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STANDARDIZATION: RESEARCH TRENDS, CURRENT DEBATES, AND INTERDISCIPLINARITY

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Standards are ubiquitous in contemporary society and play a clear role in technological development, organizational functioning, and business success. Standards are very diverse and often boundary crossing in terms of stakeholders and impact, but are such diversity and range reflected by academic studies? We take stock of standardization research over the past decade, considering the full interdisciplinary breadth of this growing field. We use bibliometrics and network analysis to map emergent trends, and conduct an in-depth review of the literature. In doing so, we find that management science, along with economics, is at the core of work on standardization, bridging academic disciplines, and leading theoretical development. Technical disciplines, such as engineering and computer science, supply the largest body of literature, but rarely cross disciplinary boundaries and remain rather isolated. Building on our review, we discuss current debates and controversies and distill four interpretative perspectives on the recent and current developments of standardization research. Finally, we propose a research agenda for standardization research and practice for the years to come.

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Accepted by Johanna Mair

Standards and standardization are ubiquitous and long-held features of our society (Brunsson, Rasche & Seidl, 2012; Chavinskaia & Loconto, 2020; Timmermans & Epstein, 2010). Almost any firm uses standards, for its products or services, processes or management systems, and many firms are involved in setting and developing these standards. Standards have been widely recognized by firms, policymakers, and academics alike as playing a pivotal role in key fields of economic, social, and technological development (e.g., Büthe & Mattli, 2011; Geels, 2004; Timmermans & Epstein, 2010), such as the energy transition (European Commission, 2022), the development of artificial intelligence (European Commission, 2021; NIST, 2019), and the emergence of the platform economy (Jacobides, Cennamo & Gawer, 2024; Shipilov & Gawer, 2020).

The ubiquity of standards in contemporary business and society is reflected by their relevance across organizational and governance settings. Managerial choices concerning standardization can affect a firm's competitive position and its overall success in the business environment (e.g., Bresnahan & Greenstein, 1999; Ranganathan, Ghosh & Rosenkopf, 2018; Shapiro & Varian, 1999; Teece, 2018; Weitzel, Beimborn & König, 2006). Success in the race for competitive advantage often depends on industry-level adoption of standards that are aligned with firm-level technological development and product innovation (e.g., Bekkers, Duysters & Verspagen, 2002; Utterback & Abernathy, 1975; Wiegmann, 2019). Within a firm, implementing standards is subject to organizational dynamics that can markedly affect work practices and employees' tasks and coordination (e.g., Boiral, 2007; Brunsson et al., 2012; Sandholtz, 2012). Beyond business, standards have far-reaching implications for corporate governance and policymaking that can, in turn, affect patterns of strategic decision-making and organizational functioning. Standardization is likewise a core topic on the business and political agendas of many governments and international institutions, which define, in turn, coercive rules for businesses, stakeholders, and society.[1]

Thus, it is not surprising that the importance of standards and standardization is recognized in the widespread attention that they have been getting in research across academic disciplines such as economics and management (e.g., Leiponen, 2008; Ranganathan et al., 2018; Teece, 2018), law, regulation, and policy (e.g., Büthe & Mattli, 2011; Delimatsis, 2015; Kanevskaia, 2023; Lemley, 2002), ethics and sustainability (e.g., Dyck & Silvestre, 2019; Henriksen, 2015; Narula et al., 2021), sociology (e.g., Slager, Gond & Moon, 2012; Tamm Hallström & Boström, 2010; Timmermans & Epstein, 2010), and IT and engineering (e.g., Lu, Wang, Niyato, Kim & Han, 2016; Shafi et al., 2017; Sheng, Yang, Yu, Vasilakos, McCann & Leung, 2013). Attention across academic disciplines provides a strong impetus for the development of standardization as a burgeoning research field across diversified yet interconnected topics. Simultaneously, this interdisciplinary breadth may hamper consistency because standards are often defined and studied differently by different disciplines.

However, despite the longstanding acknowledgment that standards drive organizational functioning and advantage (see the discussion on integration and differentiation in March & Simons, 1958; on the connections between social and economic organization in Weber, 1964; and on the stages of development of the innovative production process in Utterback & Abernathy, 1975), a thorough systematization of standards for management theory and beyond is still missing and largely needed. Previous reviews (e.g., Choi, Lee & Sung, 2011; David & Greenstein, 1990; Narayanan & Chen, 2012; Shin, Kim & Hwang, 2015; Timmermans & Epstein, 2010) showcase how research on standardization permeates multiple academic disciplines, but explore the different domains in a rather isolated fashion. In this paper, we ask: "What is the state of the art of this interdisciplinary literature on standardization?" In answering this question, our review shows that technical disciplines, such as IT and engineering, produce the largest share of standardization literature, but tend to be more isolated from other academic disciplines. On the contrary, social science disciplines, such as economics and management, tend to fuel interdisciplinarity and play a key role in orchestrating the theoretical integration and advancement of the field.[2]

[1] Policy documents on standardization and standards are issued, for example, by the U.S. administration (The White House, 2023), the European Commission (2022), and the governments of China (The State Council of the People's Republic of China, 2021) and India (Government of India, 2018).

[2] In particular, we find that around 70% of the reviewed literature focuses on the content of the standards, with findings that are often industry specific. Only 30% of the reviewed literature examines standardization from a theoretical and conceptual standpoint.

Overall, we found in the literature a tension between "centripetal" dynamics, pushed mainly by management scholarship, which call for shared definitions and topics, and "centrifugal" dynamics, mainly pulled by technical disciplines, which lead to increasing differentiation between academic languages and disciplines on the topic (e.g., Lakatos, 1978). Specifically, our review summarizes and discusses two key trends emerging from the literature: (1) standardization research is scattered across disciplines and topics, but (2) it also represents an emerging area of research calling for further theoretical consistency and integration. In our work, we add to this effort by bringing shared definitions, conceptual clarity, discussion of key trends connecting topics and academic disciplines, and a broader research agenda for the years to come.

We offer three contributions to theory and research on standardization. First, we systematize the scattered conceptual foundations of the academic disciplines' views on standards and derive discipline-specific definitions that can underlie future interdisciplinary research. Building on this, we propose an overarching definition of "standardization" as *the activity of establishing and recording a limited set of solutions to actual or potential coordination problems, expecting that these solutions will be repeatedly or continuously used, over time, by a substantial number of the parties for whom they are meant* (combining, among others, de Vries, 1997; Memon, Wagner, Pedersen, Aysha Beevi & Hansen, 2014; Slager et al., 2012; Teece, 2018). Second, our overview of existing intersections between academic disciplines and topics in research shows the broad variety of aspects that have been covered. This includes standards at the intersection between corporate strategy and intellectual property, their role in facilitating renewable energy transitions, the ethical dimensions of standards—for example, in agricultural value chains and healthcare—and how they underlie technological development in areas like telecommunications, automation, and privacy and cybersecurity. Through further bibliometrics and network analysis, we identify four theory-driven perspectives to reveal key emerging trends in the field (see the "Interpretative perspectives on standardization research" section of the paper, below). Third, the tension between interdisciplinary malleability and cross-topic fertility, on the one hand, and the need for overarching theoretical consistency, on the other hand, make the standardization research field appealing to scholars across management subfields and call for future research that bridges theoretical development and practical relevance. We derive an agenda for future research, with a focus on how management scholars can contribute to achieving this goal.

METHODS FOR REVIEW AND ANALYSIS OF THE LITERATURE

This paper's underpinnings are based on a systematic review of the standardization literature in management and across adjacent disciplines. To understand how research on standardization has evolved in the past 10 years, we use bibliometric (Diodato, 1994; Pritchard, 1969) and network visualization methods (Jacomy, Venturini, Heymann & Bastian, 2014) to analyze a dataset of research papers related to standards and standardization from 2012 to 2021. We deem this 10-year timespan suitable to give a comprehensive picture of the recent developments in the field and provide enough novelty from similar previous reviews (including Narayanan & Chen, 2012; Timmermans & Epstein, 2010).[3] The diverse nature of standardization research does not cater well to a journal-based or classification-based type of search. Instead, we used a keyword search approach across the whole body of academic publications. In this section, we provide details on the three-step method (Chen, Mehra, Tasselli & Borgatti, 2022) that we followed to select the relevant literature. In the spirit of open science, we provide information about the coding of papers (see Appendix A in Additional Materials) and detailed statistics (Appendix F and Appendix G in Additional Materials). We also make the full dataset publicly available.

Step 1: Collecting and Pooling the Set of Papers

We created the dataset that guides our review of the literature by merging the results of six keyword strings (one per academic discipline) from two of the most popular academic search engines, ISI Web of

[3] This is not the first study reviewing the standardization literature (e.g., David & Greenstein, 1990; Shin et al., 2015; Timmermans & Epstein, 2010; Wiegmann et al., 2017), but, to the best of our knowledge, it is the first systematic attempt to summarize and interpret the interdisciplinary richness of this literature. Among previous works of review, for example, Choi et al. (2011) only focused on the relation between standardization and innovation; Narayanan and Chen (2012) mapped research in the field of standardization, but limited their scope mostly to the management literature; and de Vries (2015) mapped the scientific disciplines to study standardization, but mentioned only a few exemplificative topics.

Knowledge and Scopus, with the forward citations of seven literature reviews in the field of standardization (Choi et al., 2011; David & Greenstein, 1990; Murmann & Frenken, 2006; Narayanan & Chen, 2012; Shin et al., 2015; Timmermans & Epstein, 2010; Wiegmann, de Vries & Blind, 2017). The seven literature reviews were used as a starting point to define the keywords. Following this broad and preliminary screening procedure, 6,900 academic sources were gathered. An ex ante skimming excluded search engine categories such as *medical research*, *veterinary*, *linguistics*, and *statistics*. Medical research was excluded because of the huge volume of publications using the terms "standard" and "standardization" for a different purpose (the term often refers to "standard" treatments and procedures). Similarly, statistical research was excluded because unrelated constructs such as "standard deviation" and "standard error" still resulted as an output of the search. Other areas that were considered out of scope include, for example, "standard of review," "standard of objectivity," or "standard of civilization." The research team conducted careful checks to ensure that only papers unrelated to standardization were excluded from this step of the literature selection. Consistent with the time span of our study design, both components (keyword strings and forward citations) included papers that were published in the period 2012–2021.

Step 2: Definition of Academic Disciplines and Topics

We used a set of 100 standardization papers that were randomly selected from our full dataset as a trial, and had three independent coders (each looking at all 100 papers) identify the main categories, where relevant across multiple dimensions. Based on the outcomes of this trial, as a research team, we collectively decided on a twofold coding—based on academic disciplines and topics (see below)—with a maximum of two academic disciplines and two topics for each paper. After comparing the three trials, we agreed on six broad and comprehensive academic disciplines—(1) IT/engineering, (2) law/regulation/policy, (3) economics/management, (4) sociology, (5) ethics/sustainability, (6) other sciences—and a preliminary list of 40 topics. While coding the full dataset, the number of topics grew to 56, both by adding and grouping some of them.

Step 3: Selection and Categorization of Papers

To make an in-depth topic analysis of papers feasible with our given set of resources, we narrowed the initial set of 6,900 sources down to 1,313 papers. We first filtered the sources by journal articles, data papers, and reviews (thus excluding books, papers from conference proceedings, gray literature, and other unrelated items), resulting in a first full dataset of 4,145 articles. Secondly, because this number of papers was still unmanageable to provide a theory-driven review of the current literature, we selected the most impactful papers by setting citation thresholds, which allowed us to identify approximately the top 150 most impactful papers per year. To avoid citation biases in setting these thresholds, we accounted for the fact that more recent papers had fewer opportunities to receive citations (see Table 1).

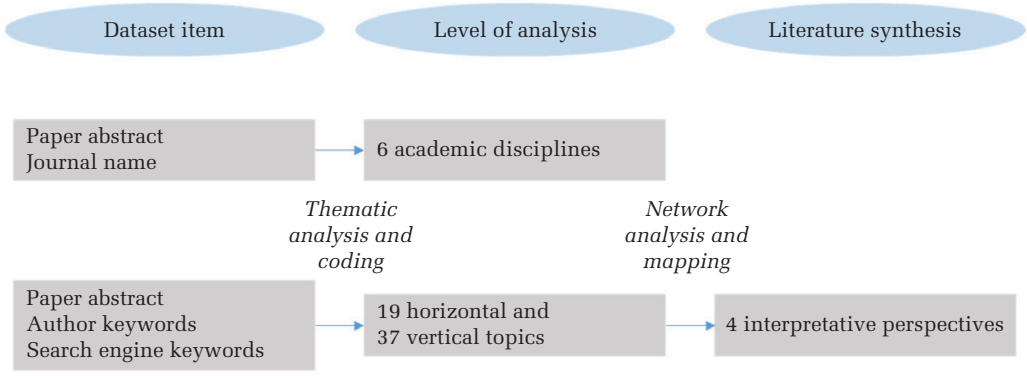
To guarantee intercoder reliability, three authors separately coded the set. Using the adopted categorization scheme, we coded all 1,313 papers that represent the final dataset. To categorize the dataset, we referred to specific items of each paper that were provided by the search engines. We summarized the information coming from these items into the academic disciplines and the topics (see Figure 1) via open coding (Corbin & Strauss, 1990). In essence, we initially labeled papers with topics according to (search engine and authors) keywords; then, based on the analysis of the papers' abstracts, we grouped them based on the presence of conceptual and linguistic overlaps between topics (e.g., policies on "greenhouse gases" and "CO_2 emissions" were both labeled as "energy policy").

The result of this final coding allowed us to categorize the paper based on two key dimensions: *academic disciplines* (e.g., *sociology* or *economics/management*) for a higher-level overview, and *topics* (e.g., *standards*

TABLE 1
Summary of the Dataset Composition for High-Impact Papers

Year	Citation Threshold	No. of Selected Papers
2012	≥ 9	142
2013	≥ 11	143
2014	≥ 11	141
2015	≥ 8	152
2016	≥ 9	147
2017	≥ 7	146
2018	≥ 6	162
2019	≥ 5	145
2020	≥ 1	156
2021	≥ 0	221
Total categorized set		1,555
Excluding duplicates and out-of-scope		1,313

FIGURE 1
Process of Coding and Analysis of the Dataset



competition or *impact assessment*) for deeper content. As mentioned above, we distinguished a total of six relevant academic disciplines and 56 topics. To simplify this coding effort, each paper was coded with up to two academic disciplines and up to two topics, allowing us to study the co-occurrence between disciplines and between topics using bibliometric network analysis techniques for visualization (e.g., Pritchard, 1969; Wasserman & Faust, 1994). The resulting network diagrams followed a network algorithm, ForceAtlas2, that arranges nodes (in our case, academic disciplines or topics) based on the strength of their ties (i.e., number of co-occurrences in papers). The larger the size of a node, the more papers form the corresponding discipline or topic. The closer the two nodes are, the more papers are coded with the two connected disciplines or topics, and the thicker the corresponding network tie is plotted in the graphs (Jacomy et al., 2014). More details on our dataset creation and the selection criteria can be found in Appendix A (Additional Materials), where we describe our review method using the PRISMA protocol and measure its quality in terms of precision and recall, for which we respectively reach a level of 87% and of 85%. Appendix B provides further details on the software and algorithm we used for the network analysis. We also recognize our dataset's limitations in Appendix C.

FOUNDATIONS ACROSS ACADEMIC DISCIPLINES

Standardization is an increasingly complex and intertwined field of research, as suggested by the wide array of disciplines and topics involved. One complexity stands in the varying interpretations that different academic disciplines may have, starting from the basic definitions of the terms "standard" and "standardization." To set a common background for the review of the literature, we delve into foundational and highly cited research articles from each discipline to describe the different knowledge domains and definitions. In Table 2, more precisely, we refer to "assumptions" as the overarching issues that each discipline covers for standardization, "knowledge created" as the main (theoretical) contributions of the cited papers, and "portability" as the extent to which firms and practitioners can benefit from such knowledge. We gathered an extensive array of definitions present in the literature to formulate a complete definition of standardization for management research. The full definitions for each academic discipline and the processes behind their formulation are explained in Appendix D (Additional Materials).

Economics/Management

Building on early foundations in organizational research that see standards as the process of homogenization of economic activities in a given industry (e.g., March & Simons, 1958), "standards" are currently defined as interface specifications and corporate practices that function as governance mechanisms within innovation ecosystems (e.g., Brunsson et al., 2012; Gao, Yu & Lyytinen, 2014; Haack, Schoeneborn & Wickert, 2012; Hinings, Gegenhuber & Greenwood, 2018; Teece, 2018). Thus, it is no surprise that the role of standards as key components of (larger) cross-industry technological architectures is broadly emphasized both in economics (Fontagné, Orefice, Piermartini & Rocha, 2015; Simcoe, 2012) and management (Cusumano, Kahl & Suarez, 2014; Dattée, Alexy & Autio, 2018) scholarship. Examples of these

TABLE 2
Summary of Assumptions, Knowledge Created, and Portability of the 10 Most Impactful Papers per Academic Discipline

Academic Discipline	Assumptions	Knowledge Created	Portability
Economics/management	Standards are indispensable for industrial transformation and the establishment of new (platform) ecosystems	In the stage of uncertainty previous to the establishment of a technology, the standardization process determines how (rapidly) society develops, selects, and adopts them, and industries evolve	Standards development organizations (SDOs) and firms play the "ecosystem" game to prioritize their interests, sometimes at the cost of slower technological progress or unintended societal consequences
Law/regulation/policy	Standards are fundamental to quantify the impact of policies (governmental and institutional). Especially in climate-related issues (renewable energies and flood-risk management), cybersecurity, and education	The inclusion of standardization in policies is mostly country specific. In this regard, the harmonization of governmental policies may be more suitable than establishing global standards (e.g., the European New Approach)	Collaboration between governments as well as with academia, to quantify and legitimate the expected impact of standards
Ethics/sustainability	Agri-food sustainability certifications, labor standards, and living standards all aim at societal benefits but may have unintended consequences	Standards' pervasiveness may hinder competition and authenticity instead of fostering them. This may incentivize ceremonial compliance rather than 'real' implementation	"Informal" stimuli for standards are more fruitful than obligations to implement. SDOs should involve multiple stakeholders, and governments should balance voluntary and mandatory practices
Sociology	Weak stakeholders are underrepresented in standardization processes. This enhances social inequalities instead of reducing them. This can be observed in very diverse fields, such as accounting, genetics, port management, and journalism	Standards are sociotechnical solutions. Even technical-intensive solutions require diverse perspectives and representation. Root causes of inequalities include wrong cultural processes, excessive governmental intervention driven by political interest, and ignorance of local and country-specific characteristics	Governments should stimulate transparent and inclusive standardization processes
IT/engineering	New generations of telecommunications, smart grids, and other technical-intensive sectors benefit from a lot of standardization activities by private firms	Technical standardization is driven by market in earlier stages (development, competition), institutions and formal SDOs intervene at later stages	Private and public actors should collaborate in standardization even in early stages, starting from the ideation and development of technologies
Other sciences	This diverse set of papers have in common that conformity assessment (particularly measurement) is part of them	Standards in fundamental sciences such as biology, physics and chemistry are essential part of the standardization process of global (interdisciplinary) challenges, such as the energy transition and world hunger	These pre-normative findings are relevant for technical research communities and scientists. Their portability should be extended to other complementary communities through normative and "horizontal" research

architectures include platforms (Gawer & Cusumano, 2014) and dominant designs (Suarez, Grodal & Gotsopoulos, 2015), where standards are considered fundamental boundary resources (Fontagné et al., 2015). This research emphasizes both the positive economic effects of standards—for example, in terms of enabling and coordination mechanisms and drivers of economies of scale (Blind, 2004; Gallagher, 2012; Ranganathan et al., 2018; Swann, 2010)—and their possible downsides, ranging from path dependence to

risk of lock-in (David, 2001; Dosi & Nelson, 2013; Puffert, 2000), which may lead to both a lower availability of technologies and to asymmetric industry structures and monopolies (Blind, 2004; Heinrich, 2014; Swann, 2010). Economic research is particularly interested in the macro-level consequence of these effects, looking at the relationships between standardization and society-level outcomes such as innovation (Baron, Ménière & Pohlmann, 2014), economic growth (Blind & Jungmittag, 2008; Zoo, de Vries & Lee, 2017), labor productivity (Acemoglu, Gancia & Zilibotti, 2012), technological life-cycles (Blind & Gauch, 2009), and global trade (Fontagné et al., 2015; WTO, 2023).

Law/Regulation/Policy

In the legal field, "standards" are seen as rules developed by governments and private actors to reduce information asymmetry in transactions, and give normative certainty to business and civil society. As opposed to the early blurred understanding of them as soft laws (Busch, 2011; Kerwer, 2005; Kirton & Trebilcock, 2004) and self-regulatory tools (Meyer, 2012), standards are increasingly mentioned as documents, approved by an official body, that support legislations and can be seen as co-regulation tools. This applies, for example, to data privacy standards (Greenleaf, 2012; Kamara, 2017), and to international standards adopted in the EU for customer safety and market transparency (Eliantonio & Cauffman, 2003; Kanevskaia, 2023). Recent juridical sources explore the debate comparing feed-in tariffs to renewable portfolio standards (RPSs) (Alizada, 2018; Dong, 2012; Sun & Nie, 2015). Foundational to this discipline is also the study of the governance of standards in their function as providing criteria and test methods, signaling quality and performance. Examples of this include the electric vehicles industry (Das, Rahman, Li & Tan, 2020; Li, Zhan, de Jong & Lukszo, 2016), the certification of bio-based products (Ladu & Blind, 2017; Wang et al., 2020), and energy labels (de Vries, 2015; Schleich, Durand & Brugger, 2021).

Ethics/Sustainability

The foundations of standardization research in this group of disciplines trace back to seminal work on the behavioral and environmental underpinnings of standards (Baumol & Oates, 1971; Hoffman, 1999; Unruh, 2000), and consider "standards" as documents providing the basis for certification schemes to assess the quality of a firm's performance and behavior (e.g., Gilbert, Rasche & Waddock, 2011; Higgins & Richards, 2019) and help institutions achieve sustainable, long-term goals (Wijen, 2014). The most impactful recent research in these disciplines defines standards as norms and coordination mechanisms for multiple stakeholders (Ponte & Cheyns, 2013). Debates revolve around their mandatory (Davies & Vadlamannati, 2013; Elton-Chalcraft, Lander, Revell, Warner & Whitworth, 2017) or voluntary (Christensen, Morsing & Thyssen, 2017; von Geibler, 2013) enforcement. In this context, emphasis is given to the ethical goals behind standards' adoption, including the extent to which firms legitimately believe in the ethics' requirements and implications of the standards they adopt, or instead follow the path of decoupling (Mercado, Hjortsø & Honig, 2018; Wijen, 2014). In terms of business settings, this research mainly discusses standardization controversies around certification schemes in international trade (Boström, Jönsson, Lockie, Mol & Oosterveer, 2015) and agricultural commodities in global value chains (Bitzer & Bijman, 2014; Bitzer & Glasbergen, 2015; Oya, Schaefer & Skalidou, 2018).

Sociology

Building on the idea that standards are "a source of authority and a level of achievement" (Timmermans & Epstein, 2010: 70), sociologists define "standards" as measurements or technical rules built by individuals, groups, and institutions that reproduce values, beliefs, and assumptions affirmed in a society (e.g., Ritzer, 1993; Williams, 1985). In sociology, the discussion around standards builds on the assumption that shared behaviors are institutionalized in society through the structuration process by which they are first adopted and later certified as normative phenomena (e.g., Berends, van Burg & van Raaij, 2011; Giddens, 1984). Key issues for sociology scholars include the underrepresentation of stakeholders in the process of standards' development (Bennett & College, 2017; Carse & Lewis, 2017; Schweber, 2013), and acknowledging social inequalities connected to the representation—in the dominant standards—only of the most influential social groups (Lamont, Beljean & Clair, 2014; Panofsky & Bliss, 2017). In this discipline, the view of standardization oscillates between research that sees it as a tool for empowerment (e.g., Dietz, Grabs & Chong, 2021; Fine, 2017), and research that sees it as a mechanism leading to market inequalities (e.g., Raynolds, 2002; Reinecke, Manning & von Hagen, 2012), dehumanization, and even racial inequalities (Hirschman & Bosk, 2020; Timmermans &

Epstein, 2010). Altogether, sociologists look at standards as norms and policies that influence the cultural processes and classifications of society (e.g., Carse & Lewis, 2017; Fenech, Giugni & Bown, 2012; Lamont et al., 2014; Schweber, 2013).

IT/Engineering

From an IT perspective, standards ensure interoperability, cybersecurity and performance measurement of technological solutions (combining Festag, 2015; Huovila, Bosch & Airaksinen, 2019; Keoh, Kumar & Tschofenig, 2014; Trappey, Trappey, Govindarajan, Chuang & Sun, 2017; Trappey, Trappey, Govindarajan, Sun & Chuang, 2016). The foundations of the engineering literature consist of two main types of publications. The first entails high-level reviews and surveys of the technical architectures underlying new disruptive technologies, describing the main protocols, requirements, and fields of application. Case examples include 5G (Shafi et al., 2017), the Internet of Things (IoT) (Keoh et al., 2014; Gazis, 2017; Sheng et al., 2013), unmanned aerials vehicles (Fotouhi et al., 2019), wireless charging technologies (Lu et al., 2016), and direct current microgrids (Kumar, Zare & Ghosh, 2017). The second type includes low-level case studies defining specifications of particular types of standards. Examples include the high-efficiency video coding standard (Pourazad, Doutre, Azimi & Nasiopoulos, 2012), optical communications standards (Cailean & Dimian, 2017; Nguyen, Islam, Yamazato & Jang, 2018), and standards on cement composition (Lee & Choi, 2018; Sanjuán & Argiz, 2012). Most of these technical standards are developed in the private sector, either through private companies (e.g., Chien, Hsu & Chang, 2013; Kim et al., 2016), or private standard-setting organizations (e.g., ETSI, the European Telecommunication Standards Institute) (Abdelkafi, Bekkers, Bolla, Rodriguez-Ascaso & Wetterwald, 2021). Our review shows how this specific discipline has undergone a surge of publications from 2016 onwards, concurrent with the start of bulky research on 5G and IoT standardization, making it today the largest discipline in terms of sources and citations.

Other Sciences

Following the inclusion criteria listed in the previous section, this residual category groups the literature related to exact disciplines such as *healthcare*, *physics, chemistry*, and *biology* (these four being the most recurring in our dataset), but also from *education*, *sports science*, and *psychology*. Similarly to the discipline of *IT/engineering*, standards are mainly defined as communication protocols, data models, and technical specifications that improve scalability, safety, quality assurance, and interoperability (e.g., de Lorenzo & Schmidt, 2018; Erlinghagen, Lichtensteiger & Markard, 2015; Memon et al., 2014; Müller & Arndt, 2012; Naumann, Bielchev, Voropai & Styczynski, 2014). The scientific community emphasizes the aspect of scalability of these standards, because they enable the diffusion of the state of the art of these sciences (Erlinghagen et al., 2015; Fearnley, McGuire, Davies & Twigg, 2012; Mainetti, Patrono, Stefanizzi & Vergallo, 2013; Memon et al., 2014). Scalable practices are important, for instance, for the use of standardized materials (Atinafu, Jin Chang, Kim & Kim, 2020; Kim & Kim, 2012), the calibration of instruments (Papp, Kozma, Lindfors & Gyurcsányi, 2020; Phala, Kumar & Hancke, 2016), and shared methods for performance benchmarking and quality assessment, with notable examples from genetics (Hwang, Kim, Lee & Marcotte, 2015), chemistry (Nam et al., 2020; Stepman et al., 2014), and agricultural sciences (Mainetti et al., 2013; Tinarelli et al., 2021).

A Shared Definition of Standardization for Management Research

Our review shows an extensive inspection of the field of standardization from many topical angles (e.g., academic standards, nutritional standards, technology standards), based on different contextual factors (e.g., interoperability, common criteria, norms, procedures). While this enriches the field with multiple characterizations and industrial applications, scholars tend to characterize the concept for their own field, and the resulting definitions largely diverge. The theoretical consistency and progress of a field, being one of our review's main objectives, calls for an integrative definition of standards and standardization. Therefore, we propose a contextualized definition for management research. Appendix E (Additional Materials) discusses the elements of this definition in more detail.

We look at "standardization" as the activity of establishing and recording a limited set of solutions to actual or potential coordination problems, expecting that these solutions will be repeatedly or continuously used, over time, by a substantial number of the parties for whom they are meant (combining, among others, de Vries, 1997; ISO/IEC, 2004: 4; Memon et al., 2014; Slager et al., 2012; Teece, 2018). The resulting set of solutions, often expressed in the

form of a written document, is the "standard." A systematic review of 30 definitions (five per discipline; see Appendix D in Additional Materials) provides us with many characterizations of standards, such as norms, procedures or methods, technical rules, regulations, interface specifications, corporate practices, documents or communication protocols, and data models. These categorizations show the wide array of forms a standard can assume and the multiple ways it can be interpreted. Given the emphasis in management scholarship on the role of standards and standardization for outcomes, specifically, we suggest that standards are *sets of solutions* (de Vries, 1997) that help address so-called *coordination problems* (Carse & Lewis, 2017; Schweber, 2013; Slager et al., 2012; van den Hurk & Verhoest, 2016). Of note, we remark the appellation of standards not as ideas, thoughts, or proposals, but as being often expressed as "documents" (ISO/IEC, 2004: 4; Trappey et al., 2016), which helps distinguish a formally written standard from a tacitly agreed social norm (Blind & Fenton, 2022; Brunsson et al., 2012).

Along with a shared definition of standardization, we also aim to provide terminological clarity to two key elements of the academic definitions that we gathered: (1) the *functions* of standards, and the (2) different ways through which they can *emerge*. Taken together, these elements represent the foundations of how standardization works when multiple organizations are involved and are of interest when studying the topic.

First, our systematic review of 30 definitions (see Appendix D in Additional Materials) showcases that each academic discipline describes standards as covering different *functions*, often aligned with the most recurring type of standards studied in such disciplines. These functions include assessing social and environmental performance (Ponte & Cheyns, 2013; Reinecke et al., 2012), facilitating control and compliance (Balzarova & Castka, 2012; Slager et al., 2012), being a coordination mechanism within innovation ecosystems (Gao et al., 2014; Teece, 2018), ensuring interoperability, cybersecurity and performance measurement of technological solutions (Festag, 2015; Trappey et al., 2017), and improving scalability, safety, quality assurance, and interoperability (Erlinghagen et al., 2015; Müller & Arndt, 2012).

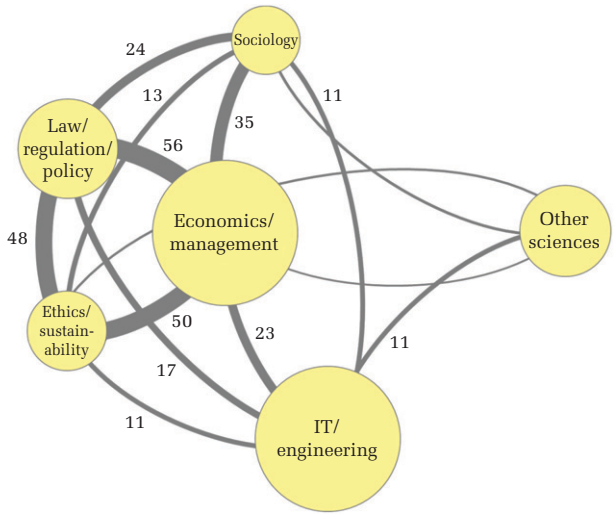
A second important feature complementing the definition of standards is their pattern of *emergence*. Building on David and Greenstein's (1990) seminal work, we argue that a standard may emerge in three ways: through a process of selection by the market, through the development and the following publication of a voluntary standard by a standards development organization (SDO), or through the official promulgation of a standard by a governmental agency. As opposed to "informal" standardization, the second and third modes are often referred to as "formal" standardization, and require the presence of a neutral, non-partisan actor that coordinates the standardization process, whether it is a formal SDO or a governmental agency (Delcamp & Leiponen, 2014; Farrell, 1989). These modes of standardization relate to three ways of achieving coordination between multiple stakeholders: via markets or price, via community or trust, or through hierarchy or authority (Adler, 2001). Until recently, some studies have described the co-participation of private companies and committees in the standardization process (e.g., Farrell & Saloner, 1988; Stango, 2004), but most theories about standardization had largely treated these three coordination mechanisms as isolated phenomena (see Botzem & Dobusch, 2012; Büthe & Mattli, 2010; David & Greenstein, 1990). This co-participation can be observed empirically in many standards battles from the literature (e.g., Cusumano, Mylonadis, Rosenbloom, 1992; Johansson, Kärreman & Foukaki, 2019; van de Kaa & de Vries, 2015; van den Ende, van de Kaa, den Uijl & de Vries, 2012). More recent research has developed theories about "multimode standardization," where the three coordination mechanisms occur concurrently with each other (Wiegmann et al., 2017).

AN INTERDISCIPLINARY SURVEY OF STANDARDIZATION RESEARCH

In the previous section, we delved into the foundations and wrapped the bases of standardization literature defining the theoretical pillars of standalone disciplines. By discussing basic knowledge insights for each of these disciplines, we found that definitions range from the idea that standards are sets of specifications (David & Greenstein, 1990; Gao et al., 2014; Schweber, 2013), to published documents (ISO/IEC, 2004; Trappey et al., 2016), or behavioral rules and norms established in a society (Lamont et al., 2014; Timmermans & Epstein, 2010). Building on this interdisciplinary variety and following the shared definition of standardization that we introduced, in the next section (Key Insights across Disciplines), we describe the key themes and explore the co-occurrence of disciplines and topics that emerge from the multiple sources of our dataset. Studying co-occurrence patterns, we observe the most and the least frequent—that is, the strongest and the weakest

links between topics and disciplines—drawing conclusions on which of them are more central (and represented in the literature) and which are more isolated (and therefore less relevant). To accomplish this survey of the literature, for ease of interpretation, we divided the full list of 56 topics into 19 horizontal and 37 vertical topics. The former includes topics that focus on conceptual and theoretical aspects of standards and standardization, and that could be applied in other standardization contexts (e.g., *legitimacy* or intellectual property rights [*IPR*]); the latter describes the actual content or context of the standards (e.g., *automation* or *healthcare*). A complete list of topics and their description are illustrated in Appendix F (Additional Materials). Finally, we interpret the literature in terms of four interpretative perspectives that summarize key trends for interdisciplinary research in the standardization research program and open to new avenues for future research. The network algorithm generated the diagrams illustrated later in Figure 2–4. In Figure 4 (below), we define the perspectives by purposely grouping topics based on the function they cover for the evolving standardization research program. To identify the perspectives' orientation to describe standardization through its theoretical lens, rather than through the content of single standards, we calculated the percentage of horizontal topics contained in the different perspectives. This exercise allows us to see whether the interpretative perspectives are more theory or content oriented and discuss what this means for standardization as an evolving and interdisciplinary research program.

FIGURE 2
Network Visualization of the Academic Disciplines of Standardization Research (2012–2021)



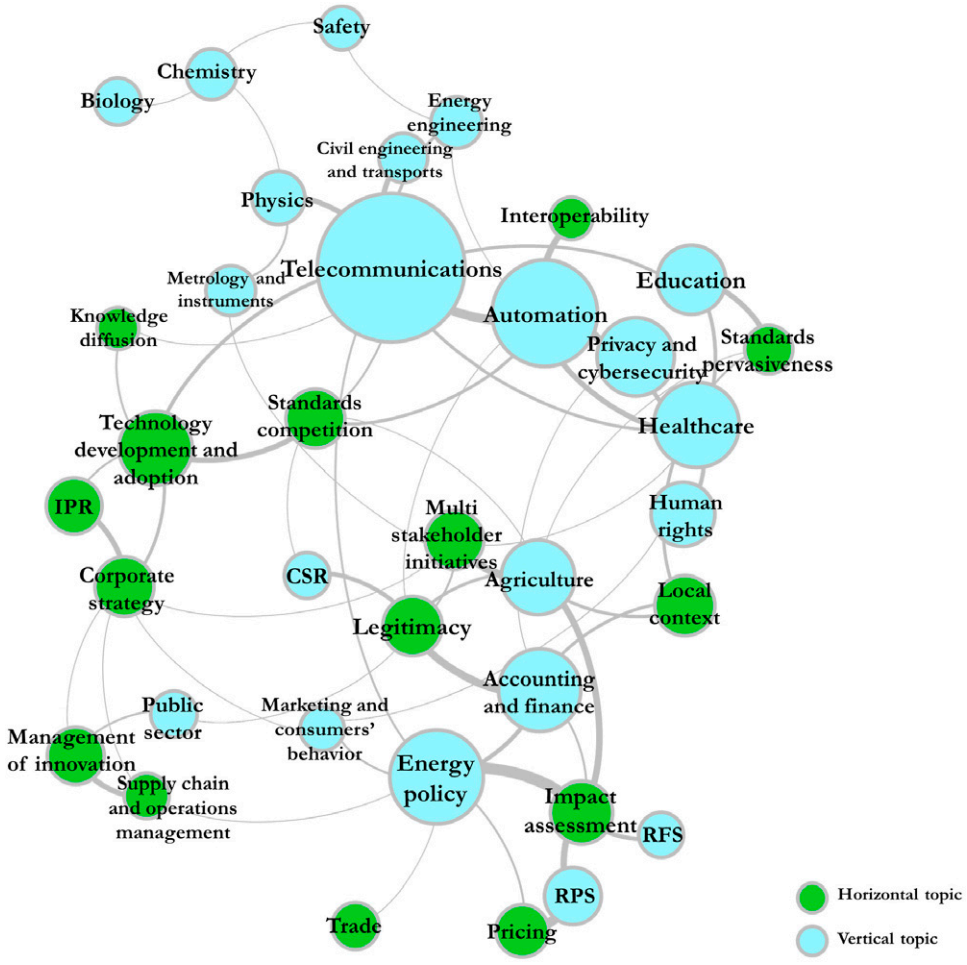
Note: Numbers show the amount of co-occurrences in the dataset.

KEY INSIGHTS ACROSS DISCIPLINES

As already shown in the foundations, research about standardization is widely dispersed across academic disciplines and topics (see Appendix F and Appendix G in Additional Materials for more information on how the reviewed papers are distributed). Our analysis shows clear differences between how papers reflect this variety in the field. First, many reviewed papers draw on knowledge from only one academic discipline and address only one topic. In our dataset, we find an abundance of such focused and often phenomenon-driven research. Examples include high-profile work from the *economics/management* discipline (Gawer & Cusumano, 2014; Ranganathan et al., 2018; Suarez et al., 2015) and all other academic disciplines (Kafle, Fukushima & Harai, 2016; Lamont et al., 2014; van den Hurk & Verhoest, 2016). This offers abundant evidence of fertility in the use of standardization across disciplines as a phenomenological object of analysis, but it also makes it difficult to accomplish theoretical integration across topics and disciplines.

However, our work also reveals that there is a substantial number of papers that create connections across the field, giving the opportunity for theoretical integration. Our review shows two common ways in which these connections are made: by drawing on knowledge from multiple academic disciplines and integrating topics across disciplines, or by addressing multiple topics simultaneously, creating qualitatively rich and often implicit connections across such topics. Examples of the first way to achieve integration include work that builds on insights from *economics/management* and *sociology* (Arnold & Loconto, 2021; Dokko, Nigam & Rosenkopf, 2012) and research combining *economics/management* with *ethics/sustainability* (e.g., Reinecke et al., 2012). Examples of the second way to achieve integration include work that combines the topics of IPR in standards with corporate strategy questions (Bekkers & Martinelli, 2012; Teece, 2018) and questions related to technology development and adoption (Vakili 2016), and work that combines the topic of standards' legitimacy with questions related to agricultural value chains (Wijen, 2014).

FIGURE 3
Network Visualization of the Topics in Standardization Research (2012–2021)

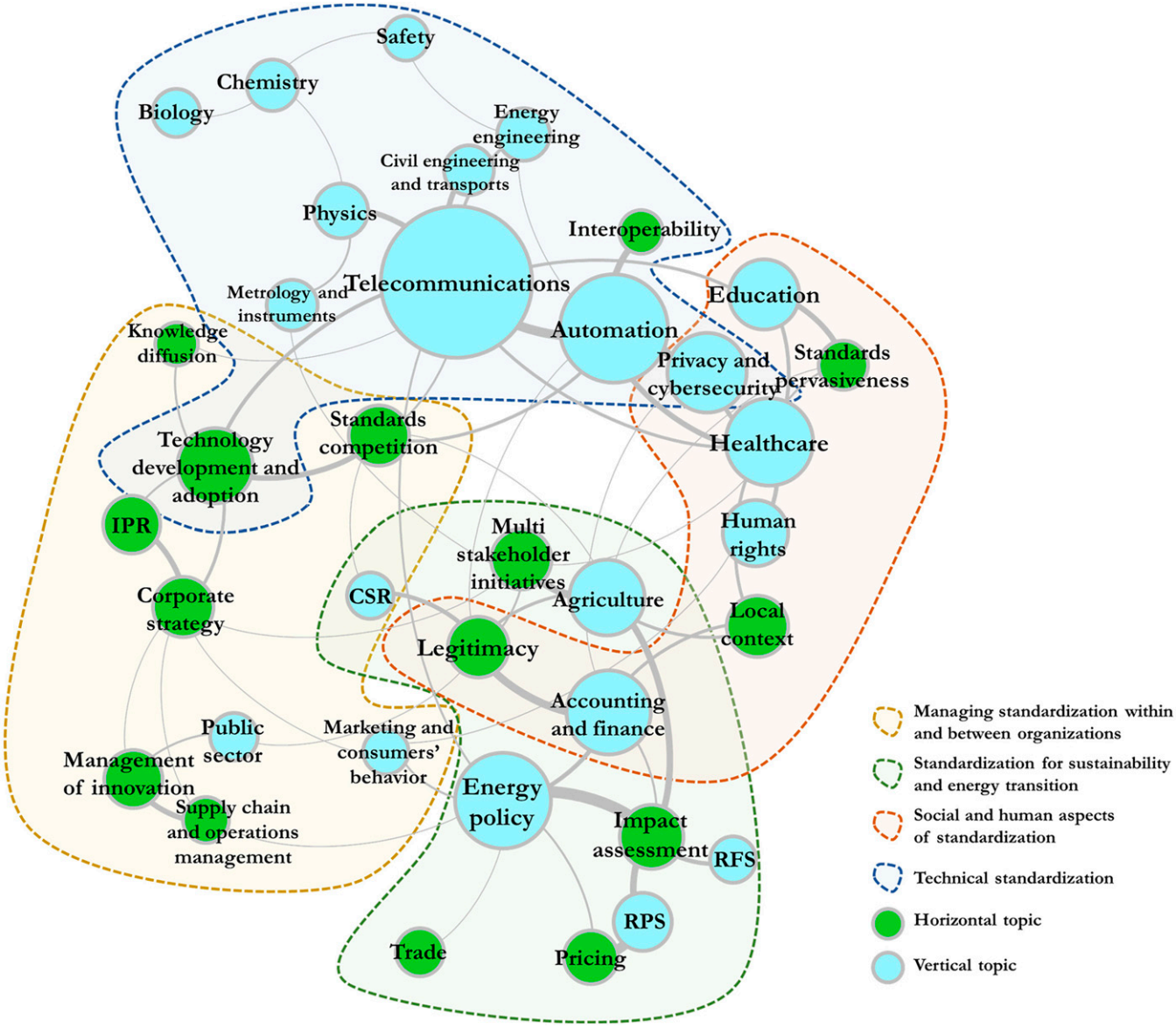


In this section, we analyze these connections in detail. We first focus on papers that draw on more than one academic discipline to understand which types of knowledge are often combined. Subsequently, we zoom in on the content of the papers that bridge discourses by exploring which topics are frequently studied in combination with each other. Based on this analysis, we discuss the integration of the literature in four interpretative perspectives, of which we describe their theoretical and empirical setting, and discuss their role within standardization research. Although our definition of these perspectives builds on the review of a field that is in continuous evolution, and thus subject to natural development following the progression of standardization research, we believe that they represent an insightful starting point to realize theoretical integration across topics and disciplines.

Connections between Academic Disciplines

Analyzing the connections between academic disciplines is valuable because it shows the sources of knowledge that are combined in the standardization field. The results of these connections are visualized in Figure 2 as follows: the size of the nodes represents the overall number of papers that draw on knowledge from the respective discipline. The thickness of the ties between two disciplines shows how many papers combine both (also shown by the numbers next to the ties). The position of a discipline in the network shows how central its knowledge is for the overall interdisciplinary work in the field. Below, we discuss the content of the literature for the most important connections in the field. Table 3 provides an overview of the contents of all identified connections, including ones that are less central for the field's development.

FIGURE 4
Network Visualization of the Interpretative Perspectives of Standardization Research (2012–2021)



The first remarkable finding is that *economics/management* is the most central discipline in connecting standardization research across disciplines, despite *IT/engineering* being most largely represented in the overall sample of papers (406 out of 1,631 papers). A total of 167 papers combine *economics/management* with insights from other disciplines, compared with 151 papers that combine insights from all other disciplines except *economics/management*. Overall, most work that draws from at least two academic disciplines (i.e., interdisciplinary) involves the social science disciplines (out of 317 papers combining two academic disciplines, 226 are at the intersection of two social science disciplines and a further 80 papers link a social science discipline to technical and other sciences). Only relatively few interdisciplinary papers (i.e., 11) draw on knowledge from *IT/engineering* and *other sciences*, suggesting these are being researched in a more isolated fashion.

Three academic disciplines (*economics/management*, *law/regulation/policy*, *ethics/sustainability*) form the core of interdisciplinary research about standardization. As Figure 2 shows, indeed, this "triangle" accounts for the largest share of connections

TABLE 3
Intersecting Areas between Disciplines

	Sociology	Law/Regulation/ Policy	Economics/ Management	IT/Engineering	Other Sciences
Ethics/ Sustainability	Standards used as private regulatory initiatives and private governance for sustainability and CSR	The role of policymakers for the energy transition and SDGs; the legitimacy of their policies; the interplay between multistakeholder initiatives and geographical factors	Organizational implications of multistakeholder initiatives in the sectors of agriculture and energy	Safety and compatibility standards in technical-intensive contexts (e.g., construction, wind energy, automation)	Standards for healthcare in developing countries
Sociology		The (unintended) consequences of standardization on fundamental human rights; the cultural norms affecting the adoption of standards in specific countries (e.g., the comparison between feed-in tariffs and RPSs)	The pervasiveness of global standards via network effects, versus the authenticity safeguarded by local standardization, in sectors such as agriculture, education, and healthcare	Standards to fight human inequalities (racial justice, gender equality) arisen in digital technologies	The intersection of healthcare, education, and human rights
Law/Regulation/ Policy			The impact assessment of policies, the pricing of RPSs; the influence of IPR on innovation (e.g., through standard-essential patents (SEPs))	The legal implication of cybersecurity, smart cities, and IoT automation	The role of public institutions in the healthcare industry
Economics/ Management				Corporate strategy and market-based standardization in technical-intensive sectors (construction, telecommunications, energy)	Standards driving innovation in the healthcare industry
IT/Engineering					The role of physics within telecommunications (e.g., wave propagation and optical communication)

among the reviewed papers (154 out of the 317 papers combining academic disciplines—i.e., almost half). In the following paragraphs, we look in more detail at the research underlying these connections.

Economics/management and law/regulation/policy. The most recurring tie (56 high-impact papers) is the one between *economics/management* and *law/regulation/policy*. A large share of this work

investigates the effects of standardization-related policy on the economy and individual firms. For example, several studies (Gao, 2015; Gao, Gao & Liu, 2021; Gao & Liu, 2012; Kwak, Lee & Chung, 2012) show how the Chinese government's standardization policy supported the catching up of Chinese firms in the mobile communications sector. On a more fundamental level, Farrell and Simcoe (2012) build on seminal work from economics and the legal discipline (Farrell & Saloner, 1988; Lemley, 2002; Lerner & Tirole, 2006)[4] to develop a game-theoretical analysis of rules for consensus standardization. They suggest that policies that de-emphasize vested interests in the standardization process (e.g., by strengthening the role of neutral parties) may contribute to more socially optimal standards. Also on a fundamental level, Blind, Petersen, and Riillo (2017) compare the effects of standards and regulation on firms' ability to innovate. More recent research investigates standards in the digital (Hinings et al., 2018; Mirtsch, Kinne & Blind, 2021) and in the sustainability contexts (Bao, Zhao, Wang & Tan, 2019; Stephan, Schmidt, Bening & Hoffmann, 2017; Tan, Ding, Zheng, Dai & Zhang, 2021; van der Loos, Negro & Hekkert, 2020; Young & Bistline, 2018). This work on sustainability mainly revolves around the effectiveness of RPSs as policy tools for promoting a sustainable economy (e.g., Bao et al., 2019; Tan et al., 2021; Young & Bistline, 2018),[5] and the role of standards and dominant designs in creating the innovations needed to reach sustainability targets (Stephan et al., 2017; van der Loos et al., 2020). Accounting standards are another vast area that is frequently researched with a combination of *economics/management* and *law/regulation/policy* lenses (Dabbicco & Steccolini, 2019; Einwiller, Ruppel & Schnauber, 2016; Houghton, Kend & Jubb, 2013; Rojszczak, 2021). Our analysis also reveals that these research streams are evolving over time. The work on standards in the digital and sustainability contexts has only been emerging relatively recently, in the second half of the period 2012–2021. During the entire period, there has been a steady stream of work on accounting standards. The work on the Chinese mobile telecommunications sector mainly stems from the earlier years covered by our review, but tended to fade away in the second half of the reviewed period (2017–2021).

Economics/management and ethics/sustainability. Also, *ethics/sustainability* is strongly tied to *economics/management* (50 co-occurrences). While the subjects of this research overlap, to some extent, with those covered in the previous paragraph, we see that the perspectives from which they are studied often differ. Research that combines *ethics/sustainability* with *economics/management* often places values, such as fairness and human rights, at the core of its reasoning (e.g., Husted, Montiel & Christmann, 2016; Meemken, 2020; Narula, 2019; Yanuardi, Vijge & Biermann, 2021). In terms of subjects, this research mainly revolves around, first, standards in the context of renewable energy and, second, standards for sustainable farming and fair trade. The first stream focuses on "vertical topics" (i.e., it studies standards in a specific application area—the energy sector, in this case—rather than aiming to generalize to standards as a broader phenomenon). Most papers in this stream appeared in the first half of the period covered by our review. They mainly study RPSs (e.g., Chen & Wang, 2013; Kwon, 2015; Novacheck & Johnson, 2015; Rouhani, Niemeier, Gao & Bel, 2016; Tanaka & Chen, 2013), which we discuss in more detail in the next section.

The second stream (standards for sustainable farming and fair trade) is even more prominent among the research that draws on *economics/management* and *ethics/sustainability*. Papers related to this stream are represented throughout the entire period covered in our dataset, but the stream has particularly been gaining increasing prominence from 2017 onwards. The earlier work includes a highly cited paper by Reinecke et al. (2012), who studied the case of sustainability standards in the global coffee industry. Based on their research, they developed the notion of a "standards market," where multiple standards with similar purposes exist in parallel. According to Reinecke et al. (2012), the dynamics in such a "standards market" may give rise to "meta-standardization," where standards converge at a high level of characteristics but compete by differentiating themselves regarding how these characteristics are implemented. Later work on standards for sustainable farming and fair trade includes case studies of standards in specific settings (e.g., Brako, Richard & Alexandros, 2021; Campos, Álvarez, Oviedo, Mesa, Caparrós & Ovando, 2020; Johnson, 2019; Yanuardi et al., 2021), as well as more general empirical and modeling approaches to the topic (Meemken, 2020; Mohan, 2020; Poret, 2019).

[4] This work is not included in our review, since it was published in a timeframe that has already been covered by earlier reviews (Choi et al., 2011; Narayanan & Chen, 2012; Timmermans & Epstein, 2010).

[5] See the discussion of this research in the section on connections between topics.

For example, Yanuardi et al. (2021) show that governance standards in the Indonesian raw materials sector have helped improve the participation of civil society in the industry; however, they did not live up to their potential in improving transparency and accountability. To mention a few other relevant examples, Brako et al. (2021) study standards in the Ghanaian cocoa industry to show mixed effects of sustainability standards and certification on the living conditions of farmers. Meemken's (2020) meta-analysis on the topic shows that sustainability standards contribute to improving the conditions in agricultural supply chains in poor countries. Other authors take a more critical stance on sustainability standards. Narula (2019) points toward their negative effects for actors in the informal economies of poor countries who lack the means to comply with the requirements. Silvestre, Viana, and de Sousa Monteiro (2020) highlight the issue of supply chain corruption, which may lead to standards only being implemented in a symbolic manner without any real effect. They also develop a typology of corrupt practices in supply chains, which contribute to such outcomes. Christensen et al. (2017) respond to such critical views on sustainability standards by arguing in favor of "licenses to critique" in organizations. According to them, organizational practices that allow for inquiry and contestation need to be established in global value chains to offset tendencies toward closure in standards implementation. Overall, this work shows that standards have a strong effect on global supply chains, but do not, under all conditions, bring the intended improvements for farmers and other marginalized actors in the global south.

Law/regulation/policy and ethics/sustainability. The tie between *law/regulation/policy* and *ethics/sustainability* completes the "triangle" at the core of interdisciplinary standardization research, as identified in Figure 2 (48 papers). The connection between these two disciplines is dominated by a discourse about the role of standards and other private instruments in (trans)national governance. Central to this discourse are questions related to the legitimacy of private sector-led standards as governance instruments (e.g., Boström & Tamm Hallström, 2013; de la Plaza Esteban, Visseren-Hamakers & de Jong, 2014; Flynn & Hacking, 2019; von Geibler, 2013). Subjects discussed in relation to legitimacy include (a) stakeholder involvement, (b) the extent to which standards reflect what is desirable from a societal point of view, (c) how the coexistence of multiple standards affects their effectiveness as governance instruments, and (d) how international standards relate to national legislation and the local context. The key contributions to this debate can be summarized by mentioning examples of research that looks at the multistakeholder nature of standardization and at the societal challenges that are associated with standardization. For instance, Boström and Tamm Hallström (2013) argue that the involvement of many stakeholders contributes to standards being a legitimate form of governance, but also causes them to be fragile because they rely on the involved stakeholders' continued support. Von Geibler (2013) follows this intuition, highlighting that societal challenges may, to some extent, be seen as market opportunities by enterprising standard-setters. According to this research, there is the risk of imbalance among the multiple and often-diverse stakeholder groups that are involved in standardization. Based on a study of standards in the palm oil industry, this research questions whether the resulting standards meet needs for sustainability. In the context of the circular economy, Flynn and Hacking (2019) build on this conversation to conclude that standards may increase the quality of recycled materials and instill confidence in the market but are also likely to prioritize costs over quality. They link these findings to a call for standards to "challenge neoliberal market relations rather than simply follow them" (Flynn & Hacking, 2019: 1266).

A related, still-parallel discourse analyzes standards' effectiveness as a potential governance mechanism. Derkx and Glasbergen (2014) claim, for example, that the coexistence of competing standards can cause fragmented governance and therefore call for meta-governance to address this issue. Their findings provide lessons for the success of governance initiatives in the domain of standardization and call into question the notion that private sector-developed standards lack ambition. The coexistence of multiple standards in one field is also observed in Manning and Reinecke's (2016) study of sustainability standards for coffee. However, they do not interpret this insight as a fragmentation of governance, but as a modular approach that can help standard-setters collectively "manage to lower the ambiguity of the ongoing global sustainability discourse … and facilitate coordination among multiple actors with potentially conflicting interests" (Manning & Reinecke, 2016: 628).

Inspired by such fundamental debates about the legitimacy and effectiveness of standards in stakeholders' governance, some authors also investigate how standards are implemented in local contexts and interact with national regulations. Examples of

this stream are studies of sustainability standards and national regulation in the Indonesian and Brazilian palm oil and soy industries (Hospes, 2014; Macdonald, 2020), and in the Russian forestry sector (Malets, 2015). Beyond this, RPSs (discussed in detail below) and related policies are also a recurring topic in papers combining the *ethics/sustainability* and *law/regulation/policy* disciplines (e.g., Christensen & Hobbs, 2016; Dong, Shi, Ding, Li & Shi, 2019; Schelly, 2014).

Connections between sociology and other social science disciplines. Outside the "triangle" that we identified as core to the interdisciplinary discourse, the link between *economics/management* and *sociology* is the strongest (35 papers). Furthermore, *sociology* is connected to *law/regulation/policy* (24 papers) and *ethics/sustainability* (13 papers). Our dataset shows that this connection is driven largely by research that draws on a variety of sociological approaches to study how actors in standardization address managerial and social issues. Sociological approaches used in this literature include topics ranging from negotiated order to actor–network theory, structuration theory, institutional work, and collective action. In terms of subjects, three themes stand out from this part of review: (1) implementation of standards in institutional and organizational contexts (Arnold & Loconto, 2021; Constantinides & Barrett, 2015; Nurunnabi, 2015; Sandholtz, 2012; Wilhelm, Bullinger & Chromik, 2020); (2) development of standards and dominant designs at the industry level (e.g., Dokko et al., 2012; Kester, Noel, Lin, Zarazua de Rubens & Sovacool, 2019; Lee, Harindranath, Oh & Kim, 2015; Slager et al., 2012; Sydow, Windeler, Schubert & Möllering, 2012); and (3) social dynamics in the adoption of sustainability standards in agricultural supply chains (e.g., Arnold & Loconto, 2021; Davey & Richards, 2013; Tennent & Lockie, 2012; Wijen & Chiroleu-Assouline, 2019).

Research on implementing standards in organizations identifies dynamics, which relate to the involved parties' framing and a standard's fit in existing norms and practices (Arnold & Loconto, 2021; Constantinides & Barrett, 2015; Sandholtz, 2012). To mention a relevant example, Sandholtz (2012) applied a decoupling approach to his case study of ISO 9001[6] implementation in two units of the same company. He observed that organizational factors can cause the same standard to have remarkably different outcomes: chaotic work practices and a culture of cynicism in one unit versus effective practices that are enthusiastically followed in another one. Applying a collective action lens to the information systems context, Constantinides and Barrett (2015) endorse implementing standards in bottom-up processes, as top-down approaches can lead to unintended outcomes. Arnold and Loconto (2021) mirror these insights by arguing that it is not sufficient to consider individual standards, because they are often implemented in combination. Using a case study of the Ghanaian pineapple industry, they develop the concept of "nesting" to explain how actors negotiate their own way of fitting standards with each other.

The stream on standards development investigates how actors engage in collective action to create and maintain standards at the industry level (e.g., Dokko et al., 2012; Lee et al., 2015; Slager et al., 2012; Sydow et al., 2012). Within this stream, we observe a variety of theoretical approaches used to describe the development and success of specific standards. Theories are used by researchers in quite a malleable way to introduce case studies. In the case of the FTSE4Good Index,[7] for example, Slager et al. (2012) apply an institutional perspective to find that institutional work revolves around three activities: calculative framing, engaging, and valorizing. Sydow et al. (2012) use structuration theory to study standards in the semiconductor tool manufacturing industry. They show how standards emerge through *both* path dependency and agency of the involved actors. Lee et al. (2015) use actor–network theory to investigate how members of alliances in the Korean mobile payment industry enlisted the support of other actors and technology to shape standards. While most of this literature focuses on new standards, Dokko et al. (2012) study periods between the emergence of new standards. Building on the concept of negotiated order (Strauss, 1978), they argue that standards do not perpetuate themselves during these periods. Instead, actors engage in negotiated-order processes to reinforce standards.

The final stream that connects *sociology* with other social science disciplines investigates social dynamics in the adoption of sustainability standards in agricultural value chains. For example, both Tennent and Lockie (2012) and Davey and Richards (2013) study how standards affect power relationships in food value chains. Both papers conclude that retailer-controlled food standards give supermarkets substantial power over farmers, because they are quasi-mandatory

[6] ISO 9001 is a standard for quality management systems that is used in millions of organizations around the world.

[7] The FTSE4Good Index is a standard for socially responsible corporate behavior.

governance instruments to which food producers must comply to access the market. Tennent and Lockie (2012) investigate how organizing in cooperatives helps farmers deal with these standards, whereas Davey and Richards (2013) focus on the certification under these standards and study how standard owners' interference in the supposedly independent audit process further exacerbates the power imbalances created by these standards. Another example is the work by Wijen and Chiroleu-Assouline (2019), who frame the relationships among the stakeholders of standards in agricultural value chains in terms of controversy and argue that this controversy ultimately had a positive impact on sustainability transitions of these value chains.

We also observe trends in how research develops over time in the connection between *sociology* and other social science disciplines. Throughout the entire period 2012–2021, there was a steady stream of work about standard implementation in organizations. The same applies to the sociological perspective on standards in agricultural supply chains. Work on standards development, which combines *sociology* with other academic disciplines, predominantly occurs in the first years of our review. While there is much work on standards development in later years (e.g., Ranganathan et al., 2018; Toh & Miller, 2017), it lacks the sociological perspective included in the earlier work.

Other connections between academic disciplines. In comparison to the connections discussed above, there are relatively few papers drawing on *IT/engineering* or *other sciences* in connection with other disciplines. The work that does exist with these combinations is relatively scattered in terms of the researched subjects. Some examples include work on the energy transition, economic assessment, and the legal compliance of new sustainable technologies, such as interconnected smart grids and additive manufacturing (Erlinghagen et al., 2015; Han, 2015; Ho & O'Sullivan, 2017). In these areas, research often takes a phenomenon-driven approach and aims at designing frameworks, roadmaps, and models.

Connections between Topics

As explained earlier, we considered the core subjects in each paper and coded them accordingly with up to two topics per paper. This supports a more fine-grained analysis. Overall, we identified 56 topics across all papers in our review. Table 4 exhibits the seven most recurring topics within each academic discipline. For each discipline, we also calculated their rate of horizontal and vertical orientation, in order to understand the extent to which these are inclined toward the theoretical setting of standardization rather than the content or field of application of standards.

Within this level of coding, we found a substantial amount of work that creates connections across the field by combining two topics (e.g., IPR and corporate strategy). Overall, 36 topics are researched repeatedly in tandem with another topic. We do not analyze in detail the remaining 20 topics (e.g., forestry, genetics), which have no or only one connection with another topic. Indeed, these remaining 20 topics tend to be relatively isolated in the topological network mapping of the standardization literature. Figure 3 maps the connections between topics in the 2012–2021 timeframe (i.e., the entire timespan in our dataset). Figure 3 shows which topics are closely related to each other. In the subsequent paragraphs, we address some key insights that can be derived from this analysis. We focus on connections between topics that stand out in terms of their prominence in the field or are particularly relevant from a managerial perspective.

Corporate strategy and IPR. Questions around strategic issues related to standards and IPR in standardization are at the core of managerial research on the topic. This is also reflected in our coding, where a substantial number of papers are assigned to these two topics: 43 papers have been coded as addressing corporate strategy (e.g., Blind & Mangelsdorf, 2016; Jones, Leiponen & Vasudeva, 2021; Ranganathan et al., 2018; Ranganathan & Rosenkopf, 2014; Suarez et al., 2015), many of which address topics that include cooperation, networks, and alliances in standardization. IPR issues, often related to standard-essential patents (SEPs), are at the core of 40 papers in our dataset (e.g., Baron, Pohlmann & Blind, 2016; Bekkers, Iversen & Blind, 2012; Kang & Bekkers, 2015; Kang & Motohashi, 2015; Lerner & Tirole, 2015; Vakili, 2016). Both topics occur together with several others (e.g., management of innovation, technology development and adoption), and have a strong link with each other.

A first insight from this connection is the value that standards can bring to the management of IPR. Thus, it is no surprise that the most highly cited and arguably most influential paper on the intersection of corporate strategy and IPR is the work by Teece (2018) on profiting from innovation in the digital economy. This paper argues that standards and SEPs are two inter-related key elements of strategies for monetizing innovation in the digital era. In a similar

TABLE 4
Top Seven Most Recurring Topics and Horizontal versus Vertical Nature of Each Discipline

	Economics/Management		Ethics/Sustainability		Law/Regulation/Policy	
Topic Nature **% Total Coding**	**Horizontal** **58%**	**Vertical** **42%**	**Horizontal** **39%**	**Vertical** **61%**	**Horizontal** **36%**	**Vertical** **64%**
1	Technology development and adoption			Agriculture		Energy policy
2		Accounting and finance		Energy policy		Accounting and finance
3	Corporate strategies		Multistakeholder initiatives			Agriculture
4	Standards' competition		Local context			Renewable portfolio standards
5	Management of innovation			Human rights	Impact assessment	
6		Energy policy	Legitimacy		Legitimacy	
7	Impact assessment			Renewable portfolio standards		Healthcare

	Sociology		IT/Engineering		Other Sciences	
Topic Nature **% Total Coding**	**Horizontal** **35%**	**Vertical** **65%**	**Horizontal** **12%**	**Vertical** **88%**	**Horizontal** **4%**	**Vertical** **96%**
1		Education		Telecommunications		Healthcare
2		Human rights		Automation		Telecommunications
3		Healthcare		Privacy and cybersecurity		Physics
4	Standards pervasiveness			Energy policy		Chemistry
5		Accounting and finance		Energy engineering		Biology
6		Agriculture		Civil engineering and transports		Metrology and instruments
7	Legitimacy			Healthcare		Education

vein, Toh and Miller (2017) show how firms can maximize the value of their intellectual property by strategically deciding how much and which IPR to disclose in standardization, in light of trade-offs between increasing their technology's value and risks of expropriation of this value by competitors.

A second topic at the intersection of IPR and corporate strategy in our dataset concerns alliances in standardization (Baron & Pohlmann, 2013; Lou, Yao & Zhang, 2022). This work investigates how companies coordinate their standard-related R&D activities in alliances and consortia, and how they distribute the related IPR among each other. For example, Baron and Pohlmann (2013) compare standards development in consortia, such as the World Wide Web Consortium, with the work in formal standard bodies, such as the International Organization for Standardization (ISO). They find that consortia often include firms with complementary, rather than competing, IPR portfolios, and can be used to settle conflicts before standards development in formal standard bodies is initiated.

Technology development or adoption and standards competition. The combination of technology development or adoption and standards competition represents a second literature stream at the heart of strategy and innovation management scholars' interest. This is also evident from the frequency with which both topics appear in our dataset (see Appendix F in Additional Materials). Technology development or adoption is indeed the most frequent horizontal topic (72 papers; e.g., Dokko et al., 2012; Gauch & Blind, 2015; Jain, 2012), with a high number of papers explaining how technologies co-evolve with standards. Standards competition is further discussed in 46 papers (e.g., Chen, Qian & Narayanan, 2017; Gallagher, 2012; Reinecke et al., 2012) and usually occurs when de facto standards or dominant designs emerge in a market battle (Cusumano et al., 2014; Wiegmann et al., 2017).

Dominant designs are also a key issue of interest at the intersection between these two topics, as emerges from the following examples. Benner and Tripsas (2012), for instance, investigate how demand-side factors influence the role of technological factors in the emergence of dominant designs. In a similar vein, Eisenman (2013) argues that standards competition and dominant designs are influenced by a variety of contextual, non-technological factors related to sociology, marketing, and psychology. Gustafsson, Jääskeläinen, Maula and Uotila's (2016) literature review of industry emergence highlights the key role of standards and dominant designs in the "growth stage" of a new industry. Similarly, Raffaelli's (2019) case study of the Swiss mechanical watchmaking industry shows how incumbent firms can reinvent themselves in light of competing technologies supplanting the existing dominant design. In their variety, all these examples illustrate the breadth of aspects that have been studied in the context of dominant designs at the intersection between technology development or adoption and standards competition.

Accounting or finance and legitimacy. We already identified legitimacy to be a key concern in the research combining the *law/regulation/policy* and *ethics/sustainability* disciplines (see discussion above). The analysis of topics reveals a second area where the legitimacy of standards is a key concern: 15 papers in our dataset address this issue explicitly. They mainly ask whether the standardization process, in which international accounting standards are developed, considers all stakeholders fairly (e.g., Bamber & McMeeking, 2016; Jorissen, Lybaert, Orens & van der Tas, 2013; Kok & Maroun, 2021; Sinclair & Bolt, 2013; Wingard, Bosman & Amisi, 2016). Durocher, Fortin, Allini, and Zagaria (2019), for example, formulate this research question by studying the consequences of the potential imbalances associated with how the resulting accounting standards are perceived by financial analysts. Other work critically assesses the International Accounting Standards Board's accountability in light of the 2008 financial crisis (Botzem, 2014).

RPSs. RPSs are a frequently recurring vertical topic in the research captured by our dataset (more than 40 papers), making this a prominent subject in the standardization field. RPSs are predominantly researched using *economics/management*, *law/regulation/policy*, and *ethics/sustainability* perspectives, and feature prominently in the work connecting these three academic disciplines. RPSs are closely linked to regulation and define requirements for energy producers regarding the share of renewable energy sources that they must include in their production portfolios (e.g., Barbose, Bird, Heeter, Flores-Espino & Wiser, 2015; Sun & Nie, 2015). Research on the topic addresses a variety of issues that range from the effects of RPSs on prices and competition between firms in the energy market (Tanaka & Chen, 2013) to the interactions between RPSs and other sustainability policies for energy production (Chen & Wang, 2013), and the analysis of the comparisons of RPSs with other policy designs for promoting clean energy production like feed-in tariffs (Kwon, 2015; Novacheck & Johnson, 2015; Yang, Jing, Wang, Nie & Sun, 2021) to the study of their overall costs and benefits for single actors and

for the broader society (e.g., Barbose et al., 2015; Rouhani et al., 2016; Wiser et al., 2017).

In terms of connections between RPSs and other topics, we observe considerable changes in the literature over the timeframe of our review (2012–2021). RPS research tends to be connected to pricing over the entire timeframe, often in the context of cost–benefit analyses (e.g., Barbose et al., 2015; Rouhani et al., 2016; Wiser et al., 2017). However, the connection with impact assessment emerged only in a later period, with the first paper making this connection being published only in 2018 (Bento, Garg & Kaffine, 2018). This work decomposes the effects of RPSs into multiple constituents (substitution effects, output tax effects, output effects) and shows that increases in RPS requirements can lead to either large-scale investment in renewables or substantial reductions in emissions. Following this paper, in the period between 2018 and 2021, six other papers explored this connection.

Telecommunications, automation, and privacy and cybersecurity. Given the strict link between standards and technology, technical topics represent a substantial share of our dataset, with telecommunications (209 papers; e.g., Lu et al., 2016; Nasrallah et al., 2019; Shafi et al., 2017) and automation (132 papers; e.g., Ayoub, Samhat, Nouvel, Mroue & Prevotet, 2019; Chen, Wan & Li, 2012; Sheng et al., 2013) being overall the two topics with the largest number of papers in our dataset (see Appendix F in Additional Materials). We see strong connections between these topics: 46 papers link telecommunications, automation, and privacy and cybersecurity. Papers in this part of the network focus on the technical content of standards, often in the context of the IoT. Key issues about these topics include communication between IoT devices (e.g., Ali, Yigang, Shi, Sui & Yuang, 2020; Burasa, Djerafi & Wu, 2021; Han et al., 2020; Sharma, Kanaujia & Kumar, 2021); IoT security and encryption (e.g., Keoh et al., 2014; Sciancalepore, Piro, Vogli, Boggia, Grieco & Cavone, 2016; Radanliev et al., 2020); and vehicle-to-X communication (e.g., Abou-zeid, Pervez, Adinoyi, Aljlayl & Yanikomeroglu, 2019; Harounabadi, Soleymani, Bhadauria, Leyh & Roth-Mandutz, 2021; Wang, Mao & Gong, 2017). To some extent, the connections between topics are likely to reflect technological developments in standardization: although most of the papers studied communication standards throughout the whole review period (2012–2021), notably, the link between standards, automation, and IoT only proliferates in the last years of the review (after three early papers appeared in 2014–2016, the topic gained prominence from 2018 onwards). From this perspective, our review of the technical standardization literature may be a new data source for future managerial studies on technology trajectories.

Interpretative Perspectives on Standardization Research

As shown by our review of the literature, research about standardization is dispersed across various academic disciplines and topics; however, the overlap and the connections between disciplines and topics reveal the emergence of key trends that suggest burgeoning theoretical consistency and represent the opportunity for further integration. By focusing on the links between disciplines and topics, we show that this dispersed literature tends to converge into a coherent field of research. Standardization research emerges from our analysis as an evolving research program in which the nurturing and articulation of various and often-disparate ideas give impetus and originality to new theorizing across disciplines and topics (e.g., Lakatos, 1970). To help generate the Lakatosian interpretive understanding of the hard "core" of ideas distinctive to the standardization research program, we interpret the reviewed literature on an aggregate level by proposing and discussing four interpretative perspectives that summarize the core insights from standardization research.

There are four emerging overarching discourses in the decade of literature that we reviewed, which represent four interpretative perspectives of inter-related topics within the standardization literature: (1) standardization management within or between organizations, (2) standardization for sustainability and energy transition, (3) social and human aspects of standardization, and (4) technical standardization. Figure 4 shows which topics underlie each of the four perspectives, and which connections already exist across the boundaries between perspectives. Table 5 provides an overview of these perspectives. It also shows to what degree the perspectives are oriented *horizontally*, by providing the percentage of included topics that we coded as *horizontal versus vertical* (both as a raw number and weighted by the number of papers covering each topic).

Following Lakatos (1970), these perspectives represent the sets of protective belt theories that, we suggest, can be clearly derived from the most frequent connections between disciplines and topics in standardization research. Through the brief

TABLE 5
Research Perspectives on Standardization in the Past 10 Years (2012–2021)

	Managing Standardization within and Between Organizations	Standardization for Sustainability and Energy Transition	Social and Human Aspects of Standardization	Technical Standardization
	← *Horizontal*		*Vertical* →	
Horizontal orientation[a]	64%	46%	38%	18%
Horizontal orientation[b]	77%	37%	24%	13%
Main theoretical setting	Innovation ecosystems; diffusion of knowledge; IPR, standards competition and corporate strategy, harmonization of standards	Energy impact assessment; cost–benefit analysis; feed-in tariffs; policy analysis; global multistakeholder initiatives	Legitimacy of standard-developing processes; unintended consequences; anticipatory standards; frameworks for social norms and values; governmentality of standards; sociology of quantification	Technological trajectories and technology adoption
Main empirical setting	Standards in the tech and energy sectors; accounting and reporting standards; standards for the public sector; standards for international cooperation and trade	Standards for renewables; standards for agriculture; eco-labels; water and food certifications; standards and SDGs; standards for smart grids; CSR	Cultural standards in communities and local contexts; labor and living standards; standards in and for education; privacy issues from automation and artificial intelligence	Standards in 5G and 6G; interoperability of smart devices through standardized chips and sensors; compatibility and quality standards of smart cities; biomedical privacy; data encryption; protocols of cryptography
Topics included	Technology development and adoption; corporate strategy; management of innovation; standards competition; IPR; network analysis and effects; supply chain and operations management; public sector; CSR; marketing and consumer behavior; knowledge diffusion	Energy policy; impact assessment; multistakeholder initiatives; accounting and finance; renewable portfolio standards; agriculture; pricing; renewable fuel standards; metrology and instruments; legitimacy; trade; harmonization; CSR	Education; healthcare; privacy and cybersecurity; legitimacy; accounting and finance; local context; human rights; standards pervasiveness	Telecommunications; automation; privacy and cybersecurity; physics; metrology/instruments; technology development and adoption; civil engineering and transportation; interoperability; safety; chemistry; energy engineering

[a] Percentage of horizontal topics.
[b] Weighted by number of papers per topic.

discussion of these perspectives, our approach seeks to draw from the core concepts in this variegate literature to suggest new opportunities for researchers and practitioners to develop the standardization research program further while keeping its protective belt of conceptual distinctiveness. For this reason, these four interpretative perspectives incorporate both the interdisciplinary complexity of the literature and its paramount attention to practice-oriented topics aimed at solving standardization issues for firms, businesses, and society.

Managing standardization within and between organizations. In our review, the economic and organizational nature of standards and standardization makes the *economics/management* discipline the linking pin of the standardization research program. The figures and our discussion of the literature show the broad array of topics that are researched as part of this perspective. We both see that scholars from different sub-disciplines of management take an interest in standards and standardization as a phenomenon, and that insights from studying the

phenomenon are used to develop theory in the respective sub-disciplines. Examples of this phenomenon include approaches to the field from strategic management (e.g., Ranganathan & Rosenkopf, 2014; Teece, 2018; Toh & Miller, 2017), innovation management (e.g., Blind et al., 2017; Foucart & Li, 2021), organizational theory (e.g., Brunsson et al., 2012; Haack et al., 2012), and international management (e.g., Brem & Nylund, 2021; Fransen, Kolk & Rivera-Santos, 2019; Kraus, Meier, Eggers, Bouncken & Schuessler, 2016). Standardization management seems to emerge as a meta-lens that captures the distinctiveness of the standardization research program by providing flexibility and malleability in the definitions and operationalizations of standards across topics. Future research is needed to bridge this intellectual portability with the theoretical awareness of the distinctiveness of a standardization approach versus competing or collaborating theories across subfields of management research (i.e., strategic management or organization theories).

Standardization for sustainability and the energy transition. Not surprisingly, given the increasing relevance of sustainability in the broader social science disciplines in the past decade, our review of the literature shows that there is wide agreement on the key role of standards for reaching sustainability goals and addressing grand challenges like climate change. Their role in driving the energy transition is widely researched across the entire period that we considered. The centrality of standardization theorizing in the energy transition field depends on the relevance of quality and compatibility standards in ensuring coordination between all actors involved in these complex sociotechnical systems (e.g., van de Kaa, Kamp & Rezaei, 2017). Interestingly, in most of this research, the standardization lens remains phenomenological: there is limited attention to standards and standardization as a theoretical lens, or as an emerging discipline. On the contrary, standards are seen as "objects" of analysis that apply to technical considerations of energy transition as much as to other technical or technological components. From this perspective, we see the need for theoretical development of the role of standards as conceptual constructs that can enrich our understanding of the technical correlates of sustainability across topics and disciplines.

A new theoretical attention to standardization can be also fueled by the surging stream of research on the economic assessment of the energy transition: as shown by this perspective, different types of cost–benefit analyses are conducted to ensure that stakeholders meet the requirements of, among others, RPSs (Alizada, 2018), renewable fuel standards (Huang, Khanna, Önal & Chen, 2013), environmental management standards (ISO 14001) (Husted et al., 2016), and corporate average fuel economy (CAFE) standards (Sen, Noori & Tatari, 2017). This development of the literature can foster interdisciplinary collaboration between economists, policy experts, engineers, and energy and environmental scholars. In this evolving field, standardization can be seen as a conceptual lens integrating the links between technical and economic aspects of the energy transition.

Remarkably, our analysis also reveals what is not yet researched within this perspective—these are opportunities for future research. Despite the substantial body of work on legitimacy and fair stakeholder representation in other areas of standardization, which include accounting (e.g., Botzem, 2014; Durocher et al., 2019) and agricultural value chains (e.g., Arnold & Loconto, 2021; Reinecke et al., 2012), this topic is notably absent in the literature on energy transition. Considering the theoretical relevance of corporate vested interests and the imbalance between the power of diverse stakeholders for the development of the standardization research program across disciplines (i.e., sociology, accounting, policy studies, ethics, and sustainability), we call for further work incorporating this debate into the research agenda of standardization.

Social and human aspects of standardization. Considering that the standardization research program inherently bridges technical and social topics across disciplines, there is no doubt that a prevalent perspective of research addresses the broad and often disparate societal aspects of standardization. Given its breadth, this perspective appears relatively heterogeneous in terms of topics and representation across disciplines. However, a few key trends emerge that can guide our interpretive effort. Research under this perspective includes, for example, the body of work on standards in privacy and cybersecurity (Rossi, 2021), or in relation to healthcare (e.g., Bhardwaj & Kumar, 2021; Prodanoff, White-Williams & Chi, 2021). Furthermore, given the rising attention to standards in the context of sustainability, we see in this perspective an increasing amount of research on human rights topics, such as labor standards (e.g., Baumann-Pauly, Nolan, van Heerden & Samway, 2017; van Roozendaal, 2015). Large parts of this research draw on knowledge from the *ethics/sustainability*,

law/regulation/policy, and *sociology* disciplines. This work tends to have consistent managerial relevance, mainly from a corporate social responsibility (CSR) standpoint, and this is why we also see recent work from the management discipline that engages with such perspective in this context (e.g., Husted et al., 2016; Silvestre et al., 2020; van Roozendaal, 2015). In our view, future research is needed to integrate the analysis of the human and social aspects of standardization with its technical underpinnings. Although in a nascent phase in this literature, work on the social and ethical aspects of AI could represent an interesting starting point to advance this perspective into the theoretical integration of the multifaceted nature of contemporary standards.

Technical standardization. As already shown by our review, and with no surprise, given the relative prevalence of technical literature in our dataset, research on technical standardization represents a very substantial part of our literature review, yet is mostly isolated from the other perspectives. This dual pattern of most frequent representation in the literature and yet isolation from the interdisciplinary corpus of research represents simultaneously a strength and a weakness of this perspective. Indeed, it reveals the theoretical fragility of standardization in the technical disciplines (in which, as already discussed, standards are often confined to the atheoretical role of objects, tools, or artifacts). Still, the relative conceptual under-development of the understanding of standards in this literature represents an undoubted opportunity for integration with other disciplines, as suggested in the final paragraph of the previous perspective. The main reasons for this isolation include the relatively high technical specialization of journals and research communities, whose languages are often impermeable to researchers from other disciplines. Moreover, we observe, in the literature, the remarked tendency to choose new, blossoming, and often "hot" topics that can attract attention and research grants (e.g., new communication networks and smart grids) because they are in need of technical research for their development (Fan et al., 2013; Han et al., 2020). However, we see a clear trade-off between the singular attractiveness of these topics and the goal of developing a theoretically cohesive and progressive standardization research program.

Despite this risk of isolation, the most promising opportunities for integration come from research on *telecommunications* and *automation*, which are the most frequent and closely related topics in this perspective. To the extent that ICT and automation permeate many other fields, these two topics are also the key drivers of cross-fertilization across disciplines. We also suggest that theories on technology development and management could further contribute to the integration of this perspective with others (Henfridsson, Mathiassen & Svahn, 2014). To the extent that ongoing technological developments drive firms' innovation and ultimately their long-term performance, this perspective could serve as an extensive data source to track technology trajectories, which could be further integrated into managerial research aimed at investigating the connections between technological choices of firms and their innovation success (e.g., Moreira, Klueter & Tasselli, 2020).

DISCUSSION AND RESEARCH AGENDA

To our knowledge, this paper provides the first large-scale review of literature on standards and standardization across management and other academic disciplines. Our work is motivated by the ubiquity of standards, and by their importance for organizations, policymaking, and many other actors in society. In the literature, this is often mentioned in the context of major issues affecting business and society, such that standards are named as key for ecosystems (Bogers, Sims & West, 2019; Shipilov & Gawer, 2020), the platform economy (Jacobides et al., 2024; Tassey, 2000; Teece, 2018), sociotechnical transitions toward a more sustainable society (Geels, 2004), and achieving the targets of the United Nations' Sustainable Development Goals (SDGs) (van Tulder & van Mil, 2023). Yet, while there are many references to standards in these overarching contexts, these references often remain relatively vague on how standards can contribute to such transformations of business and society. Arguably, developing such an understanding also involves a normative stance on how standards can contribute to goals, such as economic efficiency, sustainability, ethics, fairness, and technological impartiality. Our comprehensive review of research in the period 2012–2021 takes stock of the insights that already exist on this contribution, and envisages promising directions for future research. In doing so, we observe research that (a) is scattered across academic disciplines and topics, yet (b) can be seen as revolving around standardization as a common phenomenon. We also see some work taking a normative stance—such as the research on standards in agricultural value chains, with its strong focus on ethics and sustainability (e.g., Arnold & Loconto,

2021; Meemken, 2020; Wijen & Chiroleu-Assouline, 2019).

A large share of the reviewed research (approximately 70%) focuses on standards in specific areas of business, society, and technology, such as telecommunications, healthcare, agriculture, and the energy transition. This research tends to view standards as means to solve particular problems and studies their specific applications. The very diverse application areas addressed in this work reflect standards being recognized as tools that can solve a large variety of issues. Mirroring Lakatos (1970), such research can be qualified as "centrifugal" because the variety of topics that are addressed reinforces the scattered nature of knowledge in the field. Only a smaller share of the reviewed work aims to integrate knowledge on standardization, and treats it as its main object of interest. We qualify this as "centripetal" research, due to its potential for pulling the field together and unifying it. Given the risk of centrifugal research drifting atheoretical themes and topics apart, we suggest that the field as a whole would benefit from more theoretical alignment and integration, focusing on research that aims to develop theory about the core of the most important phenomena. Such consistency may develop from the numerous connections across academic disciplines and topics described in the previous section. Our interpretation of these connections in terms of the "integrative research perspectives" presented in the section above (i.e., managing standardization within and between organizations, standardization for sustainability and the energy transition, social and human aspects of standardization, and technical standardization) is a first step in this direction.

However, we also recognize that, given the nascent and burgeoning phase of this field, many gaps remain to be addressed before having a truly integrative understanding of standardization. In our research agenda, we address the need for more "centrifugal" research focusing on contents, applications, implementation, and goals of standards. However, given our call for theoretical integration, we concentrate in particular on "centripetal" research, which is needed to pull the centrifugal forces together and build more coherent knowledge on standardization. Here, we focus on three areas where we see a particular need for interdisciplinary research to fill this gap: (1) a process approach to standardization, (2) new approaches to understanding and measuring the impact of standards, and (3) studies on standardization policy and governance.

"Centrifugal" Research Directions: Focus on the Content, Applications, and Goals of Standards

The majority of the papers in our review, especially in the technical disciplines, address vertical (i.e., content-oriented) topics (87% of the papers in the perspective "technical standardization," 76% in the perspective "social and human aspects in standardization," and 63% in the perspective "standardization for sustainability and the energy transition"). This focus on vertical topics, which address specific application areas of standards, means that they contribute to the "centrifugal" forces in the field. We see a high relevance of such "centrifugal work" for the large-scale issues that motivate our research agenda (standards' role in shaping the platform economy, ecosystems, sustainable transitions, and the SDGs). Yet, we also notice that the topics covered by these papers are often researched in an isolated fashion or in combination with other vertical topics, meaning that large parts of this research do not aim to contribute to overarching theories about standardization. In the relatively rare instances when research combines "vertical" and "horizontal" topics, it can contribute to both the "centrifugal" and "centripetal" tendencies in the field. For example, normative work on agricultural value chains (vertical topic) and legitimacy or multiple stakeholder initiatives (horizontal topics) (e.g., Arnold & Loconto, 2021; Hospes, 2014; Meemken, 2020; Schouten & Bitzer, 2015) analyzes standards' contributions in the specific agricultural context. At the same time, this research identifies reasons why standards may fall short of expectations for positive contributions to society, which can serve as a basis for further "centripetal" theorizing. A second example of work that was initially triggered by "vertical" questions and eventually also contributed to "horizontal" theorizing is the early work on telecommunication standards ("vertical" topic), which triggered the investigation of SEPs (as part of the broader horizontal topic of *IPR*) (e.g., Bekkers, 2001). SEPs are extremely relevant in that field but increasingly also in others, and the early "centrifugal" work on SEPs in the telecommunications context subsequently developed into a "centripetal" stream about SEPs across industry contexts (e.g., Bekkers et al., 2012; Kang & Motohashi, 2015; Toh & Miller, 2017). Research on SEPs has been feeding into policy studies across the globe, such as that of the U.S. National Academies of Science (Maskus et al., 2013), and recent studies (e.g., Bekkers, Tur, Henkel, van der Vorst, Driesse & Contreras, 2022) formed the basis

for new proposed legislation on SEPs by the European Commission (2023), recently adopted by the European Parliament (2024).

For the further development of purely "centrifugal" research, we see an opportunity for interdisciplinary work. Many of the vertical topics that are currently considered from a predominantly technical angle, such as standards for cyber–physical systems (e.g., Framling, Kubler & Buda, 2014; Jha et al., 2021; Nikoukar, Raza, Poole, Gunes & Dezfouli, 2018; Trappey et al., 2016) or standards for healthcare (Alkraiji, Jackson & Murray, 2016; Grisot & Vassilakopoulou, 2013; Timmermans, 2015), also have important implications for business and society. Combining viewpoints from the technical disciplines with those of, for instance, *economics/management*, *law/regulation/policy*, and *ethics/sustainability*, can generate deeper knowledge on how standards can contribute to solving large-scale issues. We also consider it important that such work takes a strong normative stance in light of the challenges faced by business and society, especially when it involves the *ethics/sustainability* discipline. Examples of these emerging challenges include the role of standards in robotic surgery and medical automation (Arora et al., 2023; O'Sullivan et al., 2019) and potential discrimination raised by the use of standards in algorithms (Oliva, 2020; Raghavan, Barocas, Kleinberg & Levy, 2020).

Furthermore, research on predominantly vertical topics, such as telecommunications, privacy and data security, and healthcare, remains relevant for managerial and social science disciplines, for two reasons. First, this research provides rich and timely empirical data that can be used by other researchers. For example, work on technical aspects of telecommunication standards may be used to trace technology trajectories in this area, which can be related to other concepts of interest to management researchers, such as strategic decisions. Second, technical research on specific application areas of standards may also deliver insights about the functioning of standards in general (i.e., it may also contribute to the centripetal aspects of our research agenda). As outlined above, some research already combines in-depth studies of vertical topics with contributions to horizontal aspects (e.g., Arnold & Loconto, 2021; Hospes, 2014; Meemken, 2020; Schouten & Bitzer, 2015). However, our analysis of the literature reveals that there are still many gaps between vertical and horizontal topics, where there is potential for connections (see Figure 3). For example, we see potential for investigating the role of CSR standards in the context of corporate strategy, and there appears to be a natural, but still unexplored, link between research on healthcare and education standards with questions related to legitimacy or impact assessment. By creating these and similar hitherto under-investigated connections between vertical and horizontal topics, the gap between "centrifugal" and "centripetal" tendencies may be closed in a manner similar to what we observed in the areas of agriculture and telecommunications (e.g., Arnold & Loconto, 2021; Bekkers, 2001; Hospes, 2014; Meemken, 2020; Schouten & Bitzer, 2015). Ultimately, such more application-oriented research can also contribute to further theoretical integration of the field. The path toward theoretical integration is the specific object of the next research agenda section, which focuses on "centripetal" research directions.

"Centripetal" Research Directions: Toward the Emergence of a Theory of Standardization

The findings of our review suggest that standardization research in management, economics, and the social science disciplines moves toward the direction of progressive theoretical integration (see Tables 4 and 5, which show how research in these disciplines addresses mainly horizontal—i.e., theoretical—topics). Building on this insight, we suggest three further directions that can help generate theoretical development on standards as constructs that contribute to explaining major transformations in business and society:

1. Taking a process approach to standardization allows us to identify major gaps in extant research. Addressing these gaps can contribute to further theoretical integration.
2. While there is a consensus on standards' importance for business and society, a better understanding and improved ways of measuring their impacts are needed to explain how they make this contribution.
3. Policy and governance of standardization have already been established as areas of research, but new developments in the field necessitate additional research and theorizing.

In the subsequent paragraphs, we explain these three points in detail and present our proposals for the next steps.

Process approach to standardization. Previous research has conceptualized standardization as a process, which (1) starts with multiple parties recognizing the need for a standard, then (2) triggers its

development, and is then (3) followed by the standard's spread, adoption, and implementation (de Vries, 2010). While the steps of this process were described more than a decade ago, research so far has especially focused only on the second step—standard development (e.g., Boström & Tamm Hallström, 2013; Jain, 2012; Ranganathan et al., 2018; Toh & Miller, 2017; Wiegmann et al., 2017).

Specifically, we are aware of barely any work on how this process is started up (stage 1). This relates to stakeholders' needs and motivations for having a standard. How do standards emerge, and who comes up with the original idea or need of a standard? How does the idea of a certain standard relate to parallel developments in technology, business, and society? How are stakeholders mobilized to generate a standard, or to oppose its development? Which forces may counter the initiation of standard development, and which contingencies in this phase affect its further trajectory? Given the widespread recognition of a need for standards to support major transitions in business and society, we see answers to these questions as essential for understanding how standards are created. We call for interdisciplinary research to understand how the initiation of standardization processes is driven by business strategies, sociological developments involving societal stakeholders, legal and regulatory considerations, and technological development.

Moreover, the study of standard spread, adoption, and implementation (stage 3) is vital for understanding managerial actions related to standards, and for measuring how standards affect businesses and society as a whole. Yet, our review shows that previous work has been limited to a few specific settings, such as agricultural value chains studied through a sociological lens (e.g., Arnold & Loconto, 2021; Meemken, 2020), the spread of dominant designs and de facto standards (e.g., Chen et al., 2017; Suarez et al., 2015), and some work on standard adoption inside organizations (e.g., Boiral, 2007; Sandholtz, 2012). The idiosyncrasies of these settings and the very specific research questions make it difficult to develop generalizable theories on standard adoption and implementation. For example, the work on agricultural value chains (e.g., Arnold & Loconto, 2021; Meemken, 2020) focuses on dynamics and power imbalances between stakeholders in the global north and south, which do not exist in this form in many other industries. The work on adoption of de facto standards and dominant designs (e.g., Chen et al., 2017; Suarez et al., 2015) primarily studies market-based standardization and largely ignores standards created in phase (2) in the committee-based and government-based models (see David & Greenstein, 1990; Wiegmann et al., 2017).

Research in other settings is therefore needed. Management scholarship can provide important foundations, for example, by cross-fertilizing with theories of *networks and ecosystems* (see Bogers et al., 2019; Jacobides, Cennamo & Gawer, 2018). This can help understand dynamics in the adoption and implementation of standards, which depend on interdependent actors who are likely to be organized in ecosystem-like networks. In addition, we see a specific need for research on *standard taking* (i.e., organizations adopting standards that have been developed by others). This raises relevant questions, which have not yet been investigated. For example, from a strategy perspective, there is a lack of work on managers' decisions about whether to apply existing standards or engage in developing new ones, or how to choose between competing standards. Management scholars may also go beyond current work in organization theory to understand how managers affect the effectiveness of standards adoption.

Standards development (stage 2), as emerging from our review, has been researched most intensively, but we also see scope for additional (interdisciplinary) work here. This part of the process involves designing solutions to be included in standards and decision-making. Current research mostly addresses these elements in isolation: some older studies on the design aspect of standard development build on new product development theories (Nakamura, 1993; Susanto, 1988) and research on decision-making in standard development commonly uses game theory or stakeholder theory (e.g., Farrell & Simcoe, 2012; Jakobs, 2023; van de Kaa & Greeven, 2017). These theoretical perspectives may be combined, reflecting what happens in practice during real standardization processes, where experts who draft a standard may also be the ones to approve that same standard (de Vries, 1999). Therefore, in-depth empirical studies are needed to understand how these parts of the process relate to each other. This research can utilize insights from several academic disciplines. For example, ethicists have studied how standardization can be made inclusive (e.g., Meijer, Wiarda, Doorn & van de Kaa, 2023), and sociologists study standardization under a collective action perspective (e.g., Dokko et al., 2012; Lee et al., 2015; Slager et al., 2012; Sydow et al., 2012). Furthermore, extant work on standard development from a managerial perspective (e.g., Baron et al., 2016; Ranganathan et al., 2018; Toh & Miller, 2017) is somewhat lopsided

toward the activities of large firms, often in the ICT sector. We see opportunities to extend this research and take the perspective of other actors in standardization. For example, while small- and medium-sized enterprises face substantial hurdles in standardization (de Vries, Blind, Mangelsdorf, Verheul & van der Zwan, 2009), there is barely any research that investigates how they navigate the field.

Understanding and measuring the impacts of standards. Standards have a substantial impact on individuals, businesses, the economy, and society. This impact lays at the foundation of their (potential) role in shaping large developments in business and society. Yet, our understanding of how this impact comes about and how it can be measured remains relatively limited. Previous work focuses on some specific aspects, such as standards' contributions to economic growth and the GDP (e.g., Blind & Jungmittag, 2008; Blind, Jungmittag & Mangelsdorf, 2011), intra-organizational dynamics spurred by standards (e.g., Boiral, 2007; Sandholtz, 2012), and the impacts of specific standards (e.g., Boiral, Guillaumie, Heras-Saizarbitoria & Tayo Tene, 2018; Manders, de Vries & Blind, 2016; Meemken, 2020).[8] A broader perspective, including a theoretical understanding of the mechanisms behind standards' impacts and empirical evidence for them, is largely missing. Following the process perspective above, work needs to start with a focus on standard implementation. This work should, for example, explain how standards' impacts are contingent on their contexts, how standards interact with one another in creating impact, and how to quantify this impact. Once these questions have been answered, we see a need for more normative research that explains what should be done during the initiation and development stages to achieve standards with desirable impacts.

Given the broad variety of potential impacts, we again see a need for interdisciplinary research. While standards' impacts are largely driven by businesses, the sociological work in our review (e.g., Arnold & Loconto, 2021; Meemken, 2020) shows that standards affect many areas of society, including the most marginalized players. This also brings a strong ethical dimension to the topic, and standards' impacts may also have implications for policy and law.

Studies on standardization policy and governance. Approaches to governing standardization and their underlying policies are key in determining how standardization functions; for example, in terms of how stakeholders can contribute to standard development, whether all stakeholders' needs are considered, and whether there are effective mechanisms for reaching coordination (e.g., Austin & Milner, 2001; Kanevskaia, 2023; Tate, 2001). These approaches differ across industries, cultures, geographical and national contexts; for example, in terms of links between standards and regulation, modes of standardization, and the stakeholders that are typically involved (Tate, 2001). Furthermore, recent developments have introduced strong elements of geopolitics into policy and governance of standardization. For example, the Chinese government has been using standardization as a tool to increase national industries' competitiveness (e.g., Gao, 2015; Gao et al., 2021; Gao & Liu, 2012; Kwak et al., 2012), and the European Commission aims to align standards with "European values" (European Commission, 2022). Standardization policies that have been shared by various governments in recent years seem to emphasize standards that suit national and regional needs (European Commission, 2022; Government of India, 2018; State Council of the People's Republic of China, 2021; The White House, 2023). Yet, it remains unclear how different approaches to policy and governance, both in general and in light of such recent developments, affect the functioning of standards and standardization.

Our review revealed that the discourse on how governance and policy relate to standards primarily focuses on their role as "private" governance instruments (e.g., Boström & Tamm Hallström, 2013; de la Plaza Esteban et al., 2014; Flynn & Hacking, 2019; von Geibler, 2013), whose legitimacy varies depending on the context in which they are developed, used, and adopted (e.g., Derkx & Glasbergen, 2014; Manning & Reinecke, 2016). The focus of this research lies on how standards affect the governance of, for example, value chains and CSR initiatives, but it offers few insights on how standards and standardization themselves are governed. Furthermore, the context-specific nature of standards in practice needs to be factored into theoretical alignment and common conceptual integration. Without overarching studies of standards across contexts, a possible centrifugal force may emerge that subjects the definition and meaning of standards to local and often idiosyncratic cultural, political, and organizational contexts. As an emerging preliminary result from our review, we suggest that debates on how standards themselves are governed through law and policy could benefit from the integration of vertical (i.e., research analyzing the development and adoption of standards in specific local contexts; e.g., Manning, Boons, von Hagen &

[8] The latter research may be characterized as "vertical."

Reinecke, 2012; Raffaelli, 2019) and horizontal (i.e., research looking for common conceptualizations across different national and geographical contexts; e.g., Botzem & Dobusch, 2012; Brunsson et al., 2012; Derkx & Glasbergen, 2014) views on the topic. Specifically, we suggest that this integrative work should merge two levels of analysis: (1) the macro level, to better understand how standardization is governed by national and, if applicable, regional policies; and (2) the micro level, to understand how individual firms and other stakeholders navigate this field.

First, studies on the differences in international approaches to standardization on a macro level should integrate *sociology* and the *law/regulation/policy* disciplines in order to generate a better understanding of the organizational setup of standardization (e.g., roles played by SDOs themselves, and by companies, industry consortia, governments, NGOs, and other stakeholders). This integrative research is needed to investigate how the setup of standardization contributes to different outcomes; for example, in terms of international trade and competitiveness, balance between business and societal interests, and legitimacy of the resulting standards.

Furthermore, we see a need for more integrative "activist" research that bridges technical and social science disciplines to study how standards can contribute to more fairness on a national and global scale. This work can bridge technical knowledge from IT, engineering, and other "hard" sciences with insights from the ethics and sustainability work identified in our review (e.g., Brako et al., 2021; Flynn & Hacking, 2019; von Geibler, 2013). In this direction, we also see a promising opportunity for conducting design science research (see Romme, 2003; Simon, 1969) that develops new approaches to governing standards at the global level to promote values such as fairness and ethical consumption.

Second, at the micro level, research is needed to take the perspective of institutional actors, businesses, and other stakeholder organizations to understand how they can reap the benefits of standards and standardization (e.g., Tate, 2001). Questions to be investigated include, for example, the kinds of resources and capabilities that firms need to effectively adapt their approaches to standardization in international settings; whether and how firms can use differences in standards across the globe to their advantage; and how policymakers react to firms' strategic behavior to support societally desirable standardization outcomes.

From an institutional perspective, further research should also investigate the hybrid role played by SDOs in the context of standardization policy and governance. SDOs play a central role in guiding standardization processes (Brunsson et al., 2012). There is some work on national standard bodies (Bonner & Potter, 2000; de Vries, 1999; McWilliam, 2001) and some recent research shows the importance of SDOs' management for firms and other actors in standardization (Baron & Spulber, 2018; Wiegmann, Eggers, de Vries & Blind, 2022). However, there is still a lack of research that investigates more precisely how SDOs are managed, and what effects this has on their ability to effectively facilitate the development and implementation of standards. For example, SDOs are generally seen as neutral facilitators of the standardization process. However, in a world where standards are expected to generate a positive impact on society, it is questionable whether it is possible (or even desirable) for SDOs to be value free in light of the interests that stakeholders bring to the table. How exactly their role plays out in light of such fundamental dilemmas is an important question that is still unexplored in the current literature. Research may build on a conceptualization of standardization as an activity that occurs in networks of stakeholders with different and often-competing utility functions, and in which the SDO takes on the role of a network administrative organization (see Provan, Fish & Sydow, 2007; Provan & Kenis, 2007). This would allow bridge theories about the governance of standardization with theories on interorganizational social networks, which might show the process of standards development and adoption as a dynamic network process in which a multitude of different actors is involved (e.g., Stevenson & Greenberg, 2000).

CONCLUSIONS AND FINAL REMARKS

We conclude our review and our research agenda with an overarching question: "Does the standardization field need its own theories, or can it use, adapt, and merge theories from adjacent fields?" Following Lakatos (1970), we suggest that the answer bridges both elements of this duality. Standardization is an emerging field of research in need of more theoretical consistency, without losing its ability to scout, select, and include a wide array of conceptual and phenomenon-led topics across academic disciplines. Our review of contemporary research reveals a balanced tension between the role of social science disciplines (steering the evolution of standardization theorizing) and the role of technical disciplines (providing empirical findings and adding novel phenomenon-driven perspectives). So, we recommended continuing content-related "vertical"

research, conducted by hybrid teams of subject-matter experts and social scientists. Management scholars will play a key role in such teams because they can link organizational decisions to the processes of standards-making and standards-taking, in all their different stages. At the same time, we recommend advancing research on the multiple "horizontal" themes identified in our study. Such research would again benefit from interdisciplinary teams, enabling the development of novel standardization theories that build on and integrate existing notions from the social science disciplines. With standardization being an important business phenomenon, we believe that it has the potential to develop into a specialism within business science.

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