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The Role of Standards in the Development and Delivery of Sustainable Products: A Research Framework

Pavel Castka 

UC Business School, University of Canterbury, Christchurch 8041, New Zealand; pavel.castka@canterbury.ac.nz;
Tel.: +64-336-93761

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Abstract: The progress towards sustainable development could be accelerated by the adoption of progressive technologies and the development of new “green” products. The anecdotal evidence suggests that the acceptance of these products is, in part, affected by the development and acceptance of new standards as well as by the management of standardization in firms. Yet, there is a lack of a clearly focused research agenda that would systematically address the management of standardization in firms—particularly from a sustainability perspective. This paper addresses this gap and develops a research framework that is organized in three areas—intrafirm capabilities (the role of standards in the development of firms’ capabilities in—and through—standardization-related activities), interorganizational relationships (the role of standards in the development of interorganizational relationships) and accountability (the role of standards for accountability in firms and supply chains). Each area provides a set of representative research questions for future research. The paper also aims to encourage scholars in the field to address standardization from a strategic perspective, to develop an understanding about the complex nature of the management of standardization and trace its economic and sustainability consequences.

Keywords: standards; sustainability; value chains; strategy; accountability

“Pre-existing standards for electrical installations within buildings were written under the assumption that there are only devices in a building that consume electricity but no electricity producing devices”. New standards had to be developed to establish market access to innovative electricity producing devices. [1].

1. Introduction

Standards play an essential role in business: enabling cooperation (i.e., through interoperability and harmonization), improving productivity, reducing information asymmetry and increasing trust. Firms have to consider and comply with a plethora of standards, including de facto standards (developed through market-based interactions) and de jure standards (standards developed through formal committees). Some standards are mandatory [2] while others are voluntary and driven by key industry players or NGOs [3]. Standards are especially essential for global supply chains and international trade: governments negotiate Mutual Recognition Agreements (MRAs) based on internationally agreed standards; international auctions (e.g., wool) require products to be tested by accredited laboratories. Firms need to comply with various product and process standards and in doing so gain access to international markets [4,5] and signal their capabilities [6]. The opening quote of this paper introduces yet another important aspect of standardization: standards can also impact the acceptance of new and innovative products (such as sustainable products), or, more broadly, affect the competitiveness of firms. Standards influence entire supply chains, innovation eco-systems [7] and national economies by establishing reference points, platforms for collaboration and determining trade relations [8]. Moreover, individual companies, industry consortia as well as national governments

use standards not only to enhance collaboration but also to lock-in their products and technologies to prevent the diffusion of alternatives [9]—and hence creating a competitive advantage.

As Jakobs [10] observes, “standardization has become a major strategic tool especially for the large players.” Standards and standardization therefore present a highly complex subject area for managers and have significant economic and financial consequences for their firms and supply chains. Navigating through the complex eco-systems of standards presents an important challenge for firms. Individual firms need a strategic approach to the management of standardization across their value chain—starting from new product development to their approach to end-user management—and translate their standardization strategy across their supply chains. However, many scholars have highlighted that the ‘management of standardization’ is underdeveloped in the academic literature, whilst it is also considered challenging by managers [1]. This paper aims to determine the key areas for future research and addresses this gap by determining a *research framework for the management of standardization*. The research framework is developed through a critical reflection process [11] based on the review of new trends in standardization (identified in professional literature and in discussions with standardization professionals). In doing so, the paper enhances the current academic literature which, in part, addressed some aspects of the management of standardization, such as impact, adoption, diffusion of selected standards (for instance, UN Global Compact [12]), ethical sourcing standards [13] and supplier development standards [14], supply chain auditing [15] and conformity assessment [8,16,17]. At the same time, the current research seems rather fragmented and focused on few aspects of standardization [18]. Moreover, the existing research—whilst contributing to practice—also lags behind due to the timeliness associated with the research itself and the timeliness of the publication process. Therefore, it is also important to develop future research agendas based on current trends and experience of industry experts [19].

New trends in standardization are, in part, associated with the current societal trends and political agendas, such as sustainability (i.e., standards for emissions and verification methods) or technological innovations (i.e., standardization of blockchain technology [20]). Some of these trends are worth noticing. First, innovations often lack adequate standards, or these are based on outdated assumptions—as the opening quote suggests [1]—thus hindering the acceptance of new technologies. New technologies therefore require the development of new standards and conformity assessment methodologies [21], which in turn enable their market acceptance and global diffusion [22,23]. Second, new standardization initiatives also aim for the harmonization of technologies across the globe—particularly important in the domain of environmental technologies and IT technologies such as blockchain. For instance, new standards for EV charging stations provide common solutions to avoid market fragmentation and improve harmonization and interoperability in supply chains (i.e., ISO 17268 covers gaseous hydrogen land-vehicle refuelling connection devices [24]). Third, governments continue to use standards to impact international business and are becoming increasingly strategic in employing standards to advance national competitiveness [25]; for instance, in infrastructural projects (e.g., China’s Belt and Road Initiative) or in the development of industry clusters [26]. Governments also develop and impose standards and regulatory measures on firms, which impact global operations and supply chains, for instance GDPR in the European Union or Modern Slavery Laws recently introduced in various countries. Fourth, the issues of the credibility of audits and conformity assessment continue to rattle supply chains. For instance, deception in product testing standards has been central to scandals such as VW’s Diesel gate or several food-related scandals (the presence of horse DNA in beef products and donkey meat substituted for halal meat [27]). Firms recognize the risk associated with poor audits (quality, social, environmental) and unreliable testing—sparking discussions about accountability and investments into technological advancements of audits and conformity assessment [28].

The research framework developed in this paper reflects these trends, and the framework is organized around three areas. The first area concerns *intrafirm capabilities* and discusses how firms develop their capabilities in—and through—standardization-related activities. Standards can significantly impact structural and infrastructural aspects of firms' operations, and firms' standardization-related competencies can lead to improved performance. The second area of our research framework focuses on *interorganizational relationships* [29] and discusses how interorganizational relationships are developed through standards. The third area in the research framework concerns *accountability* and discusses the role of standards for accountability in firms and supply chains. In each area (and later whilst discussing the overlaps between the three areas), the paper discusses the current trends and links these trends to questions that are relevant to managerial decision-making and improvements in firms' performance.

The paper is organized in the following way. In Section 2, the paper discusses the fundamentals of standards and standardization. This section introduces significant aspects of standardization and provides clarity of key terms that are used in the paper and in the research framework. This section also discusses standards in the context of firms' processes and links standards with key value chain activities. Section 3 describes the rationale behind the research framework and how the framework was developed. Section 4 contains a discussion of the research framework and provides a set of 11 research questions that are recommended for future research. Limitations, as well as alternative angles on the research into the management of standardization, are discussed in Section 5.

2. Fundamentals of Standards and Standardization

Standardization is a complex eco-system of various actors (governments, individual firms, industry consortia, NGOs, certification bodies, testing laboratories, scientists and others). These actors develop standards through different standardization processes [30]. Wiegmann, de Vries and Blind [22] refer to these processes as modes of standardization and define three modes: committee-based, market-based and government-based. Each mode of standardization represents specific mechanisms and specific stakeholder groups that develop and enforce standards [31]. For instance, committee-based standardization refers to a cooperative mode that is orchestrated by standardization bodies (e.g., ISO) or industry consortia (e.g., IATA); the market is based, then, is characterized by a competition between several standards aiming to dominate the marketplace [32].

The standardization profession defines various types of standards. Standardization institutions, such as the European Committee for Standardization (CEN) and the European Committee for Electrotechnical Standardization (CENELEC), define four general types of standards. Fundamental standards provide definitions and terminology and aim to provide a common language for standardization developments. For instance, fundamental standards for Artificial Intelligence (AI) or Internet of Things (IoT) are currently being developed for that reason [20]. Test methods and analysis standards provide methodologies to measure characteristics (such as temperature and chemical composition). Management systems standards (sometimes referred to as “meta-standards”; Corbett and Yeung [33]) define key organizational processes and their relationships. Management systems standards aim to improve various aspects of a firm's performance (quality, health and safety, environmental) and create a common platform for interorganizational relationships. Specification standards define the characteristics of a product or a service and the key performance thresholds (such as fitness for use, interface and interoperability, health and safety, environmental protection, etc.).

The scope of standards varies widely. On the one hand, standards can address a particular technical detail (i.e., gas installation in buildings) or a testing method (i.e., verification of environmental performance). On the other hand, standards can cover systems and processes of the entire firm. For instance, management systems standards define systems for environmental management (ISO 14001) that are generic to any firm and which do not prescribe any performance levels. Another good examples are standards that define the architecture of technical systems (i.e., the German RAMI4.0 model for Industry 4.0 or standards related to mobile telecommunications). Chain of custody standards then

extend the scope into the supply chain (or product life-cycle) and cover the distribution of the product from the raw materials to the end-customer. For instance, chain of custody standards in forestry (FSC Chain of Custody by Forest Stewardship Council for sustainable forests) or ISO 22000 for food safety management system extends the scope beyond the processes of the focal firm. Therefore, the scope is characterized by the nature and number of different issues that are subject to evaluation and verification processes associated with standards [34].

Standardization serves multiple objectives. For instance, specifications standards simplify the exchange of goods and services and therefore reduce the *transaction cost* between involved parties. Likewise, test methods and analysis standards create a common platform for trading. For instance, if a firm wants to participate at wool auctions, the International Wool Textiles Organization requires all products to be tested against an approved testing standard. The transactions between parties require *trust*. In the context of standardization, trust and confidence are achieved by multilayer governance [35]. This refers to a system of certification and accreditation—also referred to as “Quality Infrastructure (QI)” [36]. In a majority of countries, a national standardization body oversees the functioning of a QI—for instance, the American National Standards Institute (ANSI) in the US, the Canadian Standards Association (CSA) in Canada or the Joint Accreditation System of Australia and New Zealand (JAS-ANZ). Quality Infrastructures are important for international trade by providing trustworthy and consistent mechanisms for the exchange of goods and services [8]. Likewise, Mutual Trade Agreements are anchored in reliable QIs in trading countries and trading regions. For instance, countries forgo testing in the importing country based on a recognized testing in an exporting country (Berkowitz et al, 2006). Many countries and their national standards bodies use standardization and QI as a means to enhance national *competitiveness*. To that end, countries develop national standards strategies and align standardization with areas that are strategically important for national interests [37]. At the national level, standards are used, for instance, to assist new clusters to develop the competence and ability to compete in international markets (e.g., in Germany, standards are used to develop Industry 4.0 competence [26]). Internationally, nations influence the development of standards that benefit their firms or industries. Individual firms also use standards to increase their competitiveness. For instance, standards help firms to establish new technological formats [9] or technological solutions [2].

Standards in the Context of a Firm

Standards affect individual functions within a firm, such as the management of work flow processes [38] as well as interorganizational relationships [29]. Standards influence firms’ access to international markets [8], and global supply chains rely on standards to maintain quality [14], safety, transparency [39], environmental management, social responsibility and other aspects of sustainability [34,40]. Firms and supply chains are also being challenged by the increasing digitalization and development of smart technologies and rely on standards to integrate these technologies in their daily routines [28]. Standards have a practical impact on all activities across the value chain—from new product development to end-user management (Table 1).

There is a substantial literature that covers the role of standards in relation to individual value chain activities. For instance, process improvement—and management systems standards—is the most covered aspect of standards in management literature [18]—especially from quality and environmental perspectives. New product development—and the role of standards in the NPD process—is widely covered from a technical [32], regulatory [2], knowledge transfer [45] or product/process transformation perspective [46]. Regardless of the academic domain, the current literature covers quite narrowly focused topics but remains largely underdeveloped in terms of a holistic and strategic perspective on the role of standards in managerial decision-making—as was argued at the outset of this paper.

Table 1. The role of standards in key value chain activities.

Activities	Role of Standards	Examples from the Literature
New Product Development	Enabling acceptance of new products in the market	Product testing signals product's quality to the market [32] Product compliance ensures that the product meets regulatory requirements [2]
Sourcing and Supply	Enabling supply of critical components/resources	Specification standards enable cooperation between multiple firms in delivering critical parts/service according to specification [41]
Process Improvement	Enabling consistency of manufacturing process or service delivery	Process and management systems standards define critical elements of a system to deliver consistent products/services [18,42]
Managing Complementary Networks	Enabling cooperation between firms	Complementary networks rely on standards to determine critical interfaces that allow product/service acceptance in a specific eco-system [1] or in relation to specific innovations [7,43]
Distribution	Enabling traceability from raw materials to end-customers	Chain of custody standards provide platforms for supply chain partners to trace products from raw materials to end-customer [44]
End-user management	Enabling product acceptance by end-users	Customer interface standards define the pattern of interaction between the individual user and an end-product [2] Installation specification standards provide guidelines for installation and ensure product warranties [1]

3. Towards the Research Framework

The reviews of research into standards (and determination of future research agendas and questions) are typically organized around existing studies—building on their most distinctive features. Often, such “organization” of findings is driven by their practical relevance. For instance, the literature review by Heras-Saizarbitoria and Boiral [47] determines various issues related to meta-standards, namely “global governance, diffusion processes, motivations, benefits of adoption and impacts on performance, internalization, integration, consultancy and auditing”. Similarly, Castka and Corbett [18] organize their review of management systems standards around key topics of “diffusion/adoption, impact and governance”. On the other hand, de Vries et al [19] take a broader outlook on standards and trends in standardization and organize their review in terms of “Basic Understanding of Standardization, Diversity in Standardization Practices, Impacts of Standards, Management of Standardization, Conformity Assessment and Intellectual Property Rights”. These examples demonstrate that there are many ways in which research in this domain can be organized and conceptually grounded.

Conceptual Grounding of Research Framework

Conceptual grounding refers to “the process of linking concepts represented in a noological system to its real-world referents” [48]. As was mentioned at the outset of the paper, the paper is based on the review of new trends in standardization and systematically organized through a critical reflection process [11]. The critical reflection process is based on the identification of trends in standardization. These trends were primarily derived from the discussion with professionals (the author has been involved in several standardization committees for more than a decade) and academics in the field. Furthermore, the reflection is enhanced by a review of reports of international trade, professional standards literature and impact studies by think-tanks that were identified by experts to further understand the context of their arguments. As part of the reflection process, a review of articles in ISO FOCUS over the 2015–2019 period—a flagship magazine of the International Organization for Standardization (ISO)—was also conducted in order to find illustrative examples of the trends.

There are multiple ways in which to conceptually (and theoretically) ground research and develop a research framework. As was discussed at the outset of this section, conceptualization based on diffusion/adoption of standards, impact of standards and governance of standards might be considered. Likewise, management theories can provide the underpinning to develop the research framework. For instance, the framework can be grounded in theoretical perspectives that are often adopted in research. In the standardization context, institutional theory or diffusion of innovation theory are examples of often-used management theories [49].

The research framework presented in this paper was developed based on the following principles. First, because of the firm level perspective, the framework was organized in such a way as to enable the determination of topics that address the role of standards and standardization in the context of a firm and of managerial decision-making at the firm level. This is in line with the “Management of Standardization” perspective [19]—essentially studying firms’ decision-making processes that strategically integrate standards into firms’ operations. Second, Wiegmann [1] suggests that the management of standardization needs to consider firms, the industry and a wider context. Therefore, the framework also needed to expand the intrafirm perspective to incorporate a wider context. Third, the framework needed to incorporate current trends in standardization. Following these principles, the *Framework for Management of Standardization* (Figure 1) was determined. The framework recognizes that standards and standardization are critical mechanisms in managing firms that span across processes within firms (intrafirm capabilities) and across supply chains (interorganizational relationships). The framework also recognizes that standards are accountability mechanisms and that recent scandals (e.g., Dieselgate) and the increased focus on the impact of standards and related certifications (e.g., in the domain of social and environmental management) warrant a more central place for accountability-related issues in our framework. The inclusion of the accountability perspective also has a significant practical relevance: standards are often linked to conformity assessment, and their credibility depends on the consistency and trustworthiness of the conformity assessment.

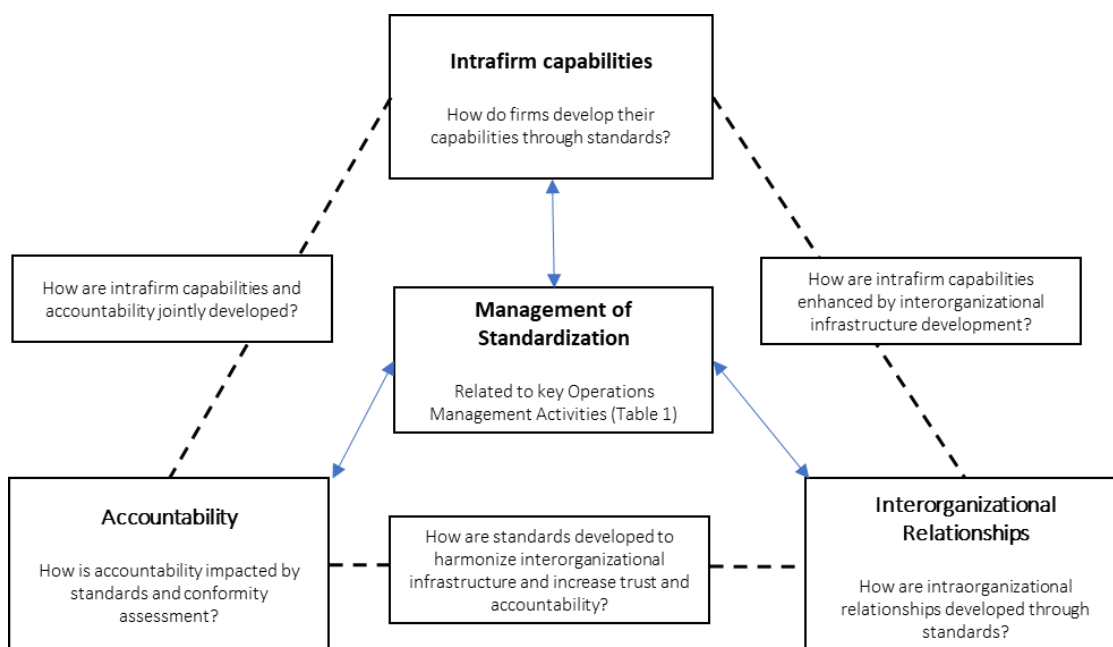


Figure 1. Framework for Management of Standardization.

In the following sections, the areas of the research framework are discussed, and a set of 11 research questions is drawn from this discussion.

4. Discussion

4.1. Intrafirm Capabilities

Standards can assist intrafirm development in many ways. Management systems standards, for instance, allow platforms to develop systems for environmental management, social responsibility, H&S and other aspects of sustainable development [18]. The adoption of management systems standards enhances a firm's capabilities and often improves its performance—i.e., the adoption of health and safety standards creates a safer working environment [50]. Specification standards, on the other hand, provide specification for products and ensure a product's market acceptability. The adoption of these standards also enhances the staff's technical competence. In many instances, firms are required to comply with multiple standards of various types. For instance, a plastic pipe manufacturer can comply with 40 plus standards that cover the entire value chain: from the inspection of incoming pipes and manufacturing according to product specification standards to ensuring standardized installation with contractors [51]. The adoption of these standards thus adds to a firms' capabilities [52].

Not only do standards present opportunities for intrafirm development, but, at the same time, the unawareness about standards (and about changes in standards) poses significant economic and financial risks for a firm [1]. One of the potential risks are infringements and fines resulting from non-compliance. For instance, the European Union's General Data Protection Regulation (GDPR) impacted firms that offer goods or services to EU residents. Firms need to adopt the requirements of these standards to avoid fines. Not being aware of standards leads to the risk of substantial additional costs in ensuring regulatory compliance—i.e., the European New Approach [53]. Firms might also be using standards that are obsolete or deemed inadequate or deceptive—and the association with such standards presents a reputational risk for a firm [28]. Firms therefore need to develop mechanisms to monitor the external environment to anticipate the changes in standards and standardization.

The opportunities and risks related to standards highlight the strategic importance of standards for intrafirm development. In response to ongoing changes, firms need to find ways to adopt standards quickly and use them to their advantage. In doing so, firms develop unique internal competencies [54], allowing them to progressively add new standards [55] and hence develop absorptive capacity [56] through knowledge conversion [57]. Even though the literature paid attention to some aspects of standards adoption (i.e., how firms embed management systems standards into existing organizational routines [58]), there is a scarcity of research on how firms use standards strategically to develop a competitive advantage [1]. Hence the first research question:

- **Q1:** *How do firms incorporate standards into their strategic decision-making and develop absorptive capacity through standards and standardization? What is the relationship between the absorptive capacity developed through standards and standardization and a firm's performance? How do such strategies differ for various aspects of sustainability?*

New product development (NPD) is an essential part of value chain activities (Table 1) [59]. The NPD process is concerned with inventing, prototyping, testing and introducing new products [60]. Time-to-market and simultaneous product and process development (e.g., design for manufacturability) are important NPD performance indicators [59]. Firms' performance in the NPD development is contingent on many factors, such as knowledge, brand reputation and budget [61], and it is also affected by standards. Firms that are familiar with standards and embed standards into their NPD process develop a competitive advantage—for instance, in terms of time-to-market performance [1] or by enabling the integration of the product/process interfaces [46]. Compliance standards—when carefully considered during NPD—ensure market acceptability [2]. New products (especially products aimed for export and heavily regulated products) need supporting standards and testing in order to be accepted both domestically and at international markets [23].

For firms that compete through new product development, standards are crucial to intrafirm development. Standards, just like patents, impact the direction of innovative activities [45] and reduce uncertainty by pointing NPD into a particular direction [37,62]. The successful management of standardization at the NPD stage is critical for other activities in the value chain. Hence the following research question:

- **Q2:** *How do firms incorporate standards in new product development (NPD)? How does the management of standardization impact NPD performance, particularly with regard to a reduced time-to-market, or a transition from prototyping to production or product acceptance? What are the economic and sustainability consequences of the management of standardization (related to NPD) on downstream operation management activities?*

If a product falls outside of the scope of existing standards, a lack of standardization impedes a product's time-to-market [21] and negatively affects the new product development process. Innovative products need to be standardized to allow for mass production and to ensure consumer safety. Standardization also helps to build focus, cohesion and critical mass in the formative stages of a market [23]. The examples from practice demonstrate that innovative firms do find new product standardization challenging. For instance, new green tech products by CarbonCure Technologies or Terragon Environmental Technologies provide illustrative examples of cases where highly desirable and innovative products do not fit the current standard and regulatory frameworks. Due to such misalignment, the adoption of their products is negatively affected [21]. CarbonCure Technologies use a patented innovation consisting in injecting waste carbon dioxide into concrete as it is being mixed, to strength the product while stopping the gas from entering the atmosphere. Terragon Environmental Technologies provide "practical, inexpensive and environmentally safe appliances that can be used by anyone to generate energy and water from materials previously considered waste" [21]. These examples bring forward the broader question of a firm's involvement in the development of new standards.

Standards are developed through various modes of standardization (as discussed in Section 2 of the paper), and firms select ways to get involved. Representatives from large firms, for instance, participate or lead international standards development committees, including Airbus (Chair of ISO/TC 279, Innovation management), Boeing (Chair of technical committee ISO/TC 184, Automation systems and integration, subcommittee SC 4, Industrial data), Sneider Electric (Chair of technical committee ISO/TC 184, Automation systems and integration) or Huawei (Chair of the new technical committee ISO/IEC JTC 1, Information technology, subcommittee SC 42, Artificial intelligence). Smaller firms also get involved. However, their participation is more common as part of national standards development committees, where these firms aim to influence national standards or to learn about the benefits of standards for their firms [63]. Part of the standards development process is also lobbying for standards that benefit a firm or for governmental purchasing policies that advantage complying firms [22]. Individual companies also engage in market battles and use standards to lock-in the dominant technologies, such as 5G, USB and Wi-Fi [9], as well as customer interface standards such as PC user graphic interfaces or robotic surgery video interfaces [2].

The literature covers the underlying processes of various modes of standardization [22]. However, there is a lack of studies addressing when, how and under which circumstances should a firm get engaged in standards development. These questions are not only pertinent to large firms (Airbus, Boeing, Huawei) but also to smaller firms (such as CarbonCure Technologies and Terragon Environmental, that were previously discussed). Some of these questions were recently discussed in the literature [37] but more empirical evidence is needed. This discussion leads to the following research question:

- **Q3:** *Under what circumstances and how should a firm engage in the development of standards? What resources, knowledge and relationships are required to participate in the development of standards? What is the optimal level of investment into the standardization efforts?*

4.2. Interorganizational Relationships

Organizations operate in a relational context of environmental interconnectedness [29], and interorganizational relationships are a critical part of supply chain management. Standards aim to enable interorganizational relationships by providing common platforms for interconnectedness through management systems standards, interface standards, product standards as well as testing standards. The underlying premise of standardization is that of lowering of a transaction cost as well as assisting in the diffusion of knowledge and technologies through global harmonization [23].

There are several examples of standards that aim to harmonize interorganizational relationships. For instance, standards for shipping containers significantly impacted global shipping by providing standardized shipping container sizes [64]. GS 1 standards provide a system of unique product identification across the globe. Management systems standards such as ISO 14001 for environmental management systems provides standardized intrafirm infrastructures for a more efficient collaboration across supply chains. Apart from such established standards, there is a constant influx of new standards to address harmonization in supply chains. For instance, the harmonization of infrastructure for Electric Vehicles has been recently addressed by several ISO standards [24]. Likewise, new standards were developed to assist with the aviation industry's coordination [65].

The harmonization through standards not only provides benefits for supply chains but also results in social benefits and benefits for multiple stakeholders. When an innovation is standardized, it is diffused in supply chains and enables innovations for firms upstream and downstream [23]. Standards harmonize and ensure interoperability [10] to protect consumers—for instance, by addressing the compatibility between various generations of the same product. Standardization also aims to avoid market fragmentation and to speed up the uptake of innovations, as in the case of Electric Vehicles (EVs). ECOS (2019) reports that “inconsistent infrastructure functionalities across member states is ultimately hampering the widespread adoption of electric vehicles in Europe”.

However, it is unclear under what circumstances the coordination efforts succeed, especially under increasingly complex multi-mode standardization processes [22]. There is a great opportunity for researchers to address fundamental questions about how such collaboration should be coordinated—especially taking into consideration the trade-off between “cooperating” and “competing”. This raises the following research question:

- **Q4:** *How do and how should firms and other stakeholders collaborate in the development of interorganizational relationships through standardization? Are current modes of standardization suitable for the development of new standards?*

IT and new technology standardization are subsets of standards to address interorganizational relationships that require special attention. This decade has witnessed the introduction of a number of new technologies that can significantly affect operations and supply chain management. Big data [66], blockchain, Internet of Things (IoT) and Artificial Intelligence have been touted as essential technologies of the future [67]. At the same time, there is largely a lack of common understanding and common standards governing these technologies [68]. New standards in the IT and technology realm have started to emerge. For instance, AI concepts and terminology (ISO/IEC 22989) or blockchain-related standards [20]. Most of the new standards for new technologies are at the early stage of development, and it will probably take time until these standards are finalized and adopted. In the meantime, the critical question for practitioners is what to do at the present time, when there is a lack of standards in this domain.

- **Q5:** *How does the absence of standards for new technologies impact the adoption of these technologies and the development of interorganizational relationships? What are the economic and sustainability consequences of the absence of these standards?*

Quality Infrastructures (discussed in Section 2) also provide a platform for the development of interorganizational relationships (nationally and internationally). Quality infrastructure refers to a system of institutions that determine that a product or a firm comply with the requirements of a standard (in the form of a certification). The institutions include accreditation and certification bodies, which are often overseen by national governments, typically through national standardization bodies—ANSI in the US, CENCENELEC in the EU. These bodies also cooperate to harmonize standards at the national level and align national standards with international standards.

In the last two decades, national governments started to work more strategically to align standards and conformity assessment with national competitive priorities [1]. Several governments have used standardization as a mechanism to develop the competitiveness of firms. For instance, the Singapore government developed Industry 4.0 standards to enable the transformation of key industrial sectors—and a similar approach was taken in Germany by the Standardization Council Industry 4.0 [26]. In the Netherlands, the Smart Industry Standardization Platform was created to enable cooperation in the industry and the development of new standards [68]. Costa Rica uses standards to transform coffee production into a low-carbon industry through the NAMA Café project [69]. In Canada, the Standards Council of Canada (SCC) supports the development of superclusters. Another example of governmental involvement in the sector development is in the area of medical cannabis [19]. For instance, in Canada, SCC recognized that the industry is not regulated and had struggled with the quality and consistency of the produce. Standardization helped to address these issues and created a competitive advantage for local firms internationally.

Investments in national conformity assessment and standardization infrastructures assist in the diffusion of knowledge for the benefit of multiple stakeholders [23]. Firms can gain multiple benefits from a collaboration with governments in their innovation efforts—individually or as part of a cluster development [70]. This raises many questions, such as: How should firms collaborate in a cluster to develop a competitive advantage for the industry sector? What is the impact of national cluster development on the internalization of the firms involved? Do firms develop faster? Ultimately, these questions lead to an overarching question:

- **Q6:** *In what ways does a national quality infrastructure assist in the development of industry clusters and their eco-systems? What is the impact of quality infrastructure on the performance of participating firms and industry clusters?*

The main objective of a national quality infrastructure is to reduce the transactional cost of international trade. Mutual Recognition Agreements (MRAs), for instance, streamline international trade by mutual recognition of conformity assessment results [36]. Yet research into the impact of MRA and other mechanisms in conformity assessment infrastructures is underdeveloped in the management literature (with few exceptions, such as [8]). Supply chains are significantly impacted by these agreements, from delays due to customs inspections and lack of interoperability in the shipping industry, as reported in [71]. Trade wars between countries might affect the speed of inspection beyond acceptable levels and present significant risks for firms. More research is needed to understand the impact of MRAs on supply chain management and especially optimize supply chains in view of the opportunities and risks that are associated with MRAs. These investigations might look into innovative solutions in this space. For instance, the integration of customs inspection at the warehouse in the exporting country might significantly reduce the risk for perishable goods.

- **Q7:** *How should supply chains be designed to maximize the benefits from, and minimize the risks associated with, Mutual Recognition Agreements (MRAs) and other restrictions in international trade?*

4.3. Accountability

Standards, certifications, third-party audits and codes of conduct are instruments to manage risk and accountability in firms and their supply chains [72]. These accountability instruments are employed to ensure H&S, social accountability, quality and many other aspects of management. Despite the increased focus on, and scrutiny of, the credibility of accountability instruments [28], cases of malpractice and deception continue to hamper their credibility. For instance, product testing problems have been highlighted in numerous cases: firms used improper or manipulated testing methods (i.e., VW and Dieselgate), claimed accredited testing inspections and misled customers by using logos of accredited labs [36], engaged in brainwashing by claiming unverifiable product characteristics (i.e., “all natural claims”). The European Environmental Citizens Organization for Standardization (ECOS) portrays the underlying challenges in testing with strongly formulated statements such as “do not always reflect the real-life operation of products”, “exploit regulatory loophole’s” and “allow product manufacturers to freely interpret regulatory provisions in standards” [73]. Similar messages emerge through expert discussions of the testing scandals. For instance, in relation to several meat traceability scandals, experts concluded that “methods for testing meat are only just developing” and that “one of the major changes in the move towards standardization—is that tests are no longer undertaken simply for elements that are expected to be present [27]”. Combined with auditing scandals (e.g., the H&S audit was conducted a few weeks before the Rana Plaza disaster [74]), standards, certifications, third-party audits and codes of conduct still present a significant high-risk area for managers.

- **Q8:** *How is testing and audit deception revealed? What are the economic and financial consequences of deception in testing and auditing? How do standards assist in minimizing the risk of deception in testing and auditing?*

New standards development projects are increasingly focused on interlinking the standards with broader societal aims, such as with UN’s Sustainable Development Goals (SDGs). Various initiatives (for instance, as part of ISO) now develop new standards and demonstrate their impact on SDGs [75,76]. For instance, the ISO/TS 34700 technical specification for animal welfare management or the ISO 34101 series on sustainable and traceable cocoa. Likewise, recent standards development projects tend to broaden their scope, in line with the circular economy principles. For instance, the technical committees ISO/TC 322 and ISO/TC 323 focus on sustainable finance and the circular economy. Standards such as ISO 14007 (cost-benefits analysis) and ISO 14008 (climate finance) aim to “help organizations determine the monetary value of their environmental impact and investment strategies” [77]. There is also a growth in chain of custody standards, which push firms to extend the scope of their accountability in the supply chains [44]. The examples above demonstrate that standards are increasingly pushing firms to reconsider the scope of their accountability.

- **Q9:** *How does the broadening scope of standards impact how firms approach accountability? What benefits do firms gain from broadening the scope of their accountability?*

4.4. Linkages between the Three Areas of the Research Framework

So far, the paper considered the three areas in the research framework individually and hinted at the interlinkages between these areas. In reality, the three areas are inevitably interconnected, and this section discusses the most important connections in the framework. First, the interactions between *intrafirm development* and *interorganizational relationships* are discussed.

Section 4.2 raised questions about the role of standards in the development of interorganizational collaboration as well as, for instance, whether current modes of standardization are suitable for the development of new standards. Section 4.1 discussed a related question—under what circumstances should a firm get involved in standards development? (Question 3). However, so far, the paper has not addressed an important consequence of a firm’s participation in interorganizational collaboration and in standards development: that it also enhances a firm’s standards’ absorptive capability and

impacts the intrafirm development. Indeed, firms seem to gain a competitive advantage by being part of standardization development processes [63]. For instance, firms gain advantage by closely working with national standardization bodies to ensure that their products meet the conformity assessment requirements. Being part of the standards development also ensures that firms are part of the latest development in standardization—providing them with an insight into their operational activities. Such insights can lead to improved new product development [2] or the identification of new market opportunities [78]. Therefore, a stream of research should focus on the role of participation in standards development and its value for a firm, especially because the economic and financial consequences of such participation are not clearly determined in the literature [63].

- **Q10:** *How does a firm's participation in standards development assist its development?*

Section 4.3 is largely focused on the deception, risk management and broadening of the scope of standards. However, standards and other accountability instruments also present opportunities for firms to distinguish themselves and to signal their credibility. The deception in testing and auditing has been addressed by various new standards. The underlying feature of these standards is to provide objective performance measurement methods. For instance, ISO 14034 (Environmental management—Environmental technology verification) aims to help companies that are developing innovative environmental technologies to verify their environmental gains. By using this standard, firms provide “independent verification of the performance of new environmental technologies and allows developers to demonstrate performance of their technology to the market” [79]. ISO 23828 stipulates the measurement of energy consumption in hydrogen fuel-cell vehicles. In the shipping industry, ISO/TC 8 has developed standards for measuring energy usage and efficiency, as well as standards to help ship operators select hull paints that help to reduce hull drag, which can itself improve energy efficiency [80]. Deception in food labelling has been addressed, for instance, by ISO/TS 19657 (Definitions and technical criteria for food ingredients to be considered as natural published in 2017), which provides a clear terminology for food labelling. Likewise, if an organization is aiming to broaden the scope of accountability (i.e., chain of custody, linking their performance to SDGs), there is a need for credible instruments. Standards such as ISO 14007 (cost-benefits analysis) and ISO 14008 (climate finance) are looking to provide such instruments.

These examples demonstrate the potential value of standards in the verification of the impacts of firms' products and activities. Swann [23] argues that “standards that support accurate measurement can also support innovation” and that “the innovator's incentives to produce products with particular characteristics hinged on the ability of the innovator and the customer to measure (and verify) those characteristics.” To what extent will firms turn to standards to ensure the credibility of their products? This brings us to the next research question:

- **Q11:** *What is the role of standards in enhancing the credibility of products (i.e., verification of the impact of new technologies) and operations of a firm (i.e., verification of green investments)? What benefits do firms get from using standards that verify their performance?*

Table 2 provides an overview of the research questions and references to studies that have addressed these questions (or parts thereof). The references are not meant to offer a complete overview of the existing studies. Rather, they provide a guidance for researchers for further conceptual development of individual research questions.

Table 2. Overview of the research questions and references to key studies.

Research Questions	References to Existing Studies
Q1. How do firms incorporate standards into their strategic decision-making and develop absorptive capacity through standards and standardization? What is the relationship between the absorptive capacity developed through standards and standardization and a firm's performance? How do such strategies differ for various aspects of sustainability?	[28,40,54,81,82]
Q2. How do firms incorporate standards in new product development (NPD)? How does the management of standardization impact NPD performance, particularly with regard to a reduced time-to-market, or a transition from prototyping to production or product acceptance? What are the economic and sustainability consequences of the management of standardization (related to NPD) on downstream operation management activities?	[1,2,37]
Q3. Under what circumstances and how should a firm engage in the development of standards? What resources, knowledge and relationships are required to participate in the development of standards? What is the optimal level of investment into the standardization efforts?	[22,63]
Q4. How do and how should firms and other stakeholders collaborate in the development of interorganizational relationships through standardization? Are current modes of standardization suitable for the development of new standards?	[22,23,64]
Q5. How does the absence of standards for new technologies impact the adoption of these technologies and the development of interorganizational relationships? What are the economic and sustainability consequences of the absence of these standards?	[28,66]
Q6. In what ways does a national quality infrastructure assist in the development of industry clusters and their eco-systems? What is the impact of quality infrastructure on the performance of participating firms and industry clusters?	[23,70]
Q7. How should supply chains be designed to maximize the benefits from, and minimize the risks associated with, Mutual Recognition Agreements (MRAs) and other restrictions in international trade?	[8,71]
Q8. How is testing and audit deception revealed? What are the economic and financial consequences of deception in testing and auditing? How do standards assist in minimizing the risk of deception in testing and auditing?	[72,83]
Q9. How does the broadening scope of standards impact how firms approach accountability? What benefits do firms gain from broadening the scope of their accountability?	[52,58,84]
Q10. How does a firm's participation in standards development assist its development?	[2,43,63]
Q11. What is the role of standards in enhancing the credibility of products (i.e., verification of the impact of new technologies) and operations of a firm (i.e., verification of green investments)? What benefits do firm get from using standards that verify their performance?	[23,85]

5. Limitations and Future Research

The scope of the paper is limited to strategically important processes and decisions related to the management of standardization. The paper does not focus on lower-level tactical management topics. For instance, the research framework does not include topics such as the particulars of the adoption of standards in the daily operational routines in a firm. There are multiple papers that cover this topic in the context of ISO 9001 [54,86] or in the context of multiple standards [52]. Therefore, further work is needed to consider how the management of standardization at the strategic level (developed in this paper) translates into the operations management level.

A further limitation of the paper is a lack of geopolitical perspective on standardization. Standards are used by governments to impact trade; i.e., Breznitz and Murphree [25] report how China is influencing trade for their export processors by setting new standards and challenging existing standards and their royalty rates. Likewise, China's Belt and Road Initiative (BRI) provides an example how standards are being developed and used to support international infrastructural projects under the control of the Chinese government [87]. Standardization battles at the governmental level also impact key technologies (e.g., telecommunication and 5G), and national governments have been implementing national standardization strategies (e.g., US, China, Canada, the Netherlands, the EU) that have ramifications for firms and their supply chains. Further research should focus at how governmental actions impact the management of standardization—the readers are referred to papers by van de Kaa and de Vries [9] and Wiegmann, de Vries and Blind [22] for more insights about standardization from a geopolitical perspective.

The paper also develops a generic understanding of the management of standardization. Further work might explore how this framework can be applied and how the research questions can be modified in specific sustainability contexts—for example carbon management, CSR reporting [88], supply chain reporting [89], ESG reporting [90] or in the context of particular standards such as the UN Global Compact.

The research questions from this paper could be developed from multiple theoretical perspectives (a summary of the theoretical perspectives is provided in Tuczec, Castka and Wakolbinger [49]). In the context of the research framework presented in this paper, RBV, dynamic capabilities and absorptive capacity theories would be useful in addressing the intrafirm development. Strategic action field theory [22,91] could assist with the development of interorganizational relationship development research questions. Organizational legitimacy and institutional theory [92] would align with the topics related to accountability. Further research can develop the theoretical underpinnings of the questions that are discussed in this paper.

6. Conclusions

This paper proposes a framework that serves as a basis to advance knowledge in the management of standardization. The framework is organized in three areas: intrafirm development, interorganizational relationships and accountability. The paper argues that the areas of intrafirm development, interorganizational relationships and accountability are fundamental pillars of the management of standardization and that developing the future research in these areas would align the scholarly work with the complex reality of standards and standardization that practitioners must handle. It is a hope of the author that this paper will encourage scholars in the field to address standardization from a strategic perspective, to develop an understanding of the complex nature of the management of standardization and to trace its economic and sustainability consequences—thereby contributing to the improvement of decision-making processes for the management of standardization in firms and ultimately to the principles of sustainable development.

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