-Larcker analysis is performed to measure the discriminant validity of the five constructs used in this study, namely Decision Support Systems (DSS), Optimizing Resource Usage (ORS), Predictive Analytics for Returns (PAR), Reverse Logistics (RL), and Sustainability (SUS). It is shown that the discriminant validity exists if and only if, along the diagonal, the square root of the average variance extracted (AVE) for each construct is greater than its correlation with other constructs. It shows that the AVE of each construct is higher than its correlation with any other constructs, suggesting adequacy in discriminant validity. The diagonal elements of DSS, ORS, PAR, RL, and SUS are each larger than their corresponding inter-construct correlations, suggesting that each of these constructs measures an aspect different from the remaining part of the model. In other words, the unique contribution of DSS and ORS in studying AI-based decision-making for reverse logistics process optimization is confirmed. Similarly, PAR, RL and SUS all show values that support their discriminant validity, in other words although these constructs share some common variance with each other related to AI impact on sustainability and reverse logistics they also partly capture different parts of the phenomenon under consideration. In other words, this validation assures that the constructs uniquely contribute to assessing how AI technologies influence reverse logistics and sustainability in the energy sector to receive a detailed insight into how these elements interplay in the framework of our research model.

Table 4: R2 Adjusted

Variable	R-square	R-square adjusted
Reverse Logistics	0.139	0.136
sustainability	0.326	0.319

Table 4 The R-square and R-square adjusted help to understand the variance that is explained by predictive variables for each of the dependent constructs in this study. For Reverse Logistics, also the adjusted R-square value is 0.136 and it means that around 13.6% of the variation in reverse logistics performance can be explained by the independent variables used in the model. Although this indicates a small impact, it also means that other elements of the reverse logistics processes may be significant but not included in the current model. In terms of Sustainability, the R-square adjusted value for Sustainability is 0.319 meaning the predictor variables explain 31.9% of the variance in sustainability outcomes which has a stronger level of influence than Reverse Logistics These results support the predictive and AI-driven approach to decision support systems, and illustrate the effectiveness of using resource optimization for sustainability in energy. In summary, the adjusted R-square values indicate that as well modeling performs nicely in explaining the variances of sustainability, or reverse logistics are predicted to be better for compatibility with other variables.

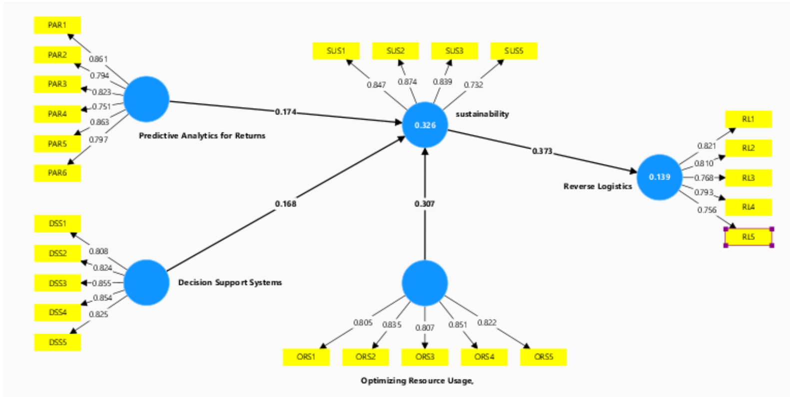

Figure 2. Measurement model

4.6 Assessment of the Measurement Model

This research examined the measurement model to detect the constructs linked with AI influence on reverse logistics improvement, moderated by sustainability performance in the energy area(Alkahtani et al., 2021). This measurement scale was designed based on previous application of AI in the context of reverse logistics, sustainability performance and resource-based view (RBV), to guarantee construct are characterized by robustness, for accurate and reliability. Industry experts from the energy sector tested the scale with a pilot study. Results: Advanced techniques such as confirmatory factor analysis (CFA) based on responses from engineering professionals and decision-makers in energy companies were used to evaluate the measurement model. The outputs of the CFA results indicate that all the constructs have both discriminant validity and reliability, which further support their adequacy for subsequent analysis(Mishra & Singh, 2022). The output from this structured SEM validation process is then used to analyze the relationship between AI, sustainability, and reverse logistics in the energy context, thereby paving the way for strategic implications of using AI technologies towards achieving sustainable goals(Kaviani et al., 2020).

5. PATH RESULT

5.1 Specific Indirect Effects

Table 6. Hypotheses testing estimates

	Original sample	Sample mean	Standard deviation	T statistics	P values	Result
Decision Support Systems -> Reverse Logistics	0.063	0.063	0.03	2.067	0.039	Supported
Decision Support Systems -> sustainability	0.168	0.166	0.072	2.329	0.02	Supported
Optimizing Resource Usage, -> Reverse Logistics	0.114	0.117	0.048	2.395	0.017	Supported
Optimizing Resource Usage, -> sustainability	0.307	0.305	0.09	3.4	0.001	Supported

Predictive Analytics for Returns -> Reverse Logistics	0.065	0.069	0.039	1.669	0.095	Unsupported
Predictive Analytics for Returns -> sustainability	0.174	0.18	0.088	1.98	0.048	Supported
sustainability -> Reverse Logistics	0.373	0.38	0.086	4.327	0	Supported

Table 6 The hypothesis testing results provide the relationships existing between Decision Support Systems (DSS), Optimizing Resource Usage (ORS), Predictive Analytics for Returns (PAR), Sustainable (SUS), and Reverse Logistics (RL) in energy. However, the type of renewable only increases the cost advantage achievable through arbitrage trading with battery storage. At the same time, for PV, it significantly reduces the long-term profitability under all scenarios(Guarnieri et al., 2020). This implies the possibility of enhancing reverse logistics processes and sustainability performance in the energy industry by implementing AI-driven decision support systems. Similarly, the results for ORS indicate a strong positive effect on reverse logistics and sustainability, confirming that by managing resources effectively, logisticians became efficient and supported sustainability practices. Therefore, predicting the sustainability influence analysis also includes scoring Predictive Analytics and Returns factors, which indicates that predictive analytics has a positive impact on sustainable performance. This is further confirmed by the relatively high variable p-value compared to the threshold significance level, which means that predictive analytics does not strongly support having a direct impact on reverse logistics(Hammes et al., 2020). At the same time, this suggests that although predictive analytics provides environmental benefits, reverse logistics efficiency is not promoted through predictive analytics. Secondly, a significant positive indirect relationship exists between sustainability and reverse logistics through its partial mediation on specific dimensions. This shows that green trust behaviors can also explain how sustainability traits repeat to be achieved at the reverse logistics level. Sustainability programs are a major factor for reverse logistics, and AI-related improvements should be designed with both goals in mind. The results suggest that incorporating sustainable presentations with AI technologies is a promising approach for efficient and sustainable reverse logistics in the energy sector.

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Decision Support Systems -> Reverse Logistics	0.063	0.063	0.03	2.067	0.039	Supported
Optimizing Resource Usage, -> Reverse Logistics	0.114	0.117	0.048	2.395	0.017	Supported
Predictive Analytics for Returns -> Reverse Logistics	0.065	0.069	0.039	1.669	0.095	Unsupported

The support for H1 states that Decision Support Systems (DSS) have a positive impact on reverse logistics according to the results. This shows that AI-enabled DSS contributes to helping improve reverse logistics by making data-driven decisions to drive improved decision-making and resource management. Also, the significance of ORS in reverse logistics is supported, and it concludes that efficient reverse logistics requires that resource use should be made optimal. The relationship between Predictive Analytics for Returns (PAR) and reverse logistics is insignificant, as indicated in the following findings. This suggests the direct effect of predictive analytics on enhancing reverse logistics is negligible in this scenario. Those are more relevant for return patterns themselves. Still, it seems that the potential of predictive analytics to facilitate reversal logistics directly is limited and needs to be combined with other AI approaches or even sustainability endeavors for such a combination to yield effective results! Conclusions The analysis indicates that some of the AI-driven approaches, like DSS and resource optimization, are fruitful in reverse logistics to make better ways to handle the reversal of material, but observing the behavior of the predictive model requires more work for each sector based on various points, especially for the energy sector.

6. FINDING

6.1 Discussion and Conclusions

The findings illustrate significant implications for AI-oriented technologies, serving the improvement of reverse logistics while also promoting sustainability in mediation within the energy industry. The results demonstrate that Decision Support Systems (DSS) and Optimizing Resource Usage (ORS) are two important reverse logistics factors where improvement is necessary to make the logistical process more efficient and sustainable. The findings suggest that DSS helps decision-making and makes reverse logistics operations run well, and ORS helps resource optimization and reduces waste; Contrary to predictions, there was no significant direct effect from Predictive Analytics for Returns (PAR) on reverse logistics, which might imply that it also might be combined with other AI tools or sustainability initiatives if the aim is to impact logistical outcomes. Interestingly, the research also shows that sustainability has an essential mediating role in amplifying the knowledge gained by AI-driven systems regarding reverse logistics, meaning that pursuing operational efficiency and environmental objectives with AIs will, therefore, require aligning sustainability considerations within such initiatives. While observations from the study carry broader implications, they may be especially applicable in energy, where AI could take bigger strides towards becoming more sustainable through better reverse logistics, reduction of waste, and a market share handed to new competitors with sustainability-focused solutions. In conclusion, this research illustrates the need for a comprehensive strategy integrating AI and sustainability to optimize supply chain efficiency toward strategic organizational objectives.

6.2 Theoretical Implications

This study offers several theoretical insights into the energy context. It is the latest addition to the current body of knowledge with respect to the integration of AI, Reverse logistics, and sustainability. The findings may help further understand the effect that AI is likely to have on reverse logistics through intermediary sustainability. The theoretical was tested with an empirically grounded prediction. Our results illustrated how such an approach might directly and negatively impact efficiency, hence lending support to the significant literature on the need for AI technologies to be employed in a manner benefiting both more efficient logistics and, at the same time, contributing to sustainability. Such studies underscore the importance of sustainability in aligning AI-based processes and reverse logistics systems, helping companies understand how implementing modern digital ad advancements may help them become environmentally and operationally successful. Moreover, this study contributes to advance the theoretical anchorage of Dynamic Capabilities Theory (DCT) and Resource-Based View (RBV), when discussing the role of AI in sustainability drawing on concrete examples from energy sector transformations towards sustainability practices. These contributions provide a foundation for future work that intersects AI with sustainability and reverse logistics and motivates further research in various sectors to learn the dynamic interplay of these aspects and their role in sustainable supply chain management for firms.

6.3 Managerial Implications

Managers in the energy sector can benefit from this study since they may find useful answers for how to use AI to improve reverse logistics and, at the same time, sustain sustainability performance. These findings suggest useful guidelines for managers to improve the implementation of AI technologies, including Decision Support Systems (DSS) and Predictive Analytics for Returns, in order to enhance both logistical efficiency and sustainability outcomes. The key practical implication here is the call for sustainable goals, and for sustainability to serve as a mediating variable that enhances the effectiveness of AI-driven initiatives targeting reverse logistics. They recommend that managers weave AI into sustainability-focused strategies both to unlock superior operational outcomes and build long-run resilience. Additionally, the results suggest that an equilibrium in the deployment of AI capabilities is needed as to how mundane business procedures can be aligned with recent technological advancements for efficient and effective reverse logistics practices. Adopting AI-enabled tools and incorporating sustainability considerations can elevate reverse logistics operations for energy companies, enabling them to compete better in the market while also fulfilling a more significant role in meeting industry-wide economic and environmental targets.

6.4 Limitations of Study

Limitation This study also has some limitations concerning the data and AI integration of reverse logistics and sustainability for energy sector resources. Second, because the study focuses on the energy sector, its conclusions might not be valid to other practices since the energy sector presents different structural and operational features compared with other industries. In addition, they examined sustainability as an intermediary for AI-enabled DSS and Predictive Analytics for Returns and failed to explore other AI technologies having the potential to affect reverse logistics. There were also financial and time constraints that affected the sample size, and hence the depth of data saturation. Moreover, the top layer executives were missing from the sample to a larger extent and though middle level management and first-line manager do most of the work in reverse logistics; these could have also limited their understanding capacity for strategic perspectives on AI that relates with sustainability. In Reverse Logistics, the study did not address how some managers had different social and educational backgrounds that may influence their perceptions or decision-making; therefore these questions present management as a single profession These limitations underscore the necessity for future work to consider how each of the impact of the article on non-included literature and expand the study to include other technologies and disciplinary interpretations that could help in reverse logistics based AI-driven sustainability.

6.5 **Conclusion**

This research fills the gap by testing whether sustainability performance mediates the effect of AI on reverse logistics in a specific industry: the energy industry. It studies the fusion of AI-based mechanisms, especially Decision Support Systems (DSS) and Predictive Analytics for Returns, in reverse logistics procedures to stand against sustainable objectives. Results: The results indicate that the indirect impact of sustainability on the positive link between AI and reverse logistics is significantly positive, affecting mainly operations efficiency but also environmental balance. This insight reveals principles that guide the alignment of technologies in AI with sustainable objectives to maximize performance in reverse logistics operations. This research provides guidance along the way for energy companies to improve organizational performance with sustainable logistics practices. Therefore, the findings are consistent with the view that AI equipment to be placed in sustainability practices is a well-established case in management style that has added attitudes by parties of interest in the energy sector not only for environmental goals but also business efficiency benefits such as reverse logistics and supply chain-wide performance.

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