



# Standardisation in the European manufacturing sector: needs, obstacles AND best practices

Eujin Pei<sup>1</sup> · Angeliki Martinou<sup>1</sup> · Ahmad Issa<sup>2</sup> · Rafael M. Afonso<sup>3</sup> · Olga Meyer<sup>2</sup>

Received: 25 August 2025 / Accepted: 1 December 2025 / Published online: 22 December 2025  
© The Author(s) 2025, modified publication 2026

## Abstract

This paper aims at understanding whether and how the European manufacturing sector can better implement standards. It argues that despite the understudy of standardisation in the manufacturing sector, new innovative technological developments force academics and practitioners alike to re-examine the relevance, the benefits and challenges of standards, from policy to implementation. The paper leverages information gathered for the purposes of the “Boosting the Exploitation of Standardisation Inputs from European Projects” (STAND4EU) project, where various standardisation stakeholders were surveyed to understand their views on the barriers in the development and adoption of standards, providing their suggestions for best practice in standardisation. Grounded under the Standards Development Lifecycle, and based on the respondents’ views, the study ultimately proposes a remediation plan to support standardisation policymaking. Therefore, this paper advances the discourse on international standards development and application, promoting the improvement of regulatory frameworks and the advancement of knowledge in standardisation.

**Keywords** Standards · Standardisation · Manufacturing · Additive manufacturing · Industrial digitalisation · Welding · Circular economy

## 1 Introduction

Standardisation establishes common and consistent procedures that help streamline production and sustainability. Examples of successful standardisation implementation include ISO/ASTM 52900–Terminology for AM–General Principles–Terminology, and ISO/ASTM 52901–Additive

Manufacturing–General principles–Requirements for purchased AM Parts.<sup>1</sup> Despite the general recognition of the benefits of standardisation, and its connection with innovation, there is limited research on the gaps, challenges and the ways to advance standardisation efforts in the manufacturing sector. Therefore, this paper aims at identifying key barriers and solutions for the efficient implementation of standardisation, by asking: can the European Manufacturing sector better implement standards? There are two objectives of this research (1) firstly, to understand key obstacles to standardisation, (2) and secondly, how these obstacles feed into fostering ways to a better standards implementation. To guide this study, this paper will address three research questions: (A) What are the key obstacles encountered in the development, adoption, and implementation of standards in the European manufacturing sector? (B) How do these obstacles vary across different technological domains (Additive Manufacturing, Welding, Smart Manufacturing, and the Circular Economy)? (C) What practices or strategies

✉ Eujin Pei  
eujin.pei@brunel.ac.uk

✉ Angeliki Martinou  
Angeliki.Martinou2@brunel.ac.uk

Ahmad Issa  
ahmad.issa@ipa.fraunhofer.de

Rafael M. Afonso  
rafonso@uatlantica.pt

Olga Meyer  
olga.meyer@ipa.fraunhofer.de

<sup>1</sup> Brunel University London, London, United Kingdom

<sup>2</sup> Fraunhofer Institute for Manufacturing Engineering and Automation IPA, Stuttgart, Germany

<sup>3</sup> European Welding Federation, Brussels, Belgium

<sup>1</sup> ASTM (n.d.). The 5 Most Important Standards in Additive Manufacturing. <https://www.astm.org/news/5-most-important-standards-additive-manufacturing>

can support more effective and sustainable standardisation processes in these domains?

The study analyses specific challenges in additive manufacturing standards and proposes concrete solutions based on stakeholder feedback. This paper is based on primary data collected and analysed for the research project titled “Boosting the Exploitation of Standardisation Inputs from European Projects” (STAND4EU), which aimed at identifying potential barriers to standardisation research and industrial innovation.<sup>2</sup> Similar to this paper, its objective was to support the development of standards by identifying and analysing the main barriers that occur in the standardisation process directly. The STAND4EU project focused on and incorporated four main technological domains STAND4EU: Additive Manufacturing (enabling technology), Welding (conventional well-established process), Smart Manufacturing, Industry 4.0, Digitalisation, Artificial Intelligence (technology-oriented), and Circular Economy. It follows a robust sequence of methods, starting with a survey (n=184), then interviews (n=44) with various experts in the manufacturing sector, and finally, focus groups through workshop events organised by the STAND4EU project consortium.

The paper can be further contextualised under the increasing EU interest in investing further research capacity to understand the relationship between standardisation and innovation, amidst the introduction of new technologies, and the nascent EU efforts to further strategize on standardisation (European Commission, 2022a; European Commission 2022b; European Commission, 2022b; European Commission, 2023a; European Commission, 2023b; European [25], Directorate-General for Internal Market, Industry, Entrepreneurship and SMEs, 2022). This includes the formation of an expert High-Level Forum on European Standardisation, to navigate standardisation strategy on the European level, which focuses on the internal market, industry, entrepreneurship, and Small-Medium Enterprises (SMEs) (High Level Forum on European Standardisation, 2024). In line with the interest of EU bodies on the performative and sustainability aspects of standardisation, the study contributes to a holistic expression of barriers in the European manufacturing standardisation sector. It aims at bridging the gap between academic research and practice, producing potential policymaking outputs, to support those involved in standardisation processes, policymaking and implementation in navigating standardisation successfully.

Furthermore, the motivation for this study lies in pre-existing, emerging or expediated challenges to the standardisation of manufacturing. Therefore, it moves beyond the relationship between innovation and standardisation,

factoring in the organic complexity of standardisation, acknowledging, for instance, the existence of discrepancies in the standardisation process amongst different organisations, bureaucratic limitations, and the different life cycles. In fact, framed and grounded under the “Standards Development Lifecycle Model” (SDLM), it recognises a series of obstacles through practitioners’ accounts.

Meanwhile, literature that addresses the impact of Industry 4.0 and Smart Manufacturing on standardisation highlights the need to expediate the facilitation of manufacturing processes, in line with the organic integration of digital technologies, data analytics and automation [39]. Uncertainty, discrepancies and different velocities over the direction of technological developments or making changes in different organisations have been hurdles in the standardisation process already. Because of globalisation and the expansive nature of supply chains, quality assurance became significant across different sectors, with frameworks like ISO (International Organization for Standardisation) providing structure and consistency [35]. Due to rapid changes on the technological front and Industry 4.0, current standards are in danger of becoming outdated and necessitating updates. Yet, achieving uniformity is difficult due to factors such as legal complications and regulations, and compliance, making the process more difficult both creation and implementation.

Finally, in terms of structure, the paper presents first a brief thematic scoping literature review, in order to identify key themes and debates in the standardisation literature, with particular focus to the descriptive discourse on the key drivers and obstacles pertaining to standardisation. Next, the methodology of the paper is presented, which follows a qualitative focused mixed-methods approach, and the methodical steps followed to conduct this study in detail, including the overarching conceptual SDL framework of the study. Results are thereby presented categorically, demonstrating needs, obstacles and best practices. The discussion further analyses the obstacles into thematic clusters, and proposes a remediation plan to stakeholders such as SMES, SDOs, Policymakers, and Research Projects.

## 2 Literature review

A quick scholarly outlook on standardisation suggests there is a consistent focus on the interaction between standardisation and innovation, and whether the former drives or impedes the latter. Research has also focused on the motivators and drivers for participating in standardisation in various settings, delving on the normative and descriptive debates on the importance and impact of standardisation. There is also nascent discourse on standardisation and sustainability. The literature also recognises persistent

<sup>2</sup> STAND4EU (2021). Stand4eu.eu. <https://www.stand4eu.eu/background.html>

coordination challenges between national, European, and international standards bodies. However, few studies examine how these coordination issues are experienced in practice at the organisational level, representing a gap that this study directly addresses.

Truly, societal changes and advancements have brought further interest to standards and standardisation in relation to additive manufacturing. For example, standards have supported streamlined communication, safety features, and innovative metric assessments [7, 30]. Dominant to the literature on standardisation is Blind's work, as leading contributor to the standardisation literature, Blind [7], has contextualised standardisation as part of a so-called "quality infrastructure", and views it as the product of a general socio-technical transformation. Blind has argued that standardisation can be understood as a transdisciplinary knowledge production and process, where many different parties can be involved [8]. In fact, when it comes to the interplay between national and international impact of standardisation, Blind acknowledges, that international standards can exploit changes to regulations national regulations, globally [9].

However, few have addressed the agency of the involved actors in standardisation [7, 33]. In that regard, Moon and Lee [33] investigated how primary actors affect the market, in three phases: the technology development, standard-setting and implementation/regulation. The authors identified four key roles: technology producers, standard-setters, regulators and technology users [33]. This kind of research further supports our understanding of the stakeholders and the roles of various parties to the standardisation process. Notably, others have even highlighted the agency and importance of researcher involved in the standardisation process and in standardisation research [2]. There are also studies that further focus on the importance of research to advancing standardisation implementation and development, and the advantage of the public availability of standards and their application for research and policy implementation [2]. A prime example of this is the Searle Centre Database on technology standards and standard setting Organizations, lauding the public availability of the database and its potential exploitation [2]. Similarly, Blind and Fenton [4] explore the benefit of standard-relevant scientific publications and the interaction of research integrated into standard development patents, which could be done more formally to maximize the advantage for all parties.

In terms of the motivation to participate in standardisation, a Chinese manufacturing study by Zhang et al., investigated what drives firms to participate in technical standardisation. The results of the study showed that technical standards impact national security developments, corporate innovation abilities and second firm performance [42,

43], p. 888). Therefore, there are strong strategic motives for firms to participate in standardisation. Moreover, the direction of competitors and of technology developments positively impact the motivation of firms to standardisation [42, 43]. Other organisations like SMEs may weigh their approach to standardisation, differently, and case by case. For example, SMEs may wish to access the knowledge of larger firms, but SMEs that are more autonomous in terms of their Research & Development (R&D) activities may be reluctant to participate in standardisation to safeguard their knowledge from competitors and assure their own competitive advantage [3].

Nevertheless, innovation remains the leading competitive driver and impact factor to standard-setting, and vice-versa [14, 37]. The significance of standards in that regard is demonstrated by another Chinese empirical study that has highlighted the positive effect of participating in the standards-setting process for corporate innovation [42, 43]. Other parts of the literature focus on the positive effect of specific standards such as ISO 9001, linking it to product innovation [31]. Standards have also been viewed as a model for sustainability [5] and as a beneficial mechanism for the successful integration of the front end of process development activities [12]. Participation within formal standardisation is positively related to firm performance in the manufacturing sector [41].

However, other research exploring the relationship of standards and innovation has shown no particular effect [10]. Another opposing critique is that studies on standardisation may not be engaging appropriately with practitioners and can be of little help to the practitioners who actually apply and create standards [15]. Nevertheless, the acknowledgment of the role of international organisations, groups and projects in advancing standardisation, for instance, in additive manufacturing, is recognised by Monzón et al. [32]. The authors recognise two key challenges to the standardisation process: the identification of the real requirements and needs of the industry, and the efficient coordination with other committees for standardisation, working in materials and processes. The latter is important due to the variable expertise in existing committees for AM-in materials, fields and sectors [32, p. 1120].

Finally, there can be other unprecedented external forces and intermediate variables that can constrain or promote standardisation, operating as push and pull factors. For example, Covid-19 impacted more significantly specific industries such as medicine and more moderately firms [7]. Methodologically, Blind and Gauch [11] have studied nanotechnology standardisation and the importance of research and standardisation, identified problems and recommended solutions. There are few instances of attempts to provide more robust recommendations or remediation plans for

industrial stakeholders in terms of standardisation—so far, other, operational material has played that role [34, 38].

Overall, so far studies on standardisation have been either too broad or too narrow domain-wise and geography-wise and not experimented with many other themes. Key to standardisation is enabling SMEs to participate in standardisation [17] and promoting researchers' involvement in publishing and patenting. Though some of the drivers and motives for to standardise have been explored under different contexts, previous studies have not managed to provide a systematic or holistic approach in identifying the obstacles and gaps to this process in the European manufacturing sector. In established domains like Welding, standards are widely institutionalised and embedded in certification and training pathways; however, in emerging domains such as Smart Manufacturing and the Circular Economy, the literature highlights ongoing debates regarding definitions, scope, and appropriate standardisation mechanisms. These differences suggest that the role and function of standards cannot be understood uniformly across technological contexts.

Despite growing attention to standardisation in manufacturing, there remains limited empirical evidence comparing how standardisation challenges are experienced across different technological domains, particularly between mature domains (e.g. Welding) and rapidly evolving ones (e.g. Circular Economy and Smart Manufacturing). Existing studies tend to examine single domains in isolation, or they focus on the technical development of standards rather than the organisational and practical issues involved in implementing them. Moreover, the literature provides little insight into how emerging fields such as the Circular Economy negotiate standards while their conceptual frameworks are still evolving. The next section reports on the data collection method and addresses this gap by drawing on survey and interview data across four distinct technological domains to compare the obstacles encountered in standardisation processes and to identify strategies that organisations consider effective in addressing these challenges.

### 3 Research methodology

This paper follows an inductive, qualitative focused, mixed methods approach. The primary data collected is derived from the STAND4EU project and its respective survey, interviews and focus groups. It follows the sequence of data collection methods that were employed for the STAND4EU project—a survey, interviews and focus groups—to identify the major obstacles of the current standards development lifecycle and to derive practical recommendations for improvement by means of a remediation plan. The data is analysed thematically, identifying emerging themes and

ideas. The technological domains were selected based on the diversity to include conventional, well-established and focused technologies, such as welding; and emergent cross-cutting and enabling technologies such as Additive Manufacturing, Smart Manufacturing and the Circular Economy.

The use of both surveys and semi-structured interviews was deliberately chosen to allow for a comprehensive examination of organisational experiences with standardisation across different technological domains. The survey enabled the collection of broad, comparable data on awareness, participation, and perceived obstacles, which was necessary to identify patterns that hold across sectors. However, survey data alone is limited in its ability to explain why these challenges occur or how organisations interpret and respond to them in practice. For this reason, semi-structured interviews were conducted to provide greater depth, nuance, and contextual understanding. Interviews allowed respondents to elaborate on organisational processes, strategic considerations, and internal decision-making in a way that cannot be captured through structured survey formats. This mixed-method approach aligns with established practice in standardisation and organisational research, where both systematic breadth and interpretive depth are required to understand multi-stakeholder environments. Furthermore, because the four technological domains differ in their level of maturity, institutionalisation, and rate of technological change, triangulating survey and interview evidence was essential to avoid overgeneralisation. By integrating both forms of data, the study can capture variation across domains, explain the sources of this variation, and develop findings that are analytically robust and grounded in real organisational experience.

#### 3.1 Standards development lifecycle (SDL) analysis

Identifying and overcoming obstacles based the Standards Development Lifecycle (SDL) is critical in ensuring that the standardisation processes are smooth and effective. The SDL framework supports this paper by offering a structured lens to examine each phase of standardisation—from development to implementation, thus helping to identify key barriers and propose targeted improvements for the European manufacturing sector. To achieve a high-impact remediation plan, it is important to solicit valuable feedback from a broader community to ensure the relevance of the identified obstacles and improve the depth of the recommended actions. To do so, first, we analysed various Standards Development Lifecycle Models (SDLM). Key considerations for the SDLMs research and analysis were set accordingly:

- Consideration of common SDLMs of national, European and international standards developing and standards setting organisations (e.g., ISO, IEC, CEN, CENELEC, IEEE,<sup>3</sup> DIN, ETSI);
- Consideration of common SDLMs (for example from research projects such as SDL MIMOSA<sup>4</sup>, BRIDGIT2 and other relevant tools NENnovation funnel<sup>5</sup>);
- Selection of common SDLMs based on the four technological domains formulated in STAND4EU (additive manufacturing, welding, smart manufacturing and artificial intelligence, and circular economy);
- Consideration of non-conventional or standout SDLMs, also from other areas that may provide additional information on further phases, content and roles, such as SAE International or NFPA.

Furthermore, key general phases of the standards development lifecycle models were distinguished, resulting in a general structure of the SDLM that reflects and identifies the common elements of the SDL models and their processes, and in addition includes further extensions and process segments that embrace more unconventional or outstanding components in the SDL. Each phase includes various steps—these phases simply provide guidance on the detailed information gathered at one step or another:

1. **Orientation and conception phase** include, for instance, such steps as orientation regarding the landscape of a standard's domain, gap analysis, development of requirements.
2. **Proposal conception and initiation phase** is commonly focusing on proposal conceptualization, engagement with experts of related technical committees and working groups, also including the proposal initiation and planning steps.
3. **Proposal review and approval phase** includes activities around the review and approval of a proposal. At this stage, the responsible committee reviews the proposal's scope, compliance, feasibility, priorities, impact, and resource planning, and initiates further steps for approval, such as an approved work item.
4. **Preparatory / development phase** commonly entails the mobilization of the working group and the actual work on the development of the standard based on the approved proposal. If necessary, membership is also clarified at this point, and the necessary meetings are

held. Some organisations provide extra services and support to the experts in the organisation to advance the standard design to completion.

5. **Voting and final approval phase** encompasses the invitation to vote and the steps around the draft review (including internal and sometimes external experts/stakeholders), followed by a number of various amendments based on the comments. The final step of this phase is to finalize the draft proposal for release and submit it for publication. Frequently, there is an additional round of voting to complete the final review of the document.
6. **Publication phase**—with the adoption of the standard, the standardisation organisation publishes the standard and makes it available to the public.

### 3.2 Stakeholder mapping

Key standardisation stakeholders were mapped out based on the four technological domains previously outlined. The stakeholders comprise of actors in technical committees, standardisation committees, innovation actors, technology providers, technology and standards adopters, Small Medium Enterprises (SMEs), research centres and academia, politics, etc. Top-level stakeholders include ISO (International Organization for Standardisation), ASTM, IEC and CEN, followed by National Standardisation Bodies, including but not limited to SIS (Sweden), BSI (UK) and DIN (Germany). A summary of stakeholder categories is:

- i. Research and Technology Organisations
- ii. Business associations
- iii. Industrial companies—Small company or enterprise
- iv. Industrial companies—Medium company or enterprise
- v. Industrial companies—Large company or enterprise
- vi. Universities or Academic Institutions
- vii. Policy Makers and Regulators

### 3.3 Data collection and analysis

For this study, needs are understood as missing dimensions in the standardisation process from the perspective of individuals and their respective organisations. Obstacles are understood as variables hampering aspects of the standardisation process. Best practices are considered as the best means and guidelines shared by key stakeholders and practitioners to facilitate the standardisation process.

An online survey and interviews were used to gather data with great scope, at national, regional, European, and international levels. The purpose of the survey and interviews was to collect, analyse and quantify the specific needs and

<sup>3</sup> IEEE SA—Developing Standards. (n.d.). Standards.ieee.org. <https://standards.ieee.org/develop/index.html>

<sup>4</sup> Standards Development Lifecycle – MIMOSA. (2024). Mimoso.org. <https://www.mimoso.org/standards-development-lifecycle/>

<sup>5</sup> NEN Webtool (2022, September 8). NEN Webtool | English <https://ninnovationfunnel.nl/en/>

requirements of the stakeholders previously identified. The survey was first carried out online during a three-month period, targeting a larger sample. Interviews were next carried out online on an individual basis, allowing stakeholders to share their experience and challenges with standardisation in more depth.

For the online survey, a set of structured and semi-structured questions were deployed to attract varied responses (Appendix A, Appendix B). The dissemination of the survey online proved valuable in reaching to as many stakeholders as possible from various locations [26]. Structured questions such as multiple choice and Likert scale questions were used in the survey in closed-ended format with a fixed response or with specific answer options for respondents to choose from [36]. These questions were useful in cross-tabulating and comparing with other types of open-ended questions in between the survey and interviews, that were used to collect more detailed and personalised answers [16].

Our sampling can be best described as convenience and snowballing, for our interviews, survey and focus groups, as it was largely based on key STAND4EU consortium contacts. The online survey gathered a total of 184 responses, and 44 valid interviews. Out of a total of 184 respondents, the online survey included 108 complete responses, 62 partial responses, and 14 disqualified responses. Finally, focus groups or unstructured conversations were employed during workshops from the 7th of June to the 27th of July 2023, which were conducted online via Teams with the exception of one workshop that was held in Singapore. The objective of these focus groups and conversations was to gather feedback on the survey and interview results and to engage with participants willing to share key best practices in standardisation.

To analyse the online survey results, complete responses, as well as partial responses, were considered to eliminate the possibility of introducing a bias to the analysis. Concerning the statistical analysis technique, simple cross-tabulation was performed to identify patterns and relationships in the survey results. Thematic analysis was performed after gathering insights based on participants' experiences, views, perceptions, beliefs, and attitudes. The data was analysed thematically and manually via Excel in spreadsheets, identifying themes through language and frequency. Obstacles

were analysed using multiple information sources (e.g., interview, survey, general research); information source types (e.g., standards body, research organisation, business association, industrial company, university, policy makers and regulators, and industry association); size of a company (if provided); mapping to the associated STAND4EU area; bottleneck type or a suggestion for improvement; detailed description; associated category of the analysis (e.g., bottleneck, improvement, or important observation). The obstacles identified were classified and assigned into different categories according to the general standardisation phases and steps. With consideration to the needs identified, the obstacles were further classified into key thematic clusters, indicating important areas to improve.

Since the study was conducted by different partners involved in the STAND4EU project, therefore appropriate ethical standards were maintained to ensure the integrity of the data collection process and the analysis of the results. These standards include obtaining informed consent from participants, protecting participants' privacy and confidentiality anonymising their data, ensuring that the survey and interview questions and responses are not misleading or coercive, and ensuring that the data is stored securely and used only for research purposes. Before delving into the results, it is useful to present some demographic data that were collected from the survey and interviews, were sampling was more purposeful.

## 4 Results and findings

To contextualise the data, first, a brief demographic statement on the survey and interviews is provided, discussing how the demographic factors may influence the results. The results in Table 1 indicated the number of respondents who took part in the interviews and survey. The distribution of stakeholder affiliations across the four core technological domains indicates that Smart Manufacturing and Additive Manufacturing were the most represented areas among participants. Smart Manufacturing had the highest overall engagement, with 106 total respondents (27 interviewees and 79 survey respondents). Additive Manufacturing formed the second largest group, with 91 stakeholders in total (25 interviews and 66 surveys). Circular Economy and Welding had moderate representation, with 63 and 39 total participants respectively. Finally, the 'Other' category in Table 1 (46 participants) reflects involvement from other general manufacturing services. Overall, the distribution suggests that respondents were mainly affiliated with Smart Manufacturing and Additive Manufacturing in this study.

In this table, the Other category refers to organisations that do not fall neatly into any of the defined stakeholder

**Table 1** Stakeholder affiliation to technology domain: survey and interviews

Stakeholder domain affiliation	Interviews	Surveys	Total respondents
Additive manufacturing	25	66	91
Welding	7	32	39
Smart manufacturing	27	79	106
Circular economy	20	43	63
Other	6	40	46

categories, such as Consultancy firms (e.g., technology, compliance, certification consultants), Training and Skills organisations, digital innovation hubs, independent experts or freelancers participating individually, Non-profit foundations or NGOs as well as other technology transfer centres that are not classed as RTOs.

Three key observations are important to highlight in that respect are:

**1. The prevalent participation of Research and Technological Organisations (RTOs and Standardisation Bodies).** The survey gathered most responses from Research and Technological Organisations (RTOs), and the least from the Policy Makers and Regulators category. There is an even participation to the survey amongst higher education–university large industrial companies and standardisation bodies. Respondents recorded their responses in more than one category. The ‘Other’ category represents respondents from certification bodies, Vocational Education and Training, professional associations, and so forth, providing mix of responses. The most prevalent group of respondents in the interviews came from standardisation bodies, though Small Industrial Companies, and RTOs were second close (Table 2).

**2. An evenly sparse geographic distribution of responses with Germany being the study’s top respondent:** The study captured a diverse geographical distribution of survey responses where Germany, Spain and Belgium scored the highest (Table 3). From the interviews, Germany scored the highest number of respondents, followed by Sweden and Belgium. There is a strong central European presence into the responses, overall.

**3. Most inputs came from experienced Middle Level Management individuals:** Participants in the survey and interviews came from different types of management level yet were mostly experienced. For instance, most participants in the survey reported having more than ten years of work experience. The largest age group among the survey participants was 36–55 years old and the second largest group was “over 55” years old. Moreover, most of the survey respondents came from Middle Level Management. Similarly, most interview participants reported having more than ten years of work experience.

#### 4.1 Standardisation needs and obstacles identification

To gauge views on the needs and obstacles in the development, use and implementation of standards, it was deemed beneficial to understand the role standards play in different organisations and innovation. Regarding the impact of standards, survey respondents described them as supporting building audit systems and thus exporting best practices.

**Table 2** Stakeholder category representation: survey and interviews

Stakeholder category representation	Survey	Interviews
Standardisation Body	21	12
Research and Technological Organisation	47	9
Business Association	10	5
University	25	8
Policymakers and Regulators	2	0
Small Industrial Company	17	10
Medium Industrial Company	9	0
Large Industrial Company	23	6
Other	13	6

**Table 3** Geographical representation of research participants

Geographical representation of research participants	Survey	Interviews
Austria	1	0
Belgium	11	4
Brazil	1	0
Bulgaria	1	0
Cyprus	1	1
Denmark	1	0
Finland	4	2
France	3	2
Gabon	1	0
Germany	44	11
Greece	7	0
Ireland	7	2
Italy	7	2
Latvia	1	0
Luxembourg	1	1
Netherlands	3	0
Norway	3	2
Peru	1	1
Portugal	7	1
Romania	1	0
Serbia	3	0
Slovenia	1	0
Spain	13	2
Sweden	4	5
Switzerland	3	2
Ukraine	1	0
United Kingdom	3	3
United States of America	2	3

Standards were described as a step towards establishing a common language for technological activities, which in turn, can verify their functionality and adherence. Standards with valuable propositions and a certain formality were also perceived as important in keeping track of standardisation, especially considering legislation affecting the products requiring standardisation. Furthermore, in terms of understanding the role of standardisation in innovation, it is important to add that 65.9% of survey respondents did not see standards constraining innovation. A sizable minority (34.1%) did, however, express the opposite view.

Nevertheless, this was not labelled as positive or negative in further technological advancement. Those participants that identified standards as constraints for innovation argued that concepts like circular economy remain practically confusing, or that standards can also push companies in the wrong directions. On one hand, standards were seen to slow down the realisation of an innovative project, on the other hand constraining innovation was still described as enabling creativity. In terms of use and implementation of more established standards, 14 different standards were described by the respondents, and of these, the Quality Management Systems Standards were most mentioned by the respondents and from all technology domains, highlighting awareness and interest.

#### Quality Management Systems Standards

ISO 9001—Quality Management Systems

ISO 9000—Fundamentals and Vocabulary

#### Environmental & Energy Management Standards

ISO 14001—Environmental Management Systems

ISO 14040—Life Cycle Assessment—Principles and Framework

ISO 50001—Energy Management Systems

#### Welding Standards

ISO 3834—Welding Quality Requirements

ISO 14731—Welding Coordination—Tasks and Responsibilities

ISO 9606—Qualification Testing of Welders

#### Additive Manufacturing Standards

ISO/ASTM 52904—Process Characteristics and Performance (Metal PBF)

ISO/ASTM 52920—Qualification of AM Operators / Personnel Competence

ISO/ASTM 52930—Guidance on Registration and Traceability in AM

ISO/ASTM 52904—Metal powder bed fusion process to meet critical applications

#### Inspection, Testing & Certification Standards

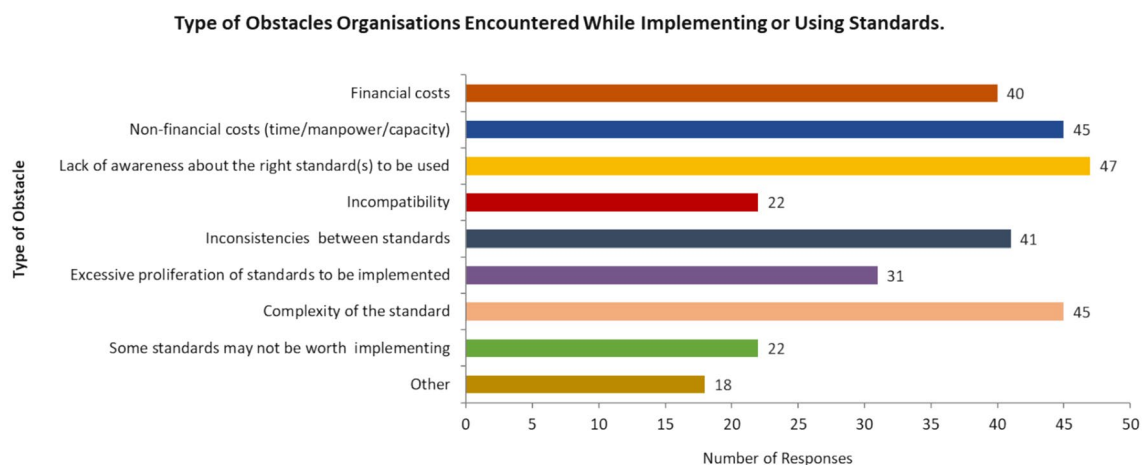
ISO/IEC 17020—Conformity Assessment—Requirements for Inspection Bodies

#### Cybersecurity Standards

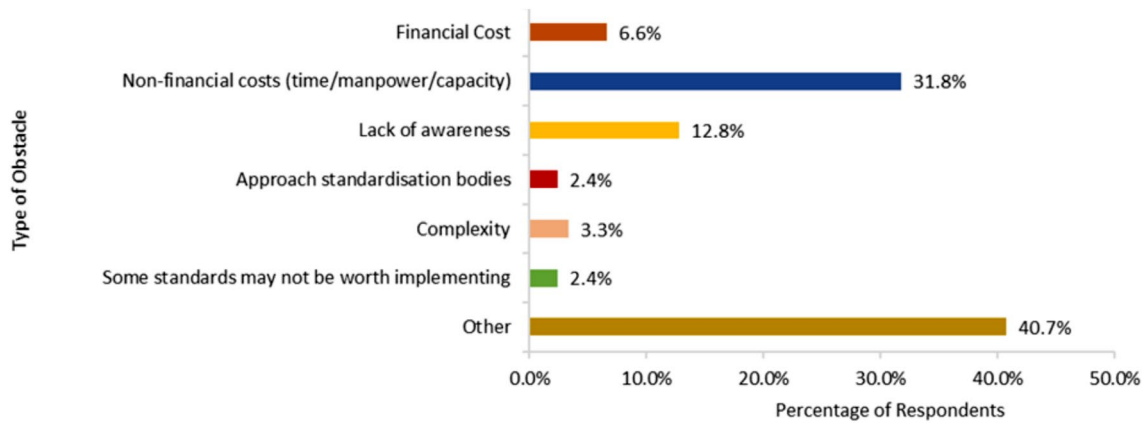
ISO/IEC 27001—Information Security Management Systems

Survey respondents were directly asked to identify obstacles in implementing or using standards (Fig. 1). In this case, most respondents pointed to a “lack of awareness about the right standards to be used”. The next most frequently identified obstacles are non-financial costs such as time, labour and capacity, and the complexity of standards. Many respondents highlighted the inconsistencies between standards, and financial costs associated with using standards. Participants were also asked to identify obstacles in developing standards, based on the standardisation development life cycle (SDL) phases (Fig. 1). Here, a list of predetermined options to choose from was demonstrated: financial costs, the lack of awareness, approaching standardisation bodies, the complexity of the process, the value of implementing some standards. Like the implementation of standards, non-financial costs (time, manpower, capacity) are regarded significantly impactful in obstructing the development of standards. In terms of “other” in Fig. 1, reasons for obstacles that organisations encounter include political impact, speed of technology development, trust inside the industry, trust from the end user, sustainable development, quality control, the readiness of standards, SMEs representation, risk regulation, and increased data sharing.

Yet, respondents mostly identified other obstacles outside the scope of the options (40.7%) (Fig. 2). Examples provided in this category include—but are not limited to—the amount of comments on standards drafts, the inability to keep track of what is published, the lack of access to all standards, hardship in making dialogue with other companies, gaining support from the community, getting a



**Fig. 1** Types of Obstacles Organisations Encountered While Implementing or Using Standards (Survey)



**Fig. 2** Obstacles Organisations Encountered during the Standardisation Development Life Cycle (SDL) Phases (Survey)

consensus during the voting process, the difficulty of developing a standard in a language outside one’s native, finding the correct project leader, and the lack of marketing. In terms of “Other” in Fig. 2, reasons include: the amount of comments on standards drafts, keeping track of what is published, lack of access to all standards, making dialogue with other companies, gaining support from the community, getting a consensus during the voting process, the difficulty of developing a standard in a language they are not native in, finding the correct project leader, and the lack of marketing.

## 4.2 Analysis of differences across technological domains

The responses indicate that perceptions of standardisation vary notably across the four technological domains, reflecting differences in technological maturity, rate of innovation, and clarity of operating frameworks. Additive Manufacturing (AM) respondents consistently emphasised the need for continued development and harmonisation of standards, particularly in areas such as process qualification, operator competence, material traceability, and quality assurance. AM is a rapidly evolving field, and stakeholders highlighted that standards often lag technological progress, leading to uncertainty in certification and industrial adoption. As a result, participants viewed standardisation as necessary for scale-up and trust, but also as an ongoing process with unresolved gaps. In contrast, Welding respondents described a mature and stable standardisation environment. Many organisations already work under long-established frameworks such as ISO 3834, ISO 14731 and ISO 9606. Here, standards are perceived as routine tools for quality and compliance, rather than topics of active debate or concern. Discussion focused more on implementation and auditing than on the development of new standards. This indicates lower perceived urgency for new standards in welding compared to AM. Smart Manufacturing responses

highlighted challenges related to interoperability and integration. Because smart manufacturing systems depend on the interaction of digital platforms, sensors, control systems and data architectures, respondents noted difficulties in applying standards consistently across heterogeneous supply chains and vendor ecosystems. Standardisation in this domain is therefore seen as necessary to enable system-level compatibility but complicated by the breadth and diversity of the technologies involved. For the Circular Economy domain, respondents expressed conceptual and definitional uncertainty. Stakeholders noted that the underlying models for environmental value, material flows and lifecycle metrics are still evolving, which creates a risk of premature or overly prescriptive standardisation. As one respondent suggested, standards may “mislead” practice if applied before the domain’s principles are widely agreed. Thus, the Circular Economy domain exhibits high interest but still maturing engagement with standardisation. Finally, respondents affiliated with the Other category tended to focus on coordination challenges, noting the need for clearer alignment across overlapping standards and between technical and management system standards (e.g., ISO 9001, ISO 14001, ISO 17020).

The interview data confirmed that challenges and obstacles differ significantly across the four technological domains. In Additive Manufacturing, the rapid pace of technological change means that standards often lag behind practice, creating uncertainty and the perception of “missing” or incomplete standards. For example, one respondent quoted that “Drafting a standard can be painful. Very slow development of standards (arguing over fine details of text...). Achieving perfection in a timely / consensus process is very difficult.” In Welding, challenges relate less to developing standards and more to uneven adoption due to differing national or regional standard frameworks. A respondent replied that “The most important obstacle is that strong influence of North American standards. People

don't use normally Eurocodes or ISO standards because there is a lack of knowledge about it.” Smart Manufacturing stakeholders highlighted delays and inefficiencies in consensus-building and document alignment such as “The challenge here is consensus management... The first obstacle we face... formal, technical, and consensus management. Oftentimes, we receive documents that don't comply with the ISO regulations... this leads to delays, and then those delays can be massive.”, while Circular Economy respondents noted that the domain's conceptual foundations are still evolving, making premature standardisation difficult and sometimes counterproductive where one respondent replied “There's no ‘one’ standard that is really working for circular economy. They start to complain about that and say ‘We need better standards. But then it's always a little bit waiting and seeing because you cannot do that yourself.’”

### 4.3 Standardisation best practices identification

Most participants had considered the use of current standards as part of their projects to determine whether any would have been useful. First, through the survey roll out, respondents shared the following best practices: engaging stakeholders in standardisation with lower participation, organising more regular exchanges with relevant projects and research organisations, and changing the standards development process to include specific/additional feedback loops from the research community and other stakeholders. Another key best practice put forward was the establishment of a foundation to develop evidence-based indicators reflecting the performance of Research & Development (R&D) in relation to standardisation efforts. Participants also raised that SDOs should be allowed to broaden their service offerings for R&D projects and investigate innovative approaches to better synchronise standardisation with R&D. Moreover, participants raised as best practice

the need for training and coaching on standardisation. Next, from our interviews, we gathered the following best practices: aligning standards with the values of the civil society, avoiding duplication of work through information-sharing across projects, creating a body to write routine reports on standardisation, developing standards even if they will not be used, developing standards that would motivate the consumers to use a product. Participants also raised further suggestions primarily increasing funding, reducing time, including creating incentives for developers, fostering inclusivity, increasing meetings. Other practices are those of making templates/pilot guides, making a platform to find standards easier, increasing communication and collaboration, implementing more digitalised processes, increasing transparency, pushing standards in a minimum viable form and updating them later, and reducing bureaucratic hurdles (Fig. 3). The “Other” category includes activities such as developing standards that encourage consumer adoption, publishing initial minimum-viable standards and refining them over time, creating platforms to improve the discoverability of standards, reducing duplication of work through information-sharing across projects, aligning standards with civil society values, establishing bodies to produce routine standardisation reports, and developing machine-readable or systemic standards.

Our third method of data collection—focus groups—concentrated on understanding best practices shared by various practitioners and stakeholders in further detail. The following thematic areas organically emerged, echoing similar practices shared in the survey and interviews:

Communication and engagement with stakeholders and committees. Key practices shared here revolve around establishing a collaborative approach to standardisation, by forming working groups and creating committees. This thematic area includes pursuing a collaborative development of standards, by synergising information and insights. It also

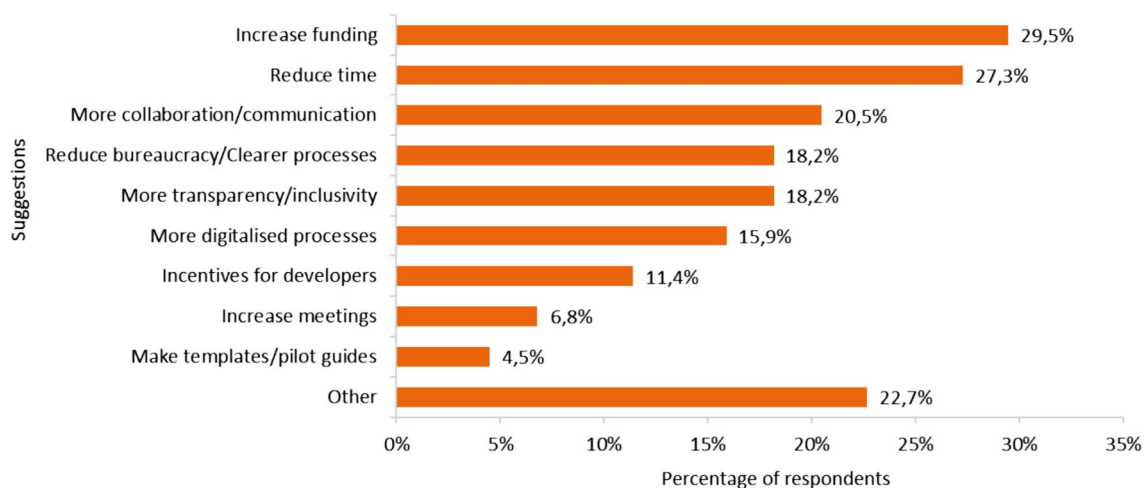


Fig. 3 Suggestions for improvement in the standardisation process (interviews)

includes pursuing the collaboration of organisations to avoid duplications and the align with other stakeholders. The key here is to is implement clear and effective communication and information exchange between the stakeholders, such as technical committees and project members. Additionally, it was advised to recruit industry experts and to take proactive measures to engage directly with national standards committees, gathering feedback from various industry stakeholders to ensure inclusivity, transparency and collaboration in the standards-setting process. This could include organising workshops and enabling further networking opportunities with standardisation organisations. On that front, another best practice put forward was that of providing further clarity on the involvement and value of SMES, and to work with SME associations.

Methods, applications, and organisation of standardisation process. This thematic area involves best practices shared in streamlining the standardisation process, eliminating steps to expedite the process. Methods shared here include employing structured standardisation approaches, such as creating a centralised database to manage standardisation efforts more effectively, meticulously analysing, developing and reviewing standards on an international level to understand further engagement with stakeholders and conducting risk analysis for standards, to estimate their future applicability.

Moreover, a form of domain knowledge transfer was suggested, for instance, by adopting best practices from other industries as sources of inspiration. Other best practices revolve around the alignment and conformity of standards: ensuring the alignment of standards with established regulations and international norms and aligning welding standards with key regulations and standards (i.e. ISO 3834). Another dimension of best practices revolves around enhancing the accessibility and awareness of standards and their value. This includes making standards publicly available. Additionally, the soft implementation of standards was deemed important, using guidelines rather than bans of products and elements. This also means using positive language for the implementation of standards as valuable tools, facilitating any other language issues amongst international entities in the process regarding the technical documentation.

The role of SMEs was highlighted again, helping them in facilitating the standardisation process, should they be lacking expertise in their teams. Be it complex, adopting an inclusive approach by incorporating innovation and sustainability in the process, was further emphasized. In terms of the efficiency and speed of the standards development, here it was suggested that time is minimised in developing standards or in between the stages and processes, engaging relevant industry stakeholders in the standards-setting process.

In that regards, timeliness as best practiced includes providing timely updates and releases of standards.

Revisions should be purposeful and should provide transparency and clarity. In that sense, implementing a robust and continuous review mechanism, periodically assessing the relevance and efficacy of established standards was advised. Participants urged that revision proposal are formalised, and that a more structured and systematic approach is followed. This could include also templates to guide researchers on how to contribute effectively. At the same time, to assure the best reproduction of standards, stringent quality controls should be in place, promoting harmonisation and connectivity.

Material and other support for standardisation. This area of best practices focuses on maximizing resources, by transforming standardisation projects into paid positions, and seeking more funding, for example, connecting with digital innovation hubs, Horizon and European projects. It also includes applying reforms and improvements in the funding process for standardisation projects and receiving support in bridging the gap between standardisation and actual research projects. Time was also considered an essential variable; it was suggested that shorter timelines are set for standardisation projects, as it can take some time to secure liaisons with projects.

Academic participation and education. Research participants highlighted the importance of the participation of academic institutions in standardisation. Best practices came in the form of engaging academia in recognising standardisation as an academic merit, with universities participating in standardisation committees. Here, universities were urged to create separate courses or include standardisation in curricula. At the same time, there is an opportunity for technical committees to create student chapters to participate in these organisations. SDOs could also provide education and training opportunities for SMEs and RTOs. Applying cross-sectoral training. Focusing on improving engineering education and trainings, proposing even cross-sectoral trainings. Following robust qualification and certification procedures.

Age and participation. Finally, the benefit of including younger people in the standardisation process was brought forward on a theoretical, practical and educational level. This is consistent with the aforementioned best practice in establishing academic-student-standardisation connections, as well as the demographic data of the age groups engaging with the survey and interviews.

## 5 Discussion

Overall, the participants' perception of standards as complex suggests that the processes of understanding, developing and applying them can often be perceived to be unclear, technical or overly bureaucratic, which can hinder their effective adoption and use. The obstacles identified through the survey, interviews and focus groups are classified thematically in twelve (12) key categories. These categories often overlap and can have a spill-over effect in obstructing standardisation. In fact, our analysis shows that the needs, obstacles and best practices shared by research participants significantly overlap thematically, and thus interchangeably and directly operate as key indicators for the direction of remediation plans and the formulation of further recommendations. The barriers identified in this study, including limited resources, time constraints, and reliance on voluntary expert contribution, are consistent with previous findings that standardisation processes often depend on uneven organisational capacity (Blind and Heß 2023). The variation observed across technological domains aligns with research highlighting that standards maturity differs significantly between established sectors, such as Welding, and rapidly developing fields like Additive Manufacturing and Smart Manufacturing [37]. In the Circular Economy domain, the challenges relating to conceptual ambiguity and evolving definitions reflect prior work cautioning against premature standardisation in emerging sustainability frameworks [8]. Additionally, the coordination and consensus-building difficulties observed here are consistent with studies describing the structural governance constraints inherent in international standardisation systems [15]. In summary, the 12 key obstacle categories are:

1. Lack of resources and funding: Standards development is time- and resource-intensive, and progress slows or stops when organisations cannot allocate sufficient staff or funding.
2. Lack of time: Time pressure can arise from short process phases or from the overall long duration of standardisation, causing delays and reduced capacity for meaningful participation.
3. Poor quality of a standard: Low-quality proposals or insufficient review can result in unclear, incomplete, or ineffective standards.
4. Lack of expertise: Limited involvement of qualified experts or adopters can weaken the technical soundness and relevance of a standard.
5. Low coordination and unclear processes: Weak coordination and inefficient procedures can lead to errors, rework, delays, and increased costs.

**Table 4** Thematic clusters of key best practices

Efficiency and speed	To update the standardisation process by making it more efficient. This includes implementing reforms, ensuring the consistency and quality of standards, however, the process should be made simpler and should include younger people
Communication	To increase the awareness and accessibility of standards. This includes acknowledging cross-domain insights, engaging with external stakeholder, and using positive and inclusive standardisation language
collaboration and inclusivity	Transparency; Research; Centralised functions and databases; Dedicated bodies for standardisation reports; Working with Small and Medium Enterprises (SMEs); Soft implementation of standards via guidelines
Funding	Lower costs and more funding; Financial incentives for those involved in the process
Education and training	To bridge the gap between standardisation and research projects, and to connect academia with practice

6. Process complexity and bureaucracy: Lengthy, multi-step procedures and administrative requirements can slow decision-making and create confusion.
7. Complexity of scope and standards landscape: Overlapping, competing, or poorly aligned standards, especially in emerging technologies make it difficult for organisations to select, apply, and integrate relevant standards.
8. Poor expert involvement: When expert participation is inconsistent or insufficient, standards risk being outdated, incomplete, or lacking acceptance.
9. Low motivation and interest: Limited awareness, low perceived benefit, or insufficient incentives can reduce stakeholder engagement in standardisation.
10. Limited transferability and support: Missing guidance, training, and education reduce the usability and adoption of standards in practice.
11. Slow development speed: The need for consensus, technical validation, and iterative review makes standardisation processes inherently slow, sometimes misaligned with technological change.
12. Lack of consensus and conflicts of interest: Divergent stakeholder priorities can make agreement difficult, requiring transparent processes and impartial decision-making to maintain fairness and legitimacy.

Research participants to the STAND4EU project's survey, interviews and workshop focus groups were also asked to provide what they understand as best practices. Their recommendations ultimately revealed five (5) key distinct areas that necessitate more attention and care. These are: 1. efficiency and speed, 2. communication, 3. collaboration and inclusivity, 4. funding, 5. education and training (Table 4). These areas can operate as key principles and directives

to improve standardisation efforts. More importantly, they demonstrate the need for flexibility, for inclusivity when it comes to stakeholder engagement and for stronger structures to support those involved in standardisation. They also suggest that the successful implementation of standardisation depends not only on addressing current barriers but also on investing in long-term capacity-building and system-wide coordination. Overall, the core themes of the best practices can serve as practical and strategic guides for shaping more effective and resilient standardisation efforts.

### 5.1 A way forward: remediation plan

The empirical results gathered on the obstacles, needs and best practices to tackle standardisation have fuelled the remediation plan proposed in this paper. The plan includes measures and suggestions that can be adopted by the standardisation bodies to make the standardisation process more flexible, such as addressing low expertise, missing funding opportunities, and the quality of standards. The widespread application of the remediation plan has already been implemented within the STAND4EU project through training and coaching activities as well as the use of the project platform. Below are some examples of the general recommendations developed and targeted at various stakeholders:

**1. Small Medium Enterprises (SMEs):** SMEs should assign internal responsibilities to cover and address standardisation, not only for personnel development, but also to improve the work within the projects and the impact of their results on the standardisation groups, considering the demonstrated growing impact on the surveyed company activities. Moreover, it is recommended that SMEs attend available trainings to build up their own standardisation and sustainability experts.

**2. Standardisation Development Organisations (SDOs):** Support to industry and standardisation experts to participate in standardisation events should be provided to stimulate the engagement of organisations with standardisation. An easier contact between SME's and SDOs should be promoted to ensure an easier contribution to standards. The advantage provided by digital tools to get in touch with an SDO should be exploited; by providing an online open comment section or an easier and quicker on-boarding process have experts and SMEs not involved in the standardisation committees contribute as well. Independent access to consulting services for SMEs should be enabled to get an overview on ongoing activities, and to get support on dealing with existing standardisation needs. The complexity of some standards should be simplified by creating a guide for implementation that reduces or deconstruct the standards, clarifying all the dependencies for SMEs, making the standards adoption more flexible.

### 3. Policy Makers (including the EU commission):

The development of a Lean Standard Development Process for EU standards is crucial for the engagement of different stakeholders in standardisation. A “Standardisation Training Centre/Service for SMEs” to encourage adoption and contribution to standards should be created. Within the Digital Innovation Hubs (or similar innovation support ecosystems), a dedicated service to support and encourage SMEs to adopt standards should be established: either as a training service or as Standardisation test cases, where the competence centres associated with the DIHs support the SMEs with standardisation activities.

A clear description and guidance of what is expected from the Research Projects concerning contributions to standardisation should be provided for the call topics, such that those projects should be aware from the proposal stage of what is expected in terms of contribution to standardisation and present an initial mapping of relevant standards and/or standardisation committees.

New funding opportunities to promote and value the involvement of organisations (R&D centres, companies, etc.) to participate in the discussions of standardisation technical committees and operationalisation activities, and to support the costs of access to standards. Further strategies to inform and create awareness to standards to young professionals and the new generation of researchers should be developed. The creation of a Centre of Excellence for Standardisation (CoE) to manage the implementation of the recommendations should be promoted. The services of this centre are targeted at various standardisation stakeholders and should include (but not limited to): Identification of standardisation gaps on national and regional (e.g. EU) levels; Provide regional-level standardisation roadmaps for different domains; Testing and validation of standards in collaboration with regional standards testbeds. This CoE should complement the existing structures and initiatives, such as the EU Excellence Hub on Standards (to facilitate stronger internal cooperation within the Commission) and the High-Level Forum for Standardisation (to identify standardisation priorities in support of EU policies and legislation).

**4. Research Projects:** It is recommended for project consortia to adequately plan standardisation activities while preparing proposals. This may include access to previous standardisation work performed on the topic, to be followed by direct interaction and engagement with experienced experts, and potential advice on the actions to be taken towards standardisation. Research projects should seek available training, which can be found for instance directly in the STAND4EU portal, at the beginning of and during their research activities, so they can ensure an effective contribution to standardisation. The engagement of universities and Research Centres into standardisation activities will

also support shortening the time between innovation and the development of associated standards. Furthermore, considering the necessity of ongoing engagement with standardisation activities beyond the project duration, it is crucial to include partners, such as industrial associations, that maintain a continuous involvement with standardisation bodies. This ensures a lasting impact and relevance of the standardisation efforts initiated during the project.

## 5.2 Limitations

This study has several limitations that should be acknowledged. First, due to resource constraints, this study opted for a relatively simple data analysis strategy, which may not fully capture the complexity of stakeholder responses. Additionally, while efforts were made to engage a broad range of participants, not all stakeholder groups, in particular end-users were adequately represented. The sample also carries the risk of selection bias, as those who chose to participate may already have a vested interest in standardisation, potentially skewing the findings toward more engaged or informed perspectives. Furthermore, geographic representation across EU countries was uneven, limiting the generalisability of results at a European level. Finally, the study provides only a snapshot in time, without a longitudinal component to assess how stakeholder perspectives might shift over the course of the standardisation lifecycle or in response to evolving policy and technological developments.

Future surveys and interviews on this topic could consider using a larger sample size to increase the accuracy of their results. This would offer a more representative view of the population. [1]. Finally, including different groups of stakeholders could provide a more complete understanding of the issues surrounding standards. Even though this was attempted, especially in the interview process, a lack of experts willing to participate was noted. Additionally, conducting the survey and the interviews in different languages and countries could capture a broader range of perspectives and experiences. It would ensure that the results are representative and can be generalised to the population of interest.

## 6 Conclusion

The paper addresses a critical gap in the standardisation of manufacturing, with a particular focus on the European sector and four key technological domains: Additive Manufacturing, Welding, Smart Manufacturing (Industry 4.0 and Artificial Intelligence), and the Circular Economy. This study contributes to the field of standardisation in

European manufacturing by delineating the key challenges and proposed remedies for standardisation implementation and development. Conceptually and theoretically grounded under the Standardisation Development Lifecycle (SDL), it surveys the views of international and European stakeholders in standardisation efforts in the European manufacturing sector, with particular focus to the development and implementation of standards. We return to the three research questions guiding this study and the following short summaries show how the collected evidence directly responds to each question.

**(A) What are the key obstacles encountered in the development, adoption, and implementation of standards in the European manufacturing sector?**—Stakeholders reported obstacles including slow consensus-building processes, lack of clarity in roles and responsibilities, and practical difficulties in applying standards consistently across organisations. Additional challenges include limited organisational capacity, uneven awareness of standards, and the resource burden associated with compliance and certification.

**(B) How do these obstacles vary across different technological domains?**—In rapidly evolving domains such as Additive Manufacturing and Smart Manufacturing, standardisation challenges are linked to technology maturity, interoperability, and the need to continually update guidance. In contrast, more established domains like Welding reported fewer development challenges, while the Circular Economy domain showed hesitancy due to ongoing conceptual ambiguity and evolving definitions.

**(C) What practices or strategies can support more effective and sustainable standardisation processes?**—Respondents highlighted the importance of early stakeholder involvement, clearer communication across standardisation bodies, and practical guidance that aligns standards with real industrial needs. Cross-sector collaboration, support for SMEs in implementation, and iterative approaches to updating standards were also viewed as critical enablers of more effective standardisation.

One of the most important contributions of this manuscript is its identification of key barriers to the adoption of manufacturing standards. Among these, the lack of awareness regarding which standards to apply stands out as the most prevalent, while other non-financial obstacles, such as time, labour, capacity, and the complexity of standards, are also highlighted. This nuanced understanding of the hurdles encountered by practitioners and industry players offers valuable new perspectives that can inform both policy and practice. The study's results echo existing concerns over the overall complexity of standardisation, however, more than that, they demonstrate where the complexity and need for the establishment of common best practices lies. This is

reflected under key areas that need to be further streamlined, such as efficiency and speed, communication, collaboration and inclusivity, funding, education, and training.

These areas constitute the basis for the provision of a remediation plan, a roadmap for remediation activities within the SDL, while minimizing barriers in the standards development process. Following the development and validation of recommendations/remedies, it is important to address the adoption possibilities of the remediation plan results and investigate their transferability to other domains outside the four domains within the STAND4EU project. With consideration to this study's limitations, it is recommended that future research delves deeper into the impact of these challenges by addressing other domains or further focusing on specific domain. Moreover, it is recommended that specific obstacles are explored to understand their impact on different phases of the SDL. Further to this, it is possible that geographical location influences the perceived complexity of standards. It is also possible that different regions or types of organisations face unique standardisation challenges.

Another direction would be to further engage with policymakers, to gather their feedback on the proposed remediation plan and its feasibility. Future research could also use our findings to compare and validate the identified obstacles across different EU industries and EU regions. It is also possible to assess the transferability of the proposed remediation plan, by investigating its applicability to other sectors in the EU beyond the STAND4EU project. Another suggestion would be to study the real-world impact and effectiveness of the remediation plan during its potential implementation. Our study highlights the importance of education and training, therefore it is recommended that future studies examine the role and effectiveness of education and training in improving standardisation practices, as well as how education and training can raise awareness. Finally, it is recommended that a longitudinal study is conducted to track how standardisation practices evolve over time across different EU industries and EU regions.

## Appendix A: Survey questions

1. I have read the Participant Information Sheet included with this questionnaire
2. I am over the age of 18
3. I understand that no personal identifying data is collected in this study, therefore I know that once I have submitted my answers I am unable to withdraw my data from the study
4. I agree that my data can be anonymised, stored and used in future research in line with Brunel University's data retention policies
5. I agree to take part in this study
6. Which of the following age categories do you fall into?
7. What work experience do you have?
8. Which kind of stakeholder category do you represent?
9. What is your role in your Organisation?
10. What is your Organisation's Name?
11. Where is your Organisation based?
12. Which of the four technological domains are you involved in? (You can select more than one)
13. How well does the use of standards support emerging technologies (such as AI, blockchain, additive manufacturing etc.) in the EU/UK?
14. Do standards constrain innovation?
15. To what extent do you agree that there is a need for training and coaching on standardisation?
16. There is a need to examine the needs of small and medium-sized businesses in joint research on standards and standardisation.
17. Have you participated in an EU or nationally funded research project?
18. Have you considered the use of current standards as part of your project to determine whether any will be useful?
19. Why hasn't your organisation considered the use of standards as part of your project?
20. The standardisation process involves 8 phases. If you are involved in any of these phases, please describe the obstacles
21. What were your project's primary motivations for addressing standardisation?
22. Have you worked together with Standards Developing Organisations (SDOs) OR National Standards Bodies (NSBs) on projects? (Examples of SDOs—ISO, IEC, CEN; Examples of NSBs—DIN, BSI, AFNOR, etc.)
23. How involved was the NSB / SDO in the project?
24. Has your project directly or indirectly been involved or resulted in a specific recommendation or proposal for the development of new or revised standards?
25. SDOs should be allowed to broaden their service offerings for R&D projects and investigate innovative approaches to better synchronise standardisation with R&D.
26. It is necessary to establish a foundation (one-stop shop) to develop evidence-based indicators reflecting the performance of R&D in relation to standardisation efforts
27. To what extent do standards or standardisation activities have an impact on your Organisation's processes/project activities?
28. How important is standards to your organisation's innovation activities?

29. Has your organisation used or implemented standards?
30. Identify the obstacles that your organisation encountered while implementing or using standards.
31. Have decisions in your organisation been affected in any way by SDOs or NSBs?
32. Is your organisation in contact with any of the standard body(ies) in your country?
33. Does your organisation participate in any Technical Committee or is involved in the development of standards?
34. Why is your organization not involved in the development of standards?
35. At what level you are involved in the development of standards? Tick as many as applicable
36. Do you think the Technical Committee is fully aware of the relevant technological, research and innovation developments?
37. What could be further done to improve the participation of stakeholders and links with the latest developments in the sector and standardisation work?
38. Would you like to participate in an interview?

## Appendix B: Interview questions

- (1) Which of the following age categories do you fall into?
- (2) What work experience do you have?
  - less than 1 year
  - 1–5 years
  - 6–10 years
  - More than 10 years
- (3) Which kind of stakeholder category do you represent?
  - Standardisation body
  - RTO Business association
  - Industrial company
    - Small
    - Medium
    - Big
  - University
  - Policy Makers and Regulators
  - Other (please specify):
- (4) What is your Organisation's Name?
- (5) Where is your Organisation based?
- (6) What is your role in your Organisation?

- Top Level Management
  - Middle Level Management
  - Lower Level Management
  - Other (please specify):
- (7) Which of the four technological domains are you involved in? (You can select more than one)
    - Additive Manufacturing
    - Welding
    - Smart Manufacturing, Industry 4.0, Digitalisation, AI
    - Circular Economy
    - Other (please specify):
  - (8) Has your organisation implemented the use of standards? Specify examples. Also, has your organisation used or implemented standards?
  - (9) What obstacles have your organisation encountered during the standardisation development life cycle (SDL) phases?

**Phase 1:** Identification of a standardisation gap (e.g. collecting relevant information from the project)

**Phase 2:** Conception of a proposal (e.g. formulation of the proposal)

**Phase 3:** Initiation of a standardisation project (e.g. selection of a suitable contact, approaching standardization bodies)

**Phase 4:** Mobilization of the working group (e.g. calls for experts)

**Phase 5:** Development of a standard (e.g. drafting a standard, voting on a standard, getting final approval)

**Phase 6:** Publication of a standard

**Phase 7:** Adoption of a standard (e.g. utilizing in a project)

**Phase 8:** Maintenance and renewal of a standard(10)

Do you feel that there is a gap (anything missing) in standardisation in your domain? E.g. technological, processes and products, etc. Have you faced any difficulties?

- (11) What were your organisation's primary motivations for addressing standardisation?
- (12) Did standards or standardisation activities have an impact on your Organisation's processes/ project activities? Can you provide some examples?
- (13) Do you think that standards constrain innovation? If so, please identify some of the constraints that your organisation has encountered?
- (14) Are you aware of any existing approaches and processes that engage actors to develop standards?

- (15) What factors influence the development or adoption of standards for emerging technologies in your organisation/ 4 domains?
- (16) Please provide some suggestions for improvements in the standardisation process.

**Acknowledgements** FUNDING INFORMATION: This work was supported by the European Union’s Horizon Europe research and innovation programme under grant agreement no 101070229–STAN-D4EU.

**Author contribution** All authors contributed and reviewed the manuscript.

**Data availability** No datasets were generated or analysed during the current study.

## Declarations

**Competing interests** The authors declare no competing interests.

**Open Access** This article is licensed under a Creative Commons Attribution 4.0 International License, which permits use, sharing, adaptation, distribution and reproduction in any medium or format, as long as you give appropriate credit to the original author(s) and the source, provide a link to the Creative Commons licence, and indicate if changes were made. The images or other third party material in this article are included in the article’s Creative Commons licence, unless indicated otherwise in a credit line to the material. If material is not included in the article’s Creative Commons licence and your intended use is not permitted by statutory regulation or exceeds the permitted use, you will need to obtain permission directly from the copyright holder. To view a copy of this licence, visit <http://creativecommons.org/licenses/by/4.0/>.

## References

- Andrade C (2020) The limitations of online surveys. *Indian J Psychol Med* 42(6):575–576. <https://doi.org/10.1177/0253717620957496>
- Baron J, Spulber DF (2018) Technology standards and standard setting organisations: introduction to the Searle Center Database. *J Econ Manage Strategy* 27:462–503
- Blind K, Mangelsdorf A (2013) Alliance formation of SMEs: empirical evidence from standardization committees. *IEEE Trans Eng Manag* 60(1):148–156
- Blind K, Fenton A (2022) Standard-relevant publications: evidence, processes and influencing factors. *Scientometrics* 127(1):577–602
- Blind K, Heß P (2023) Stakeholder perceptions of the role of standards for addressing the sustainable development goals. *Sustain Prod Consum* 37:180–190
- Blind K (2002) Driving forces for standardisation at standardisation development organisations. *Appl Econ* 34(16):1985–1998
- Blind K (2023) Maximizing the impact of standards and regulation to drive transformative innovation: a new approach. Fraunhofer Institute of Systems and Innovation Research, Karlsruhe, Berlin
- Blind K (2024) Standardization in the context of transdisciplinarity. *Sustain Sci* 19:1609–2162. <https://doi.org/10.1007/s11625-024-01524-3>
- Blind K (2024b) The role of the quality infrastructure within socio-technical transformations: a European perspective. *Technol Forecast Soc Change* 199. <https://doi.org/10.1016/j.techfore.2023.123019>
- Blind K, Jungmittag A (2005) Trade and the impact of innovations and standards: the case of Germany and the UK. *Appl Econ* 37(12):1385–1398
- Blind K, Gauch S (2009) Research and standardisation in nanotechnology: evidence from Germany. *J Technol Transf* 34:320–342. <https://doi.org/10.1007/s10961-008-9089-8>
- Blind K, Lorenz A, Rauber J (2021) Drivers for companies’ entry into standard setting organisations. *IEEE Trans Eng Manag* 68(1):33–44
- Blind K, Martin K, Leiponen A, Simcoe T (2023) Standards and innovation: a review and introduction to the special issue. *Res Policy* 52(8):104830. <https://doi.org/10.1016/j.respol.2023.104830>
- Blind K, Pohlisch J, Rainville A (2020) Innovation and standardisation as drivers of companies’ success in public procurement: an empirical analysis. *J Technol Transf* 45:664–693
- Cargill CF (2011) Why standardisation efforts fail. *J Electron Publ* 14(1). <https://doi.org/10.3998/3336451.0014.103>
- Cheung AKL (2014) Structured questionnaires. In: Michalos AC (eds) *Encyclopaedia of Quality of Life and well-being research*, pp 6399–6402. [https://doi.org/10.1007/978-94-007-0753-5\\_2888](https://doi.org/10.1007/978-94-007-0753-5_2888)
- De Vries HJ, Blind K, Mangelsdorf A, Verheul H, van der Zwan J (2009) SME access to European standardisation: enabling small and medium-sized enterprises to achieve greater benefit from standards and from involvement in standardisation. CEN Cenelec, Brussels
- Directorate-General for Internal Market, Industry, Entrepreneurship and SMEs (2022) New approach to enable global leadership of EU standards promoting values and a resilient, green and digital Single Market. Internal Market, Industry, Entrepreneurship and SMEs. [https://single-market-economy.ec.europa.eu/news/new-approach-enable-global-leadership-eu-standards-promoting-values-and-resilient-green-and-digital-2022-02-02\\_en](https://single-market-economy.ec.europa.eu/news/new-approach-enable-global-leadership-eu-standards-promoting-values-and-resilient-green-and-digital-2022-02-02_en)
- European Commission (2022a) Communication from the Commission to the European Parliament, the Council, the European Economic and Social Committee and the Committee of the regions ‘An EU strategy on standardisation: Setting global standards in support of a resilient, green and digital EU single market’
- European Commission, Directorate-General for Research and Innovation, Radauer A, Baronowski S, Yeghyan M et al (2022) Scoping study for supporting the development of a code of practice for researchers on standardisation: Final report, Publications Office of the European Union (<https://doi.org/10.2777/567608>)
- European Commission (2022b) Study on the functions and effects of European standards and in the EU (<https://ec.europa.eu/docsroom/documents/50114>) and EFTA Member States
- European Commission (2022c) An EU Strategy on Standardisation: setting global standards in support of a resilient, green and digital EU single market. European Commission. <https://ec.europa.eu/docsroom/documents/48598>
- European Commission (2023a) Commission Recommendation (EU) 2023/498 of 1 March 2023 on a code of practice on standardisation in the European Research Area (OJ L 69, 7.3.2023, p 63)
- European Commission (2023b) High-Level Forum on European Standardisation. [https://single-market-economy.ec.europa.eu/single-market/european-standards/standardisation-policy/high-level-forum-european-standardisation\\_en](https://single-market-economy.ec.europa.eu/single-market/european-standards/standardisation-policy/high-level-forum-european-standardisation_en)
- European Commission (2024) European Standardisation Panel Survey. <https://op.europa.eu/en/publication-detail/-/publication/d5c4f1a7-e75e-11ee-9ea8-01aa75ed71a1/language-en>

26. Evans JR, Mathur A (2005) The value of online surveys. *Internet Res* 15(2):195–219. <https://doi.org/10.1108/10662240510590360>
27. Heß P, Blind K (2023) The effect of the COVID-19 pandemic on standardisation. *IEEE Trans Eng Manag* 71:1542–1554
28. Heß P (2020) SDG 5 and the gender gap in standardisation: empirical evidence from Germany. *Sustainability* 12(20):8699. <https://doi.org/10.3390/su12208699>
29. High-Level Forum on European Standardisation (2024) Annual activity report 2023. European Commission. <https://ec.europa.eu/docsroom/documents/57654>
30. Kawalkar R, Dubey HK, Lokhande SP (2022) A review for advancements in standardization for additive manufacturing. *Mater Today: Proc* 50:1983–1990. <https://doi.org/10.1016/j.matpr.2021.09.333>
31. Manders B, de Vries HJ, Blind K (2016) ISO 9001 and product innovation: a literature review and research framework. *Technovation* 48:41–55
32. Monzón MD, Ortega Z, Martínez A, Ortega F (2015) Standardisation in additive manufacturing: activities carried out by international organizations and projects. *Int J Adv Manuf Technol*. <https://doi.org/10.1007/s00170-014-6334-1>
33. Moon S, Lee H (2021) The primary actors of technology standardization in the manufacturing industry. *IEEE Access* 9:101886–101901. <https://doi.org/10.1109/ACCESS.2021.3097800>
34. Optimat (2015) Research study on the benefits of linking innovation and standardisation, CEN-Cenelec, Brussels
35. Prajogo DL, Sohal AS (2004) The relationship between TQM practices, quality performance, and innovation performance. *Int J Qual Reliab Manag* 21(8):799–811
36. Roopa S, Rani M (2012) Questionnaire designing for a survey. *J Indian Orthod Soc* 46(4):273–277. <https://doi.org/10.5005/jp-journals-10021-1104>
37. Swann GMP (2005) Do standards enable or constrain innovation? In: Temple P, Witt R, Spencer C, Blind K, Jungmittag A, Swann PGM (eds) *The Empirical Economics of Standards*, UK Government Department of Trade and Industry, London, pp 76–120
38. Technopolis (2013) Study on the contribution of standardisation to innovation in European funded research projects. CEN-Cenelec, Brussels
39. Turovets Y, Vishnevskiy K (2022) Standardisation in smart manufacturing: evaluation from a supply-side perspective. In: *Intelligence systems in digital transformation: theory and applications*. Springer. The information on the book should list (Lecture Notes in Networks and Systems, 549), 2023 edited by Cengiz Kahraman and Elf Haktanir
40. Wakke P, Blind K, De Vries HJ (2015) Driving factors for service providers to participate in standardisation: insights from the Netherlands. *Ind Innov* 22(4):299–320
41. Wakke P, Blind K, Ramel F (2016) The impact of participation within formal standardisation on firm performance. *J Prod Anal* 45(3):317–330
42. Zhang M, Wang Y, Zhao Q (2020) Does participating in the standards-setting process promote innovation? Evidence from China. *China Econ Rev* 62(5):101532
43. Zhang Y, Liu J, Sheng S (2020) Strategic orientations and participation intentions for technical standardization. *Technol Anal Strateg Manag* 32(8):881–894

**Publisher's Note** Springer Nature remains neutral with regard to jurisdictional claims in published maps and institutional affiliations.