Standardization

Research Trends, Current Debates, and Interdisciplinarity

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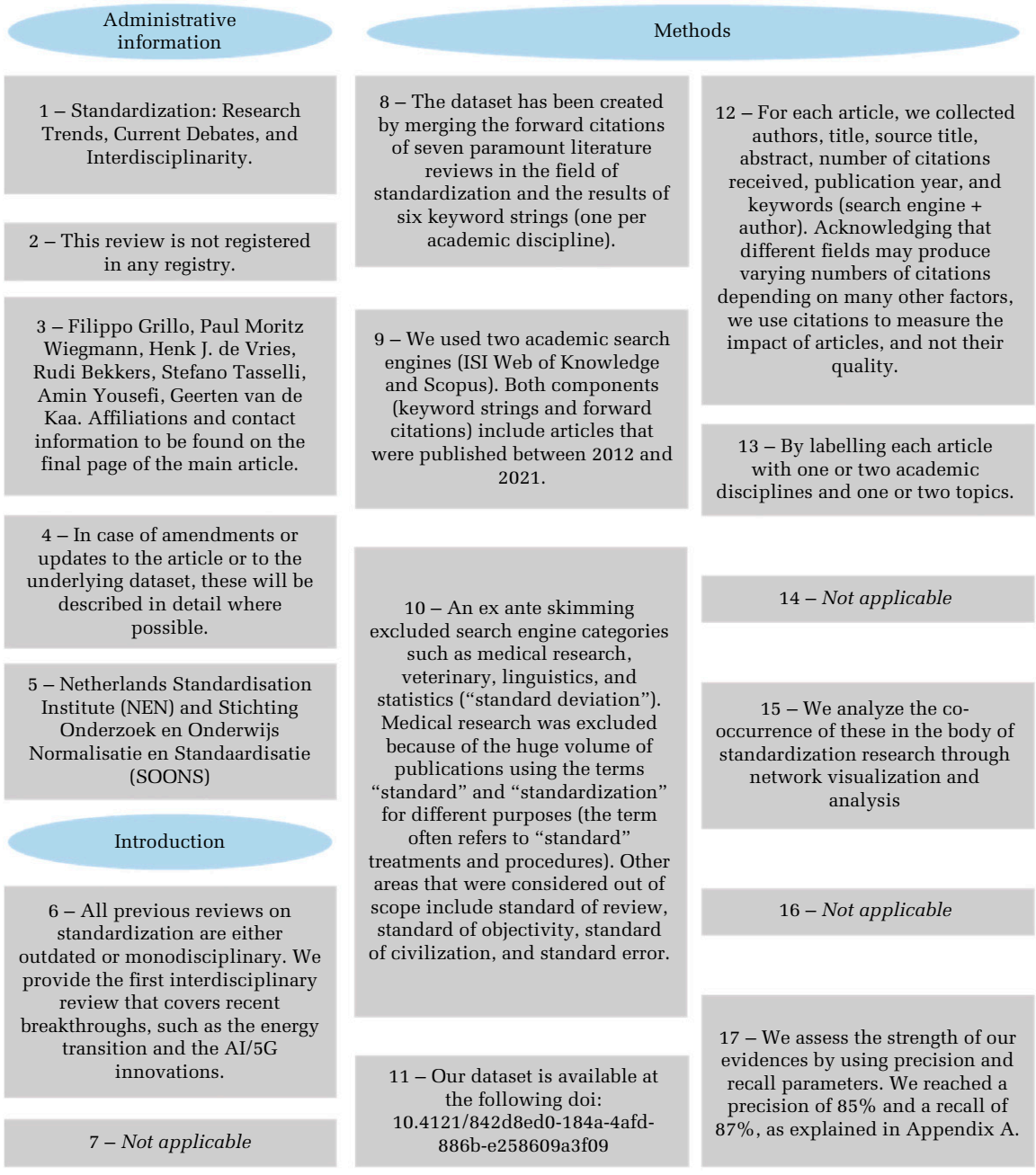
APPENDIX A
DATASET QUALITY, PRECISION, AND RECALL

Our review follows the Preferred Reporting Items for Systematic Reviews and Meta-Analyses Protocol (PRISMA-P). The 17 points of the protocol, as described by Shamseer et al. (2015), are explained in Figure A1.

To measure the quality of our dataset, we assess its precision and recall, where "precision" refers to how pertinent and relevant the papers included in the dataset are, and "recall" expresses the sample's completeness compared to all available sources (Donner, Rimmert & van Eck, 2020; Gehanno, Rollin, Le Jean, Louvel, Darmoni & Shaw, 2009). These are

FIGURE A1
Our Systematic Approach Described through the PRISMA Protocol



Note: Our dataset is available at https://data.4tu.nl/datasets/842d8ed0-184a-4afd-886b-e258609a3f09/1

inversely related functions, meaning that a very precise dataset is likely to have a low recall and vice versa (Gehanno et al., 2009). Eventually, we reached an estimated precision level of 87% (i.e., while coding the papers, 13% of them were considered out of scope) and an estimated recall of 85%, expressing the extent of standardization literature represented in our sample. Agreeing on the extensive number of papers on standards available in the literature, we aimed for a more precise dataset not to compromise the quality and reliability of our data.

Precision is measured as the share of correctly retrieved publications among the total number of retrieved publications (Donner et al., 2020). While categorizing the high-impact dataset (i.e., the dataset is filtered according to the citation thresholds found in Table 1 of the main paper), we found 202 papers, out of 1,555, that did not fit the scope of our definition of standardization. According to the formula by Donner et al. (2020), this means a "precision" of roughly 87% of our dataset.

Likewise, Donner et al. (2020) define "recall" as the share of correctly retrieved publications among all relevant publications. To measure recall, we took two independent sources from our dataset that complied with our definition of standardization. We extracted the set of papers citing these sources, and applied the same filters we applied to our dataset, such as the publication year (2012–2021), citation thresholds, and document type (only articles and reviews). Then, we only included the sources that had the word "standardization" or "standardization" in the abstract. From this subset of papers, we checked how many of them were also present in our main dataset by tracking the duplicates. We have completed this exercise for Farrell and Saloner's (1985) "Standardization, Compatibility, and Innovation" and for Tassey's (2000) "Standardization in Technology-Based Markets," obtaining a result of 89% in the former case (17 out of the 19 skimmed sources were present in our main dataset) and 81% in the latter (21 out of 26 sources), averaging an estimated recall of 85%.

APPENDIX B
NETWORK VISUALIZATION

The network diagrams have been drawn using the software Gephi. The network nodes are based on either academic disciplines (see Figure 2 of the main article) or topics (Figures 3 and 4 of the main article); the ties between the nodes are based on the number of sources that were categorized with the two nodes (i.e., co-occurrence). All graphs are designed following the same algorithm: the number of co-occurrences determines both the closeness of the nodes and the thickness of the ties. Such a layout is called ForceAtlas2 in Gephi (Jacomy, Venturini, Heymann & Bastian, 2014). This means that, if many papers are labeled with, for example, *Telecommunications* and *Education*, these two nodes are close to each other and have a thick line connecting them; in addition, the node's size is determined by the number of papers labeled with the node's topic; lastly, in Figures 3 and 4 of the main article, the nodes were colored based on the type of topic (green for the horizontal topics, light blue for the vertical ones).

Table B1 lists the top 10 pairs of topics in terms of co-occurrences in our dataset.

APPENDIX C
LIMITATIONS OF THE DATASET

Our review provides a qualitative interpretation to a large set of bibliometric data. The process has been systematic and long, yet some limitations emerged. Although scholars agree that citations are not the sole indicator of the quality of research

TABLE B1
Top 10 Most-Recurring Connections between Topics

	Topic 1	Topic 2	No. of papers
1	Energy policy	Impact assessment	23
2	Renewable portfolio standards	Pricing	20
3	Automation	Telecommunications	19
4	Automation	Privacy and cybersecurity	17
5	Accounting and finance	Legitimacy	16
6	Multistakeholder initiatives	Agriculture	16
7	Standards competition	Technology development and adoption	12
8	Telecommunications	Privacy and cybersecurity	10
9	Healthcare	Privacy and cybersecurity	9
10	Telecommunications	Technology development and adoption	8

(Bornmann & Daniel, 2008), multiple bibliometric reviews (e.g., Blind & Fenton, 2021; Jappe, 2020; Liu, Li & Wang, 2021) make use of them in order to have a proxy of relevant publications in a specific field. For this reason, we refer to our dataset as made of "impactful" papers, without referring to the quality of such papers. We indeed acknowledge that the quality of a paper can be assessed in many other ways, yet this is seldom feasible in analyzing a large set of sources.

One improvement to our method concerns the reliability of our thematic analysis. Even if performed in a sequential and unbiased way, the coding of each paper was limited to four keywords (two academic clusters and two topics), yet more terms could have been included for more profound content analysis. The triple-blinded process, though, ensured that the four keywords represented the focal content of each paper.

To reach a high precision of the dataset, we decided to exclude the medical categories while pooling the papers from search engines. Keywords such as "standard error" and "standard deviation" expanded our dataset with many papers from all medical sciences that did not fit the purpose of this article. However, many papers discussing the function of technical standards in medicine fell under our analysis, thanks to adjacent keywords such as "healthcare" and "physics." Due to this exclusion decision, we do not find the medical field as one of the vertical topics, but we now find it in the horizontal category. In fact, our distinction between horizontal and vertical is not always dichotomic, since some papers may have elements of both.

Lastly, our data include papers until June 2021. This means that our analysis partially reflects research on the COVID pandemic and the potential function of standardization to mitigate its consequences. Likewise, this applies to the Russian–Ukrainian war and the subsequent economic, energetic, and military crises.

APPENDIX D
DEFINITIONS OF STANDARDS

In Table D1, we show the process behind the creation of working definitions for *standards*, *standardization*, or adjacent terms. For each discipline, starting from the most cited paper onwards, we extracted either a definition or a characterization for one of these terms. Most of the definitions or characterizations may be limited to an application area (e.g., "measurement" or "sustainability" standards). Once we gathered five definitions, we interpreted them commenting on the context and the function of standards they describe. Finally, we combined them into a unique working definition for each discipline. Table D1 shows quite some diversity in definitions per discipline. The working definitions reflect our attempts to seek commonalities within the discipline. These working definitions differ substantially as well.

APPENDIX E
DEFINITION OF STANDARDIZATION FOR MANAGEMENT RESEARCH

In the main paper, we try to develop a common definition for management research, applicable to all disciplines. We use the present appendix to explain the process used to arrive at our definition. The International Standardization for Standardization (ISO) and the International Electrotechnical Commission (IEC) define "standardization" as the activity of establishing, with regard to actual or potential problems, provisions for common and repeated use, aimed at the achievement of the optimal degree of order in a given context. In particular, this activity consists of the processes of formulating, issuing, and implementing standards (ISO/IEC, 2004: 4).

This definition is limited to standard-setting organizations, without specifying the *actual and potential problems* standards are established for. Discussing the characterizations of standards from 16 definitions, mostly from practitioners, de Vries (1997) formulated a wider definition, drawing the need for *common and repeated use* from the ISO/IEC definition (updated in 2004), to differentiate an agreed solution from a standard. Since then, even if no academic discourse emerged on the definition of standardization, literature from different academic disciplines has produced a wide variety of definitions. Here, we gather terms describing characterizations, actors involved, functions, types of obligation, and other elements from the different "disciplinary" definitions in Appendix D.

First, the definitions incorporate many characterizations of standards; for example, *norms, procedures or methods* (discipline 1),[i] *technical rules* (2), *regulations* (3), *interface specifications and corporate practices* (4), *documents* (5) or *communication protocols, data models, and technical specifications* (6). Though most standards are technology related, this does not apply to all of them, making the appellation *technical rules* appear too specific. The appellation as *documents*, instead, shows how a formalized

TABLE D1
Working Definitions for Each Academic Discipline

Academic discipline		Sources for definitions	Our interpretation	Working definition
(1)	Ethics/ sustainability	Standards are norms selected as a model by which to judge and compare people, products or actions, and which provide a common language to evaluators, the evaluated and their audiences (Ponte & Cheyns, 2013: 461)	Emphasizes the measurement function of standards	Standards are voluntary set of norms, procedures, or methods for assessing the social and environmental performance of products, processes, people, or organizations
		Sustainability standards may be understood as "voluntary predefined norms and procedures for organizational behavior with regard to social and/or environmental issues" (Christensen, Morsing & Thyssen, 2017: 241)	Specific to sustainable voluntary standards	
		A sustainability standard can be defined as a set of "voluntary predefined rules, procedures, and methods to systematically assess, measure, audit, and/or communicate the social and environmental behavior and/or performance of firms" (Reinecke, Manning & von Hagen, 2012: 793)	Specific to corporate sustainable voluntary standards, emphasizes the measurement and the communicative functions	
		Voluntary standards are governance mechanisms that have recently taken off to achieve a positive impact of corporate actions on social actors or the natural environment (Wijen, 2014: 4)	Specific to corporate voluntary standards	
		Multistakeholder standards as standards that ensure membership of those concerned; with governance open for all stakeholders and with various parties taking on a "watchdog" function (Balzarova & Castka, 2012: 266; taken from Fransen & Kolk, 2007)	Emphasizes the presence of both private and public actors in the standardization process, and distinguishes governance and control as key stages in the standardization process	
(2)	Sociology	Standards, and, in particular, transnational standards, are formal rules designed to play a coordinating function, through the specification of voluntary "best practice" rules. They are developed by non-state organizations, and compliance often depends on pressure from third parties (i.e., other than the state or the firm) (Schweber, 2013: 131)	Excludes governmental standards. Also, most standards tend to be a compromise between stakeholders: the best practice, if any, is often not acceptable to the majority	Standards are measurements and technical rules built by individuals, groups, and institutions for their control and compliance, reproducing particular societal values, beliefs, and assumptions
		Standardization is the process by which individuals, groups and institutions construct "uniformities across time and space" through "the generation of agreed-upon rules" (Lamont, Beljean & Clair, 2014: 19, taken from Timmermans & Epstein, 2010)	Emphasizes the function of standards as solution providers, but excludes standards that set performance criteria or provide test methods	

TABLE D1
(Continued)

Academic discipline		Sources for definitions	Our interpretation	Working definition
		Standards are the protocols, practices, procedures, and technologies that establish the rules for coordination across sociotechnical systems, and, in so doing, establish path dependencies that shape future social and economic priorities. Because standards are designed and codified by particular actors in specific times and places, it follows that they are sites of power and resistance; they reflect and reproduce particular values, beliefs, and assumptions (Carse & Lewis, 2017: 13)	Emphasizes the negative outcomes of standards (path dependency, power concentration). Technologies cannot establish rules but, rather, the actors behind such technologies	
		Standardization is increasingly recognized as a form of regulation and standards are regarded as "instruments of control" that facilitate coordination by defining the appropriate attributes of the standardized subject, rendering these aspects visible to external inspection and opening up the possibility of sanctioning non-compliance (Slager, Gond & Moon, 2012: 764)	Explains the regulatory function of mandatory standards, whose non-compliance can be sanctioned	
		Standardization in the metrological sense results in the creation or definition of equivalent things, whereas standardization in the infrastructural sense refers to extending or implementing standards as technical guides or rules. Rather than being an integral component of metrology, then, standards should be considered a related, rather than synonymous, phenomenon (Cooper, 2015: 1791)	Emphasizes the double function of standards of providing measurement references and technical guidelines	
(3)	Law/regulation/ policy	Renewable portfolio standards (RPSs) are a relatively new policy mechanism being put to use in several countries to reduce costs, link the regulated market outcome to an environmental target, and reduce government involvement (Sun & Nie, 2015: 255)	Specific to RPSs, whose function is the one of performance measurement for firms	Standards are a form of regulation developed by governments and private actors from business and civil society, usually laid down in a document that is approved by a recognized body
		An intensity standard refers to a policy that regulates an externality per unit of output (Holland, 2012: 377)	Similarly to RPSs, intensity standards are an alternative method to measure firms' emissions	
		Standards are tools for the reduction of transaction and agency costs (Botzem, 2014)	Explains the coordinating function of standards	

TABLE D1
(Continued)

Academic discipline	Sources for definitions	Our interpretation	Working definition
	Standards are defined as a form of regulation—that is, a specific type of rule—which is formed on the basis of a degree of common understanding among standard-setting actors. It comprises a set of solutions to actual or potential problems, and is meant for common and repeated use. Standards are usually laid down in a document that is approved by a recognized body. They provide rules, guidelines, or characteristics for activities (process oriented) or results (output oriented), thereby coordinating interaction (van den Hurk & Verhoest, 2016: 10)	Explains the function of standards as regulations (i.e., mandated by a recognized body)	
	Private standards are forms of voluntary rule-setting involving non-state actors from business and civil society (Dobusch & Quack, 2013: 4)	Specific to private standards	
(4) Economics/ management	The standardization of organizations relates to how standards are adopted, diffused, implemented, avoided, and altered in the course of their implementation. Standardization by organizations concerns the fact that most standards are the product of formal organizations. Last, but not least, standardization can be viewed as a form of organization. In the latter context, standards provide organization outside of formal organizations and hence can be perceived as an important governance mechanism underlying many aspects of contemporary society (Brunsson, Rasche & Seidl, 2012: 5–6)	Provides a useful distinction between three aspects of the standardization process (taking standards, making standards, and the multistakeholder governance)	Standards are interface specifications and corporate practices that function as coordination mechanisms within innovation ecosystems
	Technological standards provide foundational platforms on top of which rival firms build their product and service offerings. They appear primarily in the form of dominant designs. Dominant designs (e.g., Henry Ford's Model T, Apple's iPhone) emerge via market competition and become de facto standards, unlike the wireless telecom and other types of complex standards that are cooperatively developed, usually under the auspices of standard-setting bodies like the European Telecommunications Standards Institute and the Institute of Electrical and Electronic Engineers (Teece, 2018: 1380)	Emphasizes the role of some types of standards (mostly compatibility standards) within ecosystems and their relationship with dominant designs and platforms	

TABLE D1
(Continued)

Academic discipline		Sources for definitions	Our interpretation	Working definition
		A standard defines the overall architecture of a technology system, accompanied by a set of interface specifications among component subsystems. Standardization is the process of developing, ratifying, and implementing standards (Gao, Yu & Lyytinen, 2014: 201)	Similarly to Teece (2018), it emphasizes the role of compatibility standards within ecosystems	
		With corporate responsibility (CR) standardization, we refer to the institutionalization of a standard—that is, the progressive cognitive validation of a CR-related practice (Haack, Schoeneborn & Wickert, 2012: 3)	Specific to CR standards	
		We define standards as digital technologies that enable, constrain, and coordinate numerous actors' actions and interactions in ecosystems, fields, or industries (Hinings, Gegenhuber & Greenwood, 2018: 53)	Emphasizes again the role of standards in larger technological architectures (ecosystems, industries)	
(5)	IT/ engineering	Standardization activities play a crucial role in securing the IoT ecosystem, both in terms of improving interoperability of IoT devices in general and to pave the way toward wider industry adoption of security solutions (Keoh, Kumar & Tschofenig, 2014: 266)	Specific to compatibility and (cyber) safety standards	Standards are documents that ensure interoperability, cybersecurity, and performance measurement of technological solutions
		Standardization for wireless vehicular communication ensures, as in other domains, interoperability, supports regulations and legislation, and creates larger markets (Festag, 2015: 409)	Emphasizes functions of standards (interoperability, market creation, and support for regulation)	
		Standardization helps industry avoid interoperability issues and understand the technology landscape as the new technology frontier is created (Trappey, Trappey, Govindarajan, Chuang & Sun, 2017: 210)	Emphasizes the functions of interoperability and coordination (put in other words, the industry actors understanding of the new technology frontier)	
		Standards are published documents that serve as a fundamental building block for product or process development and include methods for insuring usability, predictability, safety all parties involved in the manufacture of goods or delivery of services. A standard ensures intra and interoperability of products and services	Specific to mandatory written standards	

TABLE D1
(Continued)

Academic discipline		Sources for definitions	Our interpretation	Working definition
		produced and its compliance is mandatory for product commercialization (Trappey, Trappey, Govindarajan, Sun & Chuang, 2016: 7358)		
		Standardization of indicators provides harmonization in indicators, reliability and transparency in calculation methods, and comparability of results (Huovila, Bosch & Airaksinen, 2019: 142)	Emphasizes the function of performance measurement	
(6)	Other sciences	Technology standards and specifications provide the basis to achieve interoperability, integration, and scalability through standardized protocols and data models (Memon, Wagner, Pedersen, Aysha Beevi & Hansen, 2014: 4323)	Specific to protocols, emphasizes interoperability and scalability	Standards are communication protocols, data models, and technical specifications that improve scalability, safety, quality assurance, and interoperability
		Standards can be expected to enable interoperability, reduce costs through economies of scale, and create mass markets. More generally, common standards facilitate the diffusion of new technologies and the development of entire technological field (Erlinghagen, Lichtensteiger & Markard, 2015: 1250)	Emphasizes interoperability and scalability	
		Smart grid ICT standards mainly define communication protocols and interface specifications, but other aspects, like cybersecurity and function modeling, are also described (Naumann, Bielchev, Voropai & Styczynski, 2014: 103)	Specific to smart grid ICT standards, in the form of protocols, interface specifications, and cybersecurity standards	
		Standards allow decoupling of design from production from assembly from deployment—and they help to reduce the lack of reproducibility of results that plagues the scientific and technical literature in biology and biotechnology (de Lorenzo & Schmidt, 2018: 171)	Explains the implications of standards on production processes, contextualized to biology and biotechnology	
		Standards can improve communication, compatibility, interchangeability, reproducibility, effective use, fitness for use, safety, quality assurance, and, ultimately, consumer protection and environmental protection (Müller & Arndt, 2012: 24)	Does not provide a definition but lists some advantages of standards	

writing is what distinguishes a standard from a social norm (see also Blind & Fenton, 2021; Brunsson et al., 2012). A second element concerns who develops these standards: *individuals, groups and institutions* (2) or *governments and private actors* (3). The other disciplines do not specify any actor, and this seems to be the best choice, given the vastness of stakeholders' categories that have developed standards in the past. Third, (3) mentions *approved by a recognized body*. This would exclude standards stemming from, for instance, industry consortia, individual companies, or NGOs, limiting the scope of our definition. Fourth, some elements combined from the definitions can be annexed to our definition. This applies to the functions of standards, since they *assess social and environmental performance* (1), *facilitate control and compliance* (2), *are coordination mechanism within innovation ecosystems* (4), *ensure interoperability, cybersecurity, and performance measurement of technological solutions* (5), and *improve scalability, safety, quality assurance, and interoperability* (6). The same applies to aims or benefits of standardization mentioned in some of the definitions (2, 5, 6), and to the two rates of obligation a standard can have, being either (1) *voluntary* or (3) a form of *regulation*. Lastly, to specify which *problems* ISO and IEC refer to, we build from many sources describing them as *coordination problems* (Carse & Lewis, 2017; Schweber, 2013; Slager et al., 2012; van den Hurk & Verhoest, 2016). Altogether, these elements lead to our 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. The resulting set of solutions, often expressed in the form of a written document, is the standard.

APPENDIX F
DESCRIPTIVE FIGURES OF STANDARDIZATION RESEARCH

This appendix contains extensive information about the dataset that was used by the authors to shape the findings mentioned in the main paper.

Table F1 includes a description of the most cited articles for each timespan and for each discipline, while Figure F1 exhibits the annual share of each academic discipline in our dataset. The most evident trend is the increase in *IT/engineering* in the last five years. A closer investigation of the papers itself

TABLE F1
Content of the Top 5 Papers per Academic Discipline

Academic discipline	No. of papers	Top 5 papers per number of citations (2012–2016)	Top 5 papers per number of citations (2017–2021)
Ethics/sustainability	189	Papers on certifications based on agricultural standards for palm oil (Ponte & Cheyns, 2013; Von Geibler, 2013) and coffee (Reinecke et al., 2012), institutions' adoption of sustainability standards (Wijen, 2014), an empirical analysis of labor standards in different countries (Davies & Vadlamannati, 2013)	Papers on certifications based on agricultural standards for palm oil (Brandi, 2017; Higgins & Richards, 2019), the ethics of teaching standards (Elton-Chalcraft, Lander, Revell, Warner & Whitworth, 2017), energy access as a living standard (Rao & Pachauri, 2017), and disclosure of sustainability standards (Christensen et al., 2017)
Sociology	146	Two case studies on the legitimacy of global accounting standards (Albu, Albu & Alexander, 2014; Guerreiro, Rodrigues & Craig, 2012), a framework for standardization against social inequalities (Lamont et al., 2014), an investigation of responsible investment standards (Slager et al., 2012), a paper on the governmentality of standards in the construction industry (Schweber, 2013)	A position paper on the usage of clicks as a standardized metric in journalism (Christin, 2018), an analysis of the governmental enforcement of labor standards (Fine, 2017), and papers on the use of standardized definitions for population ethnicity in genetics (Panofsky & Bliss, 2017), fair and inclusive infrastructure standards (Carse & Lewis, 2017), and the inclusion of producers in global supply chain governance (Bennett & College, 2017)

TABLE F1
(Continued)

Academic discipline	No. of papers	Top 5 papers per number of citations (2012–2016)	Top 5 papers per number of citations (2017–2021)
Law/regulation/policy	251	Two comparative studies of feed-in tariffs versus RPSs (Dong, 2012; Sun & Nie, 2015), and papers on the standardization of flood maps to allow local governments to mitigate flood risks (Porter & Demeritt, 2012), emission standards versus emission taxes (Holland, 2012), and standardization to support regulation of electric vehicles (Li, Zhan, de Jong & Lukszo, 2016)	An essay on how predictive micro directives can prevail on laws and standards (Casey & Niblett, 2017), a paper on the use of education standards by the OECD (Addey, 2017), a comparative study of feed-in tariffs versus RPSs (Alizada, 2018), and two papers on how governments regulate via standards and certificates, in the bio-based industry (Ladu & Blind, 2017) and on cybersecurity (Srinivas, Das & Kumar, 2019)
Economics/management	411	Four conceptual papers on the role of standards in platforms ecosystems (Gawer & Cusumano, 2014) and industrial evolution (Benner & Tripsas, 2012; Cusumano, Kahl & Suarez, 2014), and the dynamics of standardization in organization theory (Brunsson et al., 2012); a paper on lending and credit standards in the 2008 subprime crisis (Dell'Ariccia, Igan & Laeven, 2012)	Papers on the role of standards in innovation ecosystems (Dattée, Alexy & Autio, 2018; Hinings et al., 2018; Teece, 2018), and on the energy industry—technology selection for biomass thermochemical conversion (van de Kaa, Kamp & Rezaei, 2017) and impact assessment of wind power plants (Aghbashlo, Tabatabaei, Hosseini, Dashti & Mojarab Soufiyan, 2018)
IT/engineering	409	Five descriptive papers on novel IT-related standards: the Internet Engineering Task Force (IETF) protocols on IoT (Sheng, Yang, Yu, Vasilakos, McCann & Leung, 2013; Keoh et al., 2014), Business Model Process and Notation (BPMN) (Chinosi & Trombetta, 2012), and the general architecture of standards for wireless charging technologies (Lu, Wang, Niyato, Kim & Han, 2016) and smart grids (Fan et al., 2013)	Three review papers on novel IT-related standards: fifth-generation of networks (Shafi et al., 2017), direct current (DC) microgrid technology (Kumar, Zare & Ghosh, 2017), IoT protocols from the IETF, Institute of Electrical and Electronic Engineers, IEC, and European Telecommunications Standards Institute (Trappey et al., 2017), and two survey papers on unmanned aerial vehicles (UAV) and cellular communications (Fotouhi et al., 2019), and on machine-to-machine and IoT technologies (Gazis, 2017)
Other sciences	227	An estimation of the mass of the Higgs boson using a standardized model (Khachatryan et al., 2015), a paper on the use of standard silicon levels in metal-oxide semiconductors (Abediasl & Hashemi, 2015), a review of standardization of *Terahertz* (THz) communications (Kürner & Priebe, 2014), a paper on the standardization of performance benchmarking in genetics (Hwang, Kim, Lee & Marcotte, 2015), and a framework for living standards in the healthcare sector (Memon et al., 2014)	An analysis on the use of standard steady-state algorithms in genetics (Corus & Oliveto, 2018), a paper on the use of standard silicon levels in metal-oxide semiconductors (Zhu, Shi, Li & Lau, 2018), a paper on minimal standards for describing new species of agrobacteria (De Lajudie et al., 2019), a paper on the use of standard and non-standard solvents in chromatography (Ghanem & Wang, 2018), and a review on the use of standards to measure biological functions (de Lorenzo & Schmidt, 2018)

FIGURE F1
Yearly Share in the Number of Scientific Papers on Standardization per Discipline

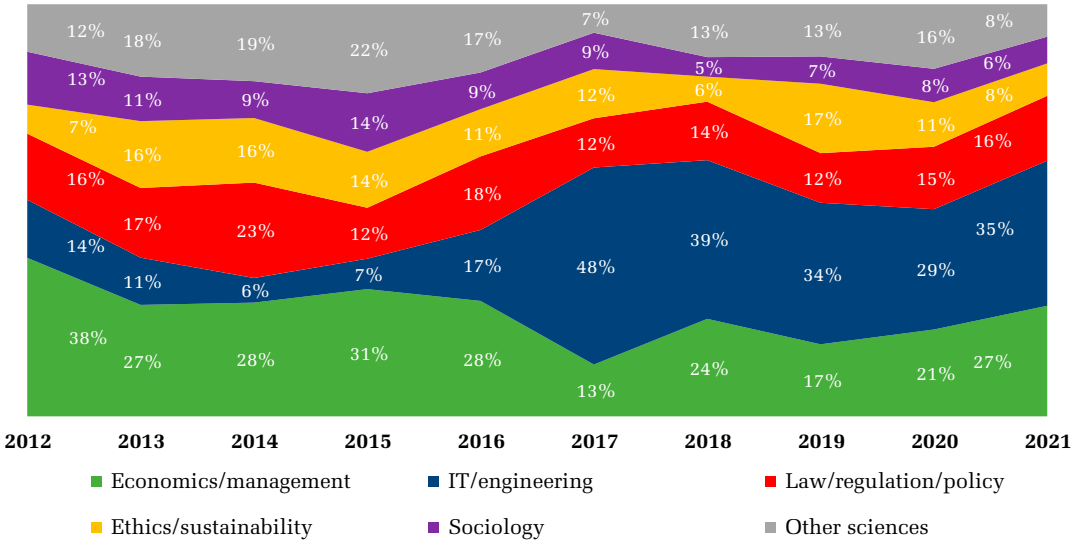


TABLE F2
Horizontal Topics for Standardization Research

Horizontal topic	No. of papers	Description
Technology development and adoption	72	Adoption, diffusion, emergence, architecture, and transfer of technology standards
Impact assessment	51	Measurement of economic and social impacts of standards and related regulations
Legitimacy	48	Perception or assumption that a standard or standardization process is desirable, proper, or appropriate within the rules and belief systems in which they operate
Standards competition	46	Standards battles, the emergence of dominant designs and the factors contributing to market success
Local context	45	Standardization at the level of individual countries as well as local communities, exploring themes like standards to support authenticity, community standardization, and a variety of sociocultural factors
Multistakeholder initiatives	45	Partnerships between governments, private actors, and society, including quality standards and conformity assessment, such as the standards underlying fair trade and eco-labels
Corporate strategy	43	Studies on how to strategically use standardization in companies
Innovation management	40	Interplay between standardization and innovation, both at an institutional and corporate level
IPR	40	Standard-essential patents, the relationship between standards development organizations and patent owners, and the trade-off between patenting and standardization
Pricing	32	Tariffs, royalties, license fees, and cost–benefit analysis of standards
Standards pervasiveness	27	The repercussions of standards in broad societal groups; includes notions such as standards governmentality, sociology of expectations (how shared expectations of plausible futures shape the evolution of sociotechnical systems), sociology of quantification, and unintended consequences

TABLE F2
(Continued)

Horizontal topic	No. of papers	Description
Trade	23	The role of standards in facilitating the exchange of goods and services between countries, regions, and institutions, including the role of the World Trade Organization and free trade agreements
Harmonization	18	The globalization and convergence of standards across different institutional and jurisdictional regimes
Network analysis and effects	15	The increase of economic and social utility of standards the more adopters they have, generating increasing returns of scale
Interoperability	15	The compatibility of formats and interfaces; includes the notion of open standards
Platforms	14	Organizations comprising two or more groups of customers or stakeholders where standards play the role of boundary resources
Knowledge diffusion	13	The interplay between standardization and information disclosure between standards stakeholders
Meta-governance	7	The management of plural schemas to induce more coordination in the governance of public and private organizations
History	6	Articles on the history of standards and standardization

Note: Since every paper can be associated with up to two topics, the sum of papers in all rows is higher than the total number of papers in the dataset.

TABLE F3
Vertical Topics of Standardization Research

Vertical topic	No. of papers	Description
Telecommunications	209	Developments in the IT and telecommunications industry, such as (standards for) wireless communication, 5G, virtualization and data transmission
Automation	132	IT-related topics such as Industry 4.0, artificial intelligence, IoT, and smart cities
Energy policy	109	Themes related to the energy value chain, such as standardization in the management of renewable and non-renewable energy sources, standardization for smart grids, gas efficiency and CO_2 emissions, and standards for electric vehicles
Healthcare	97	Nursing standards, legal procedures in the healthcare industry, and, more recently, the COVID-19 pandemic
Accounting and finance	87	Standards on tax, auditing and financial reporting principles, and emerging themes like responsible finance and green finance
Privacy and cybersecurity	79	Encryption and cryptography standards and legal implications within the field of privacy
Agriculture	73	Water and food systems, food supply chains, organic products, and standards on activities like cultivation, irrigation, and farming
Education	63	Standards in higher and lower education, such as teaching standards or professional standards
Human rights	54	Labor standards, living and minimum wage standards, well-being policies, social work, and standards for equality
Renewable portfolio standards	41	Obligations for companies to produce electricity from renewable energy sources
Physics	34	Specifications of standards incorporating physics artifacts or processes, such as sensors, optical and electronic components, and spectroscopy
Energy engineering	30	Technical and infrastructural aspects of the energy sector
Chemistry	29	Specification of standards incorporating chemical processes; includes biochemistry

TABLE F3
(Continued)

Vertical topic	No. of papers	Description
Metrology/instruments	28	Standards for quantities and units, measurement processes, and equipment used for the latter
Civil engineering and transport	26	The standardization of building practices and materials, as well as urban management and smart transportation systems
Public sector	22	The role of governments and institutions in standardization, with a focus on public procurement, public–private partnerships, public investments, and eGovernment
Biology	22	Specifications of standards in the field of biology and biotechnologies
CSR	20	Contribution of standards to corporate social responsibility
Renewable fuel standards	19	Standards for renewable fuels for transportation systems
Supply chain and operations management	19	Standardization supporting (local and global) supply chain management and operations, such as quality management, six-sigma, and enterprise resource planning
Marketing and consumer behavior	18	The cultural and psychological factors influencing the adoption of standards by humans
SDGs	17	Relationship between standardization and the 17 UN Sustainable Development Goals
Safety	16	Research on safety standards and physical or environmental risk management
Image and video processing	15	Standards (protocols) for image and video coding and encryption
Sports	10	Standardization of rules and regulations in different sports
Psychology	8	Psychological research on standardization
International relations	6	Standardization as a tool for global governance
Geology	5	Standardization for earth sciences and seismology
Genetics	5	Standard measurements for clinical genetics and genomics

shows that this shift is predominantly driven by the breakthrough of technical research on Industry 4.0 and on 5G telecommunications from 2016 onwards. *Economics/management* is a steadily relevant discipline for standardization studies, but it sees a slight relative decrease in the last five years, concurrent with the surge of *IT/engineering. Sustainability* and *Law/regulation/policy* have kept rather stable shares of standardization research over the years. *Sociology* has been decreasingly impactful: a significant amount of sources deriving from the work of Timmermans and Epstein (2010) and other previous studies (e.g., Busch, 2011; Thévenot, 2009; Timmermans & Almeling, 2009) did not follow up in more recent years.

On the other hand, research topics are the second dimension of our analysis after the academic disciplines. Identifying the core topics in each paper, we distinguish between horizontal and vertical topics. Horizontal topics relate to standardization as such, no matter the technical contents of the standards (e.g., *impact assessment*, *intellectual property rights (IPR)*, *multistakeholder initiatives*) and include academic theories and streams relevant to the standardization field as a whole (e.g., *technology development and adoption*, *legitimacy*, *standards competition*). Vertical topics relate to the contents of standards and their area of application (e.g., *renewable portfolio standards*, *safety, metrology/instruments*), including other technical and scientific domains (e.g., *biology*, *physics*, *education*) and functions or departments of organizations (e.g., *accounting and finance*, *privacy and cybersecurity*, *corporate social responsibility*). Table F2 and Table F3 show how many papers we coded with each horizontal and vertical topic of standardization and provide working definitions of these topics. Interestingly, we note that the field is quite diverse, and there is no single topic dominating the literature.

APPENDIX G
MOST IMPACTFUL JOURNALS IN STANDARDIZATION RESEARCH

Which research communities are most involved in the standardization field? Scientific journals in which studies are published may form an indication for this. Table G1 lists the top 10 journals by the number of high-impact publications in our dataset.

TABLE G1
Top 10 Journals for High-Impact Publications on Standardization

Journal	No. of papers	Energy and environmental research	Technical and engineering research	Management and policy
Energy Policy	29	✓		
IEEE Communications Magazine	27		✓	
Research Policy	26			✓
IEEE Access	24		✓	
Journal of Cleaner Production	24	✓		
Technological Forecasting and Social Change	16			✓
IEEE Communications Standards Magazine	14		✓	
Telecommunications Policy	14		✓	
Energy Economics	13	✓		
Organization Studies	12			✓

We grouped them into three main categories: energy and environmental, technical and engineering, and research on management and policy.

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