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The role of research and other inputs for the development and impacts of standards

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Abstract
Research as input into standardisation processes is becoming more important because of its role as a knowledge and technology transfer channel. Furthermore, standards have to become more science-based, particularly if they are part of the regulatory framework, such as in the European Union. Therefore, a conceptual model of standardisation as a channel of technology transfer has been expanded further to consider standards in the regulatory framework. The empirical study aims to identify the demands of industry and other stakeholders for standards as potential research results and other drivers and inputs. A survey among over thirty thousand experts active in the German standardisation body DIN generated almost three thousand responses, mainly from the industry. The responses from the experts reveal that policy initiatives, including regulations and customer requirements, alongside own and collaborative research, are the most relevant sources for standard development. Research input is assessed to be most important for measurement and testing standards, with quality and environmental standards closely followed. The primary benefit of utilizing research as input for standardisation is free access to scientific insights and the capability to stay updated with scientific advancements. Eventually, we correlate the relevance of inputs into standards by assessing various impact dimensions, revealing significant linkages. Finally, we link the empirical findings to the presented model and derive avenues for future theory-building research.

Keywords Standardisation · Research · Regulation

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1 Introduction

Standards have essential economic functions to support companies' competitiveness by increasing their productivity in their production processes and improving the quality of their products. In addition, further social impacts of standards are considered (Wiegmann et al., 2023), for example, linked to the Social Development Goals (SDGs) (Blind & Heß, 2023).

Meanwhile, standardisation has been accepted as a knowledge and technology transfer channel (Perkmann et al., 2021) complementary to well-established intellectual property rights, particularly patents and start-ups. In addition, many standards are closely linked to the regulatory framework in the European Union, which requires them to be evidence and science based (OECD, 2021). Therefore, the initial and still dominant involvement of industry as the primary stakeholder group in pursuing their interests (Blind & Mangelsdorf, 2016) in standardisation has not only been questioned from an input legitimacy perspective (Botzem & Dobusch, 2012) but also to increase the efficiency of standardisation as knowledge transfer channel or even transdisciplinary approach (Blind, 2024a). Combining these trends, research results as inputs for standardisation processes are becoming more critical. However, scientific publications as an indicator of research output have not yet been broadly referenced in standard documents (Blind & Fenton, 2022).

Therefore, the motivation to conduct the performed explorative research is driven by the question of the relevance of research as input for standardisation in comparison with other sources, like requirements of customers, but also the regulatory framework, including policy initiatives linked to the SDGs (Blind & Heß, 2023). Since there is a tension between exploiting the benefits of existing standards by companies (Baron et al., 2016) and their replacement by new and more ambitious research-based standards, one has to look at both the advantages and disadvantages of integrating systematic research results into the existing body of standards. Furthermore, due to the involvement of researchers and their organisations, research funding organisations, standardisation bodies and their committees, and industry, various opportunities and instruments exist to consider in transferring research results into standardisation. Finally, possible impacts of research-based standards have to be closely investigated, for example, by looking at the correlations between the input sources and the general impacts of standards.

The remainder of the paper is structured as follows. First, we present the existing body of literature on the relationship between research and standardisation before we present a new extended conceptual framework of standardisation as a knowledge and technology transfer channel. In the fourth chapter, the methodology, i.e., the performance of our survey among experts involved in standardisation, is presented. Unfortunately, we have no further external data to validate the survey results. The fifth chapter presents the survey results before we conclude with a discussion and an outlook toward possible future research.

1.1 Literature review

The relationships between research and standardisation can embedded in the following bodies of research.

Knowledge and technology transfer is generally described as the transfer of know-how, technical knowledge, or technology from one organisational environment to another, with many variations depending on the research discipline and purpose (Bozeman, 2000). It

typically occurs between universities, research institutions, and companies, but also within companies. Following Roessner (2000), Perkmann et al., (2013, 2021) consider as channels in their comprehensive reviews consulting, contract or sponsored research by industry, joint collaborative research, but also informal contacts or advice, training of personnel including placement or supervision of students. In addition, they include joint publications and patenting, conferences or workshops, membership in advisory boards, even joint creation of physical facilities, academic entrepreneurship, and work with standardisation bodies.

Eventually, standardisation has been considered an option for university-industry relations (Perkmann et al., 2021) and, therefore, for knowledge and technology transfer. In contrast, a decade ago, it was still ignored (Perkmann et al., 2013.), although the first studies were published 15 years ago (e.g., Blind & Gauch, 2009).[1] Companies also develop internal standards, which may be transferred into SDOs' processes (Blind & Müller, 2020). Furthermore, the employees involved in the standardisation processes are responsible for transferring knowledge from the committees back into their companies. Within the internal research and development processes, companies often ignore the opportunities of standardisation (e.g., Großmann et al., 2016) but perceive it increasingly as a synchronised development tool, e.g., in biotechnology (Lorenz et al., 2019).

Standardisation, therefore, forms a platform for knowledge and technology transfer along the research and innovation process, i.e., it is an opportunity to exchange information and access complementary external R&D assets (Bar & Leiponen, 2014). Within biotechnology (Lorenz et al., 2019), standards promote the exchange of knowledge and the coordination of research and development efforts and enable the (organisational) discrepancy between laboratories and production processes to be overcome. By harmonising terminology in the standardisation process and standards themselves, as is generally the case in transfer activities, an effective communication channel between the front end (the practical application) and the back end (the scientific work behind it) is crucial. An open corporate culture and the participation of different disciplines are necessary for this exchange.

However, standardisation has to be put in the context of other knowledge exploitation and transfer strategies, like publishing and patenting. Generally, companies consider patenting new technological developments before engaging in standardisation (e.g., Abdelkafi et al., 2016). Großmann et al. (2016) investigated the link between the product development process and standardisation in three companies (two automotive manufacturers and one automotive supplier). Although they consider this integration relevant, the two automotive companies have not explicitly integrated their standardisation strategies into their product development. The product development process requires a review of existing standards. In addition, internal technologies developed by the company are brought into standardisation late in the product development process, i.e., after the company has a good command of these technologies. A survey of engineers in two automotive companies reveals quite different and contradicting motivations for getting involved in patenting, standardisation, or even the publication of scientific papers (Blind et al., 2022a). Eventually, these conflicts might reduce engineers' involvement in standardisation. Blind et al. (2022b) have analysed the interaction between publishing, patenting, and participation in standardisation and the innovation performance of German companies. They find positive relations but also tensions between patenting and both publishing and standardisation.

[1] However, in the recent review by Grillo et al. (2024) on standardisation research, this dimension is only considered in the context of standard-essential patents.

Considering researchers as stakeholders in standardisation processes, we can present the following insights. Scientists from research institutions tend to be underrepresented in SDOs, e.g., in the German standardisation body DIN, less than 10% of the experts are from public or private research institutes (Blind & Heß, 2023). Zi and Blind (2015) show that researchers who publish in highly renowned journals are less involved in standardisation processes than in industry-related and technical journals. The reason for this is the prioritisation of the respective research groups and the corresponding weighing of opportunity costs: researchers who focus on highly cited journals invest a great deal of time in the quality of an article due to the demanding peer review processes (Blind et al., 2017). On the other hand, researchers who publish in practice-oriented journals often come from applied research and usually cooperate with practice partners in their research projects or work towards a defined practical goal. Consequently, their topics are of greater importance for standardisation. The participation of scientists from applied research in processes of standardisation committees is correspondingly higher, which is also confirmed by Blind and Fenton (2022), who discover a relatively higher involvement of applied-focused research organisations based on standard relevant publications cited in international standards released by the International Standardization Organization (ISO).

After revealing the general importance of research as a driver for standardisation, limited work has been done on its relevance for specific standards, starting with Blind and Gauch (2009). They attribute different types of standards, i.e., terminology, measuring and testing, quality, and interoperability, to various phases in the research and innovation process.

1.2 An extended transfer model of standardisation

To conceptualise the interface between research and standardisation, Blind and Gauch (2009) developed a general framework to analyse traditional technology transfer from research and development to standardisation and the reverse transfer from standardisation and standards back to research and development. They applied an established technology transfer model developed by Bozeman (2000), which considers the different transfer objects and media. Research and development activities produce knowledge that can be partly codified in publications, patents, and other codified content, e.g., databases. Besides codified knowledge, research activities generate tacit knowledge in the researchers. In research consortia and networks, a large amount of the knowledge is implicit and linked to the members of the networks. Successful standardisation, in terms of including relevant and up-to-date scientific and technological knowledge in a standard, is thereby necessarily based upon the inclusion of researchers in the standardisation process (see also Blind & Fenton, 2022).

The transfer of codified knowledge from research to standardisation can be realised by considering scientific literature (Blind & Fenton, 2022) and patents (Bekkers et al., 2020). The latter is even required in the standardisation processes of formal standard-setting organisations to settle relevant intellectual property rights and licensing issues (e.g., Bekkers et al., 2023). More important is the transfer of tacit knowledge from researchers to standardisation processes via their direct participation.

To consider the role of standardisation in the European Union, which is defined by the EU Regulation 1025/2012 and relevant for all Member States, the initial conceptual model by Blind and Gauch (2009) has to be expanded by the influence of the regulatory framework

on the standardisation process and standards.[2] Gottinger et al. (2023) reveal the interaction between research, standardisation, and regulation for the bioeconomy area. However, they present case-specific empirical evidence but no conceptual model. Figure 1 displays an expanded conceptual model considering the government as a further source of inputs in the standardisation process.[3] Bozeman (2000) and Bozeman et al. (2015) perceive the government as one actor of the demand environment, which influences the transfer agent directly, e.g., via requirements in research funding. Related to standardisation as a transfer agent, i.e., the organisation organising the knowledge and technology transfer, this could mean public funding of research for standards as the transfer medium, like scientific publications in traditional models. In addition to research, where knowledge is generated, standardisation produces coordination via the consensus principle between different stakeholders. However, it could also be the case that the government mandates standard-setting organisations to develop specific standards as the European Commission does. Furthermore, the regulations released by the government can directly reference standards specifying the implementation of their regulations. Eventually, the implementation should comply with the published standards voluntarily, whereas it is obligatory and related to regulations. Consequently, there are several feedback loops not only to research and standardisation but also to regulation, which has been revealed by Gottinger et al. (2023) for the bioeconomy in the European Union.

In summary, we present a complex knowledge and technology transfer model that better reflects the real situation, at least in the European Union and, therefore, also in Germany, which is the focus of our empirical investigation.[4]

[2] An alternative approach would be to rely on Weiss (1979), who differentiates between the Knowledge-Driven Model, which assumes technologies based on successfully applied research offer opportunities for public policies, and the Problem-Solving Model, in which policy initiatives drive research.

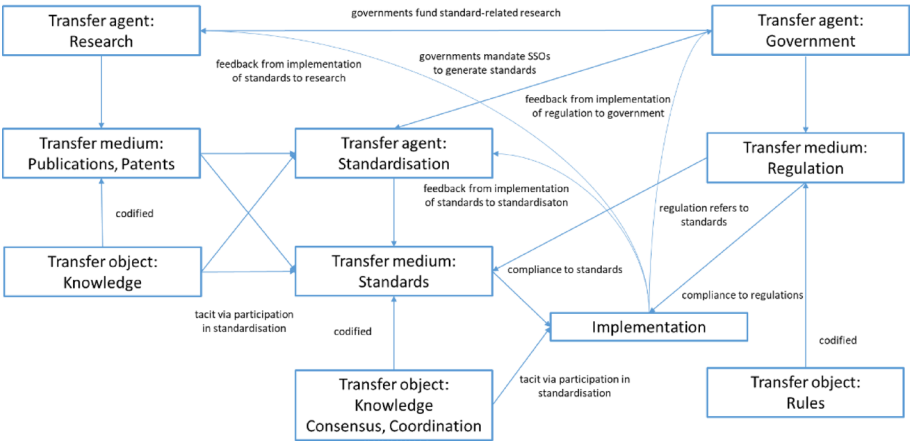


Fig. 1 Standardisation in the Context of Research and Regulation

[3] We are aware that customer and supplier requirements influence standardisation processes. However, to avoid an overly complex model, we focus the conceptual model on the more external sources of research and regulation.

[4] The influence of market needs on standardisation is not reflected in the model because it is considered a baseline requirement for developing standards. In addition, it would have complicated Fig. 1 further.

2 Methodology

Our methodological approach is based on a survey of stakeholders active in standardisation, asking for their experiences and perceptions about the interface between research and standardisation. We use the German Standardisation Panel (DNP) established in 2012 to address not only a sample but also the universe of a broad range of organisations (especially firms) active in standardisation at the German Standardisation Institute DIN. Of 28.157 experts contacted on the 14th of October 2023, the World Standards Day, and reminded two times, 2.987 responded to the survey until the 2nd of January 2024. The response is similar in quality and structure as in the previous waves of the German Standardisation Panel (please (see Blind & Heß, 2023; Heß & Blind, 2024a, 2024b), which indicates that a common method bias does not exist. In addition, the sector and size distribution of all organisations active in DIN is found by Heß (2020).

One section of the questionnaire contained questions on the significance of research within the standardisation process, both in general and concerning specific types of standards. It explored the advantages, disadvantages, and potential impacts of integrating research findings into standardisation efforts. Participants were asked to assess the relevance of different input sources for standard development, including research. Additionally, they were prompted to evaluate the importance of research as input for various types of standards and to consider both the advantages and disadvantages of integrating research findings into standardisation processes. Furthermore, respondents were asked to assess the effectiveness of different approaches to incorporating research results into standard development and to identify potential impacts of standards based on research input on innovation, new products, and processes. Through these questions, the survey sought to comprehensively understand stakeholders' views on the role of research in standardisation. The introductory section of the questionnaire, which has been repeated annually since 2012, allows the experts to assess the impacts of standards for different dimensions relevant to their organization (see, for example, Heß and Blind, 2023).

Most respondents work in industry, mainly mechanical and electrical engineering companies. However, other stakeholders, like experts from non-governmental organisations (NGOs), higher education institutes (HEIs), public research organisations (PROs), and the public sector also answered the questionnaire. Overall, we have a balance between large organisations with over 250 employees and small organisations, particularly small and medium-sized enterprises (SMEs). More than 80% of the experts are male, and more than 60% are above fifty. Around half of the responding organisations perform research and development (R&D) and have introduced product or process innovations (Table 1).

3 Results

Based on the answers of almost three thousand respondents, we could reveal several insights to answer our research question, particularly differentiating between industry and other stakeholders.

Table 1 Sample by Sector

Sector	N	%
Total	2987	100
Mechanical Engineering	304	10.18%
Public administration and defense; compulsory social security	275	9.21%
Electrical Engineering	252	8.44%
Automotive Engineering	236	7.90%
Education, activities of membership organisations	233	7.80%
Chemical and Pharmaceutical Industry	228	7.63%
Certification and testing	198	6.63%
Construction	197	6.60%
Other service activities	138	4.62%
Metal Production	138	4.62%
Energy, Water, and Oil	121	4.05%
Medical Engineering	117	3.92%
Professional and scientific activities	106	3.55%
Consumer Goods Production	99	3.31%
Information and Communication	68	2.28%
Transporting and storage	54	1.81%
Plant construction	50	1.67%
Manufacture of other non-metallic mineral products	48	1.61%
Agriculture, forestry, and fishing	34	1.14%
Human health and social work activities	32	1.07%
Wholesale and retail trade; repair of motor vehicles and motorcycles	17	0.57%
Mining and quarrying	13	0.44%
Optics	13	0.44%
Other	6	0.20%
Activities of extraterritorial organisations and bodies	5	0.17%
NA	2	0.07%

3.1 Relevance of input sources for standard development

To assess the general role of research for standard development, the experts have been asked about the relevance of numerous input sources identified from the literature, e.g., Featherstone et al. (2016) or Moon and Lee (2022), but also validated via interviews with selected experts from industry in preparation of the questionnaire.[5]

The experts' answers reveal that policy and regulation initiatives are the most relevant inputs for developing standards followed by customers' requirements and insights from their research and collaborative public research. Less important are research results generated by other organisations. Requirements by suppliers and service providers, even their business model, are perceived as having limited relevance as input for standardisation. The experts position open-source software and hardware on the lowest level, which underlines their still complex relationship with standardisation, because different communities drive them to follow unalike processes, including a different IPR regime (Blind & Böhm, 2019). According

[5] Cronbach Alpha is 0.70.

to the experts' views, own, collaborative, and even others' research results are essential input sources for developing standards.

To put these assessments into the context of other studies, we refer to the insights from the German edition of the Community Innovation Survey about the relevance of knowledge sources for innovation development (Rammer & Schubert, 2022). The most important source for German innovators is their own company, which includes their research, followed by customers, competitors, and suppliers. Overall, the ranking of the sources is quite similar, which shows the reliability of the approach (Fig. 2).

In the next step, we ask for the role of research as input for developing the different types of standards.[6] Most relevant for the respondents to the survey is research for the generation of measurement and testing standards, which the high rating of research for measurement and testing can explain. However, research is also relevant for quality standards, which is unexpected because quality improvement is not so close to research and development. In the third position in the experts' assessment, we find environmental and sustainability standards, which can be explained by the increasing relevance of sustainability both in research and standardisation (see already Blind & Heß, 2023). According to experts, standards for safety and health issues and interoperability, compatibility, and interfaces require significant input from research. Product and process standards do not need much research from the surveyed population as input because they are generally more influenced by the requirements of markets, customers, and companies' production processes. Terminology and semantics are the least dependent on research input based on the experts' assessment (Fig. 3).

3.2 Advantages and disadvantages of research results as input for standard development

To improve the interface between research and standardisation, we must know more about the advantages and disadvantages of using research results to develop standards.[7]

From the perspective of the surveyed experts, the most relevant advantages are free access to scientific publications and other materials on the Internet and keeping track of scientific progress. Furthermore, research is perceived to provide a better evidence base for

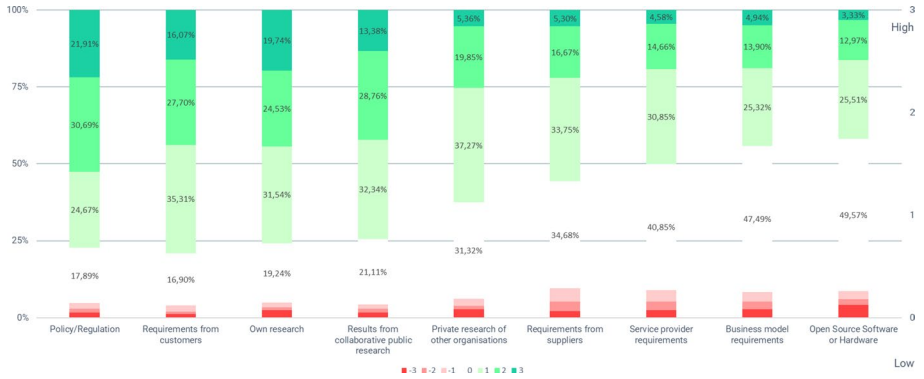


Fig. 2 Relevance of input sources for standard development (n = 1292 to 1527)

[6] Cronbach Alpha is 0.89.

[7] Cronbach Alpha are 0.90 and 0.70.



Fig. 3 Relevance of research results as input for different types of standards (n = 961 to 1164)

the development of standards[8] and impulses for new standardisation initiatives. Using scientific evidence for quality and environmental and sustainability-related standards follow in the experts' ranking of advantages. For standards supporting regulation,[9] it is also assumed to be an advantage of using research as input for their standardisation. Leveraging one's research results via standards for developing one's own product and process innovation is of similar importance for the surveyed experts as the role of scientific evidence in developing standards is relevant for follow-up research.[10] This assessment confirms the positive relationship between research, standardisation, and innovation.[11] The least relevant is the opportunity to prevent, via standardisation, competing research content from becoming market-dominant solutions. Overall, the surveyed standardisation experts perceive integrating research results in standard development as positive (Figs. 4 and 5).

Whereas most respondents support all advantages of integrating research results in standards, the disadvantages are perceived as less relevant. The most severe perceived problems are that research results are not yet validated in practice, are not ready as input for standardisation, and are too abstract, immature, and ambitious.[12] Furthermore, there is a lack of R&D staff available as experts in standardisation. In addition, if included, IPRs might restrict standardisation activities. Furthermore, some respondents complain about the limited support from other companies, in particular, or stakeholders in general, which can be explained by their—probably contradicting—specific interests in influencing the content of standards.[13] If patented content is included in standards, licenses for standard-essential patents (SEPs)

[8] See Blind and Fenton (2022) on the increasing number of scientific references in ISO standards in general and Gottinger et al. (2023) on their role for standards in the bioeconomy.

[9] See Gottinger et al. (2023) for the first empirical analysis of the complex linkages between scientific publications, standards, and regulation in the bioeconomy, whereas Blind (2023) elaborates on their interactions for transformative innovation and Blind (2024b) for socio-technical transformations.

[10] A smaller share of respondents perceives the virtuous long-term cycle between research, standardisation, and standards already postulated by Blind and Gauch (2009).

[11] See also the positive correlation revealed by Blind et al., (2022a, 2022b) for a representative sample of innovative companies in Germany.

[12] These disadvantages are particularly problematic for smaller organisations. The challenge is that research results might be too far away from customers' needs, which aligns with the high relevance of customers' interests as relevant input into standardisation, as elaborated above.

[13] See Blind and Mangelsdorf (2016).

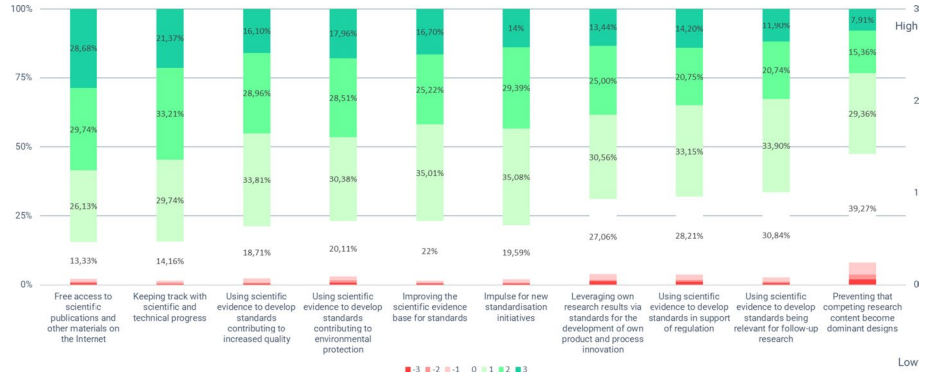


Fig. 4 Relevance of advantages of research results as input for standard development (n = 902 to 1199)



Fig. 5 Relevance of disadvantages of research results as input for standard development (n = 1026 to 1335)

are needed. Others complain of low rewards under royalty-free licensing regimes for SEPs, which some standardisation organisations have implemented. However, most respondents do not perceive the whole set of problems related to intellectual property rights in standardisation as a challenge. Complementary, the proprietary use of one's research results is not recognised as complicated. However, some respondents see integrating research results as tricky since standardisation is often not considered in research processes (Fig. 6).

3.3 Approaches to integrate research results as input for standard development

To promote the elaborated advantages and reduce the disadvantages related to incorporating research results as input for standard development, the respondents had the chance to assess the effectiveness of various approaches.[14] The primary objective of the Code of Practice on standardisation in the European Research Area (European Commission, 2023), promoting standardisation as an instrument of knowledge valorisation within Higher Education Insti-

[14] Cronbach Alpha is 0.80.

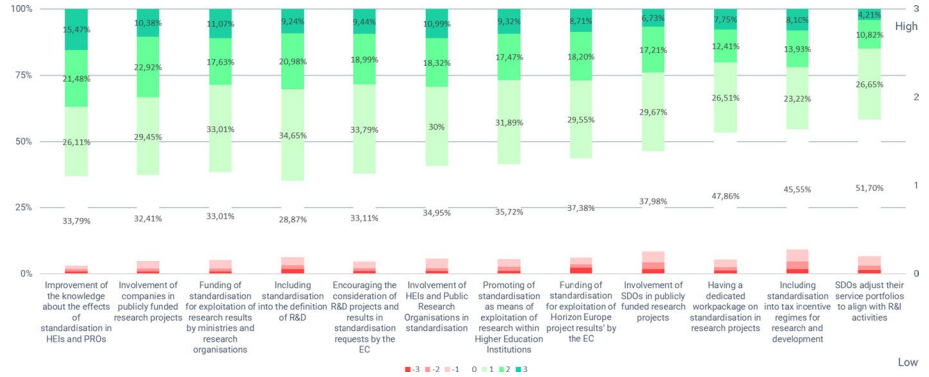


Fig. 6 Assessment of the importance of various approaches to integrate research results as input for standard development (n = 987 to 1311)

tutions (HEIs) and Public Research Organisations (PROs), is most appropriate for them.[15] Companies' involvement in public research is rated second, followed by the funding of standardisation as means of exploitation as one option of knowledge valorisation by national ministries and research funding organisations. However, to a lower level, funding for the standardisation of Horizon Europe project results by the European Commission is appreciated. Some respondents propose encouraging the consideration of R&D results in the standardisation requests by the European Commission. Interestingly, the more conceptual and long-term proposal of including standardisation into the definition of R & D is effective by most respondents but also completely ineffective by a few experts. Most respondents support the increased participation of Higher Education Institutes (HEIs) and Public Research Organisations (PROs) in standardisation and promotion within HEIs and PROs. Having dedicated work packages on standardisation in research projects is also rated as beneficial, as well as the more generic claim of including standardisation into tax incentive regimes for research and development. Finally, the involvement of SDOs in publicly funded research projects is supported only by a minority. In contrast, the adjustment of SDOs' service portfolios to align with R & I activities is ineffective by most respondents.

Overall, the Code of Practice's focus on standardisation and pushing it within HEIs and PROs is perceived to be quite effective. Complementary, more funding of standardisation at the national and European levels to exploit research is perceived to be effective in pushing the integration of research results into standardisation development. Finally, the inclusion of standardisation in the definition of R&D is a discussion that deserves further consideration. In contrast, SDO strategies and services have to be changed significantly.

[15] According to the European Commission, "Knowledge valorisation is the process of creating social and economic value from knowledge by linking different areas and sectors and transforming data, know-how, and research results into sustainable products, services, solutions and knowledge-based policies that benefit society." See https://research-and-innovation.ec.europa.eu/research-area/industrial-research-and-innovation/eu-valorisation-policy_en.

3.4 Assessed impacts of standards based on research results as input on innovation

In the last section, the respondents were invited to assess the broader impacts of standards based on research results as input on innovation.[16] On the one hand, faster or easier access to European or international markets could be achieved. On the other hand, the confidence level of consumers would be improved, which is closely related to the broader use of recognised methods and processes and better documentation of R&I results. The highest assessment of these impact dimensions can be linked to the highly assessed influence of standards on market entry and legal security. Although, these significant correlations are not a proof of the internal consistency and validity of the survey findings, they do not challenge them. However, it also reveals that further integration of research results into standards strengthens the impacts of standards to facilitate market access and legal certainty. At the technical level, interoperability is improved. At the governance level, integrating research results in standardisation improves the capacity to respond to EU regulations/policies. In addition, experts perceive that integrating research into standards could enhance the development and design of products, services, or processes. Furthermore, research results are expected to be disseminated faster via standards.

However, research integrated into standards does not necessarily improve the signaling of product or process quality, or the public procurement of innovation is expected. In addition, more intensified collaboration with HEIs and PROs is also not anticipated. Finally, larger economies of scale for products and services will not likely be exploited via research integrated into standards, revealing a well-known tension.

Overall, integrating research into standards is expected to accelerate and amplify the diffusion of knowledge and methodologies and strengthen their primary functions, like market access, consumer confidence, and interoperability. Finally, standards based on research are expected to better align with EU policy and regulation (Fig. 7).

[16] Cronbach Alpha is 0.86.

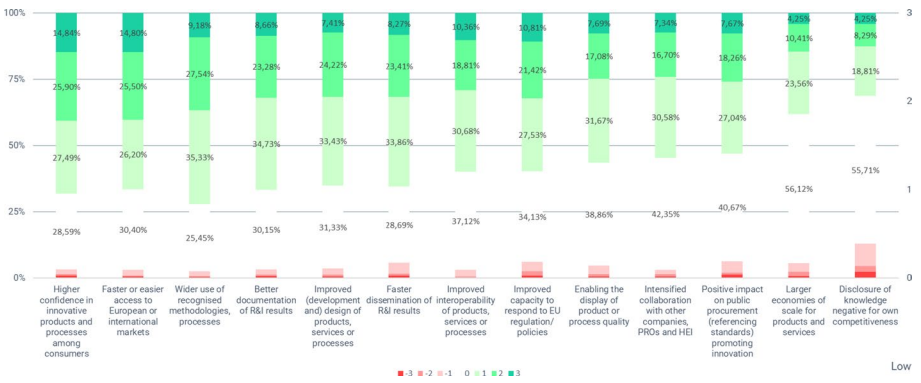


Fig. 7 Assessment of the importance of impacts of standards based on research results as input on innovation (n = 951 to 1267)

3.5 Inputs into standardisation and impacts of standards

Although we have no approaches or data to externally validate the answers to the survey shown in the previous sections, we can perform an internal validation. Mainly, we perform correlation analysis based on the answers of the experts to three questions and their general assessment of the relevance of different impact dimensions of standards, i.e., legal security, market-entry, interoperability, increase in productivity improvement of quality R&D, innovation, competitiveness, bargaining position, sustainability, and resilience. The latter part has been asked in previous waves of the German Standardisation Panel, e.g., Heß and Blind (2023) display time series of the assessments.

The correlations between inputs into standardisation and the assessed impacts of standards in Table 2 are all highly significant. Therefore, we concentrate on those with coefficients above 0.2 to highlight the strongest linkages. Related to own research, no correlation coefficient is above 0.2. However, the value related to the impact of standards on R&D reveals the highest value, which underlines the internal consistency of the answers. Other organisations' research also does not generate correlation coefficients above the suggested threshold. However, input from common publicly funded research into standardisation is 0.24 and, therefore, highest correlated with the impact of standards on the quality, followed by 0.23 for interoperability. Input from publicly funded research is positively associated with quality enhancement and interoperability-promoting standards, indicating that common research specifically emphasizes these two dimensions. For interoperability, common research in ICT might be beneficial. The input of open source software or hardware is strongly interrelated with the impacts of standards on sustainability and R&D. Reusing existing software code certainly saves resources and eventually contributes to sustainability. The requirements of customers in the development of standards are most strongly correlated with their positive impact on the negotiation power related to suppliers, followed by resilience. Within the vertical supply chain, the stronger consideration of customers' requirements in standards is associated with a more dominant position related to suppliers.

Considering suppliers' input in standardisation processes is less strongly correlated with all the impact factors of standards. In contrast, the requirement of service providers is particularly correlated with the impacts of standards on resilience and sustainability, which have only recently received more attention triggered by the discussion about the Sustainable Development Goals (Blind & Heß, 2023) and the COVID-19 pandemic (Heß & Blind, 2023). Finally, the input of policy and regulation on standards' development is highest correlated with the impact of standards on quality, sustainability, legal security, and negotiation power against suppliers. Whereas the high correlation with legal security confirms the consistency of the answers, policy initiatives are strongly associated with the quality and sustainability-enhancing impacts of standards. In addition, legal requirements are also strongly linked with the opportunity to strengthen the negotiation power against suppliers.

In summary, the correlation coefficients, which are all highly significant with p-values below 0.01 displayed in Table 2, reveal the consistency of the answers and that input from commonly conducted research, customers' requirements, and policy initiatives are positively associated with various impact dimensions of standards, mainly related to sustainability and resilience.

In a further step, we again correlate the relevance of research for different types of standards with assessing their various impact dimensions. All correlation coefficients are highly

Table 2 Correlation coefficients between inputs into standardisation and the assessed impacts of standards

Input into standardisation Assessed the impact of standards	Own research	Private research of other organisations	Results from collaborative public research	Open Source Software or Hardware	Require-ments from customers	Requirements from suppliers	Service provider requirements	Business model requirements	Policy/ Regula-tion
Legal security	0.10***	0.12***	0.19***	0.14***	0.10***	0.09***	0.08**	0.11***	**0.20****
Market entry conditions	0.10***	0.07*	0.12***	0.09***	0.12***	0.13***	0.11***	0.15***	0.16***
Technical interoperability	0.16***	0.16***	**0.23****	0.15***	0.16***	0.13***	0.12***	0.12***	0.19***
Productivity	0.09***	0.14***	0.13***	0.17***	0.15***	0.12***	0.14***	0.19***	0.13***
Quality	0.10***	0.17***	**0.24****	0.19***	0.17***	0.14***	0.17***	0.16***	**0.22****
Competitiveness	0.10***	0.11***	0.12***	0.17***	0.16***	0.14***	0.16***	0.17***	0.08**
R&D	0.16***	0.14***	0.16***	**0.20****	0.14***	0.10***	0.14***	0.15***	0.12***
Bargaining position	0.14***	0.16***	0.19***	0.15***	**0.23****	0.16***	0.15***	0.12***	**0.20****
Sustainability	0.15***	0.15***	0.17***	**0.21****	0.19***	0.14***	**0.20****	**0.20****	**0.21****
Resilience	0.13***	0.14***	0.14***	0.19***	**0.20****	0.16***	**0.20****	0.19***	0.17***

Significance levels: *** $p<0.01$, ** $p<0.05$, * $p<0.10$

significant with p-values below 0.01, and several correlation coefficients receive values above 0.3, which we will focus on. The coefficients are highest related to the impact dimensions of quality and sustainability and lowest related to legal security, market-entry, and competitiveness. The highest values above 0.3 appear between the relevance of research for interoperability standards and the impact of standards on interoperability and quality standards and their effect on quality. The input of research into process standards is highest correlated with the impact of standards on sustainability, which is also the case for the input of research on environmental protection and sustainability. These high values underline the consistency of the answers of the respondents, but also that specific standards are strongly associated with the impact dimensions they contribute to (Table 3).

In the last step, we correlate the assessment of the importance of the impacts of standards based on research results as input on innovation with evaluating the general impact dimensions of standards. Again, all correlations are highly significant, with p-values below 0.01 displayed in Table 4. However, we focus on those relations with a coefficient above 0.25. Here, the improved development and design of products, services, and processes are strongly correlated with the impact of standards on sustainability, R&D, resilience, and quality. The ability to present product and process quality via research-based standards is particularly strongly correlated with assessing the standards' impact dimension related to sustainability, quality, productivity, and resilience. Suppose consumers' confidence in innovative products and processes is evaluated to be strengthened. In that case, the impacts of standards on the bargaining power related to suppliers and on sustainability are notably higher assessed. Faster and easier access to European or international markets via research-based standards positively correlates with their estimated impact on suppliers and resilience. The effect on the latter and sustainability is specifically highly correlated with the influence of research-based standards on improved capacity to react to EU regulations and policy. Finally, the research-driven improved interoperability of products, services, and processes positively correlates with their impact on sustainability, resilience, interoperability, and the negotiation power related to suppliers. These highlighted examples of high correlation coefficients confirm the generally positive linkages between the specific impacts of research-based standards and their principle impact dimensions.

On the one hand, the conducted correlation analysis serves as an internal validation check of the experts' answers because we lack external validation for the survey responses. On the other hand, these simple correlations reveal a close linkage between the inputs into standards and their perceived impacts through their high significance levels. Notably, the assessment of research inputs from public-funded research correlated with evaluating the effects of standards quality and interoperability, whereas this is lower correlated with individually generated research results. The assessment of customer requirements as inputs was strongly linked to the influence of standards on negotiation power related to suppliers and on resilience. Evaluating policy and regulation inputs into standards are highly correlated with the gauged impacts of standards on quality, sustainability, and legal security.

Furthermore, the relevance of research input for developing different types of standards matters for their impact dimensions according to the experts' answers. Finally, we examined correlations between the importance of research-based standards on innovation and standards' general impact dimensions, which confirm the generally positive linkages between research-based standards and their specific impact dimensions but also reveal the importance of particular mechanisms. This last analysis could be considered in a more sophis-

Table 3 Correlation coefficients between the assessment of the importance of research for specific types of standards and assessed impacts of standards

Importance of specific types of standards Assessed impact of standards	Termi-nology/ semantics/ ontology	Measurement/testing	Interoperability/compatibility/interfaces	Quality	Products/services (charac-teristics)	Processes (production/management)	Health protection	Environmental protection and sustainability	Safety protec-tion
Legal security	0.17***	0.20***	0.19***	0.15***	0.13***	0.12***	0.18***	0.15***	0.10***
Market entry conditions	0.14***	0.20***	0.19***	0.19***	0.15***	0.13***	0.16***	0.10***	0.14***
Technical Interoperability	0.21***	0.15***	**0.31****	0.20***	0.18***	0.18***	0.17***	0.16***	0.19***
Productivity	0.22***	0.07**	0.22***	0.22***	0.21***	0.25***	0.19***	0.20***	0.18***
Quality	0.25***	0.21***	0.26***	**0.31****	0.26***	0.30***	0.28***	0.28***	0.24***
Competitiveness	0.12***	0.13***	0.17***	0.18***	0.20***	0.17***	0.17***	0.13***	0.15***
R&D	0.16***	0.13***	0.17***	0.24***	0.20***	0.23***	0.18***	0.18***	0.17***
Bargaining position	0.21***	0.21***	0.28***	**0.30****	0.21***	0.24***	0.22***	0.17***	0.17***
Sustainability	0.24***	0.15***	0.23***	0.23***	0.25***	**0.35****	0.28***	**0.34****	0.27***
Resilience	0.24***	0.12***	0.24***	0.20***	0.21***	0.26***	0.22***	0.23***	0.21***

Significance levels: *** $p<0.01$, ** $p<0.05$, * $p<0.10$

ticated conceptual model. However, it also serves as a base for further research about the complex linkages between the inputs into standards and their impacts.

4 Discussion and Outlook

Linking the survey results back to our research question and the conceptual model; we observe that the experts involved in standardisation assess the relevance of research results and impulses from policy and regulation as equally important inputs into standardisation, which is a significant new insight. In addition, research results are perceived to have different implications for the various types of standards, whose role in the phases of the research process has been elaborated on by Blind and Gauch (2009). Regarding the high relevance of regulations, previous survey results about motives to standardise by Blind and Mangelsdorf (2016) are confirmed, which reveal specifying regulations via standards as the main driver. Regarding future research, the database of standardisation requests hosted by DG GROW of the European Commission is a source for investigating this question further, relying on another type of data source and avoiding the common method bias of our current approach.

According to the surveyed experts, the most essential advantages of integrating research into standards are free access to research results and being updated with current developments in science and technology. The positive impact of increasing the science base of standards, which pushes their credibility if referenced in regulations, has yet to be broadly perceived as an advantage because only a minority of standards currently reference scientific publications (Blind & Fenton, 2022).

Most of the ex-ante proposed measures and those mentioned by the respondents focus on supporting the transfer of research results into standardisation, which confirms a previous survey among participants of research projects under the framework programme Horizon 2020 (European Commission et al., 2022). However, the respondents do not prioritize considering the linkages to regulation, e.g., via standardisation requests.

Finally, when looking at the perceived impact of standards based on research results as input on innovation, consumers' strengthened confidence in innovative products and processes receives the highest assessment. Therefore, regulators, who also aim to improve consumers' trust, should consider this link. In addition, more research-based standards help most respondents strengthen their capacity to react to regulations and policy initiatives. However, the link to standards referenced in public procurement is not yet vital.

Overall, the insights from the survey do not question the conceptual model. Some aspects are even explicitly confirmed. However, we are only at the beginning of analysing the complex relationships between research, standardisation, and regulation. Based on documents for the specific bioeconomy case, Gottinger et al. (2023) disentangle the reciprocal links between these three areas. Therefore, in addition to the survey approach challenged by response biases, standard documents provide a starting point to collect data about their linkages, but further data has to be built up, e.g., for scientific publications referenced in regulations. In addition, further methodological approaches must be developed to tackle the complex and increasingly dynamic relationships to build more science- and innovation-friendly, as well as society's demands reflecting mechanisms for knowledge and technology transfer as regulatory frameworks.

Table 4 Correlation coefficients between the relevance of research for different types of standards and the assessed impacts of standards

Relevance of research for different types of standards Assessed impact of standards	Better documentation of R&I results	Faster dissemination of R&I results	Wider use of recognised methodologies, processes	Improved (development and) design of products, services or processes	Larger economies of scale for products and services	Enabling the display of product or process quality	Higher confidence in innovative products and processes among consumers	Faster or easier access to European or international markets	Improved capacity to respond to EU regulations/policies	Improved interoperability of products, services, or processes	Positive impact on public procurement (referencing standards) promoting innovation	Intensified collaboration with other companies, PROs, and HEI
Legal security	0.17***	0.13***	0.20***	0.17***	0.06*	0.13***	0.21***	0.19***	0.15***	0.21***	0.17***	0.14***
Market entry conditions	0.16***	0.08**	0.18***	0.17***	0.09**	0.15***	0.19***	0.20***	0.19***	0.21***	0.11***	0.10***
Technical interoperability	0.14***	0.14***	**0.25*****	0.22***	0.12***	0.21***	0.22***	0.23***	0.18***	**0.29*****	0.21***	0.20***
Productivity	0.19***	0.23***	0.20***	0.21***	0.23***	**0.25*****	0.21***	0.20***	0.21***	**0.25*****	0.23***	0.19***
Quality	0.23***	0.18***	0.23***	**0.26*****	0.23***	**0.28*****	0.23***	0.21***	0.24***	**0.27*****	0.20***	0.23***
Competitiveness	0.16***	0.13***	0.15***	0.19***	0.18***	0.23***	0.19***	0.18***	0.21***	0.18***	0.17***	0.15***
R&D	0.21***	0.23***	0.19***	**0.28*****	0.19***	0.22***	0.20***	0.20***	0.24***	0.24***	0.17***	0.18***
Bargaining position	0.21***	0.15***	0.23***	0.20***	0.18***	0.23***	**0.26*****	**0.27*****	0.24***	**0.26*****	0.20***	0.19***
Sustainability	0.21***	0.21***	0.24***	**0.30*****	**0.26*****	**0.30*****	**0.26*****	0.22***	**0.28*****	**0.30*****	0.22***	0.23***
Resilience	0.18***	0.18***	0.21***	**0.28*****	0.21***	**0.25*****	**0.25*****	**0.27*****	**0.28*****	**0.30*****	0.21***	0.21***

Significance levels: *** $p<0.01$, ** $p<0.05$, * $p<0.10$

The presented conceptual model can be further sophisticated by considering the linkages between the inputs into standards and their impacts, which materialise after implementation. Currently, the implementation of standards is the final element in the conceptual model, although it has some feedback loops both back to research and policy. Further insights about the complex relationship between the inputs into standards and their impacts based on other data sources could help to open the black box of implementing standards and the illustrated but not further elaborated feedback loops.

As indicated, our research approach faces several limitations. Despite the sound base of answers from experts involved in standardisation to our survey, their assessment is framed by their personal experiences and organisational environment. Furthermore, the answers from those standardisation experts being not involved or having a limited exchange with researchers to the very research-specific questions might be less informed than those being actively involved in standardisation and research. A further limitation of our approach is the focus on the standardisation experts active in the German Standardisation body DIN, which also claims to provide a representative picture of Germany but not necessarily of other European countries and, to a lesser extent, even non-European countries. However, Germany is the most active country in European and international standardisation bodies. Therefore, it can also serve as a benchmark due to the high research intensity of its companies involved in standardisation (Blind et al., 2022b).

Most research on knowledge and technology transfer in general (Perkmann et al., 2013, 2021) and particularly standardisation (Grillo et al., 2024), including our paper, is phenomenon-driven; future research should deploy data on this phenomenon to build and test theory. First, future studies might view standardisation as proactive behavior in knowledge-intensive organisations (Crant, 2000). Another opportunity for contributing to theory may arise from studying how experts in standardisation respond to social influence or local norms, such as those prevailing in their immediate, departmental work contexts (Bercovitz & Feldman, 2008), and how these relate to global norms or incentive schemes for instance at the level of scientific disciplines. This may also provide suggestions for determining the locus of possible policy interventions to support researchers' engagement in standardisation.

Within the institutional theory, engagement in standardisation may offer insights into how individuals within organisations manage exposure to different logics, i.e., that of academic science and of commercial R&D (Murray, 2010), including standardization. Whereas working with industry in R&D is likely to generate conflicting pressures, including whether research results should be public or private and whether research should be oriented towards publication or technical application (David, 2004), conflicts in standardisation might raise the ambitions of performance requirements.

Finally, insights from innovation theories and transdisciplinary research (Blind, 2024a), specifically around knowledge combination, networks, and tacit knowledge, might not only explain outcomes from academic engagement (Beaudry & Kananian, 2013; Lavie & Drori, 2012; Melkers & Xiao, 2012; Thursby & Thursby, 2011) but also standardisation. Particularly, researchers' positions in interpersonal networks can be important for their participation and success in contributing to standards.

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