The Potential of ICT Adoption in Promoting Sustainable and Resilient Supply Chains: Evidence from Greek Logistics Firms

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Abstract: The logistics sector is undergoing a sustainable and resilient transformation guided by the concepts of green supply chain management (GSCM) and supply chain resilience (SCR). While the existing literature posits ICT technologies as individual enablers that enhance organizational performance in areas like sustainable operations, resource economization and organizational resilience, a gap remains in comprehending the nuanced role of Information and Communications Technology (ICT) in linking GSCM and SCR outcomes. This research delves into how top management perceives the alignment of ICT adoption with GSCM and SCR objectives within logistics firms. Data were gathered from 53 managers in Greek logistics firms. After utilizing factor analysis, the findings indicate that (1) a significant correlation exists between GSCM/SCR states and ICT adoption; (2) firms with higher ICT adoption rates more effectively address GSCM and SCR challenges; and (3) notably, larger firms with more resources have a slight edge over smaller counterparts with less focus on ICT. Policymakers and industry leaders in the logistics sector can leverage these insights to prioritize ICT-related initiatives, especially in regions with similar contexts to Greece.

Keywords: sustainability; green supply chain management; ICT technologies; supply chain resilience

1. Introduction

The profound impact of recent global crises has underscored the vulnerabilities of contemporary supply chain (SC) networks. From pandemics and geopolitical risks to supply shortages and logistical disruptions, businesses operating within these networks have faced extraordinary challenges [1,2]. These disruptions have magnified the necessity of creating resilient SCs that can respond effectively to disturbances and quickly return to normal or acceptable performance states. The quest for SC resilience, however, is multifaceted. It is characterized by the confluence of societal, environmental and economic considerations [1,2].

Digital transformation and the advent of disruptive information and communication technology (ICT) solutions have profound implications for SCs. These technologies enhance information flow, support performance monitoring and foster disruption recovery, thereby contributing significantly to supply chain resilience (SCR) and green supply chain management (GSCM) [3–9]. The role of ICT extends further, directly influencing energy efficiency, real-time environmental monitoring and resource management [10–12]. However, it is crucial to address the fact that ICT is not without its shortcomings. Notably, the sector itself is responsible for about 2% of the world’s energy consumption [11] and the implementation of ICT may introduce new risks and dependencies [9]. While ICT can optimize resource utilization and emissions reduction [13,14], certain applications like
blockchain, although promising in terms of transparency and waste minimization, are energy-intensive and could negatively impact the environment.

The concept of business sustainability, which pivots on the triple bottom line of social, environmental and financial performance, serves as a critical backdrop to our discussion [1,15]. GSCM, an offshoot of this ethos, has gained prominence in the last two decades due to its emphasis on applying environmental management principles across all stages of the SC, with the ultimate objective of zero waste [7,16,17]. The implementation of GSCM also appears to offer buffering effects during disruptions and enhances financial performance, confirming the significant role of environmental sustainability in building resilient SC networks [18–22]. The management of green SCs is a complex task involving strategic, tactical and operational decision-making processes. Additionally, internal and external drivers, such as leadership commitment and reduced costs, influence the implementation of GSCM practices [2,23].

Adopting an integrated approach that recognizes and leverages the complementarities and synergies between ICT and SCR/GSCM factors can potentially yield optimal outcomes at the firm level. Moreover, depending on the strategic orientation and leadership stature of the firm, it may spur performance enhancements across the supply chain. This hypothesis is founded on the rationale that firms adept at utilizing ICT, prioritizing environmental sustainability [21] and incorporating resilience into their SCs are likely to attain a competitive edge and sustain long-term viability, while influencing positive developments across the supply network. Particularly during the transitional phases towards digitalization and greener practices, ICT tools emerge as potent enablers fostering increased resilience and sustainability for firms engaged in SCs [15]. On the flip side, enhanced resilience can potentially generate economic scale benefits, consequently incentivizing the broader adoption of ICT tools and facilitating improved sustainability outcomes, thereby fostering a resilient SC while aligning with the societal objectives of zero-pollution and carbon-neutral transitions. Furthermore, it is crucial to note the emerging sustainability debates surrounding the environmental impact of digital and ICT systems, especially considering the energy consumption patterns of data centers, necessitating careful consideration in the decision-making processes of firm management.

The confluence of IT/ICT, GSCM and SCR forms an integral hub within the framework of SC strategies and operations [24]. These technologies, encompassing big data analytics, Artificial Intelligence (AI) and blockchain, among others, serve as vital catalysts in amplifying both resilience and sustainability in SCs [25–27]. They facilitate seamless communication, adept risk mitigation and the cultivation of green practices, hence fortifying SCR [28–30] and fostering sustainable operations [31,32]. Nevertheless, meticulous strategic decision making becomes pivotal during the assimilation of these elements, given the plausible trade-offs [33,34]. While green initiatives can enhance resilience, they could potentially impinge on profitability if not adeptly managed. Moreover, while IT/ICT augments SC operations, it necessitates prudent considerations regarding information security and the environmental ramifications of IT deployment and utilization [35–37]. Hence, enterprises are mandated to judiciously navigate these intricacies while harnessing IT/ICT to engender more environmentally friendly and resilient SC networks.

However, empirically investigating the intricate interdependency between ICT, SCR, and GSCM poses substantial challenges, primarily due to the pervasive and transformative nature of digital platforms, and information and communication tools that permeate all aspects of firm management and operations at all times and scales [38], fostering hybrid systems that intertwine both social–technological [39] and physical dimensions. In the midst of the current complex crises characterized by geopolitical transitions, energy deficits and ongoing environmental and ecological dilemmas [39,40], understanding how firms adapt within the nuances of regional and local logistics environments is vital. These adaptations bear significant weight, as the efficacious mitigation of environmental repercussions associated with a business and its SC predominantly relies on adherence to local regulatory frameworks and the availability of pertinent technical knowledge and expertise. This also
involves optimizing the flow of information and value across the entire chain. Based on the above-mentioned gaps, the following research questions are deemed necessary:

- How can logistics firms balance the trade-offs between resilience, profitability and environmental impact within IT/ICT-enabled supply chains?
- To what extent does company size and resource availability impact the level of ICT innovation implementation for GSCM and SCR in logistics firms?
- What are the differences in adoption strategies to IT/ICT advancements for GSCM and SCR in logistics firms at a regional level, and how do these strategies correlate with regional dynamics and supply chain performance?

This paper aims to shed light on the tactics and approaches deployed by local logistics firms in transitioning towards sustainable and resilient global and local SC operations. Contrasting with the global SCM theory’s viewpoints, which are grounded on network-centric, globally situated firms in SC, capable of exerting substantial influence and control over the entire value chain [5,10,15,41], this manuscript posits that enterprises within local logistic clusters, typically specializing in last-mile and distribution functions, witness a more complex and less streamlined relationship among the three constituent elements (GSCM, ICT, and SCR). This relationship is substantially influenced by the company’s contextual factors and often manifests as nuanced, ambiguous and intricate [42], with each facet dynamically interacting and evolving with the others in often unpredictable and suboptimal ways, embodying both discrepancies and synergies [43].

This paper endeavors to contribute to the burgeoning literature by narrowly dissecting two pivotal linkages from the firm management perspective: the first exploring the interrelation between ICT adoption and GSCM, and the second examining the correlation between ICT and SCR. In undertaking this endeavor, the paper embarks on an in-depth analysis of the convergence between ICT, SCR and GSCM, leveraging the existing literature and a targeted survey conducted among Greek logistics firms. By scrutinizing these relationships through empirical survey data garnered from logistics firm managers, the paper discerns the interconnections and feedback loops among these concepts, highlighting the critical factors identified by managers and elucidating the varying significance accorded to the role of ICT in SCR and GSCM within their current decision-making processes. The findings promise to be a valuable addition to the escalating discourse on sustainable business transitions and supply chain management literature.

In consonance with contemporary business management discourse, this paper perceives logistics firms as complex entities, exploiting and molding a spectrum of options within their capacity and resource constraints, dictating their strategic, operational and tactical decisions. These decisions perpetually intersect with ICT systems, business resilience and sustainability outcomes at varying levels, intertwining within the nexus of individual firm–supply network–broader logistics systems [38,39]. Indeed, the salience of these factors on firm/system performance can fluctuate depending on the firm’s distinct position within the industry and supply network.

The remainder of this paper is structured as follows: Section 2 focuses on a comprehensive literature review that addresses the topics of SCR and GSCM strategies, as well as the dynamics of ICT adoption in relation to SCR and GSCM strategies. In Section 3, we delineate the methodology that was meticulously crafted for this study, paving the way for a well-rounded investigation into the subject matter. Moving forward, Section 4 brings forth the findings of our study, offering a lucid presentation of the data amassed. These results are subsequently analyzed and discussed in depth in Section 5, where we unravel the intricate layers of the research, fostering a rich dialogue around the findings. The paper ends with some concluding remarks.

2. Literature Review

2.1. SC Resilience and Green/Sustainable SC Strategies

The interconnectedness of resilience, GSCM and sustainable supply chain management (SSCM) is evident from various studies. The role of Green (G), Resilient (R), Agile
(A), and Sustainability (S) (GRAS) enablers in SC sustainability was emphasized, with a particular focus on the organizational culture of firms, environmental certification programs and financial strength [44]. The integration of Lean, Agile, Resilient and Green (LARG) practices into supply chain management is becoming increasingly important for ensuring both environmental sustainability and resilience in businesses [18,33,42,43,45–48]. Research suggests the use of integrated LARG paradigms to ensure lean, responsive and environmentally friendly SCs. They also offer benchmarks for assessing the sustainability of SCs and identifying synergies and divergences within the SC [18,43,45]. The “G-Resilient” SC model aims to mitigate disruption effects and uncertainties, offering practical strategies for risk handling [42]. Some identified critical practices include just-in-time (lean practice), flexible transportation (resilient practice) and environmentally friendly packaging (green practice). However, a balance is required due to the trade-offs among these practices [33]. On a global scale, agile and green responses under disruption and “gresilient” SC management that combines green and resilient aspects in supplier selection gain importance [47,48].

Addressing SC disruption and risks across SC networks is considered increasingly important, with the integration of “gresilient” supplier selection and order allocation decisions with vehicle-routing decisions under disruption proving beneficial [19]. The implementation of GSCM practices was also shown to have a buffering effect, helping firms recover from disruptions quickly [40]. The research by [40] suggests that environmentally sustainable practices can play a pivotal role in enhancing firms’ resilience, particularly during supply chain disruptions, such as those seen in the COVID-19 crisis. The implementation of green supply chain management has been linked to improved financial performance, underlining the need for businesses to integrate sustainability into their practices for environmental benefits and financial gains. This is echoed by the study by [20], which provides empirical evidence showing that companies that adopted GSCM practices faced less negative abnormal stock returns during the COVID-19 crisis. The research affirms the perception of GSCM as an effective risk management tool and highlights the importance of sustainable practices in SC management for risk mitigation and financial improvement in a post-COVID-19 world. In line with these findings, ref. [21] examined the implications of environmental performance on firms’ resilience. The study reveals that firms with higher environmental performance are not only more resilient but also recover quicker after environmental shocks. This suggests that environmental commitment can equip firms with organizational skills and legitimacy, fostering stakeholder support that can expedite recovery after environmental controversies. Thus, the study advocates for environmental commitment, indicating that it can offer benefits beyond just environmental sustainability. Finally, designing Green-Resilient Supply Chain Networks through risk mitigation strategies, including supplier coalitions and multi-sourcing strategies at the retailer level, can reduce costs and carbon emissions [22].

The increasing use and dependence on ICT systems carries significant implications for environmental sustainability, particularly in the context of carbon footprint. Concurrently, as the relationship between ICT and green supply chain management (GSCM) deepens, then, in agreement with recent research, more integrated carbon management strategies become increasingly important [49] for both ICT and SCM. This is because the environmental impact of ICT when considering its embodied carbon footprint, such as in the voluminous intermediary inputs it depends upon, is far greater than its direct impacts [49], while ICT industry activities have been shown to have negative effects on carbon intensity in major economies such as China [50], warranting a more balanced approach to ICT growth with ecological and distributional considerations as to the carbon balance in international trade between developing and developed economies [51].

2.2. SC Resilience and ICT Adoption

ICT can enhance SCR by enabling faster and more efficient communication and collaboration among SC partners, providing real-time data on SC performance and facilitating the sharing of information on disruptions and risks. The adoption of ICT can also support
the implementation of various SCR strategies, such as inventory optimization, flexible sourcing and risk mitigation planning. Therefore, ICT adoption is an important factor in building SCR. The role of Information Management (IM) in enhancing SCR has been a focal point in recent research, particularly due to increasing global disruptions like the COVID-19 pandemic and international conflicts [52–54]. Integral aspects of IM, such as information security culture, information leakage management, efficient information sharing and effective technology utilization, are known to mediate the relationship between IM and SCR [37,52,55]. Ref. [30] emphasizes the role of real-time information use in substantially enhancing SCR, underlining the significant partial mediation by operational agility. Additionally, ref. [28] recommends a multi-objective optimization model for choosing effective SCR strategies, thereby establishing the importance of strategic decision making in IM. Further, ref. [29] demonstrates how SC capabilities, including IM, directly influence SCR and sustainable SC performance. Similarly, technological innovation and its relationship with SCR and operational performance is examined by [52], indicating the critical role of IM in building SCR.

Researchers also note the impact of Fourth Industrial Revolution (4IR) technologies on SMEs’ SCR, illustrating a positive link between 4IR adoption and SCR [56]. The adoption of Industry 4.0 significantly impacts SCR, highlighting the importance of information visibility in the SC [57]. Blockchain technology and Artificial Intelligence (AI) have also been touted as having the potential to bolster SCR [58,59]. In the realm of Big Data Analytics (BDA), studies provide empirical evidence that BDA capabilities enhance healthcare SC responsiveness and innovation, thereby bolstering SCR [60]. The significance of BDA capabilities extends to improving firm performance through SCR, particularly when combined with a risk management culture [61]. Researchers further argue for harmonizing the data analytics capability and SCR to recover quickly from disruptions or to minimize their ripple effect in the SC [8]. This view is echoed by Hsu (2022), who emphasizes integrating BDA with SCR, while also stressing the importance of information sharing and effective IT infrastructure.

The significance of IM extends to managing information and cyber risks across the SC to significantly affect SCR [62]. From an organizational perspective, ref. [63] underscores the importance of SCR in contributing to risk management and market performance, thus reinforcing the importance of effective IM in enhancing SCR. Emerging IT capability’s role in enhancing SCR and corporate sustainability is investigated by [53], highlighting the growing significance of technological innovation in an evolving global environment. Ref. [64] explores the interrelation between agility and resilience and how they relate to IM. Ref. [65] looks at the relationship between types of integration, SCR and service performance from the third-party logistics providers (3PLs) perspective, underscoring the importance of internal integration facilitated by effective IM. Studies by [36,37,55]) stress the role of information security culture in mitigating the adverse impact of information leakage on information sharing effectiveness, thereby enhancing SCR. In contrast, ref. [54] sheds light on the potential negative impact of certain aspects of technology, such as procurement automation, on SCR, thereby indicating that while technology plays a crucial role in SCR, not all aspects of automation are beneficial.

2.3. ICT and Green/Sustainable SC Strategies

The integration of ICT technologies with GSCM and SSCM is central to several studies. There is a consistent theme highlighting the transformative role of these technologies in enhancing SC performance, operational performance and firm performance [31,32]. Crucially, the application of technologies such as BDA, AI and blockchain plays a significant role in advancing environmental process integration, green SC collaboration and the overall sustainability practices in various industries [25–27]. Advanced ICT resources are key to successful e-GSCM implementation, leading to superior environmental performance and competitiveness. In addition, relationship learning activities and green innovation performance are vital managerial actions that contribute to the growth of customer capital, with ICT playing a complementary role [66,67]. The role of ICT in facilitating green SC
information integration, positively impacting SC process ambidexterity, is also critical [68]. Innovative ICT technologies like blockchain and Internet of Things (IoT) also have significant implications for GSCM and SSCM, with impacts ranging from enhancing green SC integration to boosting green SC performance [69,70]. Despite these benefits, it is worth noting that adopting green practices and systems, such as GSCM, may result in trade-offs between sustainability and profitability. However, such dilemmas can be effectively moderated with the use of green information systems (GISs), effectively balancing these trade-offs [34]. That said, there is a need to consider the environmental impact of the production and use of ICT itself [35].

In the wider context, the adoption of green technologies should focus not only on environmental sustainability but also on economic and social value. ICT has a role that extends beyond reducing energy to enabling sustainability capabilities and delivering sustainable values [71]. Ultimately, the use of green energy technologies can further enhance the sustainability of the SC [72]. Trust and collaboration are highlighted as pivotal factors in GSCM implementation, as demonstrated by a study on South Korean companies. A positive orientation towards GSCM improves firm performance, a result mediated by trust and information sharing among SC partners [73].

2.4. Research Gaps and Contributions

The available literature on SCR and GSCM, as described above, demonstrates a keen understanding of the interconnectedness of these concepts, particularly through the lens of IT/ICT. However, there are notable gaps that need to be bridged to develop a more comprehensive understanding. For example, the critical challenge of balancing resilience, profitability and environmental impact in IT/ICT-enabled supply chains is acknowledged but not fully explored. In addition, the available literature has partially addressed how the size of a company and its available resources affect the implementation level of ICT innovations for GSCM and SCR. Therefore, a more granular understanding is needed. The extent to which company size and resource allocation influence the pace and scale of ICT adoption could offer insights into the tailored strategies that different-sized firms could employ to enhance their supply chain’s green and resilient attributes. Finally, while global trends in IT/ICT adoption for GSCM and SCR are highlighted, there is a significant gap in comparative regional studies. There is an essential need to understand how logistics firms across different regions adapt IT/ICT advancements for GSCM and SCR. These insights are crucial, as they can uncover how regional dynamics influence supply chain performance and the adoption of green and resilient practices.

Addressing the identified research gaps, this study offers a dense contribution by establishing a correlation between ICT adoption and enhanced GSCM and SCR within logistics firms in Greece. The findings present a nuanced understanding that larger firms with abundant resources demonstrate superior performance in integrating ICT for supply chain sustainability and resilience. This suggests that company size and resource endowment are indeed pivotal in determining the effectiveness of ICT implementation, thereby bridging a notable gap in the literature. Furthermore, the study highlights that despite recognizing the importance of ICT, the actual application in support of GSCM and SCR is not at an optimal level across the firms surveyed. The research also surfaces key barriers, including lack of training, high system costs and the necessity for process redesign. These insights imply that not only the ‘what’ but also the ‘how’ of ICT implementation requires further exploration, especially for smaller firms, to develop tailored strategies that align with their resource capabilities. By focusing on a specific region, this research underscores the regional variance in ICT adoption, offering a basis for comparative analysis that is currently lacking in global studies. Consequently, this study provides concrete evidence that can inform strategies to navigate the complexities of IT/ICT in improving supply chain sustainability and resilience within differing regional and organizational contexts.

The novelty of this study lies in its integrated exploration of two significant interconnections from a firm management perspective: the dynamic link between ICT adoption
and green/sustainable supply chain management (GSCM), and the relationship between ICT and SC resilience (SCR). Unlike extant literature, this research uniquely integrates the intermediating role of ICT, especially providing new evidence from the logistics sector. The empirical insights derived from the perspectives of logistics firm managers shed light on the intricate interdependencies, variable states of technology adoption and firm management considerations about the intermediating role of ICT in SCR and GSCM strategies. Building on these insights, the findings underline the importance and varying roles attributed to ICT in SCR and GSCM in contemporary managerial decisions. This research contributes to the broader discourse on sustainable business transitions by offering (a) a fresh look and empirical evidence based on the management practitioner’s perspective, thereby enriching the supply chain management literature, and (b) offering insights to decision makers on the relevant gaps in leveraging ICT to achieving SCR and GSCM outcomes as experienced by logistics firms.

3. Methodology

The research methodology depicted in Figure 1 employs a structured approach to examine the correlation between Information and Communications Technology (ICT) innovations with supply chain resilience (SCR) and green supply chain management (GSCM). The study proceeded in three systematic steps. First, a comprehensive literature review was undertaken, examining the relationships between three critical relational pairs in the specialist management literature: (a) supply chain (SC) resilience and green/sustainable supply chain (GSC) strategies, (b) SC resilience and information and communication technology (ICT) adoption, and (c) ICT adoption and GSC strategies. Second, an empirical survey was administered to top management of 53 logistics firms based in Greece. The third step encompassed a rigorous analysis of the obtained data using factor analysis and summary statistics.

Drawing from the detailed literature review delineated earlier, we examine two central research hypotheses that are anchored in the synergy between ICT adoption, SCR and GSCM. Our initial hypothesis posits that ICT innovations function as a pivotal tool in augmenting SCR. As corroborated by the literature, ICT innovations equip organizations with the adeptness to execute SCR strategies proficiently, facilitating a swift and robust response to disruptive occurrences and adapting to evolving performance benchmarks. Thus, we conjecture a positive correlation between the deployment of ICT innovations and the cultivation of SCR. The subsequent hypothesis under scrutiny explores the role of ICT innovations as a vital catalyst in fostering GSCM. It is discernible from the literature that ICT applications frequently serve as instrumental facilitators in the initiation and governance of eco-friendly practices within organizations, directly bolstering GSCM positively.

![Figure 1. Methodology adopted in this paper.](image-url)
stakeholders in the SC. This tool encompasses 56 diverse items, strategically segmented into four sections to gather holistic insights. The inaugural section solicits information on the responding firms’ characteristics, encapsulating questions on their industrial specialization, operational scale and geographical reach. Here, firm size, delineated by workforce size and annual financial turnover, is identified as a control variable, acknowledging the potential of larger firms to allocate more substantial resources towards ICT incorporation as suggested in the literature. The ensuing section, consisting of questions 8–31, focuses on evaluating the integration level of GSCM and the influence of ICT innovations therein. This segment seeks to gauge the extent of GSCM implementation and the degree to which ICT innovations catalyze it, offering a detailed lens into the operational intricacies of the participating firms. Subsequently, the third segment (questions 32–47) delves into exploring SCR, along with the ICT innovations facilitating it, seeking nuanced insights into the organizational resilience in the context of SCs. Notably, this section initiates with elucidative definitions of GSCM and SCR, aiming to foster a deeper understanding and accurate responses. Transitioning to the final section, we concentrate on identifying potential barriers that impede the seamless incorporation of ICT innovations within firms, presenting participants with a series of questions (48–55) that aim to spotlight the prevalent challenges. Moreover, we inquire into the specific ICT innovations leveraged by the firms (question 56), offering a glimpse into the prevailing industry trends and facilitating an open discourse on potential additions to the listed innovations.

The responses to these items were captured using a 7-point Likert scale, reflecting the extent to which the participant companies integrated the related concepts, ranging from 1 signifying “Never” to 7 denoting “Always”. To ensure the accuracy and effectiveness of this instrument, a pilot study was undertaken, wherein the questionnaire was dispensed to 10 companies, rigorously evaluating its reliability, validity and consistency. Post validation, the finalized version was disseminated through direct emails and professional networks like LinkedIn, targeting personnel at managerial and executive levels in the logistics sector. Leveraging Google Forms facilitated effortless and accessible participation through various digital platforms, including PCs, tablets and smartphones. Targeting a diverse group of Greek firms associated with the “Hellenic Federation of Enterprises” (SEV) and the “Association of Health–Research and Biotechnology Industry” (SEIV), primarily functioning in the shipping and logistics sphere, we achieved a response rate of 17.6%, with 53 out of an initial pool of 300 companies participating. The collected data underwent statistical analysis using the IBM SPSS version 24, paving the way for insightful revelations and discussion in the forthcoming sections.

We applied Principal Components Analysis (PCA) for identifying and computing composite scores for the underlying factors. PCA serves as a pivotal statistical technique that significantly reduces the complexity inherent in multivariate data without compromising critical information. This reduction is crucial for enhancing the interpretability of high-dimensional datasets, making PCA indispensable in data visualization and pattern recognition. By reorienting the original data along new axes—the principal components—based on their variance, PCA distills the essence of the data into fewer dimensions. These principal components are ranked by their ability to represent the dataset’s variability, with the first component capturing the most. This prioritization allows for a reduced yet powerful depiction of the data, often through a two-dimensional plot formed by the leading components [74]. The utility of PCA spans various fields [75,76]. This versatility underlines the role of PCA as a fundamental analytical tool for simplifying and interpreting complex data structures.

4. Results

The distribution of company types in the sample is as follows: 37.74% are suppliers, 20.75% are manufacturers, 16.98% operate as Third Party Logistics (3PL) providers, 7.55% function as freight forwarders and 5.66% are retailers. In terms of departmental representation, 30.19% of the participants work in supply chain management, 15.09% are
situated in the logistics department, 13.21% are involved in finance and 11.32% work in warehousing. Analyzing the sectors these companies belong to, we find that transportation and logistics leads with a representation of 20.75%. This is followed by the food industry at 13.21%, information and communication technologies (ICTs) at 11.32% and the healthcare and pharmaceutical sector at 9.43%.

In evaluating the employee demographics, a significant portion of the surveyed companies (39.62%) house a workforce ranging from 11 to 50 individuals. This is followed by firms employing more than 250 people (26.42%) and companies with a staff count between 51 and 250 (22.64%). A smaller fraction, 11.32%, operates with fewer than 10 employees. When we turn our focus to the annual turnover, delineated in million euros, we observe that 30.19% of the companies report figures between EUR 11 and 50 million, followed closely by 28.30% recording turnovers between EUR 3 and 10 million. Additionally, 22.64% declared an annual turnover exceeding EUR 50 million, with 18.87% indicating a turnover less than EUR 2 million. Furthermore, a considerable majority, 83.02%, have their assets concentrated in the Attica region, while 67.92% conduct operations nationwide. In Table 1, we present the profile of the companies under study.

Table 1. Industry/sector profile of the companies.

<table>
<thead>
<tr>
<th>No.</th>
<th>Industry/Sector</th>
<th>Number of Employees</th>
<th>Annual Turnover (in Million EUR)</th>
<th>Location</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Pharmaceutical</td>
<td>51–250</td>
<td>11–50</td>
<td>Attica</td>
</tr>
<tr>
<td>2</td>
<td>Information and Communication Technologies</td>
<td>51–250</td>
<td>11–50</td>
<td>Attica</td>
</tr>
<tr>
<td>3</td>
<td>Food, Retail, Transport and Medicines</td>
<td>&gt;250</td>
<td>&gt;50</td>
<td>Attica</td>
</tr>
<tr>
<td>4</td>
<td>Transport and Logistics</td>
<td>&gt;250</td>
<td>&gt;50</td>
<td>Attica</td>
</tr>
<tr>
<td>5</td>
<td>Healthcare</td>
<td>11–50</td>
<td>&lt;2</td>
<td>Attica</td>
</tr>
<tr>
<td>6</td>
<td>Agricultural Supplies</td>
<td>11–50</td>
<td>&lt;2</td>
<td>Attica</td>
</tr>
<tr>
<td>7</td>
<td>Transport and Logistics</td>
<td>&gt;250</td>
<td>&gt;50</td>
<td>Attica</td>
</tr>
<tr>
<td>8</td>
<td>Maritime</td>
<td>11–50</td>
<td>11–50</td>
<td>Attica</td>
</tr>
<tr>
<td>9</td>
<td>Transport and Logistics</td>
<td>51–250</td>
<td>11–50</td>
<td>Attica</td>
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<tr>
<td>10</td>
<td>Food</td>
<td>&gt;250</td>
<td>&gt;50</td>
<td>Attica</td>
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In our study, we sought to gauge various aspects relating to the implementation of GSCM, the extent of ICT innovation utilization in fostering GSCM and SCR, and the challenges encountered during the deployment of these ICT innovations. The insights drawn from the participants’ responses are systematically illustrated in a series of figures. These figures collectively paint a comprehensive picture of the current landscape of ICT adoption in facilitating GSCM and SCR strategies within the industry. Figure 2 delineates the degree to which the participating companies have adopted GSCM strategies. The distribution of responses varies per statement. For instance, “Top management support for green initiatives” and “Implementation of green initiatives” have a higher concentration of responses in the 6 and 7 range, indicating stronger agreement or higher levels of these factors. Conversely, “Willingness to invest in green initiatives” has a more even distribution across the scale, suggesting a more varied perception of investment willingness among respondents.

Subsequently, Figure 3 portrays the responses regarding the use of ICT innovations specifically aimed at enhancing GSCM practices. The highest valued application of ICT is for the measurement of greenhouse gas (GHG) emissions, which was perceived as extremely important (45.3% rating it as a 7 on the importance scale). This underlines a strong consensus on the significance of accurately tracking emissions data as a cornerstone for understanding and reducing environmental impact. Close behind, with a strong emphasis on its importance, is ICT for the management of natural resources and emissions evaluations, with 35.8% of respondents rating it as a 7. This reflects a keen interest in the role of ICT in managing natural resources more efficiently and in assessing emissions, which are critical aspects of sustainable environmental management. On the lower end of the spectrum, we have ICT for waste management, which, while still significant, seems to be a less pressing concern compared to others, with only 24.5% of respondents rating it as a 7. Although seen as important, it may be perceived as a more established or possibly less urgent area where ICT can contribute. Finally, the application of ICT for fuel consumption optimization is the least emphasized as extremely important, with just 32.1% of responses
giving it the highest importance rating. This suggests that while it is recognized as valuable, it might be that respondents see greater potential or more innovative applications in other areas of ICT for sustainability.

Shifting the focus towards SCR, Figure 4 encapsulates the feedback on the current development status of SCR practices within the surveyed companies. In essence, maintaining high situational awareness and being aware of inventory levels are seen as paramount in SCM, indicating a focus on proactive and informed decision making. In contrast, the immediacy of integrating SC elements and the speed of response to disruptions, although still considered important, are viewed with slightly less urgency.

Figure 5 brings to light the participants’ stance on utilizing ICT innovations to bolster SCR strategies. The use of ICT to identify and analyze risk sources and to efficiently respond to disruptions are seen as the highest priorities among the surveyed supply chain management areas. Meanwhile, the importance of ICT for accessing real-time market data and inventory levels is recognized but considered less critical than the capabilities for risk management and response agility.

Furthermore, Figure 6 lays out the perceived hurdles in assimilating ICT innovations within their operational framework. The structural rigidity of organizations and the high costs associated with ICT are seen as the most significant challenges in supply chain management, potentially impacting the ability to fully leverage technology. On the other hand, the inherent risks of ICT and the willingness of partners to adapt are acknowledged but are not considered critical compared to the aforementioned challenges.

To round off the analysis, Figure 7 highlights the particular ICT innovations that have been embraced by the companies as part of their operational strategy. The data illustrate that ERP and cloud software systems are the most embraced technologies, indicating a trend towards integrated management systems and cloud computing in organizational processes. In contrast, robotic automation for specific tasks and specialized systems like TMS and simulation are not as widely adopted, potentially due to their specialized nature or investment requirements.

The first conclusions that can be derived is that the degree to which the surveyed companies implement GSCM is moderate, whereas the degree to which firms have developed SCR is slightly higher. In both cases, the firms do not implement ICT innovations in a high level in order to support and develop these concepts. The main obstacles are the lack of personnel training and education, the high costs to acquire and maintain such systems, and the requirement of redesigning business processes.

The degree of GSCM integration within the company can be seen in Figure 2.
**Figure 3.** Utilization of ICT Innovations in enhancing GSCM strategies.

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<tr>
<th>ICT for sustainable energy sources selection</th>
<th>ICT for waste management</th>
<th>ICT for fuel consumption optimization</th>
<th>ICT for management of natural resources and emissions evaluations</th>
<th>ICT for joint efforts for environmental sustainability</th>
<th>ICT for energy efficiency data and metadata</th>
<th>ICT for environmental data visualization</th>
<th>ICT for fleet management and fleet service requirements</th>
<th>ICT for optimal routes/vehicle routing</th>
<th>ICT for reverse logistics efficiency</th>
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**Figure 4.** Implementation levels of SCR within companies.

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<th>supply chain integration</th>
<th>strategies for supply chain resilience</th>
<th>maintain high situational awareness</th>
<th>be aware of inventory levels</th>
<th>culture of risk management</th>
<th>recover after a supply chain disruption</th>
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**Figure 5.** Utilization of ICT innovations in enhancing SCR.
A factor analysis was carried out to evaluate the extent to which items 8 through 55 of the questionnaire accurately represent the five designated constructs: GSCM implementation; ICT utilization in GSCM; SCR; ICT use for enhancing SCR; and the challenges encountered in the implementation of ICT. Initially, the factorability of all the items was examined. It was observed that all items were correlated strongly or moderately (correlation coefficients greater than 0.4) with at least one other item. Second, the Kaiser–Meyer–Olkin measure of sampling adequacy was 0.565, and Bartlett’s test of sphericity was statistically significant (p-value < 0.01). All the communalities were above 0.5, confirming that all items had common variance with at least one other item. Consequently, a factor analysis was deemed to be suitable with all 48 items.

The extraction method used was PCA since the primary goal was to identify and compute composite scores for the underlying factors. PCA generated nine factors. The initial eigenvalues indicated that the first five factors explained 40.78%, 11.39%, 7.49%, 6.45% and 4.29% of the variance, respectively, whereas each of the remaining four factors explained less than 3.55% of the variance. The solutions for five to nine factors were examined, using the promax rotation method. The five-factor solution, which explained cumulatively 70.4% of the variance, was preferred due to its ease of interpreting them according to the questionnaire’s structure and the ‘leveling off’ of eigenvalues on the scree plot after five factors. All items in this analysis had primary factor loadings over 0.45. The extracted factors were named GSCM, ICT_GSCM, SCR, ICT_SCR and OBST after the corresponding questionnaire’s parts. Internal consistency for each of the factors was examined using Cronbach’s alphas, which were all above 0.6. Items 49, 50, 52 and 54 were removed from
the analysis since they did not contribute to the OBST factor. The promax rotation method was used since there are moderate statistically significant positive correlations (Spearman’s correlation coefficient ranging from 0.4 to 0.6, \( p \)-values < 0.01) between the first four factors (excluding OBST). Finally, the factors related to ICT use for achieving GSCM and resilience (ICT\_GSCM and ICT\_SCR) are weakly to moderately positively and significantly correlated to the companies size (Spearman’s correlation coefficient ranging from 0.3 to 0.4, \( p \)-value < 0.01).

The study illustrates that the level at which the concept of GSCM is applied by the examined logistics firms located in Greece is not high, in contrast to that of SCR, which is applied to a relevant greater extent. In summary, the main results of the research are the following:

- **Moderate GSCM adoption**: The research reaffirms that the adoption of GSCM practices is moderate across the firms studied. This suggests that while there is awareness of the need for sustainable practices, the full potential of GSCM is not yet being realized.
- **Higher SCR development**: The development of SCR is noted to be slightly higher than that of GSCM. This indicates a proactive approach by firms towards building more robust and adaptive supply chain frameworks that can better handle disruptions and uncertainties.
- **ICT innovations underutilized**: There is a clear indication that ICT innovations are not employed to a sufficient degree to support the development of both GSCM and SCR. Although these technologies are crucial for optimizing supply chain sustainability and resilience, their integration remains suboptimal.
- **Correlation with financial performance**: Firms with higher annual turnover are more advanced in both GSCM and SCR initiatives and are also the ones that are more inclined to implement ICT solutions. This suggests that financial strength provides firms with the capacity to invest in and prioritize these strategic areas.
- **Key obstacles**: The study identifies significant barriers impeding the adoption of ICT innovations. These include the lack of personnel training and education, high acquisition and maintenance costs of such systems, and the challenges associated with re-engineering business processes to accommodate these new technologies.

5. Discussion

The analysis indicated that a distinct five-factor structure for 44 out of the 48 items examined was evident, based on a principal components exploratory factor analysis with a promax rotation, and these factors were moderately internally consistent. Factor analysis provided insights regarding ICT use for achieving GSCM and SCR. This is quite intuitive since the results suggest that managers whose firms report higher rates of adoption of ICT technologies are very frequently coping more effectively with GSCM and SCR requirements. Consequently, the two research hypotheses cannot be rejected. Moreover, larger and resource-rich businesses also fare better than smaller businesses with a poorer ICT focus, meaning that they develop in higher-degree GSCM and SCR, as well as implementing ICT innovations for this purpose.

Logistics firms participating in contemporary global SC networks face inherent complexities in SCs, including numerous interdependencies, efficiency-driven orientations, and competitive globalized market structures, which have heightened the risks of disruptions. Consequently, scholars have focused on analyzing SC risk and resilience concepts to address these challenges \[24\]. Environmental sustainability has emerged as a critical issue in modern SCs due to the substantial emissions of greenhouse gases, resource depletion, pollution and extensive energy consumption resulting from production, transportation, storage and consumption activities. GSCM has been identified as a key agenda for both regulatory bodies and corporations, encompassing practices such as green design, green purchasing, green production, green management and green logistics \[32\]. In the quest for enhanced SCR and GSCM, the integration of ICT innovations has proved pivotal \[25–27\].
By employing innovative ICT platforms and solutions, firms in SCs can benefit from improved real-time data tracking, communication efficiency, risk mitigation and the adoption of green practices. Furthermore, ICT innovations facilitate a reduction in information asymmetry, enabling businesses to efficiently respond to supply chain disruptions and unforeseen events, thereby fostering SCR [28–30]. Moreover, ICT tools contribute to comprehensive environmental impact monitoring, tracking of environmental information and indicators, as well as minimizing resource and energy consumption, thus reinforcing the adoption of environmentally friendly practices throughout the SC, consistent with GSCM principles [32].

In light of the above, the paper highlighted that the understanding of firm responses and adaptations in regional and local logistics environments has become imperative [39,40]. In this regard, the examination of challenges and obstacles associated with the adoption of ICT innovations for sustainable SCs, including factors such as personnel training and education, (perceived high) acquisition and maintenance costs of ICT systems, and the need for business process redesign, assume considerable importance. Additionally, the exploration of firm-specific experiences and the identification of factors influencing variations in the adoption of ICT for sustainability provided insights into the experience of businesses in navigating these complexities [33,34].

Especially for smaller logistics firms operating in distribution and last mile logistics, the ones that formed the majority of the study’s sample in Greece, SCR was seen as positively correlated to the adoption of ICT innovations while being less strongly correlated to GSCM, the latter indicating a lack of appeal of the concept and slower adoption of the relevant tools and platforms of GSCM by participant firms. This was more evident especially for the smaller segment size in turnover and employee numbers, indicating resource constraints and the need to improve capacity and capability at the scale of the firm, as well as outsourced capability and opportunities for knowledge transfer at the supply network and local economy scale.

In line with the literature, the study suggested that the integration of ICT innovations and the adoption of GSCM practices play instrumental roles in strengthening SCR and sustainability [25–27,31,32]. In this respect, strategic decision making, along with the adept utilization of ICT tools, emerges as a key aspect in successfully creating greener and more resilient SCs [33,34]. By embracing ICT innovations and adopting sustainable practices, logistics firms can bolster their competitive position while contributing to a more sustainable and resilient global and local logistics ecosystem.

The results from our study on logistics firms in Greece and the literature on the role of ICT in SCR and GSCM suggest a nuanced picture of the adoption and integration of these concepts within different geographic and industrial contexts. Our study’s revelation of moderate GSCM adoption among Greek logistics firms runs parallel to observations made by [77] regarding the underutilization of ICT for inventory management in Thailand’s manufacturing sector. While there is an acknowledgment of the sustainable practices’ importance, as also identified by [78] in East Java, the full spectrum of the potential of GSCM, especially underpinned by ICT, remains unrealized in the Greek context. This represents a point of convergence in understanding that awareness does not necessarily equate to comprehensive application.

In terms of SCR, our study indicates a more robust development compared to GSCM, which echoes the findings of [79] that underline the importance of resilience and agility in supply chains post-COVID-19. It appears that firms, irrespective of location, are giving precedence to resilience, potentially due to recent global disruptions. However, the underutilization of ICT innovations noted in our study signifies a divergence from the perspectives of [26,80], who highlight the significant contributions of AI and IT capacities in bolstering SCR in their respective industries and regions. Our findings about the financial performance correlation also present an interesting layer, suggesting that unlike firms in our study, those with higher turnover are more adept at implementing ICT solutions, an insight that might not be as explicitly stated in the referenced literature but is implicitly
understood, as financial resources often enable better integration of technology. Lastly, the key obstacles we identify resonate with the call of ref. [81] for more research, implying that such barriers are not unique to Greek logistics firms but are a widespread challenge in harnessing the full potential of green IT and systems for environmental performance.

**Limitations and Extension**

This research has various limitations worth mentioning. First, the generalizability of the findings is restricted due to the sample size, the specific range of firm activities (comprising local supply, distribution and shipping), and the location of firms and geographical dispersion in a single country. To enhance the breadth and applicability of the research, future studies should consider diversifying the sample to include firms with varying locations (including multi-sited enterprises and those in different regions), diverse functions within the supply chain, and different positions within the business network hierarchy. Nevertheless, for firms more closely embedded in local supply and distribution operations, the sample was deemed sufficiently representative and forms a good basis for analysis of a firm’s ICT adoption choices in pursuing GSCM and SCR objectives. In addition, the firms’ actual ability to influence performance over the greening or resilience of the extended global SC (rather than one or two tiers of suppliers/clients) is a critical but often underestimated factor. Hence, cross-country studies of logistics networks are essential to a future research agenda, examining the drivenness and power dynamics shaping sustainability and resilience outcomes within the supply chain or network.

Further empirical research of supply network metabolic processes (raw material inputs, energy, water, land use, waste) is necessary for forming a more critical and holistic understanding of SCR and sustainability outcomes of firm actions in terms of economic, environmental and societal value generated through firm actions. Additional input from certification and standard-setting bodies on environmental performance and compliance auditing can inform the understanding of gaps and compliance mechanisms in GSCM and SC sustainability. To adhere to triple bottom line sustainability, the impacts on employment, societal impacts and business governance could be further incorporated into this analysis, potentially drawing from extant ESG surveys or carefully selected empirical cases. The survey revealed a number of ICT devices, platforms and innovations that firm managers consider significant. To attain a more holistic analysis of technology needs and availability, examining a comprehensive array of ICT innovations, both available and implemented, would be of considerable interest for future investigations. Such an expansion would enable a more thorough comprehension of the prevailing business technology landscape and shed light on the technological prospects of Greek companies.

In addition, augmenting the scope of research by conducting expert interviews with executives would render a more encompassing and insightful portrayal of the prevailing market conditions, obstacles and intervening variables in technology adoption, and the future trajectories of Greek enterprises. Since the respondents were higher-level company managers with authority to speak on issues of company strategy and choices, the responses offer a good basis for analysis based on management knowledge. Thus, there are opportunities to compare results, within firms and with third party providers of services and support in ICT and digitalization, and the set of services on ICT innovations used in GSCM and SCR. For future studies in this domain, it is recommended to delve deeper into the reasons underpinning companies’ hesitance to adopt ICT innovations, especially with respect to GSCM and resilience considerations. While the present survey identified factors such as insufficient personnel training and education, high acquisition and maintenance costs, and the exigency for business process redesign as primary deterrents, supplementary research could elucidate divergent experiences across various firms. Such efforts would enable a comprehensive understanding of the determinants distinguishing companies that successfully implement ICTs from those that do not, thereby facilitating targeted support mechanisms for the latter.
6. Conclusions

Logistics firms are navigating the complex interplay between resilience, profitability and environmental impact in IT/ICT-enabled SCs with varying levels of sophistication and success. The research revealed that the adoption of ICT innovations plays a pivotal role in enhancing both GSCM and SCR, and several conclusions may be drawn from the analysis. First, this research identified that logistics firms are facing a significant juncture, where technological advancement converges with sustainable business practices as seen from the sample of Greek logistics firms. Second, while there is a noticeable trend towards the adoption of GSCM initiatives, the study indicates a marginally increased inclination towards SCR principles. This suggests a prevailing trend towards businesses that are more adaptable and resilient. Third, the adoption of ICT as a tool to bolster these sustainable and resilient practices is lagging. Many firms encounter challenges, such as high costs of implementation, a deficit in trained personnel and the pressing need for business process overhauls. Fourth, the data draw a direct link between business size and the level of GSCM and SCR adoption. Larger firms, with more resources at their disposal, tend to utilize ICT innovations more extensively. This observation is in line with global trends, where more substantial enterprises tend to be better equipped to integrate and benefit from ICT, resulting in the advancement of more sustainable and more resilient supply chains. Last but not least, the research emphasizes the instrumental role of ICT in cultivating a sustainable and resilient business landscape. The power of these technologies lies in their capacity to augment real-time data monitoring, optimize communication efficiency and counteract risks tied to supply chain disturbances. Additionally, the uptake of ICT leads to reduced environmental footprints via precise monitoring and sustainable resource management, resonating with GSCM principles.

In response to the findings, it is essential for policymakers and industry leaders to create an environment conducive to the broader adoption of ICT innovations with the purpose of increasing sustainability and resilience. First, the integration of these technologies would enhance the competitiveness of logistics firms while also promoting a more sustainable and robust logistics framework, both locally and globally. Industry leaders can help accelerate and champion the necessary transformation through initiatives such as sustainability audits and assessments and the use of performance monitoring systems, such as KPIs, as a part of integrated transition roadmaps.

Second, there should be a concerted effort to devise strategies that emphasize knowledge dissemination, extensive personnel training, effective resource allocation and investment at the firm, industry and policy levels. This is especially important for smaller firms that often have more limited capacity to adopt innovations. National industrial and competitiveness policies can also be leveraged to intervene in increasing the capacity for technology adoption through technological prototypes, public R&D and public–private partnerships on the required technological investments in the logistics ecosystem.

Third, guiding this transformative shift is significant to ensure a smooth transition towards an eco-friendly and resilient supply chain ecosystem. Convening and empowering logistics stakeholders in adopting systematic efforts to improve the sustainability and resilience of supply chains is key in bridging societal level aims with corporate objectives. This evolution is vital for catering to the needs of a rapidly evolving, globalized logistics market, in the context of the climate crisis and diverse sources of risk and disruption.

Fourth, in light of the evidence about the sizable carbon footprint of ICT services, ICT companies and the end users of ICTs ought to prioritize energy saving and renewable energy use in their logistics services and associated ICT components. Comprehensive carbon management strategies can help bridge the gap between ICT contributions towards energy and resource economies while reducing the significant energy and environmental footprint of ICT.
Author Contributions: Conceptualization, V.P., C.A. and T.K.D.; methodology, N.P.R., V.P. and C.A.; validation, N.P.R., V.P., C.A. and T.K.D.; formal analysis, V.P., C.A., D.S. and N.P.R.; investigation, V.P. and C.A.; resources, V.P. and C.A.; writing—original draft preparation, V.P., C.A. and T.K.D.; writing—review and editing, N.P.R.; supervision, C.A. and T.K.D. All authors have read and agreed to the published version of the manuscript.

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