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Environmental Data Management for Green Product Innovation: A Multiple Case Study on the Role of Green Information Systems

Chiara Ravetti, Flavia Cicerelli, Andrea Tuni, and Emilio Paolucci

***Abstract*—Developing innovative green products requires detailed, standardized, high-quality data across firms and supply chains; the absence of such data or asymmetric access to environmental information can compromise corporate sustainability objectives. Emerging data management technologies have significant potential to advance sustainability, yet the mechanisms through which purpose-built digital tools leverage corporate environmental data to enable green innovation remain understudied. This article investigates the role of green information systems (GIS)—key digital infrastructure for managing environmental data—in fostering green product innovation in the industrial electronics sector. Using an abductive multiple-case study methodology in a multitier supply chain, we identify the core challenges of managing complex environmental data and evaluate the effectiveness of GIS-driven solutions. Triangulating across different data sources, we find that GIS can be used to enhance data management, transparency, and benchmarking capabilities, which then support green innovation. However, significant barriers persist, including insufficient data granularity and system-wide coverage, together with a lack of technical skills and a limited willingness to share sustainability metrics. The best practices emerging from systematic combining of theory and empirical patterns consist of strategic, dynamic, and collaborative integration of these systems. This article advances the understanding of how best-practice applications of environmental data management technologies can promote sustainability. Although GIS are crucial enablers of green product innovation, they are not sufficient on their own and require complementary capabilities and systemic approaches to realize their full potential.**

***Managerial Relevance Statement*—This study offers practical guidance for managers striving to integrate green product innovation into complex, interconnected operations and supply chains. By highlighting the advantages and shortcomings of Green Information Systems (GIS) for addressing data-related challenges and enabling eco-design and green product innovation, our findings provide a pathway for action. Managers can leverage GIS technologies to enhance the management, traceability, and comparability of environmental data, thus supporting informed decision-making. The study identifies key best practices to overcome common obstacles, such as limited data availability, a lack of data sharing, and the absence of standardized metrics. Accordingly, managers should: 1) prioritize forward-looking data management strategies instead of compliance-oriented strategies; 2) invest in integrating GIS infrastructures into internal processes, by fostering internal technical expertise to maximize the competitive value of these systems; and 3) build strategic partnerships with supply chain actors to better align evolving sustainability goals. By adopting a proactive approach to integrating GIS into sustainability strategies, managers can not only address pressing environmental challenges but also position their organizations as leaders in sustainable innovation and green product development. This article contributes to the following UN SDGs: SDG 9 and SDG 12.**

***Index Terms*—Asymmetric information, data analytics, environmental data, green information systems (GIS), green product innovation.**

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I. Introduction

COMPANIES are increasingly expected to embrace transformative strategies to improve their sustainability performance [1]. Sustainability-oriented innovation is key to coupling economic growth with environmental responsibility [2], [3]. However, translating these innovations into tangible improvements is not straightforward. A major challenge faced by firms seeking to introduce environmental innovations is the acquisition, management, and analysis of extensive data on green inputs, impacts, and performance outcomes [4].

Accurate environmental data are indispensable for the development of greener products and the underlying impact-reduction processes, such as ecodesign. Without robust measurement of the environmental impacts of the materials and processes required for green products throughout their lifecycles, it is impossible to claim any improvement in their environmental performance. Thus, companies developing innovative green products must manage the intricacies of obtaining, integrating, and processing vast volumes of environmental data, not only within their organizations but also along their extended supply chains [5]. These data include measurements of resources, energy, and water consumption, emissions of greenhouse gases and other pollutants, material recovery rates, and other circular economy indicators, as well as certifications relevant to environmental performance [1]. These pieces of information must

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be integrated with data from suppliers and customers. However, heterogeneous measurement approaches and limited data sharing within supply chains make it difficult and costly to obtain high-quality, verifiable information [5].

In this context, emerging digital technologies for environmental data management and analytics represent powerful tools to support companies in improving their environmental sustainability in a rigorous and traceable manner. Information Technology (IT) is increasingly recognized as a significant enabler of sustainability initiatives. Green Information Systems (GIS), defined as "the design and implementation of information systems that contribute to sustainable business processes," can play a key role in bridging data management and sustainability transitions [6], [7]. GIS are digital infrastructures designed to monitor, manage, and reduce ecological impacts through data-driven processes and decision-making [6], [7]. Their implementation can support environmental compliance and mitigate the impacts of information asymmetries [1], [8]. By integrating data from various sources, GIS can create a more comprehensive picture of the environmental footprint of products and processes. Moreover, they can foster transparency, accountability, and trust among supply chain actors, thereby encouraging collaboration and knowledge sharing, as well as benchmarking different solutions [5].

Although some effects of GIS on environmental performance have already been documented in other studies [5], [9], [10], [11], their specific role as potential enablers of green product innovation has received limited attention. Prior research has increasingly explored the role of other advanced digital technologies and data analytics in supporting green innovation and sustainability performance, particularly in the context of Big Data [12], [13], [14]. However, the specific role of GIS is underexamined in the technology management literature and remains mostly confined to the IT literature [6]. Moreover, prior articles have primarily adopted large-scale, quantitative approaches to link digital infrastructures, knowledge management, and green innovation [15], [16], [17]. While valuable, these perspectives offer limited insight into the organizational and interorganizational complexity, tensions, and adaptation challenges involved in implementing GIS infrastructures for environmental data management. They also provide limited understanding of the managerial limitations and implementation challenges of GIS, including coordination costs, and potential tensions across organizational boundaries. Taken together, these limitations leave an incomplete understanding of whether and how GIS can support green product innovation in complex organizational settings.

To address this gap, this article explores whether and how GIS support environmental data management and green product innovation. Specifically, we examine how GIS help firms collect, integrate, process, visualize, monitor, and report environmental data, thereby addressing a major barrier to sustainability-oriented innovation in terms of data management and analytics.

Using information processing theory (IPT) and agency theory as initial theoretical lenses, we iteratively refined our analysis as empirical patterns emerged and examined how best-practice applications of GIS can act as a strategic technology to manage environmental information and support green product innovation. Accordingly, we address the following research questions.

RQ1: How do GIS contribute to environmental data management?

RQ2: To what extent do GIS support green product innovation?

RQ3: What are the best practices in GIS management to support green product innovation?

We answer these questions through an exploratory multiple-case study in industrial electronics, a particularly relevant context for examining how GIS can support environmental data management and green product innovation. First, the industry is characterized by complex products and multitier supply chains, which can amplify information asymmetries due to limited availability, visibility, and sharing of detailed environmental data. Second, many leading firms in this sector operate advanced digital infrastructures and compete through fast innovation cycles and substantial R&D investments, making them well-suited for examining innovation dynamics. Third, the sector plays an important role in the sustainability transition: producers face increasing pressure to reduce product footprints, enhance circularity, and comply with environmental requirements from customers, regulators, and downstream partners. At the same time, industrial electronics can enable sustainability-oriented innovations in areas, such as renewable energy, electric mobility, and resource-efficient monitoring and automation. Hence, industrial electronics provides an ideal context to examine environmental data management and governance in support of green product innovation. By studying a high-tech, digitally mature, innovation-driven industry, this article offers actionable guidance for managers and policymakers to improve the use of environmental data to drive sustainable innovation.

The rest of this article is organized as follows. Section II presents the theoretical background. Section III explains our methodology. Section IV presents the results and Section V discusses the findings, their theoretical and managerial implications, limitations, and avenues for future article. Finally, Section VI concludes this article.

II. Theoretical Background

Organizations are increasingly seeking to integrate sustainability into their product development, innovation strategies, supply chain management, and operations [16], [18]. However, the knowledge and information required to support effective environmental improvements and achieve net-zero objectives are frequently lacking or ambiguous [14], [19]. Such challenges stem from the inherently multifaceted nature of sustainability and are further exacerbated by the complexity of products—especially high-tech ones—and the interdependent structure of contemporary global supply chains [20], [21]. To date, there is little evidence on whether purpose-built technologies such as GIS can address challenges related to green data management. Moreover, despite growing interest in digital infrastructures for sustainability, prior article offers limited empirical insight into *how* GIS can support green product innovation, rather than merely facilitate compliance and reporting. This leaves an

unresolved issue: how can GIS convert complex environmental data into decision-relevant knowledge for innovation, and how is this shaped by intrafirm information management and interorganizational governance? We address this gap by integrating IPT and agency theory with in-depth qualitative data to identify best practices in GIS management.

We draw on the complementary insights from IPT and agency theory to develop an initial framework detailing how firms use information systems to process sustainability-related data and align internal capabilities with external sustainability demands, particularly under conditions of data ambiguity, fragmentation, and limited collaboration. We iteratively apply and revise the theoretical lenses through an abductive research design, whereby we move between theory and empirical evidence from case studies to refine our conceptual understanding. Sections A and B illustrate the main theoretical building blocks that guide our analysis.

A. *Information Processing Theory and Environmental Sustainability*

A long-standing insight in organizational theory is that firms' innovation capacity depends on how effectively they acquire, interpret, and mobilize information. This issue becomes more acute as digital technologies expand the volume, variety, and velocity of available data. IPT provides a foundation for explaining how organizations build structures and practices to cope with such information processing demands. Since its inception in the 1970s, IPT has evolved to tackle the information processing challenges that organizations face, particularly as complexities arise from the growing amounts of data and contextual uncertainty [22]. According to IPT, firms must balance their information processing *needs*, which are typically driven by external pressures—in our context, the sustainability transition—with their internal information processing *capacity*, i.e., the ability to gather, interpret, and use information effectively for decision-making and coordination [23], [24], [25].

These two core building blocks of IPT are highly relevant in the context of corporate environmental sustainability data. Since sustainability-related metrics cover a wide range of environmental indicators that extend beyond single firms, especially for complex products in multitier supply chains, technological solutions for data management should account for these interorganizational dynamics and needs. IPT has been used to examine dyadic relationships, particularly between buyers and suppliers, and broader supply networks [26], [27]. With increasingly complex business environments, the main information processing challenges arise from the interconnectedness and dynamic nature of the information that is shared among multiple organizations [28]. Thus, IPT provides a theoretical anchor for understanding the tradeoffs between *needs* and *capabilities*—within firms and in interactions with other companies in the supply network—that organizations must navigate in the multifaceted information landscape surrounding environmental sustainability.

B. *Asymmetric Information, Green Supply Chain Management, and Environmental Data*

Complementing insights from IPT, agency theory helps explain incentives and frictions underlying organizational challenges related to environmental data, especially in green supply chain management. Agency theory highlights how asymmetric information can create barriers to transparency, monitoring, and coordination among firms, and thus constrain technological innovation and effective sustainability strategies. The complexity of tracing environmental impacts throughout the sourcing, production, and distribution phases makes it difficult to obtain and analyze reliable environmental data timely. As firms respond to increasing stakeholder pressure and environmental expectations—the information needs highlighted by IPT—these information gaps could undermine the implementation of sustainable practices that go beyond traditional cost-efficiency goals [29].

Distorted incentives to misrepresent impacts can emerge in buyer–supplier relationships, particularly when information asymmetries prevent buyers (principals) from accurately verifying the suppliers' (agents) practices [30], [31]. Agency theory also highlights that asymmetric information is exacerbated when violations of contractual terms or norms are difficult to verify, enabling distortions and misleading actions [32]. This verifiability dimension underlies the need to have transparent, traceable, and accurate data to avoid rule violation (e.g., environmental standards) or the omission or withholding of relevant information for private gain. Moreover, in contexts with low verifiability, relational aspects such as clear communication, trust-building, and addressing potential misunderstandings are crucial [33]. Codifying precise expectations and data requirements becomes particularly challenging in the dynamic landscape of sustainability. The evolution of societal norms around environmental responsibility often outpaces formal contractual agreements, thus making it difficult to define and monitor sustainable practices, metrics, and information [32].

Through the lens of agency theory, we expect interactions between companies in green supply chain management to be distorted in two ways due to asymmetric information. First, parties with greater access to information may act opportunistically; e.g., they may conceal information from other stakeholders, such as customers or regulators [34]. Selective disclosure hinders transparency, makes it difficult to identify and address unsustainable practices along the supply chain, and undermines the credibility of genuine sustainability efforts. Second, the complex nature of sustainability can lead to performance ambiguity, as it is difficult to assess environmental impacts accurately [35]. This ambiguity creates opportunities to misrepresent environmental performance (greenwashing) or exploit loopholes in measurement frameworks [36]. For instance, companies may selectively highlight positive environmental data in their marketing materials, while neglecting to disclose other negative aspects of their operations [35]. Performance ambiguity can mislead stakeholders, create a false perception of a company's environmental responsibility, and diminish systemic incentives to identify new

solutions to foster sustainability, with detrimental consequences for the entire supply chain [33], [37], [38].

While these theoretical mechanisms are well established in the literature that applies IPT or agency theory to other types of data, their implications for environmental data management remain unexamined. To address this gap, we turn first to the literature on GIS, considering how these systems can harness emerging digital technologies, enhance the knowledge-processing capabilities of organizations, and potentially reduce information asymmetries. Thus, we provide a basis for our empirical analysis of their role in shaping green product innovation.

C. Green Information Systems (GIS) and Green Product Innovation

GIS are purpose-built or adapted digital infrastructures—encompassing software platforms, data architectures, and organizational routines—designed to collect, process, and analyze environmental data to support sustainability-related decision-making [5], [9], [10]. Unlike generic IT systems, GIS integrate a range of environmental metrics such as energy consumption, emissions, waste flows, and lifecycle impacts directly into business operations [39]. Many GIS are implemented via third-party platforms (e.g., Sphera, Enablon, and EcoVadis), which offer centralized capabilities for emissions tracking, supplier sustainability assessments, and environmental, social and governance (ESG) reporting. These platforms often serve as integration hubs that combine data streams from Internet-of-Things (IoT) sensors, enterprise resource planning systems, and external databases, and support advanced forecasting, benchmarking, and anomaly detection. In doing so, they create a dedicated digital infrastructure in which organizations can integrate emerging technologies—such as Big Data analytics, artificial intelligence (AI), and machine learning—to enhance environmental data processing and decision-making [12]. The configurations of GIS vary widely depending on the organizational context and the level of sustainability maturity. Some firms adopt modular architectures, whereby they aggregate data from facilities, procurement, and logistics into data lakes, while others rely on platform-based models that interface with internal systems via application programming interfaces.

However, the integration of GIS into innovation processes is not without problems. GIS functionalities cannot address fragmented data ownership, siloed IT architectures, and nonstandardized environmental KPIs. Thus, rather than seamless technical solutions, GIS should be critically understood as complex sociotechnical infrastructures, shaped by organizational constraints and institutional pressures. The literature on how to adapt and manage GIS to support green innovation, however, is scant, and GIS potential and shortcomings have not been examined in depth in empirical studies.

Because of their multidimensional nature, GIS can support companies' sustainability transition in different ways. First, GIS facilitate systematic collection and analysis of data related to an organization's environmental impact, including energy consumption, resource utilization, waste generation, water use, and greenhouse gas emissions [10]. These comprehensive data are crucial for informed decision-making, as it allows organizations to identify areas for improvement, set realistic goals, and track progress toward sustainability objectives. Second, GIS assist companies in addressing the complexities of environmental compliance. By deconstructing regulations, such as the EU's WEEE and RoHS directives,[1] GIS can support compliance by translating indicators into actionable insights and facilitating the integration of regulatory constraints into business processes and product design [1]. Moreover, GIS can empower organizations with real-time monitoring capabilities, enabling them to continuously assess performance through data related to materials, production, and product disposal [1]. Third, GIS can simplify information sharing within an organization and with external stakeholders, including suppliers and customers [5], which can foster transparency and accountability by allowing organizations to demonstrate their commitment to environmental sustainability and to collaborate with external entities to achieve shared goals.

Finally, by harnessing the power of data-driven decision-making, GIS can serve as critical enablers of environmental outcomes: prior article suggests a positive correlation between GIS and environmental performance [8]. The integration of tailored digital infrastructures such as GIS can be instrumental in fostering not only measurements and assessments but also innovation toward new green product development [5], [40].

Green product innovation focuses on developing new products that minimize environmental impacts throughout their lifecycle, and it encompasses raw material sourcing, design, production, usage, and disposal [41]. Although this process offers significant environmental benefits, it is inherently uncertain due to factors such as market demands, evolving regulations and technologies. GIS can support the development of new green products, for instance, through the systematic gathering and analysis of essential data to conduct life cycle assessments (LCAs), a crucial tool for evaluating the environmental impact of a product throughout its entire lifecycle and to support ecodesign [42].

Moreover, by advancing information sharing, GIS facilitate knowledge exchange and learning between internal teams and external partners, thereby allowing organizations to leverage the collective expertise of different entities, and potentially mitigate the risks and uncertainties associated with green product innovation [5], [35], [43]. However, adopting these technologies requires an upfront investment by organizations to build and integrate appropriate systems and to develop technical expertise and a data-driven organizational culture [44].

Thus, GIS offer capabilities to meet sustainability challenges in data management, but also require additional resources for successful implementation. Building on IPT and agency theory, we expect GIS to help companies address their environmental information needs and mitigate issues related to information

[1]The EU's Waste Electrical and Electronic Equipment (WEEE) Directive mandates the collection, recycling, and recovery of electronic waste, while the Restriction of Hazardous Substances (RoHS) Directive restricts the use of specific hazardous materials in the manufacturing of electrical and electronic equipment. Both aim to reduce the environmental impact of electronics throughout their lifecycle.

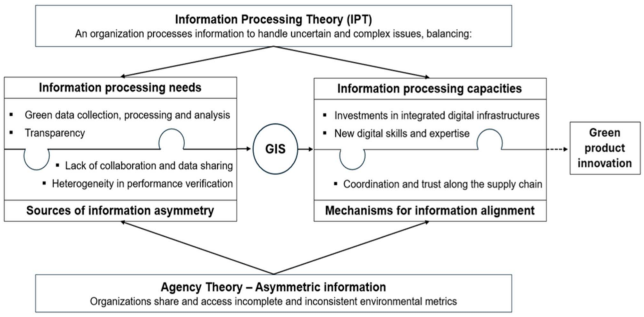


Fig. 1. Contextualization of the role of GIS technologies within the complementary building blocks from information processing theory and agency theory. Source: authors' elaboration.

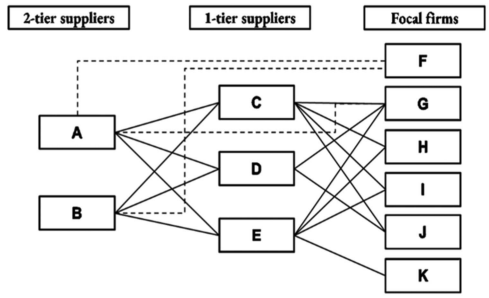


Fig. 2. Supply chain network of the selected companies. Solid lines represent direct supplier–buyer relations, while dotted lines illustrate indirect relationships, i.e., when focal firms directly interact with two-tier suppliers. Source: authors' elaboration.

asymmetries, while concurrently requiring additional capacities. Fig. 1 illustrates how IPT and agency theory frame this dual role of GIS.

The main information processing needs highlighted by IPT are also critical areas for potential information asymmetries according to agency theory; similarly, the information processing capacities that a company must develop to manage environmental knowledge constitute some of the core mechanisms to realign incentives to mitigate information asymmetries. GIS can bridge these data needs and asymmetries by providing appropriate data capabilities and solutions. However, the challenges related to practical implementation and the best practices that can lead GIS to foster green innovation have not yet been explored in depth in the literature. In sum, we lack an explanation of how GIS practices and governance arrangements enable firms to process ambiguous environmental data, improve verifiability across supply chain tiers, and translate these mechanisms into green product innovation. Addressing this gap motivates our multiple-case study and the integrative IPT–agency theory framework in Fig. 1, which we refine using detailed empirical evidence in the remainder of the article.

III. Research Methodology

A. Research Design

Building on the theoretical background, we anticipated a multifaceted relationship between GIS and green product innovation, influenced by stakeholders' incentives and interests. Therefore, we adopted an abductive multiple-case study methodology to answer our research questions and iteratively connect prior theoretical insights to emergent patterns from the data [45]. This approach is well suited to our research purpose, as it allows in-depth exploration of a contemporary phenomenon within its real-life context, capturing nuances and complexities of the real-world setting [46]. We chose a holistic multiple-case study design, treating individual organizations as the primary unit of analysis. Since we expected that many challenges due to information asymmetries in environmental data would arise along supply chains, we chose companies within a single supply network, as detailed in Section III-B.

To ensure rigor and analytical quality, before data collection we developed a comprehensive research protocol that included interview guidelines, data collection, and management rules. We maintained a case database with interview recordings and transcripts, archival documents, observation notes, and coding memos. Furthermore, throughout the data collection and analysis stages, we took specific measures to ensure that the research adhered to key quality criteria established by [46]: construct validity, internal validity, external validity, and reliability. Details of these measures are presented in Table A1 in the Appendix.

B. Case Study Selection

We relied on purposive sampling to select relevant case studies for in-depth investigation [47]. We employed a snowball sampling approach to identify candidate organizations, beginning with a first-tier company with which we had already established a research relationship [20]. We built a mapped sampling frame of their supply network, identifying strategic or sustainability-critical clients and suppliers, and then expanded the sample upstream and downstream with a similar logic.

Case selection applied the following inclusion criteria: companies had to 1) operate in industrial electronics manufacturing; 2) be multinationals with extensive and geographically dispersed supply chains; and 3) have adopted a sustainability strategy to reduce their environmental impact, as articulated in their sustainability report or other relevant documents [Carbon Disclosure Project ratings, sustainability policy, code of conduct for suppliers, carbon footprint certifications, environmental product declarations (EPDs), etc.].

We deliberately included variation in supply-chain position and GIS maturity (including firms with no GIS) and aimed at maximizing the variety of products across different segments of the industry. This enabled theoretical contrast and an assessment of boundary conditions of emerging explanations, while retaining coherence in the sample, as all companies belong to the same supply network. Overall, we identified 24 relevant companies as initial candidates and examined their available secondary materials for context. We contacted all candidate firms and 11 of them agreed to participate in the primary data collection (Fig. 2). Nonparticipation mainly reflected lack of availability and/or confidentiality constraints.

By limiting the scope of the analysis to a single sector, we reduce confounding heterogeneity arising from industry-specific factors, thereby enhancing case comparability and reducing alternative contextual explanations [47]. Moreover, industrial electronics represents an information-intensive and substantively important setting to study the relationships between data management technologies, such as GIS and green innovation, given the supply chain structure, innovation dynamics, and environmental impacts of this industry [48]. Industrial electronics plays a key role in sustainability transitions, as it enables digitalization, mass electrification, and renewable energy technologies [49]. At the same time, it is a material- and energy-intensive sector that generates a substantial flow of electronic waste [48], [50], [51]. Because of its environmental footprint, the industry faces increasing pressure from regulatory bodies to adopt stricter sustainability measures and implement circular and net-zero strategies.

Furthermore, a key feature of industrial electronics value chains is that production is distributed across multiple tiers of specialized firms, and focal companies rarely control all stages from design to component manufacturing, assembly, and testing [48]. Strong demand growth in applications such as industrial automation, power-control equipment, energy management, and electric vehicles (EVs)-charging infrastructure increases parts variety and accelerates product innovation. Deep, interdependent supplier networks, high product complexity, and rapid innovation make this sector an ideal testbed for examining whether GIS can build data-processing capacity that reduces cross-tier information asymmetries and enables data-driven environmental innovation.

For these reasons, mechanisms observed in this context are plausibly relevant to other industries with multitier supply networks, rising environmental disclosure requirements as well as high product complexity and innovation intensity, even if technologies and regulatory details differ.

C. Data Collection and Analysis

We gathered data between June 2022 and April 2024 from four different sources to enhance data triangulation and obtain a comprehensive and nuanced understanding of the phenomena under investigation. Our data collection process unfolded in two phases.

In the first phase, we collected archival data from diverse secondary sources, including publicly available materials, such as sustainability reports, codes of conduct, ESG ratings, and statements on relevant topics released by the studied organizations to obtain initial contextual insights. We then conducted semistructured interviews with key informants within each organization.[2] These early interviews, conducted by one or more of the coauthors, adopted a conversational nature, while incorporating focused questions from the case study protocol [46]. This phase also included field visits to two sites of participating organizations, where we took detailed observational notes. Regarding the number of interviews, theoretical saturation was assessed iteratively during data collection and coding: after 20 interviews, no substantively new codes emerged, and additional cases primarily confirmed existing patterns.

Following the initial data collection, we iteratively reviewed and analyzed the findings, comparing them with additional literature, and we revisited the initial theoretical constructs to better reflect the insights, anomalies, and unexpected patterns that had emerged from the cases. This iterative process informed the development of a short questionnaire to guide the second round of interviews. We adopted a more structured approach in this second phase, utilizing the refined questionnaire and structured interviews to gather focused data.

All the interviews were conducted online, recorded, and transcribed to ensure accurate data analysis. Overall, we conducted 22 interviews with 11 companies and gathered 54 archival documents (Table I). Companies presented a wide range of product portfolios, which included microcontrollers, relays, smart meters, EV chargers, automation systems, sensors, power control equipment, and consumer appliances. Out of the 11 companies considered, three had no GIS, while all the others had implemented different systems with varying levels of functionality and integration (see Table A2 in the Appendix for details).

To enhance the transparency and reproducibility of our analysis, data from all sources were tabulated in spreadsheets and coded through MAXQDA qualitative data analysis software. Coding was conducted independently by two researchers and validated through iterative coauthors' review. Afterwards, two coauthors acted as critical auditors challenging interpretations in regular debriefings on doubtful cases, and disagreements were resolved by consensus [52]. Collected data were initially open coded into meaningful units [47], which were subsequently combined through an iterative approach, grouping conceptual units to generate categories [47]. Axial coding followed to further refine the codes, resulting in the identification and labeling of key constructs for environmental data challenges, the role of GIS, and the effects on green product innovation. Following an abductive process [45], we cycled between the initial findings, theoretical frameworks, and emerging themes, ultimately leading to a comprehensive set of themes discussed in Section I.

IV. Results

This section presents our findings on the interplay between GIS and green product innovation. Guided by the abductive multiple-case study methodology described in Section III, we confront the theory-driven perspective of Fig. 1 (IPT and agency theory) with empirical regularities (and anomalies) observed in the field material. This process led to the identification of cross-cutting themes that answer our research questions in three interrelated findings. Section IV-B outlines the key challenges in the management of the environmental data that characterize the underlying information processing needs of companies and are a source of information asymmetry. Section IV-B articulates how GIS can act as an instrumental technology to address some of these challenges and build information processing capabilities that could foster information alignment. Section IV-C focuses

[2]Prior to participation, informed consent was obtained from all the interviewed participants to ensure their voluntary involvement and understanding of the purpose of the study.

TABLE I
PROFILES OF THE COMPANIES AND INTERVIEWEES

Company code	Position	Employees [2023]	Turnover [€/2023]	Country	Interviewee code and role		Years in the company	Years in industry	I round of interviews	II round of interviews
A	Tier 2	15 000	1 600 bn	China	A1	General Manager (Italy)	21	39	✓	✓
B	Tier 2	51 000	15 600 bn	The Netherlands	B1	CSR and Open Innovation Manager	30	30	✓	
					B2	Sustainable Excellence Coordinator	27	27	✓	
					B3	Vice-President of Sustainability	24	30	✓	✓
C	Tier 1	108 000	29 170 bn	Switzerland	C1	Sustainability Specialist	1	1	✓	✓
D	Tier 1	7000	1800 bn	Switzerland	D1	Head of ESG	2	19	✓	✓
					D2	Sustainable Procurement	3	3	✓	
E	Tier 1	8450	1167 bn	Italy	E1	Sustainability Manager	4	11	✓	✓
F	Tier 1	700	144 mn	Spain	F1	ESG Manager	1	4	✓	✓
G	Focal Firm	61000	94 500 bn	Italy	G1	Procurement Intelligence Manager	31	31	✓	
					G2	Innovability Global Procurement Manager	2	2	✓	
H	Focal Firm	~3,000	1 536 bn	Italy	H1	Energy Engineer	3	3	✓	
					H2	Head of Procurement Intelligence	12	12	✓	
					H3	Head of Sustainability	5	9	✓	
					H4	Sustainability Procurement Referent	6	6		✓
I	Focal Firm	320 000	77 800 bn	Germany	I1	Sustainability Procurement Manager	19	19	✓	✓
					I2	Sustainability Manager	17	20	✓	
J	Focal Firm	112 450	33 100 bn	China	J1	Corporate Communication, CSR and Sustainability Director	3	9	✓	
K	Focal Firm	45 450	12 100 bn	Sweden	K1	Sustainable Manufacturing Engineer	4	4	✓	
					K2	EHS & Operations Sustainability Director	21	21	✓	
					K3	Sustainable Procurement Manager	9	9	✓	
					K4	Head of Sustainable Solutions and Product Technology	18	18	✓	

on the advancements in green product innovation, considering the contribution of GIS (or lack thereof), together with other external factors. Finally, we combine the results from this in-depth analysis of the emergent empirical patterns and the theoretical building blocks to extrapolate some of the best practices that either leverage existing GIS capabilities or compensate for their limitations (Section IV-D).

A. *Data-Related Challenges of Environmental Metrics*

The results of the case studies highlight that industrial electronics supply chains continue to be plagued by pervasive information asymmetries in environmental data use and interpretation, which, in turn, generate substantial information processing needs, reflecting the core concerns of both IPT and agency theory. We observe three macrocategories of data-related challenges raised by interviewees: data management within firms, information sharing among firms, and comparability across similar products and companies. The latter represents an abductively derived extension of IPT and agency theory's perspectives: while these theories focus on dynamics at the firm level or in firms' dyads, our case studies also point to an industry-level layer of information processing needs and agency frictions. The specific themes in each of these macrocategories of challenges are summarized in Table II, together with exemplar quotes.

Within each company, environmental data management activities (collection, cleaning, storage, integration, analysis, visualization, sharing, privacy management, and data governance) present three major challenges that can hinder the development of green products: complexity of obtaining and managing primary data, poor data quality, and lack of resources and expertise (first three rows of Table II). The difficulty of obtaining and managing high-quality and standardized primary data within each firm reflects not only technical limitations but also organizational ones, as resource constraints and a lack of expertise often prevented companies from engaging internally in environmental footprint calculation. This result reflects the core premises of IPT: effective decision-making requires a match between information processing needs and a firm's capacity to meet them—an alignment that we observed was often lacking for environmental metrics. These challenges have already been noted in the broader literature on data governance [53] and in the context of lifecycle assessments and EPDs, especially with respect to data quality issues [54], [55], [56].

Next, at the supply chain level, companies face three kinds of difficulties in obtaining data from other companies that is necessary for them to develop the environmental profile of their products (fourth to sixth rows of Table II). First, we observed a lack of appropriate information-sharing channels that ensured the confidentiality of sensitive data and the safeguarding of intellectual property rights. Indeed, some companies may use intellectual property protection as a justification to avoid sharing environmental data. Such data privacy concerns have also been identified in other studies on environmental data sharing practices, particularly regarding carbon emissions [57]. Second, we recorded numerous examples of limited willingness

TABLE II
DATA-RELATED CHALLENGES IN THE MANAGEMENT OF ENVIRONMENTAL METRICS WITH TEXTUAL EXAMPLES FROM THE INTERVIEWS

Macro-categories of challenges	Specific challenges extracted	Sample quotes from primary data collection
(1) Data management within a single firm	Complexity in obtaining/managing primary data	"But from there to really having the full picture, i.e. primary data on such a large number of products, we are still a long way off. […] It is still complicated because we are talking about very complex products."—*Company D, first-tier supplier* "If a supplier doesn't share something and they don't state that's confidential, then I would guess it's because they don't have it."—*Company F, first-tier supplier*
	Poor data quality	"We are talking about a great level of approximation."—*Company C, first-tier supplier* "We have a lot of information, but most information is, let's say based on statistics, based on self-declarations, but it's not real time from the source information."—*Company J, focal company*
	Lack of resources and technical expertise	"Being not too big suppliers, they don't have people who are there to do that [collecting data]."—*Company D, first-tier supplier* "I can say that sometimes it's really difficult, you know, to produce that the type of data that is requested. it's an issue related to the available resources as well"—*Company E, first-tier supplier*
(2) Information sharing between firms	Data governance, confidentiality and intellectual property	"There is a supplier that I know that because they say we are not their direct customers, they say there are privacy trajectories."—*Company D, first-tier supplier* "There are players who produce their own products, in those cases just having the concept of BOM would mean affecting intellectual property."—*Company H, focal company* "In general companies are very cautious about what they share with others in the value chain for fear of being I don't know, like the information might get misused or something like that."—*Company E, first-tier supplier*
	Limited willingness to share data	"But to date, apart from the sustainability report, made by marketing and published on the website, there does not seem to be much willingness to disclose on these issues."—*Company C, first-tier supplier*
	Lack of resources and expertise for inter-organizational data governance	"Company H, being a smaller entity of Company G, does not have an expediting unit internally, a unit that is in charge of doing audits in the field [...]. So, there is not someone in charge of auditing and verifying information, but very often it is all delegated to self-declarations of the supplier bound by the contract."—*Company H, focal company* "Obviously this whole process and project is easy to say but difficult to do, in the sense that we also had to create in-house skills in this respect over time, which is obviously also difficult to find on the market, because these are very new and innovative skills."—*Company D, first-tier supplier*
(3) Comparability across products and companies at a systemic level	Data unsuitable for benchmarking	"You have to normalize that data, because today […] I can write whatever I want in sustainability reports."—*Company C, first-tier supplier* "I do it properly, though at the moment there is no way to compare."—*Company C, first-tier supplier* "If I take the same piece of plastic that is molded by one supplier or another, I should have such accurate data that allows me to say supplier A [is better], because it has this energy mix, because the logistic transport is perhaps closer to my plant, etc., so I should probably choose supplier A over B. But you well understand that if the numbers that they give me are very, let's say random, it depends on how one calculates the data point. If one takes the data out of the number plate of the machine, while the other has a more advanced machine that gives the precise reading in that hour, you understand that there's a problem there, then maybe supplier A is better, but if one does an average calculation and the other one doesn't, so what?"—*Company D, first-tier supplier*
	Absence of standards for comparison	"On specific aspects where there is already a standard, like the conflict mineral that helps me manage this, where there is no standard and I'm on my own.... I'm not thinking about that."—*Company C, first-tier supplier* "What is the tool used to do this LCA, there are no standards; so, maybe the supplier does it with Ecoinvent [a database for background LCA data], yes, but maybe we use different schemes, so making these data talk, making them comparable is not really that simple. So, there is still an absence here too, maybe of standards at LCA level"—*Company D, first-tier supplier*

to share data, a result that confirms the existing findings of interorganizational information-sharing studies [58], [59], [60]. Third, we once again observed a lack of resources and expertise in collecting and verifying external information [55]. These dynamics create a fragmented information landscape in which transparency is sacrificed, asymmetric access to information can be exploited strategically, and it is difficult to assess the environmental performance of products assembled with parts and components coming from different suppliers. This finding aligns with agency theory's insights that, when information is asymmetrically distributed across interdependent actors, agents may act opportunistically [61].

Finally, even when sharing does take place, the comparability of information across different products and firms is virtually nonexistent. This is due to two factors (last two rows of Table II): first, data standardization is low, as environmental data inputs are typically shared in heterogeneous formats, making them unsuitable for benchmarking. Prior article has also noted that sustainability and ESG data are typically reported in heterogeneous formats, hindering comparability across firms [62], [63]. However, most of the existing evidence has been drawn from ESG reporting or broad sustainability assessments, and there is still limited empirical research on how these challenges manifest within high-tech supply chains, where product complexity and supplier interdependence further exacerbate data integration problems. Second, we found that a key obstacle is the absence of technical standards at the industry level for sustainability-related data. Scholars have repeatedly pointed out that the absence of technical standards for sustainability reporting and assessment undermines data consistency and comparability across industries [64], [65]. We complement this literature by showing that the lack of standardization is a bottleneck in high-tech supply chains, thereby highlighting the need for industry-level guidelines.

Overall, these findings highlight that the challenges associated with environmental data management are not merely extensions of generic data management issues but are also rooted in the distinct characteristics of sustainability-related information [66].

The information asymmetries, which stemmed from inaccessible primary data, a limited willingness or ability to share information across organizational boundaries, and the lack of standardization, give rise to a set of challenges specific to environmental data. Unlike operational data, environmental metrics are typically nonfinancial, cross-functional, and embedded in multitier supply chains, thus making them inherently difficult to verify, compare, or integrate. Thus, environmental performance ambiguity arises not only at the company level and horizontally between competing organizations, but is also intensified by vertical information asymmetries along the supply chain and at the systemic level. These results expand the relevance of the core

TABLE III
LEVELS OF GIS' CONTRIBUTION TO BRIDGE THE INFORMATION PROCESSING NEEDS AND CAPACITIES, AND TO MITIGATE ASYMMETRIC INFORMATION, WITH EXAMPLES OF TEXTUAL QUOTES FROM THE INTERVIEWS

	1. DATA MANAGEMENT WITHIN A SINGLE FIRM	2. INFORMATION SHARING BETWEEN FIRMS	3. COMPARABILITY ACROSS PRODUCTS AND FIRMS AT A SYSTEMIC LEVEL
ESTABLISHED CONTRIBUTION OF GIS	DATA MANAGEMENT "There is also the issue of data management, because there is a platform that manages the data and thus simplifies things for us. […] we started with this project of assessing the ESG performance of our suppliers." — *Company D, first-tier supplier*	TRANSPARENCY "What we do with the information, at this stage, is a lot of disclosure of the information for transparency purposes." — *Company E, first-tier supplier*	BENCHMARKING "We find very helpful in frameworks like EcoVadis [an ESG data management platform], because they do questionnaires per industry, and then they give you a rate, and then you can compare companies based on the same parameters."—*Company F, first-tier supplier*
POTENTIAL CONTRIBUTION OF GIS	DATA GENERATION AND MAINTENANCE "Easy to obtain, comparable according to a standard, provided in a format that we need and know where we to put that information and have someone responsible for that information to judge if that is relevant, these are all challenges that need to be solved."—*Company J, focal company*	MAPPING EXTENDED SUPPLY NETWORK "I'm ready to pay, if an external company come and says for a few $1,000,000 I give you tools that map your full supply chain, I would buy it."—*Company B, second-tier supplier*	HARMONIZE DATA EXCHANGE "What I would like is to be able to use a, let's say, common, international, shared platform, where we can also all use the same measuring parameters."—*Company A, second-tier supplier*
MISSING CONTRIBUTION OF GIS	GARBAGE IN, GARBAGE OUT "You have plenty of software, but the software doesn't fix your issue [of missing or low-quality data]. So, this is the biggest challenge" — *Company B, second-tier supplier*	ONLY VOLUNTARY COMPLIANCE "It would be nice if EcoVadis sent out the questionnaire and everyone did it, but unfortunately this is not the case. There are automatic messages that help remind the supplier to carry out the assessment, but in parallel the procurement team and the buyers who are in close contact try to push, tamp, remind, etc." — *Company D, first-tier supplier*	UNSTANDARDIZED ENVIRONMENTAL TOPICS "The example of greenhouse gas emission [data] is easy, there is one standard. Then you start to enter in other environmental aspects like water treatment or biodiversity, etcetera, and then you have no more standard on what data to use. It's a mess." —*Company B, second-tier supplier*

concerns of IPT and agency theory, illustrating how these play out in practice when firms attempt to navigate the complexities of environmental data.

B. GIS and Environmental Data Management: Contributions and Limitations

In a context in which environmental data are often lacking, rarely shared, and generally neither standardized nor comparable, we expect that advanced data management platforms such as GIS can offer a technological solution to mitigate some of these data-related challenges. The findings from our interviews and questionnaires provide nuanced evidence on the role of GIS and answer our first research question. Three key contributions of GIS emerged from our analysis: 1) simplifying data management and enhancing quality; 2) fostering information sharing, transparency, and collaboration; and 3) improving comparability, evaluation, and standardization. The analysis also highlighted a series of gaps that still hinder the full exploitation of GIS technologies (Table III).

First, GIS effectively contribute to data management, transparency, and benchmarking, as shown in the first row of Table III. For example, GIS simplify data processing, thereby enabling companies to collect and internally manage sustainability data efficiently, which is crucial for accurate performance assessments. Transparency can also be enhanced through the use of GIS, improving the disclosure of sustainability information. This allows improved visibility across the supply chain and reduces the likelihood of greenwashing. Additionally, we find that GIS have started to enable benchmarking: companies are now able to compare their sustainability performance on the basis of standardized industry-wide parameters, with the use of consistent metrics. Other studies have also shown that GIS improve internal data efficiency, enable more credible environmental performance measurement [1], [5], [9], foster transparency, and reduce greenwashing risks [7], [67]. We extend this literature by showing that GIS are now also employed to enable benchmarking against industry-wide metrics.

Second, the companies expressed several requests for GIS features that are currently not available, and they even indicated a willingness to pay for additional functionalities (second row of Table III). Future development of GIS could contribute to simplifying and standardizing data generation and maintenance, supply chain mapping, and standardizing data exchanges. Although standardized data collection remains a challenge, it has the potential to improve the accuracy and relevance of the data. GIS could play a crucial role also in supply chain mapping by addressing the persistent challenges related to supply chain transparency [28], [29], [66]. Although companies are willing to invest in tools to trace and monitor sustainability practices across their supply chains, this capability has not been fully implemented yet.

Finally, we also find areas for which GIS have not made a significant contribution and where it seems unlikely that any technological advancement could address these gaps (third row of Table III). First, if poor quality data inputs are entered into GIS, analytical outputs will inevitably be of low quality, no matter how advanced the data platform is ("garbage in, garbage out"). Moreover, although GIS can encourage the participation of suppliers in sustainability assessments, information is often provided on a voluntary basis limiting the effectiveness of the technology. Additionally, for some environmental topics, standards are still far from harmonized, especially for complex ecological issues, such as biodiversity, where no single comparable indicator like CO2 emissions exists. Therefore, asymmetric information persists in some areas, which leads to agency problems, since inaccurate, partial, or incomparable data can misrepresent sustainability efforts.

Overall, from an IPT and agency theory perspective, the introduction of GIS builds data-processing capacities and

TABLE IV
DEGREE OF IMPLEMENTATION OF GIS FOR GREEN PRODUCT INNOVATION, WITH EXAMPLES OF QUOTES FROM THE INTERVIEWS

	DIRECTLY enabled by GIS	Through other COMPLEMENTARY factors
SUCCESSFUL IMPLEMENTATION FOR GREEN PRODUCT INNOVATION	"There is no point in kidding ourselves 'we will do eco-design on everything', no. On everything, money will continue to be the main marker, whether it works or not. But in the meantime, I have it, I know how to do it, and I use it effectively on projects where it pays off."—*Company C, first-tier supplier* "Eleven years ago, we started a product lifecycle assessment on all our product called sustainable technology and we are the only one in the semiconductor industry to have this kind of product life cycle assessment so, it's not perfect of course, but we have a competitive advantage."—*Company B, second-tier supplier*	MARKET & CLIENTS "Regarding customers, it is obvious that our strategies were also influenced by our customers. It will not be the first time that you hear this, but to say Company G already in 2020 had started to ask in its tenders and tenders for evidence on the environmental performance of the products that we supplied, hence the EPDs. From there, we started to create an internal staff that deals with creating EPDs and doing internal LCAs and eco-design, because strong requests came from the market."—*Company D, first-tier supplier*
PARTIAL IMPLEMENTATION FOR GREEN PRODUCT INNOVATION	"To do eco-design, obviously you need primary data because how can I say this thing is better than the other, if I take an approximated average? We are starting to work on figuring out how to have an information system to get this data, because at the moment obviously EcoVadis has just another level of detail compared to what is asked by the supplier, it doesn't go into that much detail on the processes. In fact, it's not really asking for the detailed emissions of that process, the water consumption and all that like an LCA."—*Company D, first-tier supplier* "60% has still wrong estimation to be improved, and for my suppliers is the same and also for the suppliers of my suppliers etc. It will be a long journey before it fully impacts the design."—*Company B, second-tier supplier*	MARKET & CLIENTS "The data that we gathered then goes into an LCA, maybe it will change in 1-2 years down the road, but at this stage the reason why we are producing LCAs is because customers are requiring us to produce them, not because we want to drive innovation out of the information, we get out of the LCAs."—Company E, first-tier supplier INTERNAL STRATEGY "I don't think it would be like "oh, there is a new biodegradable plastic, let's try to integrate it", no, I think it would be more "what is the strategy of the company? What does the company want?" if yes, we go to the suppliers and we ask for it."—Company F, first-tier supplier
NOT IMPLEMENTED FOR GREEN PRODUCT INNOVATION	"We are not using LCAs (done with a GIS) for example to drive innovation." – *Company E, first-tier supplier* "The problem is I mean it's good, so you provide the LCA, but it does not help to design, because it's too complex."—*Company B, second-tier supplier*	REGULATORY & POLICY FORCES "Over the coming years, regulation will help, I think quite substantially in levelling the playing field for everybody. So, that then everybody can understand, can apply the same standards to understand what a good level of ESG performance [referred to green innovation] is versus a not so good level."—Company E, first-tier supplier

partially mitigates the risks of opportunistic behavior by improving the verifiability of data and reducing suppliers' scope for misrepresenting environmental performance. The established contributions of GIS, such as transparency and benchmarking, help mitigate information asymmetries by creating reputational and contractual visibility. However, when participation remains voluntary, as in many ESG reporting platforms, agency theory predicts that misaligned incentives will persist, as suppliers may strategically disclose only favorable information or withhold unfavorable data.

These findings reveal that, somewhat unexpectedly, even within a high-tech and digitally mature industry like industrial electronics, GIS have made only partial progress in addressing the data challenges that underlie corporate sustainability strategies, and significant gaps remain. The potential for improvement lies not only in enhancing the technical features of these systems, but also in fostering supply chain collaborations, securing the disclosure of high-quality data, and developing standardized frameworks and regulations for information sharing and performance evaluation. Thus, GIS effectiveness is not automatic, and instead depends on organizational, technical, and systemic factors.

C. Advances in Green Product Innovation

Next, the analysis revealed how GIS have the potential to help companies innovate in green product development, answering RQ2. Their effectiveness seems contingent upon complementary, systemic factors such as market demand, regulatory frameworks, and company strategies. In some cases, GIS played a critical role in enabling companies to innovate, when the system was fully integrated into their processes to conduct detailed product LCA and thus to perform effective ecodesign (Table IV, first row). By integrating GIS into their workflows, companies were able to trace the environmental impact of their materials, production methods, and supply chain activities, and to make informed decisions for sustainable product design and development, thus achieving a competitive advantage [5], [11], [41]. Consistent with agency theory, when agency problems rooted in information asymmetry are alleviated through GIS, which enhance data consistency and facilitate the timely use of environmental measurements, informational bottlenecks are removed, and ecoinnovation can unfold more effectively. However, other complementary factors, such as strong market demand for green products or regulatory requirements, also contribute significantly to successful green innovation strategies [3], [4]. For example, we observed in other contexts that market pressure encouraged companies to adopt GIS to create EPDs, which require internal LCAs and can drive green product innovation [68].

Conversely, in cases of partial implementation of GIS-enabled green innovation, companies are still in the process of understanding how to optimally leverage GIS (Table IV, second row). Although such companies used GIS to measure environmental performance, they were not yet able to obtain the detailed information needed from suppliers to establish ecodesign practices. Additionally, the companies were influenced by internal and external factors that encouraged only a partial approach to green product innovation (e.g., only customer requirements for LCAs motivated them to enhance their GIS capabilities). The evidence from this incomplete use of GIS reinforces insights from agency theory: when suppliers strategically withhold detailed data or provide only aggregated information, the principals (focal firms) cannot exploit GIS outputs to enable ecodesign [32], [69]. As a result, the persistence of hidden actions and unverifiable performance data limits innovation, despite investments in data infrastructures.

Finally, when GIS were not implemented for green product innovation, the companies mentioned several issues to explain why they had not been able to use GIS effectively (Table IV, third row). In some cases, GIS were not used to drive innovation

TABLE V
SUMMARY OF MACROCATEGORIES AND THEMES EXTRACTED FROM THE DATA (FROM TABLES II AND III), THEIR INTERPLAY WITH THE THEORETICAL LENSES, AND THE BEST PRACTICES THAT EMERGED ABDUCTIVELY FROM A SYNTHESIS OF THE MATERIALS

Macro-categories	Themes extracted		Theoretical counterparts		⇨ Synthesis of best practices to enable green innovation
Levels	Challenges	GIS Role	IPT	Agency theory	
Data management within a single firm	Complexity in obtaining/ managing primary data	✓ Data management, (generation) and maintenance	IP need for data collection, processing and analysis addressed by GIS	NA	Leverage GIS for *internal* environmental data integration across functions (esp. environmental metrics in R&D).
	Poor data quality	✗ Garbage in, garbage out	NA	NA	Invest to enhance data quality through integration with other technologies (e.g., sensors to collect real-time data).
	Lack of resources and technical expertise	-	Need additional IP capacities to handle GIS complexity	NA	Skill-building, training, cross-functional learning between data management, R&D and sustainability offices.
Information sharing between firms	Data governance, confidentiality and intellectual property	✓ Transparency, mapping (extended) supply chain	IP need for transparency addressed by GIS Need additional IP capacities to ensure data protection	GIS supports information alignment creating coordination and trust along the supply chain	Leverage GIS for *external* environmental data integration across companies. Implement systems that favor collaboration through strong confidentiality (e.g., aggregation, data-sharing protocols, blockchain, etc.).
	Limited willingness to share data	✗ Only voluntary compliance	NA	GIS cannot compensate the asymmetries from the lack of collaboration and data sharing	Ask for and share information that is strategic for the company; collaborate proactively, anticipating information requests rather than reacting to them.
	Lack of resources and expertise for inter-organizational data governance	-	Need additional IP capacities to handle GIS complexity	NA	Skill-building, training, cross-functional learning to bridge data management, procurement, and compliance.
Comparability of data across similar products and companies at a systemic level	Data unsuitable for benchmarking	✓ Benchmarking and more harmonized data exchange	IP need for data collection, processing and analysis as well as transparency addressed by GIS	GIS as a mechanism for information alignment addressing heterogeneity	Strategic positioning of GIS to build competitive advantage beyond compliance/industry's averages.
	Absence of standards for comparison	✗ Nonstandardized environmental topics	NA	NA	Collaboration with third parties and policymakers to establish industry-specific technical standards.

due to their complexity or because they did not align with the company's strategy. Furthermore, companies mentioned waiting for other complementary factors, such as external regulatory pressure, to drive their choices of green innovative activities, but the lack of effective GIS integration hinders their ability to realize the full benefits of detailed sustainability data to achieve green product innovation. These findings echo other research that has shown that firms often underutilize GIS, restricting their application to compliance-oriented assessments rather than embedding them in innovation strategies [1], [6]. From an agency theory standpoint, these cases illustrate how weak monitoring and a lack of incentive alignment perpetuate agency issues: whenever external enforcement (e.g., regulations or customer audits) is absent, agents have little motivation to disclose accurate data or invest in traceability [69], thereby preventing GIS from functioning as an effective enabler of green product innovation.

D. Best Practices for Sustainable Innovation

Combining the empirical insights from Sections IV-A–IV-C and circling back to the theoretical lenses of IPT and agency theory introduced in Section II, we synthesize the emergent patterns to answer RQ3 on best-practice uses of GIS to foster green product innovation. By mapping the most pressing challenges mentioned by the analyzed companies onto the corresponding GIS capacities (or lack thereof) at the three levels of data management in individual firms, data sharing between firms, and the systemic industry level, we highlight the key takeaways that extend beyond the initial theoretical constructs. From this mapping, we extrapolate the best practices that either leverage existing GIS capabilities or compensate for their limitations. Table V provides a synopsis of the themes from Tables II and III, connecting them to the theory presented in Fig. 1.

Best practices emerging from our analysis call for three interrelated actions: first, integration of internal and external environmental data into the companies' operations, together with technologies that improve data measurement quality. Indeed, one of the findings of our analysis that goes beyond the initial theoretical framing is that a central hurdle is not only managing and exchanging environmental data, but also ensuring quality of the underlying measurements, for instance through technologies such as sensors for real-time measurement. Second, firms should invest in skill-building and cross-functional learning across data management, R&D, sustainability, procurement, and compliance functions, so that data can be translated into design and sourcing decisions rather than remaining confined to reporting activities. Third, companies should pursue strategic collaboration and environmental alliances [70] to proactively govern data exchanges with supply chain partners: sharing

decision-relevant information under robust confidentiality and verification mechanisms (e.g., aggregation and data-sharing protocols and auditable traceability solutions) while engaging in industry-level standard-setting to reduce persistent ambiguity along with third parties and policymakers.

V. Discussion

In this article, we explored how GIS can support corporate sustainability by fostering green product innovation. Our analysis offers a new, in-depth understanding of the challenges and best practices of GIS management through an abductive, multiple-case study of the electronics industry. Unexpectedly, we observe that the adoption of GIS is not guaranteed by the digital maturity or size of a firm, as all the companies in our sample were large, technologically advanced, and innovation-driven. Instead, the challenges that emerged around GIS are not limited to those predicted theoretically in terms of data-processing capacity and information asymmetries, but also appear to stem from the inherent complexity of the underlying environmental data and from systemic factors. As such, the best practices to leverage GIS should not only be built on existing system functionalities but should also compensate for their limitations in addressing environmental data challenges.

A. Theoretical Contributions

This article contributes to multiple interconnected streams of literature. We bridge IPT, agency theory, and the literature on green supply chain management and green product innovation, offering several contributions grounded in the iterative analysis of empirical evidence from our multiple case studies. First, the study extends IPT by showing how environmental data management introduces specific information processing needs. Unlike traditional operational data, sustainability-related metrics are often nonstandardized, unverifiable, and distributed across multiple tiers of global supply chains. Our findings refine IPT by demonstrating that the challenges that arise around environmental data are not only about technical issues related to data volume and velocity, but also about fundamental issues of interpretability, traceability, and integration across organizational boundaries. Thus, the study introduces a sustainability-specific elaboration of IPT from an engineering management perspective that goes beyond existing IT studies on GIS [1], [6], [71], [72] and highlights how GIS management should evolve to support high-quality data collection and intra and interorganizational alignment.

Second, we contribute to agency theory by illustrating how asymmetric environmental information in supply chains leads not only to typical forms of opportunism, but also to specific "eco-opportunism"—strategic misrepresentation or selective disclosure of sustainability data that can verge on greenwashing [67], [73]. Our findings enhance the explanatory power of agency theory in sustainability contexts by showing how data infrastructures, such as GIS, can serve as partial mitigation mechanisms, although their effectiveness is constrained by systemic issues, such as voluntary compliance and fragmented standards.

Third, this article bridges the gap in the literature on GIS and green product innovation within broader green supply chain management research. While previous work broadly linked IT capabilities to organizations' sustainability performance and innovation [5], [9], we offer a more granular understanding of the mechanisms through which GIS contribute to green innovation in multitier supply chains, such as by enabling LCA, fostering cross-functional data integration, and supporting ecodesign processes. At the same time, our findings suggest caution against overestimating the automatic benefits of GIS, whose innovation-enabling potential depends on supplier engagement and the broader institutional context.

These contributions provide a more nuanced theoretical understanding of how digital infrastructures tailored to environmental data mediate the relationship between advanced data management and sustainable innovation, suggesting new directions for research at the intersection of technology, sustainability management, and interorganizational coordination.

B. Managerial Implications

Our findings offer several relevant contributions from a managerial perspective. First, to achieve best-practice GIS implementation, these technologies should be used with a strategic approach, that is, moving beyond their traditional role in retrospective environmental monitoring and performance assessment. Leading firms proactively shape their environmental data strategies to anticipate market and regulatory demands to enable long-term sustainability objectives and competitive differentiation. Second, for those managers who are interested in adopting GIS as a catalyst for green innovations, these tools should be tailored and carefully integrated into the organization to enable ecodesign processes through lifecycle assessments. The process of translating advanced data management into green product innovation requires the integration of GIS into internal R&D and product design processes, the in-house development of skills and technical expertise—ideally in cross-functional teams that understand both sustainability and innovation priorities. These implications are in line with the literature that has pointed out that digital solutions for sustainability require a strong learning orientation and human capital investments [74]. Third, managers in high-tech sectors are increasingly required to handle both complex data landscapes and sustainability challenges. With the growing regulatory pressure from environmental policies—such as the EU's Digital Product Passport—and the evolving market demand, data processing needs are likely to increase in the future. This dynamic evolution of sustainability data requirements has clearly emerged in this article, and our analysis suggests that an adaptive approach to systematically incorporating emerging technologies (AI, machine learning, IoT, Big Data analytics, and blockchain) would help enhance the capabilities of GIS [75]. This strategy, in its most advanced application, would also entail a systematic integration of GIS into sustainable supply chain management to improve both supply chain engagement and data governance in complex, multitier networks.

C. Limitations and Future Research Directions

Although this article provides valuable insights, it is important to acknowledge its limitations. First, because of the specific context of our case studies, the findings may not be transferable to all industries, company sizes, or geographical locations. Future article with a broader scope could enhance the generalizability of the conclusions to other high-tech industries. Moreover, we focused on the role of GIS within the specific context of green product innovation, which is a form of data-driven innovation closely linked to activities such as ecodesign. Therefore, the generalizability of our results to other forms of green innovation, such as green process innovation, requires further investigation. The functionalities of GIS and their impact may differ depending on the specific type of green innovation considered. Finally, this article has examined GIS and green product innovation through the lens of data processing needs and capacities, as well as information asymmetries; however, as our final set of results suggests, other factors, such as organizational and market dynamics, legislative frameworks and supply chain relationships also warrant detailed analysis, as they are likely to play significant roles. Future article should further explore the interaction of such factors with GIS technologies.

VI. Conclusion

The advent of green digital platforms and data analytic tools for environmental data management represents a vital technological change for sustainability, as they can facilitate transparency and traceability, thereby allowing organizations to monitor progress, share reliable metrics with stakeholders, and ensure accountability. A holistic and forward-looking approach to GIS can support internal decision-making and foster trust among consumers, investors, and regulators by demonstrating a commitment to developing more sustainable products with verifiable impact reductions across the supply chain. As such, GIS technologies can empower companies to transition from isolated sustainability efforts to a comprehensive, data-driven innovation strategy for achieving long-term environmental goals.

Through an abductive multiple-case study that iteratively triangulates empirical evidence with theoretical perspectives from IPT and agency theory, we argue that the best practices that most effectively leverage these technologies rely on several complementary actions: internally, firms must invest in building capacity and cross-functional learning, and adopt an integrated approach to data sharing and technological infrastructure to collect, analyze, and manage high-quality environmental data. Externally, strategic partnerships, possibly mediated by third-party industrial organizations, can support the establishment of industry-wide data standards and frameworks for secure data sharing in the absence of mandatory legal requirements. If technological developments in GIS infrastructures are accompanied by robust governance mechanisms, stakeholder engagement and systemic policy alignment, it will be possible to fully unlock the potential of these systems to support green innovation and sustainability objectives.

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