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Evaluation of Technology-Based Sustainable Practices in Logistics Service Providers by Content Analysis and SWARA Method

Bihter Karagöz Taşkın[1], Macide Berna Çağlar[2]

ABSTRACT

Purpose: The purpose of this study is to evaluate the potential of sustainability-related activities of Fourth Party Logistics (4PL) service providers and their technologically based solutions.

Methodology: It aims to evaluate alternative approaches and measure the relative importance of the technology solutions preferred by 4PL service providers within the context of sustainability efforts, first by content analysis and then by using SWARA method, in order to assess the technologically based solutions and sustainability potentials of 4PL service providers.

Findings: The information on the websites was therefore assembled in light of the data obtained, and a situation assessment was made. In the context of this study, it has been found that "Data-Driven Decision Making" possesses the highest level of significance among technology-based sustainable practices. “Vehicle Tracking Systems Technology”, on the other hand, has been ranked as having the least amount of significance.

Originality: This research evaluates digital sustainable activities on 4PL enterprises, in contrast to earlier studies. We can therefore learn more about how contemporary technology and sustainable practices converge in the logistics sector by examining the effects of digital sustainable activities on 4PL enterprises.

Keywords: Fourth-Party Logistics (4PL), Sustainability, Technology.

JEL Codes: L90, L53, 030, M15.

İçerik Analizi ve SWARA Yöntemi ile Lojistik Hizmet Sağlayıcılarında Teknoloji Tabanlı Sürdürülebilir Uygulamaların Değerlendirilmesi

ÖZET

Amaç: Bu çalışmanın amacı, Dördüncü Taraf Lojistik (4PL) hizmet sağlayıcılarının sürdürülebilirlik ile ilgili faaliyetlerinin potansiyellerini ve teknolojik temelli çözümleri açısından değerlendirmektir.

Yöntem: Bu çalışmada, 4PL hizmet sağlayıcılarının teknolojik temelli çözümlerini ve sürdürülebilirlik potansiyellerini değerlendirmek amacıyla, önce içerik analizi ve ardından SWARA yöntemi kullanılarak, sürdürülebilirlik çabaları bağlamında 4PL hizmet sağlayıcıları tarafından tercih edilen teknoloji çözümlerinin göreceli önemini ölçmeyi ve alternatif yaklaşımları değerlendirmeyi amaçlamaktadır.

Bulgular: Araştırma sonucunda 4PL hizmet sağlayıcılarının internet sitelerinden elde edilen veriler bir araya getirilmiş ve bir durum değerlendirmesi yapılmıştır. Bu çalışma kapsamında, teknoloji tabanlı sürdürülebilir uygulamalar arasında "Veri Odaklı Karar Verme"nin en yüksek anlamlılık düzeyine sahip olduğu tespit edilmiştir. “Araç Takip Sistemleri Teknolojisi” ise en az öneme sahip teknoloji olarak sıralanmıştır.

Özgünlük: Daha önceki çalışmalardan farklı olarak; bu çalışmada dijital sürdürülebilir faaliyetler 4PL işletmeler üzerinde araştırılmıştır. Böylelikle, dijital sürdürülebilir faaliyetlerin 4PL (Dördüncü Parti Lojistik) işletmeleri üzerindeki etkisinin araştırılması, modern teknoloji ve sürdürülebilirlik uygulamalarının lojistik sektöründe nasıl kesiştiğini anlamamıza katkıda bulunmaktadır.

Anahtar Kelimeler: Dördüncü Taraf Lojistik (4PL), Sürdürülebilirlik, Teknoloji.

JEL Kodları: L90, L53, 030, M15.

[1] İstanbul Arel University, Faculty of Economics and Administrative Sciences, Department of Logistics Management, İstanbul, Türkiye

[2] Başkent University, Kahramankazan Vocational School, Department of Management and Organization, Ankara, Türkiye

Corresponding Author: Macide Berna Çağlar, mbcaglar@baskent.edu.tr

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1.INTRODUCTION

Digital logistics refers to the use of technology-based applications in logistics processes. These technologies are employed to optimize logistics functions such as supply chain management, inventory management, transportation, storage, and distribution. Sustainability, on the other hand, aims to ensure the long-term viability of activities by considering environmental, economic, and societal factors. The concepts of digital logistics and sustainability come together to assist businesses in conducting more efficient and environmentally-friendly logistics operations in today's context. Digital logistics holds the potential to enhance sustainability as it offers businesses more efficient, optimized, and environmentally conscious logistics processes. However, to harness these advantages, it is crucial for businesses to select appropriate technologies, utilize data correctly, and develop strategies that align with sustainability goals.

The ability of logistics service providers to support sustainable supply chain practices is becoming more apparent, and this alignment of logistical actions among supply chain participants defines more sustainable and creative logistics business models (Boschian and Paganelli, 2016). Lead logistics providers, referred to as 4PL service providers, play a crucial role in establishing a supply chain. They undertake many of the same functions as Third-Party Logistics (3PL) service providers, but they have broader responsibilities and assist clients in achieving strategic objectives. A logistics provider functioning as a 4PL becomes a true partner with the customer, aiming to create an economical supply chain. 4PLs typically manage every moving part in the customer's supply chain and serve as the single point of contact for all parties (Matyushenko et al., 2019).

4PLs encompass carriers, warehouses, reverse logistics, and more. They eliminate silos and provide end-to-end visibility and transparency (Hawkins, 2022). Logistics services providers are becoming more and more conscious of how an effective logistics system may give their company a long-term competitive advantage. Because it is exceedingly difficult for a competitor to duplicate, a competitive advantage established upon a well-planned and implemented logistics strategy can be sustainable. Any organization's challenge is to concentrate its efforts on meeting the client needs that present the most potential for building a long-term competitive advantage (Nowodziński, 2014).

A thorough examination of 4PL companies' sustainability initiatives is necessary since they are in a unique position to impact and enhance the sustainability of supply chains as supply chain management integrators (Mehmann and Teuteberg, 2016). Implying that companies offering logistics services ought to focus on innovation to bring about lasting efficiencies and effectiveness that will benefit society as a whole (Gruchmann, et al.,2018). It is crucial to evaluate the technological prowess of 4PL providers because the use of cutting-edge technology solutions is essential to improving the efficiency and efficacy of 4PL services. Supply chains that are more robust and responsive and can adapt to changing demands from customers and stakeholders are possible when sustainability and technology are successfully included into 4PL services. Because it is exceedingly difficult for a competitor to duplicate, a competitive advantage established upon a well-planned and implemented logistics strategy can be sustainable.

In Mageto's (2022) study, limited financing, weak regulatory framework, lack of appropriate skills, senior leadership, and lack of technologies are highlighted as challenges that prevent logistics businesses from achieving their sustainability goals. By leveraging technology and expertise, 4PL businesses help streamline operations, reduce costs and improve sustainability in the logistics industry. It uses technology and analytics to provide end-to-end visibility, streamline operations and improve overall supply chain performance. In today's global competitive environment, technology and sustainability are two important factors for businesses that offer 4PL services to provide an efficient logistics service at a high service level. Based on these premises, a two-stage process was used to (1) generate knowledge using qualitative methods and (2) closely evaluate the findings using expert interviews.

This study aims to identify the digital sustainability practices adopted by 4PL service providers, which are new generation logistics businesses operating as supply chain management integrators and offering customer-oriented solutions. In order to achieve this goal, first content analysis and then SWARA method were used. For this purpose, interviews with experts were conducted after content analysis. For this purpose, interviews with experts were conducted after content analysis. As a result, our two-stage procedure successfully combined the collection of qualitative data with expert validation, enhancing the validity and reliability of our study findings. This highlights the value of a multifaceted approach in generating and evaluating information that can be used in various sectors to draw accurate and meaningful conclusions.

2. SUPPLY CHAIN MANAGEMENT and SUSTAINABILITY

With the Fourth Industrial Revolution, it is assumed that the systematic integration of digitization and technologies into businesses' production and logistics processes will lead to higher performance, lower

costs, and consequently contribute to long-term growth and the sustainable assurance of competitive advantages (Woschank et al., 2021). Focusing on supply chains can be seen as a step towards a broader environmental policy. Embracing and enhancing sustainability emerges as a challenging process that takes into account the entire supply chain, from the initial processing of raw materials to the delivery to the customer. Supply chain managers engage in sustainability efforts across various business processes, including logistics, strategic planning, information services, marketing, sales, and finance, as they are concerned with every aspect of production (Dey et al., 2011).

Table 1. Sustainability dimensions and criteria

Sustainability Dimensions	*Sustainability Criteria*	*Definition*
Economy	Logistics cost	Changes in logistics cost savings in terms of shipping, warehousing, inventory handling and management costs
	Delivery time	Delivery improvements, changes in cycle time and delivery time
	Shipping delay	Changes in the amount of delayed shipment
	Inventory	Changes in inventory volume
	Loss/damage	Changes in the amount of lost and/or damaged goods resulting from damage, theft and accidents
	Service	Changes in utilization rate (load factor) at frequent intervals
	Prediction	Changes in demand uncertainties
	Reliability	Changes in the quality of logistics in terms of transport, inventory and warehousing, e.g. perfect order, on-time deliveries
	Flexibility	Changes in scheduling conditions, eg percentage of unscheduled shipments without undue delay
	Transport volume	Changes in the total volume of transported cargo
	Scope of	Suitable applications for digitalization in logistics processes
Environment	Resource efficiency	Non-renewable resource consumption facilities in vehicle and transportation use
	Process energy	Changes in energy requirements
	Process emissions	Changes in fuel consumption, CO_2 and other greenhouse gas emissions
	Waste	Changes in the amount of recyclable waste
	Pollution	Changes in air, noise and water pollution
	Land use impact	Changes in the area of land allocated to transportation facilities and land ratios are lost.
Social	Development benefits	Open source appropriate technology applications for self-directed sustainable development
	Effects	Social effects of digitalization in logistics
	Health	Disease changes caused by the side effects of transportation (pollution, noise...)
	Security	Changes in the amount of accidental disability and death
	Labor models	Changes in labor intensity, employment plans and types of jobs
	Acceptance	Socio-economic, societal and market acceptance of digital applications

Source: Kayikci, 2018

Table 1 illustrates an ecosystem that depicts how digitization has influenced sustainability in logistics in terms of economic, environmental, and social dimensions. Accordingly, sustainability dimensions can be listed as follows (Kayikci, 2018):

Economic: An affordable system that offers efficient, collaborative solutions, transportation mode options, and supports the local economy.

Environmental: Utilizes technologies that reduce greenhouse gas emissions, pollution, and waste, minimizes the consumption of non-renewable resources, and utilizes technologies that reuse and recycle energy sources and components.

Social: Ensures the secure fulfillment of individuals'/communities' basic access needs, supports a good quality of life, and promotes equality across and within generations.

Sustainable digital logistics appears as a broader concept encompassing supply chain integration, data-driven decision-making, and warehouse management. Within this concept, it includes smart factories, the computational capabilities of integrated systems, warehouse integration, and transportation functions. Thus, it can respond to dynamic customer demands. Smart factories enable the use of sustainable methods such as recycling, reusing, and remanufacturing in production to reduce waste and enhance cost

optimization. On the other hand, the Internet of Things (IoT) enables real-time tracking of products and packages through cloud-based enterprise management systems, develops warehouse management solutions, constantly captures past and future projections, and enables better decisions along the value chain (Parhi et al., 2022).

In the context of strategic management, timing deliveries leads businesses to find eco-friendly and sustainable solutions due to high economic and environmental costs. In supply chain management, examples of sustainability-oriented strategies and technologies include reducing/renewing packaging to optimize storage and maximize capacity, utilizing recyclable materials to reduce waste, and other capacity management strategies and technologies. Additionally, digitizing procedures, accurately measuring and reporting greenhouse gas emissions resulting from the movement of goods and related logistics operations, help reduce negative environmental impacts and contribute to environmental protection (Remondino, Zanin, 2022).

3. SUSTAINABILITY and TECHNOLOGY-BASED SOLUTIONS in LOGISTICS SERVICE PROVIDERS

The transformation of businesses into a digital form is generally referred to as Industry 4.0. In this context, the way businesses operate undergoes a complete change, with all functions, from production to other activities both within and outside the industry, experiencing a significant transformation (Sony and Naik, 2020). Therefore, the global industrial landscape has been changing significantly in recent years due to successive technological advancements, developments, and innovations (Lampropoulos et al., 2019). The concept of Industry 4.0 signifies the Fourth Industrial Revolution in the 21st century, characterized by rapid changes in technology, industries, societies, and processes due to increased interconnectedness and intelligent automation (Sony and Naik, 2020). One of the most distinctive features of Industry 4.0 is the combination of various existing or new technologies to create more complex, novel technologies (Banger, 2018b: 463).

Logistics and supply chain management are subject to rapid changes due to technological, social, and market developments in the global economy (Henke et al., 2020). In supply chain management, Industry 4.0 encompasses the development and integration of innovative information and communication technologies into the industry (Sharma, 2018). In terms of supply chain management, 4PL service providers play a significant role. 4PL service providers are supply chain integrators who bring together and manage their own organization's resources, capabilities, and technology. Additionally, 4PL businesses provide comprehensive supply chain solutions for multiple participants, including customers, vendors, 3PL service providers, and information technology service providers, on an integrated platform (Xiu and Zheng, 2020). The transition from error-prone paper-based processes in warehouses to digital systems such as Warehouse Management Systems (WMS) that enable automated workflows is a clear example of Industry 4.0's impact on storage and logistics. Furthermore, the emphasis of Industry 4.0 on transparency and the operation of large-scale systems with advanced technology strongly manifests itself in the rise of 4PL service networks (Hawkins, 2022).

Aylak et al. (2020), researched to identify trends in the logistics sector in Türkiye. In 2017 and beyond, the identified trends in the logistics field are supergrid logistics, driverless vehicles, robotics and automation, the internet of things, cloud logistics, and big data. Çakılcı and Öztürkoğlu (2021) evaluated Industry 4.0 advances in the logistics sector. Also, the current logistics procedures, how they have changed in response to the new industrial revolution, potential difficulties that may occur as a result of this transformation, and proposed remedies have all been discussed. Bilgiç et al. (2020) attempted to explain, through a literature review, the unique consequences of digitalization on logistics organizations, notably on their business processes, and what type of impacts it may have in the future. Karlı and Tanyaş (2020) conducted a thorough assessment of smart logistics studies to identify gaps in the literature and inform future research on the subject. Most of the studies in Turkey are treated as a conceptual and literature study. There are also studies based on the business and in the form of status analysis.

Yang and Lin (2023) developed and examined a model that includes digitization, adopting a digital logistics platform, the institution's digital transformation, and corporate performance. They defined digitalization as the merging of digital and physical worlds in corporate processes through various information and communication technologies (Yang and Lin, 2023). Zhang et al. (2023) analyzed the impact of digital logistics on the regional economy in their study. Digital logistics is a concept that reduces the need for manual labor in various corporate applications by explaining the transportation of goods as an automatic and digital process. Furthermore, they emphasized the use of blockchain technology, machine learning, the internet of things, and artificial intelligence in improving the digital logistics process in supply chain management, highlighting their almost ubiquitous use in every business activity. They stated that the supply chain is affected by the digital logistics process in a variety of ways, such as providing notifications to

customers, supply chain forecast analysis, warehouse management, transportation management, and inventory management. (Zhang et al.,2023).

Sharakhin et al. (2021), investigated the impact of insourcing and outsourcing digital logistics solutions on the efficiency of a business operating in the Supply Chain 4.0 environment. They stated that integrating digital technologies into supply networks and industrial processes is the goal of digital logistics. They argue that the latest digital technologies evaluate a broad consumer base and can help predict product demand in a dynamic environment through instant calculations (Sharakhin, et al., 2021). To stay competitive in the freight forwarding services market, businesses must utilize a wide range of electronic data exchange platforms in their logistical operations. The key to the high performance of multimodal transport and logistics systems is the introduction of new information and communication channels between the various elements in the chain of transportation and logistics.

Additionally, the degree of digitization of these systems' business processes is a crucial criterion for determining their efficacy (Dmitriev and Plastunyak, 2019). Digital logistics improves economic efficiency for both consumers and partners. These might be expressed as technological efficiency, competitiveness, commercial gains, and socioeconomic effect (Saparbaevna, et al.,2021). Logistics services providers play a critical role in the global supply chain by transporting goods and services from suppliers to customers. Globalization has been an important factor in defining company strategies. Logistics services providers are defined as "any business that provides logistics services, including those businesses commonly referred to as 3PL, 4PL, LLP, etc." (Singhdong et al., 2021).

Based on this definition 4PL service providers typically possess advanced technology platforms, including integration with ERPs, e-commerce platforms, retail partners, and marketplaces. This facilitates the management of complex storage and fulfillment networks for 4PLs (Roseburgough, 2023).

The use of technology, including mobile technology, is widespread among 4PL service providers, as these businesses require real-time communication with all stakeholders they facilitate. Particularly, changing demands and needs from customers, quality concerns, and the increasing need for more visibility into their products during transportation are driving the adoption of technology (Ormanov, 2021: 16). 4PL service providers play a significant role in enhancing efficiency, visibility, and collaboration by offering technology-based solutions. The following are some of the priority applications explained:

3.1. Integrated Technology Platforms

An integrated technology platform for supply chain management is a comprehensive system that combines various software, tools, and technologies to optimize and streamline processes involved in managing the flow of goods, services, and information throughout the entire supply chain. The purpose of such a platform is to enhance visibility, efficiency, collaboration, and decision-making within the supply chain ecosystem. These platforms enable organizations to optimize their supply chain processes, increase customer satisfaction, reduce costs, and effectively respond to changing market dynamics.

Platforms that facilitate the integration of management systems such as Transportation Management Systems (TMS), Yard Management Systems (YMS), and Warehouse Management Systems (WMS) can organize all activities. The goal of integration platforms is to ensure the smooth execution of the supply chain with complete synchronization. This synchronization is carried to advanced stages and from the private sector, for example; It can be converted into the creation of inter-port planning models (Taha et al., 2017: 137).

4PL service providers also benefit from digital platforms that integrate various systems, including TMS, WMS, and Enterprise Resource Planning (ERP) software. This integration enables real-time data sharing across the entire supply chain, ensuring seamless communication and end-to-end visibility. In this context, these platforms become a key element of efficient and effective logistics management, leading to enhanced operational performance, cost savings, and improved customer satisfaction.

3.2. Digital Collaboration

Amidst the increased competition brought about by globalization, the dynamic development of information technology has led to significant changes in economic elements. One of the key factors contributing to this goal is the rapid execution of operations, along with process efficiency and effectiveness, necessitating collaboration coordination within the supply chain (Zurek, 2014). In this context, the high speed of operations emerges as a crucial factor for success. This speed not only enhances process efficiency and effectiveness but also contributes to maintaining a competitive advantage in the global market. However, achieving this increased operational speed requires seamless coordination across the entire activity chain. As a result, the interdependence of various components gives rise to synchronized efforts to achieve optimal outcomes and comprehensive objectives.

The role of logistics service providers often involves managing and analyzing large volumes of data, controlling transportation management, overseeing other 3PLs and transportation service providers, managing storage operations, or any other part of the supply chain. Transparency is key for a 4PL that can also function as a 3PL. For instance, they must actively collaborate with clients to demonstrate the limitations and counterbalances they bring, such as privacy agreements that restrict information and data exchange with other 3PLs and transportation, thereby fostering transparency (Matyushenko et al., 2019).

4PL service providers utilize digital collaboration tools like cloud-based platforms and electronic data interchange (EDI) to facilitate seamless communication, document exchange, and collaboration among supply chain stakeholders.

3.3. IoT and Sensor Technology

The Internet of Things (IoT) refers to systems, machines, and programs that communicate and collaborate with each other and with humans. This concept encompasses all sub-systems, processes, internal and external objects, and connects them to supplier and customer networks (Taha et al., 2017: 51).

One of the most prominent trends in the logistics and transportation industry is IoT, which leverages advanced communication technologies such as machine-to-machine (M2M) communication to connect almost every object to the internet (Borgi, 2017). As transportation systems advance and vehicles are equipped with increasingly sophisticated sensing, networking, and communication capabilities, it is anticipated that the Internet of Things will have a significant impact on logistics as vehicles interact with each other and their environment (Hopkins and Hawking, 2018). To successfully implement the Internet of Things in logistics, a strong collaboration and a general consensus on investing at a high level of engagement among different players and competitors in the supply chain are required (Macaulay et al., 2015: 25).

4PLs utilize IoT devices and sensors to track and monitor goods, equipment, and vehicles in real-time. This data enables (1) proactive decision-making, (2) optimization of asset utilization, (3) inventory level optimization, and (4) enhancement of overall supply chain efficiency.

3.4. Cloud-Based Solutions

Cloud computing represents a significant development in information and communication technologies in terms of computing, storage, and service capabilities (Lee et al., 2018). Cloud technology has become a powerful tool for supply chain management by sharing resources in real-time, offering diverse services, storing applications, and enabling access, thereby fostering the growth of supply chain management and cost savings while creating more business opportunities and a competitive environment (Puică, 2020). One of the most important advantages of cloud computing is its facilitation of platform-based new business models and increased efficiency (Miscevic et al., 2018).

Cloud-based services have become a popular method for connecting and supporting business processes across the supply chain, thus enhancing efficiency. This characteristic of the cloud provides stakeholders with access from any platform, at any time, and from any location, enabling real-time visibility into inventory levels, shipping processes, and shipment tracking through platforms that can deliver these insights (Karvela et al., 2015).

Cloud solutions provide secure storage, accessibility, and data sharing among various parties, facilitating real-time communication, collaboration, and data exchange. One of the most important advantages of cloud computing is its facilitation of platform-based new business models and increased efficiency (Miscevic et al., 2018).

3.5. Robotic Technology

The use of robotics in logistics, such as Autonomous Guided Vehicles (AGVs), Autonomous Mobile Robots (AMRs), and others, enhances the speed and efficiency of performing various tasks (Ormanov, 2021: 23). In modern logistics, numerous autonomous technology applications exist that demonstrate the safety and success of driverless vehicles, particularly in enclosed environments. Analysts anticipate a proliferation of applications not only in storage operations but also throughout the entire supply chain, especially in outdoor logistics operations, long-distance transportation, and last-mile delivery (Miscevic et al., 2018). Robots, defined as devices that largely or partially move autonomously, interact physically with humans or their environment, and can adapt their behavior based on sensor data, play a significant role in Industry 4.0. In human-robot collaboration, robots assist humans in working together. Since replacing humans entirely is not straightforward, machines take on tasks like lifting heavy loads or transporting bulky items from one place to another. The goal of collaboration is to combine human and machine skills to achieve higher outputs more precisely and accurately (Goel and Gupta, 2019: 157).

Robotic technology plays a crucial role in 4PL service operations by enhancing sustainability, automating warehouses, ensuring energy efficiency, reducing waste and errors, optimizing space utilization, and addressing safety and occupational health concerns.

3.6. Advanced Analytics and Predictions

The combination of the Internet of Things and cloud usage enables the connection of different equipment and the collection of vast amounts of data, leading to significant data storage (Gedik, 2021). Through the use of big data technology and analytics, working with data stacks enables (1) the creation of innovative perspectives, (2) the establishment of a foundation for businesses to achieve higher performance, and (3) the ability for businesses to enter untapped markets and create new markets (Banger, 2018a: 193).

Data analytics is considered to contribute to the smoother and more efficient operation of supply chains (Dfreight, 2022). Predictive analytics in the field of supply chains is used to forecast trends in goods flow, costs, and service levels. Furthermore, the importance of big data analytics techniques and strategies is emphasized in areas such as risk analysis, supply chain management, transportation, revenue management, marketing, inventory management, and forecasting. In practice, data analytics is a technique that involves analyzing large amounts of data to uncover information such as market trends and customer preferences that can help businesses improve their operations. It can also be used to predict future events and situations, aiding managers in deciding whether to change business strategies (Giusti et al., 2019).

4PL providers offer services as a single point of contact and often take responsibility for managing the entire supply chain network using advanced technologies and analytics to drive optimization and decision-making (Roseburgough, 2023). In this context, applying advanced analytics and predictive models to the vast amount of data generated within the supply chain enables 4PLs to identify patterns, forecast demand, optimize inventory levels, and provide valuable insights to clients for informed business decisions.

4. PURPOSE and METHOD of RESEARCH

The paper examines how the 4PL industry is changing and how crucial a role they are playing in advancing supply chain sustainability. In order to highlight the importance of Lead Logistics Providers, also known as 4PL service providers, in promoting sustainability and innovation in logistics, significant topics and findings from the mentioned sources have been summarized and examined for this literature study.

The literature focuses on how logistics service providers' capacity to support sustainable supply chain operations is becoming more widely acknowledged. According to Boschian and Paganelli (2016), more innovative and sustainable logistics business models are created when supply chain partners coordinate their logistical actions. This alignment denotes a change in the logistics sector's focus on sustainable practices.

Matyushenko et al. (2019) highlight the crucial function 4PLs provide in supply chains. They not only perform tasks akin to those performed by 3PLs, but they also have additional duties that help clients accomplish their strategic goals. The goal of 4PLs is to manage all moving elements and act as a single point of contact for all stakeholders in order to build economically effective supply chains.

According to Supply Chain Dive (Hawkins, 2022), 4PLs go beyond conventional logistics tasks by including carriers, warehouses, reverse logistics, and more. By doing away with silos, this comprehensive strategy gives supply chains complete visibility and transparency. It emphasizes the comprehensive nature of 4PL services.

Nowodziski (2014) emphasizes the potential for a carefully thought out and carried out logistics strategy to create a long-lasting competitive advantage. The challenge competitors face in replicating such an edge highlights its long-term viability. The strategic value of logistics in corporate operations is emphasized by this idea.

4PLs play a special role in promoting supply chain sustainability since they are integrators of supply chain management (Mehmann and Teuteberg, 2016). From this vantage point, it is clear that 4PL enterprises' sustainability actions must be carefully examined because they have the potential to dramatically affect and enhance supply chains' overall sustainability.

The need for innovation in logistics services is emphasized by Gruchmann et al. (2018) in order to attain long-term efficacy and efficiency. This suggests that logistics service providers, such as 4PLs, should concentrate on cutting-edge technology and creative fixes for the good of society as a whole.

The literature examined here highlights the growing significance of logistics service providers, especially 4PLs, in encouraging sustainability and innovation within supply chains. These suppliers are positioned as key players who influence efficient supply chain operations, build long-term competitive advantages, and

develop sustainable supply chain practices. In their pursuit of sustainability goals, overcoming obstacles and embracing technology and innovation are crucial.

The purpose of this research is to examine the sustainability potential and technology-based solutions of 4PL service providers. In addition, 4PL aims to determine the activities of service providers in the field of sustainability and the technology solutions they prefer for these activities. This study also aims to determine the importance levels of technology solutions determined as a result of content analysis by using SWARA (Step-wise Weight Assessment Ratio Analysis) method.

The study consists of two stages. In the first stage, a content analysis covering the web pages was made to determine the sustainability potential and technology-based solutions of the 4PL service providers operating in our country. In the light of the data obtained from the content analysis, the information on the internet pages was compiled and a situation determination was made. The second stage is the importance of sustainable digital solutions offered by 4PL service providers is evaluated by the SWARA method by taking expert opinion.

4.1. Content Analysis and Findings

In this study, firstly, the impact of sustainability and digitalization on 4PL logistics is explained. Sustainable practices in 4PL logistics focus on minimizing environmental impact, reducing waste, and promoting responsible supply chain management. In light of all this, the websites of 50 pre-determined 4PL service providers who are members of UND (International Transporters Association) and UTIKAD (International Transport and Logistics Service Providers Association) were examined between February 2023 and May 2023 to determine their sustainability potential and technology-based solutions. Subsequently, expert opinions were utilized to determine the importance levels of criteria obtained based on information accessed from the relevant 4PL business websites. In this context, the primary sustainable practices in 4PL service providers can be explained as follows:

Carbon Footprint Reduction: 4PL service providers can analyze transportation routes, consolidate shipments, and utilize data analytics to reduce carbon emissions and environmental impact.

Green Transport: 4PL service providers can select transportation partners who adhere to sustainability standards, such as using fuel-efficient vehicles, implementing emission reduction strategies, and promoting sustainable practices in their operations.

Sustainable Packaging: 4PL service providers can reduce waste by implementing sustainable packaging practices, including reducing material usage and incorporating recycling.

Collaboration and Stakeholder Engagement: Sustainability in 4PL involves actively engaging with stakeholders, including customers, suppliers, and local communities.

Ethics and Social Responsibility: Sustainability in 4PL also encompasses elements of social responsibility.

Reverse Logistics: Additionally, 4PLs can effectively manage reverse logistics processes, ensuring proper recycling and disposal of products.

Supply Chain Optimization: 4PLs can facilitate supply chain operations by employing data analytics and optimization techniques to optimize routes, consolidate shipments, and reduce empty backhauls. These efforts contribute to lower carbon emissions, energy consumption, and overall environmental impact.

Green Supply Chain Management: A 4PL service provider can collaborate with suppliers and stakeholders to implement sustainable practices, such as selecting eco-friendly transportation modes, optimizing packaging, and promoting responsible resource usage.

Environmental Reporting and Compliance: 4PL service providers can assist clients in monitoring and reporting environmental performance, complying with sustainability regulations, and implementing sustainability initiatives throughout the supply chain.

Furthermore, 4PL service providers play a significant role in enhancing efficiency, visibility, and collaboration by offering technology-based solutions. Following content analysis, the prioritized technology solutions preferred by 4PL service providers are listed below:

Integrated Technology Platforms: 4PL service providers utilize digital platforms that integrate various systems, including Transportation Management Systems (TMS), Warehouse Management Systems (WMS), and Enterprise Resource Planning (ERP) software. This integration enables real-time data sharing, seamless communication, and end-to-end visibility across the supply chain.

Digital Collaboration: 4PL service providers employ cloud-based platforms and digital collaboration tools such as Electronic Data Interchange (EDI) to facilitate uninterrupted communication, document exchange, and collaboration among supply chain stakeholders.

IoT and Sensor Technology: Using IoT devices and sensors, 4PLs can track and monitor goods, equipment, and vehicles in real-time. This data enables proactive decision-making, enhances asset utilization, optimizes inventory levels, and increases overall supply chain efficiency.

Cloud-Based Solutions: Cloud solutions provide secure storage, accessibility, and data sharing among various parties, facilitating real-time communication, collaboration, and data exchange.

Robotic Technology: Robotic technology plays a crucial role in enhancing sustainability in 4PL service operations, particularly in warehouse automation, energy efficiency, waste reduction, optimal space utilization, security, and occupational safety.

Advanced Analytics and Predictions: Applying advanced analytics and predictive models to vast amounts of data within the supply chain allows 4PLs to identify patterns, forecast demand, optimize inventory levels, and provide valuable insights for informed decision-making.

4.2. Research Findings and SWARA Method

In this study, content analysis was conducted to explore technology-based sustainable practices of 4PL service providers, leading to the development of a conceptual framework. Additionally, an insight into the technology-based sustainable practices possessed by 4PL service providers operating in Turkey was revealed. Table 2 contains information related to technology-based sustainable practices to be included in the expert opinions for the assessment of importance levels within the scope of the study.

In our study, the SWARA Method, which is an expert-focused approach that allows decision-makers to prioritize their preferences, has been employed. The SWARA Method enables experts to incorporate their opinions regarding the importance levels of assessment criteria in the decision-making process, with the importance ratings determined by the experts forming the cornerstone of this method (Ecer, 2020:94).

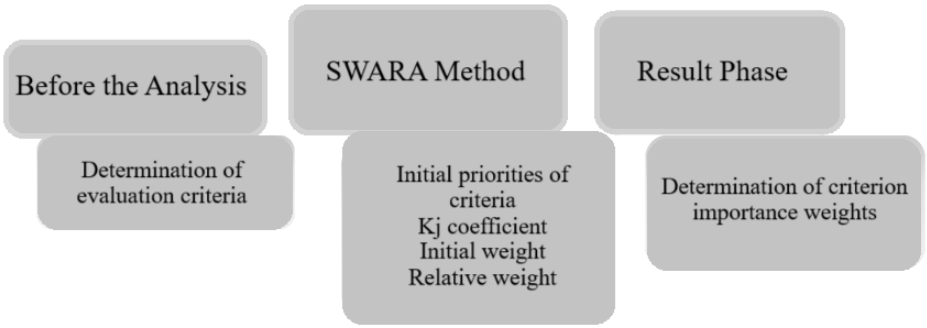

Figure 1. Steps of the SWARA method

Using the SWARA Method to determine the relative weights of the criteria can be demonstrated by following the correct sequence of the following steps (Stanujkic, 2015):

Step 1: The criteria are ranked in decreasing order of their expected importance.

Step 2: Starting from the second criterion, the participant assigns a coefficient (k_j) to each criterion, indicating its relative importance compared to the previous criterion ($s_j - 1$).

Step 3: The coefficient (k_j) is determined as follows (Equation 1):

$$k_j = \begin{cases} 1 & j = 1 \\ s_j + 1 & j > 1 \end{cases} \quad (1)$$

Step 4: The recalculated weight values are determined as the importance vector values (q_j) as in Equation 2.

$$q_j = \frac{w_j}{\sum_{k=1}^{n} w_k} \quad (2)$$

Step 5: Here, (w_j) represents the relative weight of criterion (s_j). The relative weights of evaluation criteria are determined as follows (Equation 3):

$$w_j = \begin{cases} 1 & j = 1 \\ \frac{x_{j-1}}{k_j} & j > 1 \end{cases} \quad (3)$$

Table 2. Criteria determined to be used in the study as a result of content analysis and literature review

Criterion	*Definition*
C1 - Data-Based Decision Making	4PL providers leverage data and analytics to support informed decision making. Uses advanced technologies such as Internet of Things (IoT) devices and data analytics tools to optimize transportation routes, reduce energy consumption, and increase overall supply chain visibility and efficiency
C2 - Digital Platforms and Marketplaces	Digital platforms and Marketplaces; facilitating efficient data sharing, real-time monitoring and analytics, it enables 4PL companies to optimize their logistics operations, reduce waste and make informed sustainability-focused decisions.
C3 - Warehouse Automation	Automation technologies such as robotics, automated storage and retrieval systems (AS/RS) optimize warehouse operations by reducing manpower, maximizing space utilization and improving inventory management. This helps to minimize energy consumption and waste while improving overall efficiency.
C4 - Green Transportation Applications	Green transportation practices; These include the use of route optimization software to minimize fuel consumption and emissions, the use of GPS tracking systems to monitor and manage vehicle performance, and the investment in alternative fuel vehicles or electric fleets to reduce carbon footprint.
C5 - Route Optimization and Planning	4PL provider businesses; technology platforms can optimize transport routes and delivery schedules, taking into account factors such as traffic conditions, fuel efficiency and customer preferences. In these; leading to reduced fuel consumption, lower emissions and improved delivery accuracy.
C6 - Sustainable Packaging and Materials Management	Technology solutions can help optimize packaging and materials management to minimize waste and improve recyclability. For example, using dimensional scanning and modeling software helps determine the most efficient packaging design and can reduce unnecessary material usage.
C7 - Vehicle Tracking Systems	4PL providers; uses tracking systems to monitor and optimize vehicle performance, track shipments and improve route planning.
C8 - Supply Chain Visibility	Technology solutions such as Internet of Things (IoT) devices, RFID tags and real-time tracking systems provide greater visibility and transparency throughout the supply chain. This allows 4PL service providers to monitor and optimize transport routes, minimize empty commutes and reduce fuel consumption.
C9 - Digital Documentation	Contracts, customs declarations etc. It reduces the number of papers used, paperwork, errors and delays by allowing for smooth change and management of the company.

Table 3. Demographic information of decision makers

Decision Maker	*Title*	*Experience*	*Sector/Working Area*
1	Operations Manager	17 years	Logistics
2	Assistant Professor	12 years	Transportation and logistics
3	Assistant Professor	15 years	Transportation and logistics
4	Doctor Lecturer	18 years	Logistics and supply chain
5	Assistant Professor	16 years	Transportation and logistics
6	Information Technologies Specialist	5 years	Logistics
7	Logistics Specialist	5 Years	Logistics
8	Logistics Manager	20 years	Logistics and supply chain

To examine sustainable practices and technology-based solutions at fourth-party logistics service providers the evaluations of eight experts whose information is given in Table 3. were consulted through the prepared survey form. Experts received survey forms either online or in person. It was necessary to have at least five years of academic or professional experience in the logistics sector to be selected for the expert panel. Four of the specialists who took part in the survey are faculty members in the Department of Logistics Management and have experience working in the logistics sector. In addition, 4PL, logistics information systems, and sustainability constitute the fields of study of these academicians. The other four participating experts work in corporate enterprises operating in the logistics sector.

Table 4. Calculation of criterion weights of Decision Maker - 1 by SWARA method

Criterion	*Order of importance*	S_i	k_j	Q_i	w_j
C4	1		1	1	0.20608
C1	2	20%	1.20	0.83333	0.17173
C8	3	30%	1.30	0.64103	0.13210
C3	4	20%	1.20	0.53419	0.11008
C2	5	10%	1.10	0.48563	0.10008
C9	6	10%	1.10	0.44148	0.05532
C5	7	30%	1.30	0.33960	0.06999
C6	8	10%	1.10	0.30873	0.06362
C7	9	15%	1.15	0.26846	0.09098

As an example, is given for the evaluation of Decision Maker-1 in Table 4 the following calculations are made for each evaluation, respectively.

Step 1: Using Equation 1, the coefficient (k_j) value is reached with the help of s_j's.

Step 2: The importance vector values (q_j) of each criterion were calculated.

Step 3: The weights (w_j) of the criteria are calculated.

Table 5. Criterion weights

Criterion	*Cv1*	*Cv2*	*Cv3*	*Cv4*	*Cv5*	*Cv6*	*Cv7*	*Cv8*	*Final Weight*	*Order*
C1	0.17174	0.12878	0.20608	0.73771	0.01968	0.07143	0.07246	0.07246	0.11204	1
C2	0.10008	0.20608	0.15515	0.34415	0.00772	0.08929	0.03221	0.05678	0.07813	3
C3	0.11009	0.10665	0.12212	0.52269	0.05952	0.02926	0.02013	0.05407	0.07835	2
C4	0.20608	0.18735	0.14105	0.39671	0.08929	0.01463	0.00177	0.05962	0.06444	6
C5	0.06999	0.09696	0.17843	0.43297	0.03307	0.05714	0.00699	0.06901	0.06838	4
C6	0.06362	0.14810	0.12823	0.29675	0.02756	0.03657	0.01118	0.05150	0.06163	7
C7	0.09098	0.17032	0.08849	0.21140	0.00643	0.01330	0.00538	0.04905	0.03999	9
C8	0.13210	0.12265	0.19627	0.20338	0.00402	0.04571	0.04831	0.06573	0.06639	5
C9	0.05532	0.08080	0.10619	0.23254	0.01312	0.02341	0.00336	0.06260	0.04042	8

In Table 5, there are criteria weights made for 8 decision makers. The final criterion weights were obtained by finding the geometric mean of the criterion weights of each decision maker.

Table 6. Final criterion weights criterion orders

Criterion	*Definiton*	*Order*
C1	Data-Based Decision Making	1
C3	Warehouse Automation	2
C2	Digital Platforms and Marketplaces	3
C5	Route Optimization and Planning	4
C8	Supply Chain Visibility	5
C4	Green Transportation Applications	6
C6	Sustainable Packaging and Materials Management	7
C9	Digital Documentation	8
C7	Vehicle Tracking Systems	9

As seen in Table 6; based on the expert opinions gathered, it has been determined that the most important technology-based sustainable practices are “Data-Driven Decision Making”. Following that, in order of importance, are warehouse automation, digital platforms and marketplaces, route optimization and planning, supply chain visibility, and green transportation practices. The least important is attributed to “Vehicle Tracking Systems”.

5. CONCLUSION and DISCUSSION

This research primarily aimed to theoretically explain the role and impacts of 4PL service providers in the logistics sector. By doing so, it provided a fresh perspective to the literature, expanding the theoretical framework of the 4PL concept and enriching the theoretical knowledge in the field of logistics management. The study particularly focused on Turkey's logistics sector, contributing to understanding the local

conditions and unique features of the sector within the context of Turkey. Furthermore, it assists in better evaluating the current status and future potential of Turkey's logistics sector.

This study highlights the benefits of incorporating sustainability practices and digitalization into the operations of 4PL service providers. It guides actors in the sector to make their operational processes more sustainable and to embrace technological innovations to enhance efficiency. Additionally, it underscores how sustainable technologies can enhance operational efficiency for 4PL service providers, contributing to optimizing supply chain performance and aiding businesses in managing resources more effectively and efficiently.

Within the scope of this research, it has been determined that among technology-based sustainable practices, 'Data-Driven Decision Making' holds the highest degree of importance. On the other hand, 'Vehicle Tracking Systems' technology has been identified with the least degree of importance.

Data-Driven Decision Making enables strategic decisions in the logistics sector through the analysis and interpretation of data. Warehouse automation enhances efficiency by reducing human intervention in logistics processes. Digital platforms and marketplaces facilitate operations by bringing together suppliers and customers. Route optimization and planning minimize transportation costs and time by determining the most efficient routes and schedules. Supply chain visibility improves processes like inventory management and demand forecasting by increasing information flow throughout the chain. Green transportation practices reduce environmental impact through the use of eco-friendly transportation methods. Sustainable packaging and material management support sustainability by reducing waste and promoting recycling. Digital documentation speeds up and organizes document processes by reducing paper usage. Vehicle tracking systems optimize delivery processes by tracking the location of transport vehicles.

The reason why vehicle tracking systems ranked last in terms of importance in the survey may be due to several factors. Firstly, vehicle tracking systems may now be accepted as a standard practice by many logistics service providers. In other words, this technology may not need to be emphasized to gain any competitive advantage. In this case, managers are more likely to prioritize other technological innovations or more specific competitive advantages of the logistics business. Furthermore, one reason why vehicle tracking systems are less important for logistics businesses is that they are more related to operational and day-to-day operations. In other words, their direct impact on strategic decision-making or achieving large-scale competitive advantages may be limited. These results do not necessarily imply that vehicle tracking systems are unimportant; however, they may indicate that business managers are shifting their attention to other areas that can provide more strategic or competitive advantages.

The importance degrees of these criteria can vary based on the priorities of the logistics service provider, industry requirements, and goals. For instance, route optimization might be crucial for one logistics service provider, while green transportation practices might hold greater significance for another. Prioritization can be achieved by evaluating how each topic aligns with the logistics business's strategy and objectives.

The ranking of technologies according to their importance by managers can help these businesses to better focus on their strategic goals and use their resources most effectively. For example, fuel-saving route optimization software or vehicle tracking systems can reduce transportation costs. By ranking technologies by importance, managers can determine which technologies optimize business processes more and increase efficiency. For example, real-time tracking and delivery tracing can help to better serve customers, while identifying which technologies are more effective in reducing costs. Some technologies contribute to logistics businesses by increasing customer satisfaction or improving service quality. For example, real-time tracking and delivery tracking can help provide better service to customers. Ranking technologies can help logistics businesses identify their ability to deal with specific risks.

In previous studies; it is seen that the 4PL approach is conceptually addressed from a sustainable perspective. It shows the applicability of the 4PL approach within the sustainability goals in supply chain management (Mehmann and Teuteberg, 2016). Also, global operations, linked to a sound knowledge of markets and competitive analysis, are essential for sustainable long-term success. The emergence of innovative technologies in the areas of communication, tracking, and screening, coupled with the growing trend in global partnerships and cooperation, will make fourth-party logistics crucial in terms of cost and efficiency in the coming years (Nowodziński, 2014).

This study, on the other hand, reveals that 4PL service providers are not only involved in sustainability approaches, but also involved in these activities with technology-based applications. Thus, the current study defines retention strategies for 4PL service providers to satisfy societal and environmental demands in the future. The study further advances theory by defining the 4PL business model type and its function in societal changes. This study emphasizes that the sustainability practices of 4PL service providers can

help reduce environmental impact. It encourages businesses to take more conscious steps toward reducing environmental impact and achieving sustainability goals.

The human component of logistics and supply chain management might be further addressed in future work, for example by surveying the empirical findings. The primary emphasis of this analysis is the 4PL logistics services providers industry. To support their operations, logistics businesses need to keep a close eye on current and future technologies, analyze trends before investing in technology, and identify the ones that best suit their needs. They must consider technology not only as a tool but also as a strategic competitive advantage. Embracing digital transformation not only as a technological change but also as part of your business culture can be the basis for future success and sustainable growth. In conclusion, the results of this research suggest that through technology-based sustainable practices, 4PL service providers can enhance customer service levels and gain a competitive advantage.

Author Contributions
Bihter Karagöz Taşkın: Literature Review, Conceptualization, Methodology, Data Curation, Analysis, Writing-review and editing Macide Berna Çağlar: Literature Review, Modelling, Analysis, Writing-original draft, Writing-review and editing

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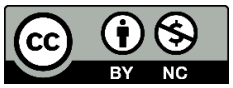
Compliance with Ethical Standards
For this study, the approval of the Ethics Committee Başkent University Academic Evaluation Coordinators was obtained with the decision dated 07.08.2023 and numbered E-62310886-605.99-255732.

Ethical Statement
It was declared by the author(s) that scientific and ethical principles have been followed in this study and all the sources used have been properly cited.



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