

Advanced Hybrid Optimization of Electric Vehicle Supply Chains in India Using Fuzzy DEMATEL and LPWBN

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Abstract:

This review paper presents a thorough examination of an active continuous chain of supply management framework by taking the case study of the automotive electric vehicle (EV) industry in India with the aid of SPJS, Fuzzy DEMATEL, and LPWBN methodologies. As the idea of electric movement becomes more popular, it has a discontinuity, interdependency on key raw materials, sparse loading infrastructure, and environmental and social forces, but the supply chain in the EV industry becomes increasingly complex. The study considers how advanced decision-making and optimization techniques may result in efficient, resilient, and sustainable EV supply chains. The Fuzzy DEMATEL methodology is applied to identify and analyze causal relationships among critical factors in a supply chain such as supplier reliability, production capacity, logistics efficiency, policy support, technological innovation, and environmental constraints. This method helps to distinguish cause-driven and effect-driven factors in vague and imprecise conditions providing a clear structural model of interrelationships among factors within an ecosystem. And the SPJS (Scheduling and Planning Job System) framework implements to schedule optimization, production planning, and resource allocation of the multi-tier supply chain networks through disassembly and reassembly to gain a value. Increased coordination among manufacturers, suppliers, and distributors is meant to ensure continuous throughput, reduce operational delays, and increase flow of value. LPWBN (Linear Programming Weighted Best Normalization) algorithm is used for multi-criteria decision making problems under uncertain conditions and prioritizing alternatives and decision criteria. The assessment of three hybrids will propose a valuable solution for strategic foresight and operational enhancements in electric vehicle supply chain management. The article highlights major concerns for India, such as raw material dependency, cost fluctuation, infrastructure gaps, and policy uncertainties. Figure 4 also provides future research directions for things like integrating digital twins, AI-centered forecasting, and green supply chain practices. The analysis shows that a fusion of SPJS, Fuzzy DEMATEL, and LPWBN can excel in the area of DSSs in terms of decision-making quality, leading to the development of a robust EVSCS framework in India, which will be sustainable and resilient for an indefinite time.

Keywords: Electric Vehicles, Supply Chain Management, Fuzzy DEMATEL, SPJS, LPWBN, Sustainable Logistics

I. INTRODUCTION

. The swift shift towards sustainable mobility has been beneficial in the implementation of electric cars (EV) in emerging economies such as India. This shift has led to complex challenges in the organization of EV supply chains which involve different stakeholders, uncertain demand patterns, infrastructure constraints, and dynamic policy environment. This has left supply management in an area of utmost importance if we want to ensure that production, distribution, and adoption of such technology is punctual [1]. Traditional systems in place for supply chain management have, more or less, proved ineffective due to inefficiencies, lack of coordination, and a visible lack of transparency. One has, however, to remember that more recent hybrid optimization approaches integrating methods such as Fuzzy DEMATEL and Local Probabilistic Weighted Bayesian Networks (LPWBN) had taken shape. Such approaches will introduce capability for causal modeling, uncertainty, and decision-making that are intelligent, hence aiding the performance and resilience of EV supply chains in India [2].

The agricultural and EV supply chains are positioned on a nearly common framework of supply chain systems concerning manufacturing, aggregation, distribution, and consumption processes. The agricultural systems have always been the yardstick with which to measure the cascading supply chain system's intricacies and varied stakeholders. In these systems, producers, intermediaries, logistics support provider, and end customer are related in a mesh of transactions and information flow. Similar patterns of an ecosystem can be perceived in the EV supply chain as well wherein the manufacturer, battery suppliers, charging infrastructure providers, dealers, and consumer interrelations play out [3]. The traditional trade systems argue the importance of coordination, transparency, and the information flow mentioned above, which are important to the modern EV supply chain.

Translating the concept of farm to market supply chain to EV supply chains would involve the flow of the supply chain-starting with the extraction of raw materials (lithium, rare earth metals), component manufacturing, vehicle assembly, distribution, and finally delivery to the end-users. Every stage involves various stakeholders and decision points that

determine the overall system efficiency [4]. EV supply chains in India face additional challenges such as fragmented supplier networks, limited domestic manufacturing capability, and dependence on imports for critical components. Inefficiencies at any stage- be it procurement, production, or distribution- could result in increased costs, delays, and decreased market competitiveness. Consequently, optimizing every part of the supply chain requires a holistic outlook that encompasses the various interdependencies between the different parts and stakeholders [5].

The intermediaries are found to fulfill important functions in the traditional and modern supply chains in making transactions possible, aggregating demand, and managing logistics. In the EV supply chains of India, intermediaries should be concerned with distribution, dealers, logistics, and third-party service providers. While these do contribute to closing the gaps that exist between producers and consumers, they also may add disarrangements in the forms of cost determinants and information lack [6]. The multiple layers of distribution obscure the (time lapse) demand data, rendering it nearly impossible for manufacturers to successfully institute any strategy to customize their forms of production. Then, those intermediaries can influence the pricing structures, which in turn can kill any direct interaction between the producer and the consumer through one of these intermediaries, reducing the level of transparency. The application of advanced optimization tools such as Fuzzy DEMATEL could differentiate supply chain network within the most minute influences of the intermediaries, thereby improving decision-making and rectifying functions [7].

There are cost-related factors, government-induced factors of subsidies and taxes, and demand-dependent ways that come into play in fixing the components of EV supply chain prices. India's high EV initial costs remain the most significant bottleneck for wider EV acceptance with scarce government support while somewhat favoring the Faster Adoption and Manufacturing of Electric Vehicles (FAME) Scheme. Supply has limits, and market acceptance is evidently limited in the countryside and semi-urban areas. The situation is further exacerbated by non-existent common models of costings and partially open structures marking the commercial activities. This adds to the issues regarding information asymmetry affecting customers and stakeholders alike [8]. Generally, this difficult situation can only be dealt with in an agonizing way through advanced analytical frameworks capable of modeling complex inner-supply-chain interactions and uncertainties. For instance, the LPWBN approach gives room for probabilistic risk assessment while allowing the optimization of pricing and distribution strategies, courtesy of localized data. Table 1 highlights the major inefficiencies of traditional supply chain systems, including poor coordination, limited data integration, lack of real-time visibility, and inability to handle dynamic uncertainties [9].

Table 1: Limitations of Traditional Supply Chain Systems

Aspect	Description
Fragmented Operations	Supply chain activities are disconnected across different stakeholders, leading to inefficiencies and lack of coordination.
Manual Processes	Heavy reliance on manual documentation and decision-making slows down operations and increases the risk of human errors.
Limited Data Integration	Absence of integrated digital systems restricts seamless data flow and reduces visibility across the supply chain.
Lack of Real-Time Data Sharing	Delayed information exchange affects responsiveness to market changes and operational disruptions.
Poor Demand Forecasting	Inaccurate or outdated data leads to inefficient demand prediction and planning.
Inefficient Inventory Management	Overstocking or stockouts occur due to lack of synchronization between demand and supply.
Limited Stakeholder Coordination	Weak collaboration among manufacturers, suppliers, and distributors reduces overall system efficiency.
Inability to Handle Uncertainty	Traditional systems struggle to adapt to demand fluctuations, supply disruptions, and policy changes.
Suboptimal Decision-Making	Lack of analytical tools results in decisions that do not consider complex interdependencies.
Increased Operational Risks	Inefficiencies and uncertainties lead to higher costs, delays, and reduced reliability.

In such cases, there is a rising need for smart and inclusive optimization setups. By using a lethal combo of Fuzzy DEMATEL and LPWBN, the pair help in powerfully identifying critical casual factors, quantifying uncertainties, and proceeding with data-oriented decision-making. Fuzzy DEMATEL is suitable in understanding cause-effect relationships among different supply chain components, but LPWBN aids probabilistic modeling for risk assessment and optimization. Such techniques taken together help realize a comprehensive analysis of EV supply chains through enabling better transparency, efficiency, and resilience.

II. BLOCKCHAIN TECHNOLOGY IN AGRICULTURE

Digital technology evolutions have profoundly impacted the development of the modern supply chain, converting the old and cumbersome operations into smart and data-driven systems. Consequently, technologies such as control systems, mobile access, big data analytics, and the Internet of Things (IoT) are being employed to further augment operational efficiency, transparency, and decision-making across sectors. This technology, since it allows remote VAT readings, predictive analysis, and optimized resource management, confers safety and cleanliness in agriculture and the making of luxurious electric vehicles. As a change-enabler that really sorts out inefficient practices in mainstream systems, digital transformation supports the articulation of strong, dynamic, and sustainable supply chains [10].

Evolution of Digital Technologies in Agriculture

The agricultural field has achieved a remarkable transformation, allowing a more efficient and sustainable practice through the employment of modern digital technologies. Precision agriculture is an important innovation helping the farmers to make efficient use of resources, utilizing inputs such as water, fertilizer, and pesticides, while using technologies such as GPS, remote sensing, and variable rate systems. With precision agriculture monitoring the various spatial and temporal dynamics in field conditions, crop productivity is improved with minimum environmental damage. At the same time, the rapid growth in internet and mobile technologies has revolutionized access to information in agriculture. Through mobile applications and other digital platforms, farmers access real-time information about weather forecasts, local market prices, technical advisories, and various government schemes [11]. These tools have transformed the information dissemination mechanism within the rural segment for better decision-making and marketing linkages. However, existing obstacles, like poor connectivity, computer illiteracy, and infrastructure limitations, constitute major stumbling blocks towards comprehensive incorporation, mainly in underdeveloped countries. Big data and analytics have aided digital transformation through the processing and analysis of enormous amounts of agricultural data generated by sensors, satellites, and market systems. Through advanced analytics, crop yields can be forecast, diseases can be identified and monitored, risks can be assessed, and increasingly reasonable supply chain operations could be optimized. Stakeholders can benefit from insights into the right actionable points and synchronized decision-making to deliver the best results, minimize losses, and harness overall efficiency. However, issues like standardization, data integration, and privacy are challenges that remain biggies.

The agriculture industry is being upgraded exercising the eulogizing vigorous meed played by the Internet of Things (IoT), that offers instant monitoring and automation capabilities. The IoT tools like soil moisture sensors, weather stations and smart irrigation systems are connected to the internet, continuously collecting data from the field, which is then sent to a central processing system [12]. Through this system, different types of farming activities can be monitored closely, making proper use of the resources available and adding to productivity. Besides, IoT integration will help in improving the supply chain by offering real-time visibility within the industry of production and logistics. With the goal of being effective, IoT seems in fact to couple with some barriers; it is observed to prevail only through moderate ROI, network delivery, data security issues, and lack of interworking elements. The modern agricultural management technologies found in converging precision farming with mobile technologies, big data analytics, and IoT have converted conventional agriculture into intelligent systems to address present-day challenges. Quite apart from boosting productivity and sustainability, they create the basic platforms to blend more and more advanced technologies like artificial intelligence and blockchain with a view to agricultural supply chain optimization. Figure 1 represents Evolution of Digital Technologies in Agriculture .

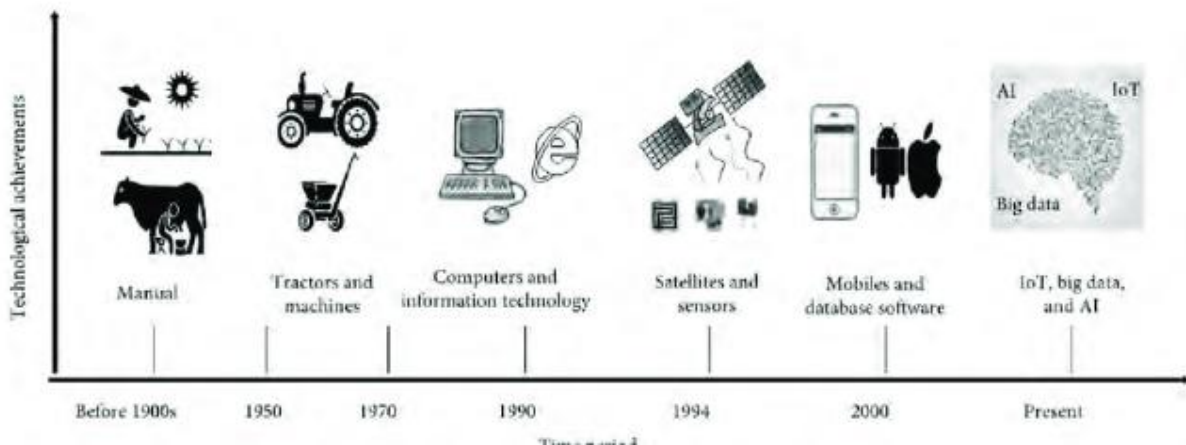


Figure 1: Evolution of Digital Technologies in Agriculture

Importance of Transparency in Agricultural Markets

For agricultural markets to perform well on all the count-efficiently, equitably, sustainably-transparency is vital for the availability of the right information when and where it is required. Transparency directly addresses the issue of asymmetry in the flow of information: the knowledge of prices, demand and quality standards is somehow lopsided between farmers and the middlemen, retailers, etc. Traditionally, farmers had to depend largely on the intermediaries, and this has further weakened the farmers' wherewithal to bargain and equate them with the potential risk of exploitation [13]. The transparency of a system allows the marketing of up-to-date, accurate, and alternative information that will not only decrease the need for middlemen, but also result in better price determination and better decision-making by the farmers. It is further argued that cooperation and empowering smallholder farmers are grounded in transparency being supported while enhancing fair trade. This helps in providing farmers greater control over the products while developing their participation in the market. This visibility then empowers farmers to determine the best prices, establish larger markets, and pay the farmers upfront, making their incomes more stable and their means of provision less uncertain. Commerce platforms with transparency can also prevent exploitation by discontinuing unfair trading schemes including price manipulation and delayed settlement payments [14]. This would promote the improved agency of farmers, putting an end to exploitation, and building trust in the market system. Figure 2 represents Big Data and Analytics in Agriculture.

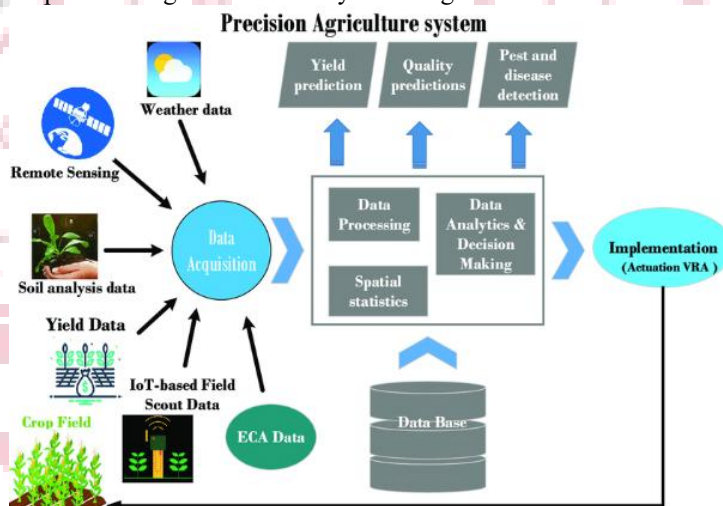


Figure 2: Big Data and Analytics in Agriculture

Meanwhile, transparency adds greatly to enabling trust and ensuring food security for consumers. Modern customers are increasingly becoming conscious about the origin, quality, and safety of agricultural produce. Transparency in the move adds traceability, which allows customers to monitor products from the farm to the table, along with particulars of how they were produced, forms of certification, and processing. Such a level of visibility enhances trust in food quality and protection while remaining supportive of regulatory compliance [15]. Also, it allows rapid posting on and dealing with issues like contamination or fraud, thereby ensuring the protection of public health. In the end, transparency fosters accountability across most stakeholders, strengthens trust across the supply chain, and nurtures building sustainable and reliable agricultural markets.

III. TRADITIONAL AGRICULTURAL SUPPLY CHAIN SYSTEMS

Recent studies have given considerable attention to the evolution and optimization of agricultural supply chains, focusing on the need of efficient, transparent, and technology-driven systems. Traditional supply chains lean towards emphasizing agility (ability to face impulses of change) and flexibility (capacity to change) as well as stakeholder cooperation to face issues arising out of uncertainties, including seasonality and market volatility. This would enhance overall productivity and responsiveness [1]. The introduction of blockchain technology, and its harnessing for traceability, transparency, and trust in agricultural supply chains has been one of the latest technological marvels alongside digital forward march, posing limitations on the scalability and integration fronts [2]. Operational inefficiencies, formed by the chronically fragmented logistics, poor coordination, and asymmetric information, continue to lower the productivity and profitability of a farmer [3]. The blockchain-based supply chains have demonstrated greater traceability and have enhanced the trust between the stakeholders, thus showing the practical application of the blockchain technology in real-world scenarios [4].

The main objective for this research is the promotion of sustainable agri-food systems that are localized, environmentally accountable, build resilience, and are supportive of equitable trade practices [5]. The integration of big data analytics in smart supply chain management improves decision-making support in planning, coordination, and operation efficiency [6]. Similarly, short food supply chains and organic farming models have emerged as trending innovative practices to foster

producer-consumer engagement and transparency [7]. The development of blockchain-based frameworks, particularly with Hyperledger platforms, has further guaranteed data security, transactionary transparency and enhanced coordination among various stakeholders [8]. With the help of the blockchain concept, the financial model, such as contract farming, has been amended to minimize information loopholes and increase the odds to get credit for smallholder farmers [9]. In a post-pandemic setting, digital inclusion can play a crucial role in ensuring coherent supply chains for smallholder farmers, as their access to modern tools and infrastructure is at a premium [10]. Various mathematical and modeling approaches have been espoused to optimize the conventional supply chains with regards to minimizing their costs and inefficiencies, particularly in relation to transport and inventory [11]. Moreover, blockchain and smart contracts can guarantee the traceability of goods, secure and tamper-proof data storage, and increased accountability within food safety systems [12]. One more stepping-stone in the development of risk-assessment frameworks has been the effective employment of big data analytics in the identification and suppression of operational and market risks within agricultural supply chains [13].

The integration of IoT (Internet of Things) technologies had led to tremendous advantages with respect to coordination and information sharing in supply chains due to methodologies like DEMATEL ISM to capture the interdependencies among the key factors [14]. In the meantime, the concurrent operation of blockchain and IoT ensures real-time monitoring and transparent traceability, ensuring throughout the supply chain the integrity of the data [15]. Hence, digital transformation initiatives, including the "Internet Plus" model, have significantly increased the efficiency of the supply chain, improving upstream and downstream integration [16]. Comparative studies among agroecological and conventional systems demonstrate sustainability practices provide greater environmental and economic advantages [17]. Another study delved into the issues of decision-making in agri-food e-supply chains, focusing on the significance of stakeholder transparency, coordination, and quality management [18]. Blockchain-based service models were proposed to help in enhancing transparency, reducing fraud, and building trust among farmers, consumers, and regulatory bodies too [19]. A successful implementation is yet to be made for digital agriculture. There are many hurdles impeding progress in changing the way things are done here-namely, challenges with data interoperability, policy alignment, skill development, and how to overcome such challenges [20]. By means of the literature, it becomes evident that blockchain, IoT, and data analytics are now more important to overcome the malnourished traditional agri-supply chains. They not only enhanced the efficiency and transparency, but they also made the development of intelligent and resilient supply chain systems imaginable which could prudently address future demand specifications. Table 2 summarizes key research contributions, technologies, methodologies, and findings related to the integration of digital solutions in agricultural supply chains.

Table 2: Overview of Agricultural Supply Chain Management and Digital Transformation Studies

Reference	Technique	Key Findings	Results	Limitations
[1]	Agile supply chain practices in agriculture	Emphasis on flexibility, rapid adaptation, stakeholder collaboration	Improved collaboration, decreased cycle time, optimized supply chain performance	Limited to traditional uncertainties; may not cover new digital interventions
[2]	Review of blockchain-driven traceability	Blockchain promotes transparency, immutability, trust, reliability	Enhanced traceability and accountability in supply chains	Challenges in scalability and integration with existing infrastructures
[3]	Operational perspective on agricultural supply chains	Fragmented logistics and poor coordination reduce efficiency	Highlighted need for better technology and information exchange	Focused on operational inefficiencies; lacks technology implementation data
[4]	Case study: blockchain in agri-food supply chains in China	Decentralized ledger improves traceability and stakeholder trust	Practical demonstration of blockchain usage in agriculture	Limited to one regional case; scalability uncertain
[5]	Sustainable agri-food terra-economies	Localized food chains enhance resilience and fairness	Improved environmental responsibility and sustainability	Conceptual; not empirically validated across regions
[6]	Big data for agricultural supply chain management	Data analytics supports planning, coordination, and trust	Improved service efficiency and decision support	Requires advanced data infrastructure; costly implementation
[7]	Peri-urban organic agriculture case studies	Shorter supply chains improve transparency and producer-consumer relations	Enhanced sustainability of local food systems	Limited to peri-urban context; generalizability restricted
[8]	Smart agriculture supply chain framework	Secure data sharing, transaction	Permissioned blockchain is suitable	Requires technical adoption and blockchain literacy

	using Hyperledger blockchain	transparency, improved coordination	for agricultural applications	
[9]	Blockchain-supported contract farming financing	Decentralized platforms reduce information asymmetry	Enhanced trust, farmer access to credit	Focused on financial aspects; limited operational insights
[10]	Digital inclusion in smallholder farmers post-COVID	Digital systems increase supply chain resilience	Improved operational efficiency; training and infrastructure needs	Digital divide may hinder adoption; limited rural coverage
[11]	Mathematical model for Indian agri-fresh food supply chain	Minimizing cost and inefficiency improves performance	Reduced transportation cost, post-harvest losses; better efficiency	Model-based; may not capture real-world complexity

IV. DIGITAL TRANSFORMATION AND IOT IN AGRICULTURE

With the occurrence of Agriculture 4.0, which intermingles modern technologies in attempts at magnifying the sustainability, productivity, and efficiency in resource usage of the agrarian sector, the whole digitalization of agriculture process has been progressing forward silently. A key area for the introduction of IoT technologies into agriculture has taken care of technology interventions for real-time monitoring, precision farming, and intelligent ad hoc decision making used to facilitate this transition into data-driven agricultural systems [22]. Digitization of agriculture for a broader landscape initiated a re-imagination of value chains in agriculture, improving governance, operations, and innovation capabilities and thereby helping build more resilient and sustainable systems [23]. Innovative models of infra-structure, say, smart- village frameworks based on IoT, have enabled such ideas to reach rural and agricultural landscapes in terms of improvement in connectivity, services, and constituency value [24]. Developing smart farm platforms on the shoulders of digital technologies, analytics, and business models have facilitated efficient and scalable agricultural operations [25]. Data analytics-powered intelligent systems, in particular, have demonstrated that they are effective in various specific-domain applications, such as quality prediction and precision management, to improve production intensity and product quality [26]. Study toward understanding the unification of digital transformation in agriculture underscores combine the technological, organizational, and strategic dimensions in order to reap its benefits fully [27]. Middleware platforms and standardized interfaces are identified as essential enablers of the interoperability that is needed for smooth exchange of data and creating integrated digital ecosystems in agriculture [28]. The digital transformation has been crucial in improving the logistics of supply chains by enhancing systems of coordination, avoiding inefficiencies and clarifying transparency in food distribution networks [29]. A link between blockchain and IoT presents a more powerful method of pushing agricultural systems where farmers would share data securely with suppliers, manage processes in real-time, and operate under automated processes. A combined system organized by such an alliance would build up traceability and data integrity, while ensuring some pertinent aspects of supply chain operations together with decision-making [30]. In sum these studies give a more valid statement about the necessity for digital transformation, consisting of IoT, blockchain, and analytics, as they speak about bringing agriculture up to modernity in response to many disadvantages found in the traditional way of farming.

V. PRICE DISCOVERY AND FAIR TRADE MECHANISMS

Price discovery is at the heart of the economic system, with the interaction of buyers and sellers, prices of goods and services are settled in accordance with the supply-and-demand trend. With the emergence of modern agriculture and food trade in digital markets, the concept of price discovery has been completely transformed-there is much more information on prices today, trade is more of an IT-centered event than an IP event, and advances are allowing for the simple and quick integration of different markets. [19] Effective price discovery guarantees fair compensation to producers and fair about consumers, established in equilibrium in the market. The traditional market in agriculture is enumerated by inefficiencies like information asymmetry, middleman dominance, and a lack of transparency. There is a situation where farmers bank on intermediaries who have some control over pricing, implying exploitation and below-par income levels for producers. The ills are well addressed now that digital platforms and other e-commerce platforms are put on the scene and have a profitable entente between buyers and sellers. Through put forth on these platforms are real-time pricing information providing historical trends and demand forecasts so that the stakeholders could come out well informed. Fair trade mechanisms play a vital role in addressing the inequality among global supply chains. Fair trade ensures that producers-especially small farmers and craftsmen-get fair prices, quality working conditions, and ever-quality livelihood. Certification organizations and standards help keep justice in place by regulating unfair trade practices and preventing exploitation. Fair trade backs social justice, gender equality, and community development as well [20].

Technologies such as blockchain, Artificial Intelligence (AI), and Internet of Things (IoT) will probably change methods of price discovery by the year 2023. Blockchain allows the generation of accurate and tamper-proof data records, reducing ground for fraud and enabling trust among potentially distrusting participants. AI-driven predictive analytics forecast market demand and guide price optimization, while IoT devices track real-time production and warehouse data. Even the laws and regulations of the government regulate the price discovery. The enforcement of MSPs, through subsidies and digitally orchestrated agriculture measures, assist in pillaring the fair price market and in protecting farmers from fluctuations. Indeed, online commodity exchanges and e-National Agriculture Market (e-NAM) offerings are rapidly adding to the sense of compliance and competitiveness in the market. To popularize the electronic platform and e-commerce mechanisms, all stakeholders should nurture the reality of technological divide, limited awareness, and lack of infrastructure existing among stakeholders residing in urban areas. The inclusivity and accessibility-hours work for proper functioning of modern price discovery systems. Therefore, one concludes by stressing that the way forward is the total integration of technology with the principles of good capitalism to create a socially just, quality, and highly interactive market ecology.

VI. CONSUMER TRUST AND TRACEABILITY

Purchasing trust is crucial for every business especially food, drugs, and maintenance-based sectors. Concerns about food safety, naturalness of the product, ethical sourcing, etc. over the last few years have, in fact, laid the foundation for modern supply chain practices. In India, the Government of India majorly uses AEPS to authenticate beneficiaries of financial transfers in rural and urban areas. The system ensures that funds and resources are not misused or lost while efficiently determining that rightful beneficiary receives the aid. Human unrest in Africa and parts of Asia targets pillaging the rural and the urban of their opportunities, enforced by the government. The traceability mechanisms have been completely transformed by technology. Blockchain technology provides an immutable accounting of the transaction hence, verifying the integrity and transparency of the data. Each step of the supply chain is logged on the decentralized ledger, making information available to consumers based on product origin, handling, certification, and so forth. With QR codes and RFID technology, real-time monitoring and product information can be accessed using smartphones. Consumer confidence in it is also influenced by organism certifications, labels, and regulatory compliance. Organic, fair trade, and environmentally-friendly labels allow the consumer to believe that they procure both quality and ethical standards in the product. At times, however, consumers are mixed up with a plurality of labels leading to the requirement of a standardized and reliable certification. The benefits for businesses are increased efficiency of the supply chain, risk reduction, and more favorable brand reputation. Ensuring that customers receive not just what they were promised, but also prefer their brands over the competitors, transparency might be the priority. Traceability aids in the isolation and withdrawal of the affected products in the quickest and safest way possible. This ensures that damage is kept at a minimum while safety is ensured. Nonetheless, the list of challenges to the implementation of traceability systems is endless, starting with the high costs, going full circle to big data concerns and compatibility issues. Many small- to medium-size enterprises (SMEs) do not possess the resources for the adoption of complex technologies due to their limited resource base. A lot of attention should also be paid to data security and privacy to keep the trust of everyone high. Table 3 presents a comprehensive overview of key dimensions, technologies, benefits, and challenges involved in implementing environmentally responsible and ethically sound practices across modern supply chains.

Table 3 : Sustainability and Ethical Practices

Aspect	Description	Key Practices	Technologies Used	Benefits	Challenges	Real-World Applications	Impact on Stakeholders
Environmental Sustainability	Focuses on reducing environmental impact and conserving natural resources	Renewable energy use, water conservation, waste reduction	IoT sensors, satellite monitoring, AI analytics	Reduced carbon footprint, resource efficiency	High implementation cost, lack of awareness	Smart farming, solar-powered irrigation	Farmers save costs; environment protected
Ethical Sourcing	Ensures materials are procured responsibly without exploitation	Fair wages, safe working conditions, responsible procurement	Blockchain, supply chain tracking systems	Improved worker welfare, ethical branding	Verification difficulties, compliance issues	Fair trade agriculture, ethical mining	Workers benefit; brands gain trust

Social Responsibility	Addresses community welfare and social equity	Community development, education, gender equality	Digital platforms, CSR management tools	Improved societal well-being	Measuring impact, resource allocation	Rural development programs	Communities gain opportunities
Economic Sustainability	Ensures long-term profitability without resource depletion	Efficient resource management, cost optimization	AI-based forecasting, ERP systems	Stable income, business growth	Market volatility	Sustainable agribusiness models	Producers and businesses gain stability
Transparency and Accountability	Promotes openness in operations and decision-making	Reporting standards, audits, certifications	Blockchain, data analytics	Builds trust, reduces fraud	Data privacy concerns	Transparent supply chains	Consumers gain confidence
Circular Economy Practices	Emphasizes reuse, recycling, and waste minimization	Recycling, upcycling, product lifecycle extension	Waste management systems, AI optimization	Reduced waste, cost savings	Infrastructure limitations	Food waste reduction systems	Environment and businesses benefit
Animal Welfare	Ensures humane treatment of animals in production systems	Ethical farming, proper nutrition, humane handling	Monitoring systems, IoT devices	Better product quality, ethical compliance	Higher costs	Organic livestock farming	Consumers trust products more
Regulatory Compliance	Adherence to environmental and ethical laws	Certification, audits, legal compliance	Compliance software, monitoring tools	Avoid penalties, ensure credibility	Complex regulations	ISO, organic certifications	Businesses maintain legitimacy
Sustainable Packaging	Use of eco-friendly materials and reduced packaging waste	Biodegradable packaging, minimal packaging	Material science innovations	Reduced pollution	Cost and scalability issues	Compostable packaging	Consumers support eco-products
Climate Change Mitigation	Reducing greenhouse gas emissions and adapting to climate risks	Carbon reduction strategies, green logistics	AI, climate modeling tools	Long-term environmental protection	Policy and financial constraints	Carbon-neutral supply chains	Global environmental benefits

VII. CONCLUSION AND FUTURE WORK

The article reviews the role of price discovery, fair trade mechanisms, consumer trust, traceability, and sustainability in the formation of modern supply chain ecosystems. It also discusses how the introduction of advanced digital technologies like AI, blockchain, and the Internet of Things (IoT) has converted traditional systems into something much more transparent, efficient, and fair in operation. The contemporary drive toward utilizing these technologies in the supervision of pricing, addresses transparency, and serves producers' interests before consumers by providing accurate information about product origin and quality. Adoption of sustainable and ethical practices also contributes significantly to sustainability, social responsibility, and long-term environmental stability. Although, the review does identify certain challenges that might deter wider adoption: technological complexity, high costs, lack of infrastructure and meager stakeholder awareness, particularly in rural and developing regions. Challenges include data security, standardization, and system interoperability, further complicating the adoption. Research on the need for global acculturation of scalable, cost-effective, user-friendly solutions

bridging the digital divide and attaining inclusivity should be accelerated. There are vast research opportunities in utilizing some of the best machine learning models for demand forecasting, price determination, and anomaly detection.

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