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Standardisation in the context of science and regulation: An analysis of the Bioeconomy

Alexandra Gottinger^{a,d,*}, Luana Ladu^{a,b}, Knut Blind^{a,c}

^a Chair of Innovation Economics, TU Berlin, Berlin, Germany

^b Bundesanstalt für Materialforschung und -prüfung (BAM), Berlin, Germany

^c Fraunhofer Institute for Systems and Innovation Research, Karlsruhe, Germany

^d Agricultural and Food Policy Group, Humboldt-Universität zu Berlin, Berlin, Germany

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ABSTRACT

Standards play a crucial role in the transition to more sustainable production and consumption models by promoting the development of new markets for innovative products. In the case of the bioeconomy, standards are particularly relevant to ensure the sustainability of products and processes. Hence, standards represent an essential strategic tool to foster sustainable development. Furthermore, the standard-setting process brings together different stakeholders, which encourages research and the transfer of knowledge to industrial practice. In particular, scientific publications assist the standardisation process by providing scientific evidence. This study investigates the role of science and regulation in the bioeconomy standardisation process. It first provides a general analysis of bioeconomy-related standards, followed by an analysis of the regulations and publications referenced in the standards. Our analysis discloses a strong use of scientific knowledge in the bioeconomy standardisation process and demonstrates the readiness to integrate novel academic findings into revised versions of the standards. In addition, it reveals that the interaction between science and regulation is an important driver for standardisation activities around the bioeconomy, needed to support sustainable transitions.

1. Introduction

The updated European bioeconomy strategy defines the bioeconomy as meta-sector that “covers all sectors and systems that rely on biological resources (e.g. plants and derived biomass, including organic waste), their functions and principles [...]”. (European Commission, 2018). The strategy highlights the pivotal role of the bioeconomy in implementing the objectives of the Green Deal and the transition to a low-carbon economy (Ronzon et al., 2022). The shifts toward low-carbon production and consumption systems are conceptualized as socio-technical transitions (Geels et al., 2017). Such transitions require changes in socio-technical systems comprising multiple interdependent elements, including technology, user practices and markets, infrastructure, regulations, and supply networks (Elzen et al., 2004; Geels, 2004; Smith et al., 2010). The complexity, uncertainty and the involvement of multiple stakeholders cause challenges for transitions to unfold and complicate the governance of socio-technical change (Elzen et al., 2004; Weber and Rohrer, 2012). Similarly, several barriers hinder the transition toward a sustainable bioeconomy (Gottinger et al., 2020). For

instance, one of the core challenges for the large-scale production of bio-based products is the lack of cost-competitiveness to fossil-based products (Wydra, 2019). In addition, technologies related to the bioeconomy are associated with high investment costs and difficulties in covering them with new business models (Hellsmark et al., 2016; Mossberg et al., 2018). Furthermore, sustainability concerns related to biomass use lead to hesitation among industrial stakeholders (Giurca, 2020).

Standards play a crucial role in mitigating these bottlenecks. First, standards can enable the existing regulatory system to adapt and support innovation, particularly in uncertain markets (Blind et al., 2017). In this sense, standards aggregate initial demand for bio-based products by increasing market transparency, overcoming perceived uncertainty about their properties, and communicating their benefits (Ladu and Blind, 2017). Second, standards are an element of the so-called new environmental policy instruments that complement traditional national environmental policy (Jordan et al., 2003). In this sense, standards function as a tool to regulate environmental issues and translate broader environmental goals (Goulden et al., 2019; Goulden et al., 2015). The

* Corresponding author at: Chair of Innovation Economics, TU Berlin, Berlin, Germany.

E-mail address: alexandra.gottinger@tu-berlin.de (A. Gottinger).

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importance of standardisation, labelling, and certification in stimulating and opening new markets for innovative bio-based products was already recognized in 2008 in the Lead Market Initiative (LMI), a demand-side policy that aims to lower barriers and bring innovative products to the market. The LMI identified bio-based products as one of the priority lines for investments and innovation (European Commission, 2016). In this regard, the European Commission mandated the European standardisation bodies (CEN) to develop and adopt standards to support bio-based related policies and legislations. Consequently, CEN established a Technical Committee (CEN/TC 411), which covers horizontal aspects, such as terminology and methods for determining bio-based content in a product, and develops standards that could promote the use of renewable biomass content in specific sectors (Ladu and Blind, 2017). In this sense, standardisation could support the implementation of legislation by specifying legal requirements or filling regulatory gaps (IEA, 2018). This is, in particular, the case of harmonized standards, which acquire the role of co- or self-regulation in support of governmental regulation (Blind and Mangelsdorf, 2016). Hence, especially on the European level standardisation activities in the context of the bioeconomy are closely linked to existing legislation.

In addition, standardisation represents a platform to bring together different stakeholders. Consequently, standard-setting organisations act as knowledge-broker and provide a space for learning (Pattberg, 2005). With these functions, standardisation bodies act as niche intermediaries by increasing the size and stability of niches in an early stage and additionally creating institutional infrastructure (Kivimaa et al., 2019). The standardisation allows condensing and implementing science into practice representing a technology and knowledge transfer channel (Blind and Gauch, 2009). As such, standards can serve as an indicator to measure knowledge structures and transfer (Asna Ashari et al., 2023; Gamber et al., 2008). The knowledge flow from research to standardization takes place, for example, through the direct participation of researchers in standardisation processes (Blind and Gauch, 2009). However, not all aspects and steps of the standard developing process are generally visible (Bowker and Star, 2000; Lampland and Star, 2009). Especially in the context of sustainably standards, existing studies aim at unpacking the invisible internal logic, which Goulden et al. (2015) describe as “black boxing of the standard” by observing the standard-setting process. Such studies offer insight into the translation of policy in sustainability standards and the role of standards as environmental policy tools (Goulden et al., 2019; Goulden et al., 2015). Furthermore, researchers study standard-setting from a network perspective. These contributions improve the understanding of the role of global networks in shaping the content of standard (Henriksen, 2015). Standard-setting organisations are also analysed in their function as knowledge-intensive intermediaries that influence global institution building (Strambach and Surmeier, 2018) or as boundary organizations where joint knowledge production takes place (Offermans and Glasbergen, 2015). Complementarily, the produced outcome of standard-setting organisations are analysed as boundary objective; Eden, 2009; Loconto and Barbier, 2017). Empirical work on multi-stakeholder initiatives and the enrolled expert groups in standard-setting within these organisations shed light on the governance of sustainability networks (Ponte and Cheyns, 2013). The research on standard-setting, in particular, in the context of multi-stakeholder initiatives, is nested in a larger debate on the distribution of power and knowledge (Silva-Castañeda and Trussart, 2016; Cheyns and Riisgaard, 2014; Loconto and Hatanaka, 2018). To sum up, the literature comprises multiple perspectives on the relation between standardisation and knowledge. However, most of the empirical work on the use of knowledge in standardisation processes builds on the observation of a small number of standards, standard development processes, or the analysis of standard-setting organisations. Acknowledging the relevance of these contributions, our study aims to approach the subject by observing a large number of standards. Therefore, recent work on standard-relevant publications provides a methodological pave way to quantitatively

explore the knowledge foundation of standardisation (Blind and Fenton, 2022). We apply this approach to standards related to the bioeconomy. In addition, we include an observation of the regulatory framework in our analysis seeking to investigate links between standardisation, sciences, and regulation. More precisely, with our study, we aim to complement existing research with three major contributions:

First, our work contributes to a better understanding of the knowledge utilization for standardisation in specific contexts. Therefore, the explorative study of Blind and Fenton (2022) serves as a starting point. Within this study, the authors explored so-called standard-relevant publications, which they defined as the scientific references included in the standards’ reference list representing the scientific evidence base of a standard. To study this phenomenon, they observed standard-relevant publications in 20,000 standards released by the International Organization of Standardization (ISO). Methodologically, the observation of standard-relevant publications offers a chance to understand the underlying knowledge of the standard developing process and allows quantifying and comparing the scientific foundation of standards, for instance, within and across different standardisation fields. In this sense, methodological contribution of our work is the application of the concept of standard-relevant publications standardisation for the bioeconomy.

Our second research objective is to improve the understanding of the link between science, regulation and standardisation. By extending the approach of Blind and Fenton (2022) we analyse the scientific references and additionally observe references to regulations in standards related to bioeconomy. More precisely, we explore the number of scientific publications and regulations referenced in bioeconomy-related standards, their changes over time, and the organisations involved in publishing standard-relevant publications. In addition, the results of this analysis build the foundation to discuss knowledge utilization and the role of regulations in standardisation processes. With this extended approach, we consider that in many cases, standards result from the interaction between different mechanisms driven by markets, committees, and governments (Wiegmann et al., 2017). The normative standard documents represent the outcome of a process based on results of science, experience, and technology, considering all parties’ views and reconciling conflicting arguments (ISO/IEC, 2004). Consequently, observing standard documents allows to explore the scientific knowledge base that enriches the standardisation process and its embeddedness in the regulatory framework.

Third, as described above, standards are crucial in creating markets and regulating specific environmental aspects. These functions are especially relevant for managing natural resources in industrial processes. Recently, scholars started to explore standards as relevant instruments to shape the bioeconomy; Ladu and Blind, 2017; Vogelpohl, 2023, Moosmann et al., 2020). Our study attempts to analyse the underlying knowledge foundation of these standards and the regulatory framework. In addition, we propose a promising avenue for further research on the role of standards within the transition toward a bioeconomy. Therefore, we discuss the potential role of specific standards, which we identify within our study to demonstrate how standardisation could support and guide the socio-technical transitions. We illustrate how standardisation potentially promotes the transitions by considering its relationship with science, on the one hand, and its embeddedness in the regulatory framework, on the other hand. We argue that studying the link between standardisation, science, and regulations helps to assess the role of standards in a particular context.

The remainder of the paper describes the theoretical background and the adopted methodology and data (Sections 2 and 3) and presents our results (Section 4). Finally, the paper discusses and summarizes our findings (Sections 5 and 6) and illustrates the study’s limitations and potential outlook (Section 7).

2. Theoretical background

Conceptually our study is based on work that theorizes the links between research and policy. The wide-ranging academic interest in knowledge utilization for policy-making generated a variety of perspectives and approaches to capture the relation between science and policy (Weiss, 1979; Amara et al., 2004). In this context, Weiss (1979) illustrates different models to describe the routes of research utilization and improve the conceptual base to explore the complex phenomenon. For instance, the Knowledge-Driven Model assumes that appropriate technologies based on successfully applied research offer an opportunity for public policies. In this model, knowledge availability of new applications created by applying and testing basic knowledge is followed by new policies. In contrast, the Problem-Solving Model describes the reverse causal effect where policy decisions drive research. This model is directly associated with an instrumental use that aims to improve decision-making by including relevant findings (Albaek, 1995; Amara et al., 2004). On the other hand, the conceptual use of knowledge provides general ideas, theories, or hypotheses, and the symbolic use legitimizes the own views of decision-makers (Amara et al., 2004; Beyer, 1997; Rich, 1991). Knowledge use also depends on contextual factors, such as the degree of issue polarization as one influential factor (Contandriopoulos et al., 2010). The degree of polarization is high when the level of consensus on an aspect is low, and the opinions regarding the problematisation of the issue, its prioritisation and salience, and the criteria for potential solutions differ strongly (Contandriopoulos et al., 2010). According to Contandriopoulos et al. (2010), producer-driven knowledge exchange is more likely in minimally polarized contexts, while in highly polarized contexts, the knowledge users are more willing to take the cost of knowledge exchange.

The outlined concepts of knowledge utilization help understand the knowledge flows in decision-making. However, due to its particularities, standardisation represents a specific case of knowledge use, which we describe in this paragraph. Formal standards are claimed to be consensus-based and up-to-date as the standardisation process integrates relevant knowledge provided by experts from the field (ISO/IEC, 2004). Certainly, some standards, for example, those related to corporate governance, are developed by practitioners such as company directors, lawyers, investors, or shareholder representatives and mainly require practical experience instead of consulting scientific knowledge (Seidl, 2007). Still, especially in emerging fields, the standardisation process relies on integrating knowledge from researchers to develop applicable results (Blind and Gauch, 2009). Consulting scientific results is particularly evident for standards related to procedural issues, for instance, in the health care, where balancing diverse interests is an enormous challenge (Timmermans and Epstein, 2010). In particular, in their (re)formative phase, standards crucially depend on stakeholder engagement, which Botzem and Dobusch (2012) define as the primary source of input legitimacy. In democracy theory, input legitimacy refers to the mechanisms for procedure decisions and participation options (Scharpf, 1999). In contrast, output legitimacy describes the quality of the decision usually associated with the subjective and objective effectiveness of the outcome in solving social problems (Scharpf, 1999). Regarding standardisation, outcome legitimacy is generated when the standard can solve collective problems or fulfill its adopters' expectations and is consequently directly linked to the adoption of standards (Botzem and Dobusch, 2012). However, multiple definitions of the standard's initial objective cause difficulties in determining its effectiveness and, consequently, its output legitimacy (Fuchs et al., 2011). Measuring the effectiveness of environmental standards is particularly challenging, as in most cases, the number of certified objects, instead of the actual environmental improvement, denote the success of a standard (Goulden et al., 2015). Respectively, some examples indicate that sustainability standard-setting tends favour environmental standards perceived as applicable by industrial stakeholders over alternative options with disruptive approaches (Goulden et al., 2019). Nevertheless,

the academic debate on the legitimacy of standardisation goes beyond the question of the effectiveness of single standards. Instead, the literature is embedded in a broader discourse on the legitimacy of private standards as part of the global sustainability governance (Henson and Humphrey, 2010). It is argued that a balance and broad participation in standard-setting forms an essential criterion for legitimacy (Fuchs et al., 2011). The participation of different stakeholders during the formation phase of a standard creates what Botzem and Dobusch (2012) define as input legitimacy. Standards functioning as public policy instruments derive legitimacy from a scientific and technical rationality that neutralizes their political significance and democratic rationality by their negotiated dimension (Borraz, 2007). In practice, the scientists and engineers often engaged in standard creation simultaneously provide their knowledge and carry the "legitimacy awarded to science" (Timmermans and Epstein, 2010; Timmermans and Epstein, 2010), which in theory, increases both types of legitimacy. Similarly, Blind and Fenton (2022) argue that knowledge could potentially be used in an instrumental or even symbolical sense in standardisation processes. This summary illustrates the relationship between knowledge utilization in standardisation processes and the legitimacy of standards.

Nevertheless, the embeddedness of some standards within the legislative framework and the involvement of different stakeholders increases the complexity of standardisation process. Complementary, firms participate in formal standardisation bodies to specify the requirements for implementing regulations via standards (Blind and Mangelsdorf, 2016). This is especially true for firms in Europe producing goods and services covered by New Approach Directives or the New Legislative Framework. The New Approach in the European Union delegates or even mandates responsibilities for setting rules to private institutions, i.e., European standardisation organizations. Whereas 'essential requirements', e.g., protection of consumers, health, or the environment, are defined in European Directives or regulations, firms in European standards bodies can define technical specifications in 'harmonized standards' that meet the requirements of these New Approach Directives (Egan, 2002). Therefore, firms in a consensus-based decision-making process in formal standardisation have incentives to define technical specifications that are favorable for themselves and the whole industry. For research institutes, Blind et al. (2018) find that researchers also have a strong interest in contributing knowledge to standardisation, e.g., to increase the safety of technologies, a dimension in general linked to governmental regulations. In summary, the industry is interested in joining in standardisation to reduce the compliance cost of regulation or even prevent regulations, whereas researchers push for a high quality of standards, e.g., to assure a high level of safety (see also Blind and Fenton, 2022). Finally, representatives of regulatory bodies or public procurement agencies are often involved in standardisation processes to represent their interests.

Hence, different stakeholders with multiple interests shape the development of a standard. In turn, standards as an outcome of this process determine the production system in various ways. In recent years, a few studies highlighted the relevance of standards and standard-setters for achieving the United Nations Sustainable Development Goals (SDGs) (Schleifer et al., 2022; Blind and Heß, 2023). In addition, several studies explore the impact of specific environmental or social standards and their ability to promote sustainable practices of firms (Murmura et al., 2017; Zimon et al., 2017). However, sustainability transitions require a set of interventions addressing market failures, structural system failures, and transformational system failures (Weber and Rohrer, 2012). Consequently, to redirect and accelerate technological change, a supportive policy mix must contain a set of complementary interacting instruments, including different instrument types, such as standards (Rogge and Reichardt, 2016). Hence, standards form part of the policy mix. At the same time, standardisation as part of the instrument mix also combines a set of standards, which potentially fulfil different transformative functions. Blind (2022) conceptualizes the role of standards based on six policy intervention points for transformative

systems change developed by Kanger et al. (2020). The theoretical foundation of these intervention points is the Multi-Level Perspective (MLP), which stresses that socio-technical transitions unfold through the interaction on three levels: regimes as a semi-coherent set of rules; niches defined as protected spaces where innovations are created and tested (Geels, 2002, 2004). How transitions emerge is linked to changes within formal, cognitive, and normative conditions that frame niche and regime actions, the so-called rule of the game (Geels and Schot, 2007). Geels and Schot (2007) discuss two endogenous change processes related to these rules: An evolutionary-economic process where rules change through market selection; and social-institutional dynamics, where actors negotiate about rules. To explore transitions pathways, some studies observe policy-making from an integrated perspective that incorporates both processes focusing on the co-evolution of policy choices and socio-technical change (Edmondson et al., 2019; Foxon et al., 2013). Apparently, recent work that considers the role of standards and standardisation for sustainability transitions starts from a similar point. For instance, Kivimaa et al. (2019) define standardisation bodies as intermediaries supporting niche embedding and developing shared institutional infrastructure. Loconto and Barbier (2017) extend this view by defining the created standard itself as an intermediary, which moves between actors and facilitates the transmission of knowledge into action. Combining these two claims indicates that standards guide transitions institutionally and foster knowledge exchange. Simultaneously, standards are embedded in its underlining knowledge foundation and, to some extent, in the existing regulatory framework. Therefore, the role of standards depends on the link and dynamics between standardisation, science, and regulations.

3. Data and methods

In order to gain insights into the use of standard-relevant publications in bioeconomy-related standards, we adopted the quantitative approach proposed by Blind and Fenton (2022). First, we identified relevant standards by applying a keyword search in the database PERINORM, which contains national and international standards. The database provides access to the full-text documents of national, international and European Standards adopted by the German Standardisation Institute (DIN). This includes international standards published by the International Organization for Standardisation (ISO), and European Standards (EN) published by the European Committee for Standardisation (CEN), the European Committee for Electrotechnical Standardization (CENELEC), or the European Telecommunications Standards Institute (ETSI).

The keyword list resulted from a multi-step approach conducted by several researchers within the implementation of the BioTOP project.¹ The first step for identifying relevant keywords was a collection of potential keywords based on screening publications abstracts. Secondly, five project members conducted an independent ranking of these selected keywords. The result was a keyword list containing 17 keywords.² This search process resulted in the identification of 294 standards. For all standards, we extracted relevant information from PERINORM. This includes the classification along the International

¹ The project BioTOP (transformation-oriented innovation policy for the bioeconomy) is a three year research project (01.09.2019 – 31.08.2022) funded by the German Federal Ministry of Education and Research. It aims to analyse the status quo of the transition towards a sustainable bioeconomy and to identify new innovation policy approaches

² The keyword search was conducted in January 2022 with following keywords: Biological Raw Material*, biomass(-)containing, bio(-)material*; bio(-)based resin, bio(-)resource*, bio(-)economy, biodegrade* bio(-)tech*, renewable biological resource*, bio(-)polymer*, Bio(-)process Technology, bio(-)based, bio(-)product Production, composta*, plant(-)based material*, biomass, renewable resource*, bio(-)plastic*

Classification for Standards (ICS), the publication year, and for updated standards also the publication year of the first version of the standard. Next, we reviewed the references in each standard document. The references are usually numerically listed at the end of the document and include references to other standards, scientific literature, databases, or regulations. For our analysis, we focused on two types of references:

- (I) Scientific literature, including articles, chapters or books, conference papers, and dissertations
- (II) Regulations, such as EU directives or national legislation

We summarized the referenced regulations and explored the number of standards referring to each mentioned regulation. In addition, we searched for all scientific references in the scientific database Web of Science (WoS). To explore the engagement of different organisations in the publication process of standard-relevant publications, we use the authors' affiliations included in the databases. Afterwards, we summarized the total number of standard-relevant publications published by each organisation, the number of standards referring to one or more publications from each organisation, and the number of citations in all standards, including references to different publications in one standard. By consulting the organisations' webpage, we added information on the organisation type differentiating between universities, independent research institutions, public research institutions, and private enterprises. In addition, we explored where the organisations are located by approaching the affiliation address in the WoS. Finally, we compared this outcome with a search in WoS to understand the structure of the research field. Therefore, we used the same keywords² and limited the search to the titles of the publications. The outcome was 24.040 publications listed in WoS.

To analyze the potential role of bioeconomy-related standards for the socio-technical transitions, we select specific standards through a screening of their titles and description. After identifying standards with a potential transformative function, we analysed the standards' content and their regulatory background.

4. Results

4.1. General analysis of bioeconomy-related standards

The first editions of the 294 identified bioeconomy-related standards were published between 1980 and 2021 (Fig. 1). Half of the standards were published in 2010 or later. Still, considering the relatively high number of standards published at the end of the 1990s and the beginning of the last decade, these periods represent two intervals with vital standardisation activities. In total, 148 out of 294 identified standards are DIN EN (European Standards adopted by DIN), followed by 107 DIN EN ISO (International standards published as European Standards and adopted by DIN). The remaining 39 standards are DIN (national standards), DIN ISO (International standards adopted by DIN), and DIN CEN/TS (Technical Specifications published by CEN and adopted by DIN).

The identified standards are related to 21 International Classification for Standards (ICS) groups (level 1). By this means the standards cover more than half of the 40 fields defined by ISO (ISO, 2015). The most frequent 1-digit ICS categories and the corresponding publication year of the first standards version are shown in Fig. 2. Furthermore, we explored the representation of the ICS subgroups. For example, the two most frequent sub-groups on the most refined scaled ICS level (2 or 3-digit) are 'Biofuels' (75.160.40) with 57 allocated standards and 'Biology. Botany. Zoology' (07.080) covered by 49 standards. Looking at the ICS distribution from a historical perspective shows that 85% of the first versions of the standards related to 'Natural and Applied Sciences' (ICS 07) were published in 2001 or earlier, while 95% of the standards associated with 'Petroleum and Related Technologies' (ICS 75) are published after 2008. Two-thirds of the standard documents allocated in

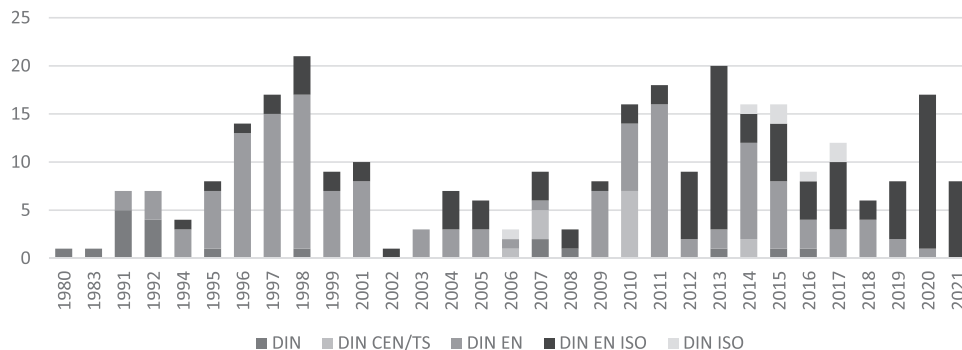


Fig. 1. Number of standards published based on the publication year of the first edition of the standards.

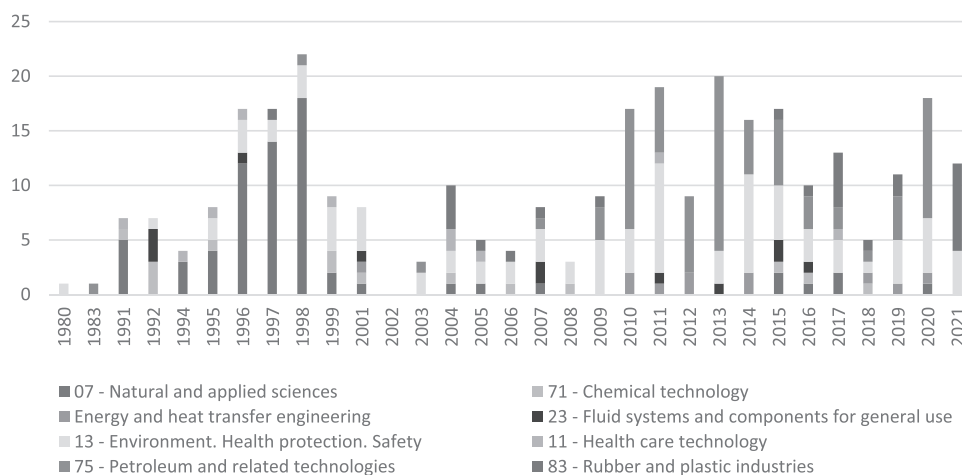


Fig. 2. Number of standards published based on the most frequent ICS groups (level 1).

the ICS group for ‘Rubber and plastic industries’ (ICS 83) were released in 2015 or later. Finally, 53% of the standards related to ‘Environment, Health Protection, and Safety’ (ICS 13) were published after 2010.

4.2. Standard-relevant publications and regulations in bioeconomy-related standards

The outcome of the analysis of the standards documents reference lists and the resulting findings on the use of scientific literature and

Table 1 Scientific publications and regulations cited in bioeconomy-related standards.

	DIN	DIN CEN/TS	DIN EN	DIN EN ISO	DIN ISO	Total
Total no. of standards	19	13	148	107	7	294
Average of scientific publications per standard	2.95	2.00	1.59	3.27	13.14	2.58
Percentage of standards referring to scientific reference(s)	57.9	61.5	35.1	48.6	85.7	43.9
Average of regulations per standard	0.37	0.38	1.16	0.11	0.00	0.67
Percentage of standards referring to regulation(s)	21.1	7.7	43.9	5.6	0.0	25.9

regulations is presented in Table 1. First, our results indicated that 43.9% of the identified standards refer to scientific literature in their bibliographies. In total, the standard documents contain 759 scientific references, meaning that, on average, each standard cites 2.58 scientific sources. Furthermore, we identified 353 out of the 759 references in WoS. Hence, a relatively high number of publications is not listed in WoS. These are publications in languages other than English, older publications, and or unpublished conference proceedings or handbooks. However, as some publications are cited in more than one standard, these 353 references are related to 318 standard-relevant publications listed in WoS. These 318 publications cover 1.3% of all 24.040 relevant publications listed in WoS.

On the other hand, our results indicate that 26% of the standards directly refer to specific regulations. In total, the identified bioeconomy-related standards cite 85 different regulations (including amendments), of which 71 are EU regulations. As shown in Table 1, references to regulation are more frequently found in DIN EN standards.

The 318 standard-relevant publications were published between 1950 and 2020. As illustrated in Fig. 3, the highest number was published in 1999. In general, most of the referenced scientific literature has been published since 2000. To compare this number of standard-relevant publications in relation to the overall development in the field, Fig. 3 also illustrates the number of publications in WoS.

A more detailed analysis of the scientific references and regulations cited in bioeconomy-related standards indicates some changes over time (see Fig. 4). First, our results show an exceptionally vital use of scientific literature and regulations within the 37 standards published in the 1990 s. These standards reference four regulations, namely two directives addressing the use and deliberate release of Gen Modified Organisms (90/219/EEC and 90/220/EEC) and two directives on the

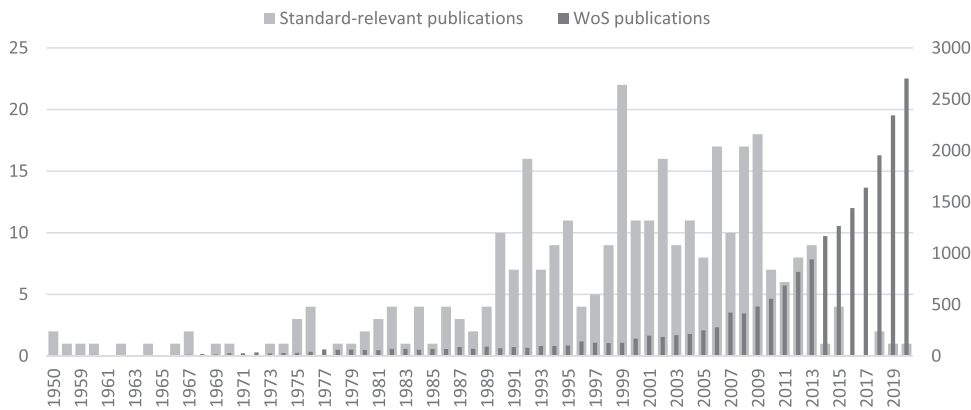


Fig. 3. Number of standard-relevant publications listed in WoS based on their publication year.

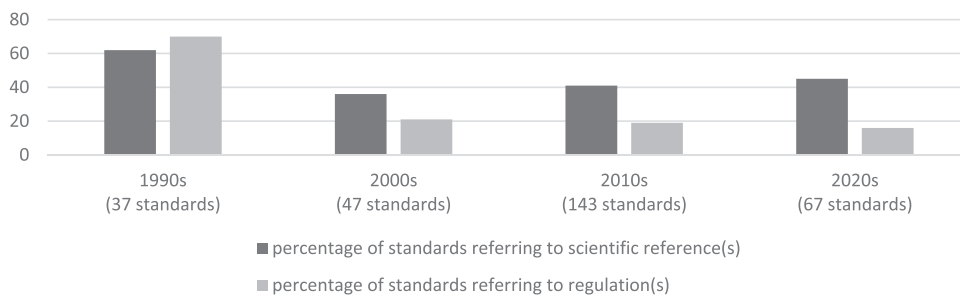


Fig. 4. Percentage of standards citing one or more scientific publications or regulation.

protection of workers from risks related to exposure to biological agents at work (90/679/EEC and 93/88/EEC). Furthermore, 92% of these standards are allocated within the ICS group ‘Natural and Applied Sciences’.

However, excluding the standards published in the 1990 s, the percentage of standards referring to scientific literature increases slightly over time. In contrast to the use of scientific sources, the figures representing the citation of regulation show a revers trend, and the percentage of standards referring to regulations decline during the following decades. During this period, the most cited regulations were the European Union Emissions Trading Scheme (EU ETS), the Renewable Energy Directive (RED), the (WFD), the Directives on Registration, Evaluation, Authorisation, and Restriction of Chemicals (REACH), and the Fuel Quality Directive (FQD). These standards published in the early and mid-2010 s particularly often referred to these directives.

Finally, we compared the publication year of the cited scientific references published in WoS, respectively, with the publication year of the standards document in which they were referenced. Additionally, we

considered the publication year of the first edition of the standard document. Fig. 5 shows the difference between the publication of the scientific articles and the publication of the standard documents in which they are cited. In those cases where the cited scientific reference is published after the release year of the first edition of the standard, the calculated figure is negative, which explains the negative value in Fig. 5.

Our results indicate that the time between the publication year of a standard-relevant publication and the publication year of the standard that refers to it decreases. For example, scientific literature published in the 1950 s and 1960 s is cited in standards primarily released more than 45 years later and still appears in the valid, partly updated standard documents. In comparison, those references published between 2010 and 2020 were referenced in standard documents published or updated less than five years later. On average, the scientific references cited in the currently valid bioeconomy-related standards were published 16 years ago. Comparing the publication year of the reference and the first standards version shows that 64 references in 17 standards were published after the release of the first version of the standard. Hence, these

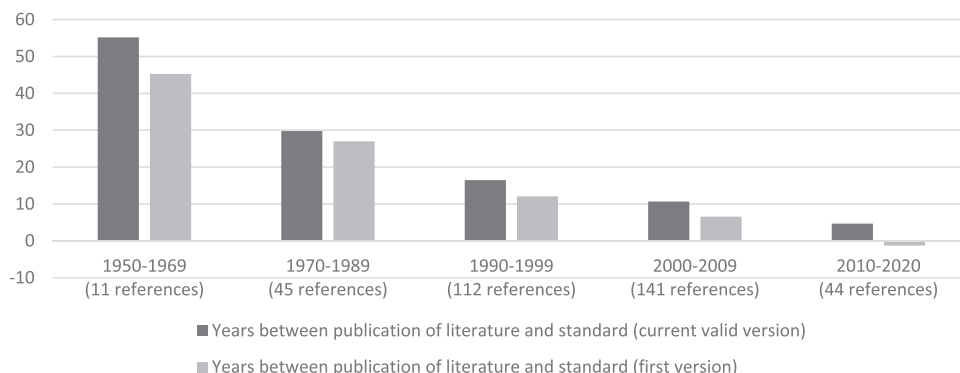


Fig. 5. Average years between the (first) publication year of the standard and the publication of the referenced scientific literature.

publications were integrated into the standards reference list during the standard update process. Of these 64 references, 31 are used to update standards for ‘Environment, Health Protection, and Safety’, and 27 are cited in standards related to ‘Natural and Applied Science’.

This analysis was also applied to the references to regulations. On average, the identified standards refer to regulations established 11 years ago. Hence, the referenced regulations identified in the bioeconomy-related standards are, on average, implemented 11 years before the release year of the standard. In comparison, the referenced standard-relevant publications were published 16 years before. Still, observing the regulations adopted before 1990 reveals a relatively long period between establishing new legislation and its reference in a standard. Namely, on average, these regulations are cited in standards first published 23 years later and remain in the updated current valid version. Moreover, on average, the regulations established in the 1990 s are referenced in standards first released eight years later, and it appears as well two years later in the updated and currently valid version. Still, references to regulations adopted from 2010 to 2020 are identified on average in standard documents published six years later. Regulations established during this period also often appear in old standards published before the regulation’s adoption. Again, the negative figure in the last time period from 2010 to 2020 (Fig. 6) indicates that at least some standard integrated new legislation during the update process. In this sense, we identified 12 standards that cite regulations, which were adopted after the publication of the first standards version.

4.3. Organisations involved in standard-relevant publications

Based on the affiliation information in Web of Science, we explored the associated organisations of the authors of standard-relevant publications. In this context, Fig. 7 provides an overview of the number of publications per organisation type. According to our findings, scientists from universities published 61% of the standard-relevant publications, while the involvement of researchers from ministerial research institutes was found in one-third of the publications. Private enterprises are involved in 20%, and independent research institutes in 15% of the standard-relevant publications. The organizations summarized as ‘others’ include, for instance, hospitals, research networks, or associations. Furthermore, 45% of the standard-relevant publications are published by a team containing scientists from different organizations. For instance, 20% of the standard-relevant publications are published by researchers from at least two universities, and 13% resulted from cooperation between universities and independent research institutions.

Furthermore, Table 2 presents the ten countries with the most standard-relevant publications. Besides the number of publications written by a scientist from an organization located in these countries, the table also shows the number of different organisations involved in publishing them. For example, our results indicate that 68 publications are written by authors working in 89 different organizations located in the United States. Other countries frequently engaged in the work on standard-relevant publications are the United Kingdom and six other

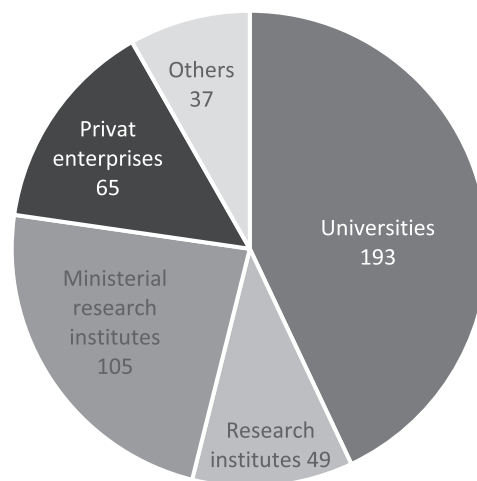


Fig. 7. Organisations involved in standard-relevant publications.

Table 2
Number of standard-relevant publications and organizations per country.

Country	Publications	Organisations
USA	68	89
UK	52	39
Germany	49	36
France	36	37
Japan	22	20
Italy	20	15
Sweden	20	14
Netherlands	18	11
Canada	16	15
Finland	16	13

European countries, and Japan and Canada. In total, organisations from 34 countries are involved in publishing standard-relevant publications in the field of bioeconomy.

As the last step, we explored the organizations individually. In sum, the authors of the 318 standard-relevant publications are affiliated with 370 different organizations. 69% of these 370 organizations published only one publication, 17% worked on two, and 9% are involved in three or four. The remaining 20 organizations involved in publishing five or more of them are shown in Table 3. Besides the number of publications (column: publications), the table also shows how often the reference list of all screened standards refers to these publications (column: citations). In addition, it illustrates how many different standards refer to one or more publications with the involvement of an author affiliated with the organization (column: standards). The findings demonstrate that most of these organizations are located in Europe.

According to our findings, the organization with the most publications is the French National Research Institute for Agriculture, Food and

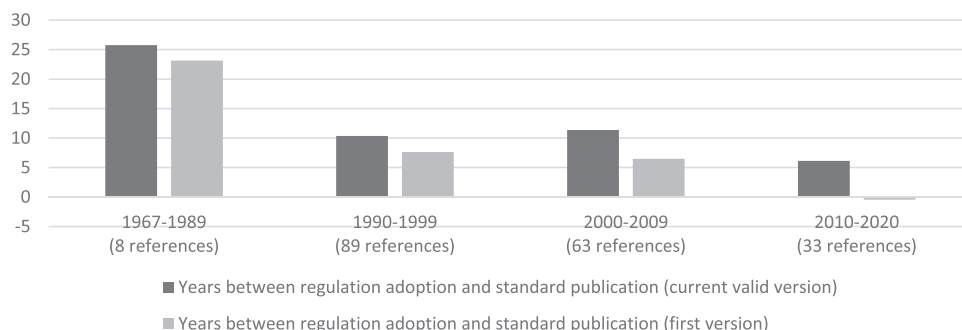


Fig. 6. Average years between the (first) publication year of the standard and the adoption year of the regulations.

Table 3
Organizations involved in publishing five or more standard-relevant publications.

Organisation	Country	Organization type	Publications	Citations	Standards
National Research Institute for Agriculture, Food and Environment (INRAE)	France	Ministerial Research Institute	21	21	7
Swedish University of Agricultural Sciences	Sweden	University	13	17	7
French National Research Institute for Sustainable Development (IRD)	France	Ministerial Research Institute	10	10	3
Czech Academy of Sciences	Czech	University	9	9	2
UK Research & Innovation (UKRI)	UK	Ministerial Research Institute	9	9	5
University of South Bohemia Ceske Budejovice	Czech	University	6	6	1
Helmholtz Institute	Germany	Research Institute	6	6	5
Unilever	UK	Private Enterprise	6	7	4
Rothamsted Research	UK	Research Institute	6	7	4
University of California System	USA	University	6	6	4
Technical University Vienna	Austria	University	5	6	3
University of Toronto	Canada	University	5	6	3
University of Copenhagen	Denmark	University	5	5	5
European Joint Research Center (JRC)	Europe	Research Institutes	5	9	8
Montpellier SupAgro	France	Research Institutes	5	5	2
French National Centre for Scientific Research (CNRS)	France	Ministerial Research Institutes	5	5	5
Leibniz Institute	Germany	Research Institutes	5	5	3
Novamont	Italy	Private Enterprise	5	7	5
Wageningen University	Netherlands	University	5	5	3
United States Department of Agriculture (USDA)	USA	Ministerial Research Institutes	5	5	4

Environment (INRAE), which published 21 standard-relevant publications, each cited once in seven different standards. The numbers also include the work of the former National Institute for Agricultural Research (INRA) and the National Research Institute of Science and Technology for the Environment and Agriculture (IRSTEA), which was merged in 2020 to form the INRAE. This organisation is one of four organisations located in France.

Moreover, we investigated if the background of authors publishing standard-relevant publications also reflects the representation of organisations within the research field in general. Therefore, we compared the 370 organizations involved in publishing standard-relevant publications with the 100 most listed affiliations of all relevant WoS publications. This analysis shows that 31 of these top 100 organizations are also cited in standard documents and 22 of the 31 published two or more standard-relevant publications.

4.4. The potential transformative role of standards for bioeconomy

The last part of our analysis explores the role of standards for socio-technical transitions. In this sense, we identified some standards that could foster transformative change in different ways. Therefore, we adopt the categorization developed by [Blind \(2022\)](#) along with six policy intervein points ([Kanger et al., 2020](#)) [Table 4](#) illustrates how standardisation potentially supports the transition towards a sustainable bioeconomy by providing some examples.

First, the bioeconomy-related standards contain mandated terminology, measurement, and testing standards developed by the CEN (European Standardization Institute) Technical Committee 411 (CEN/TC 411). Concrete examples are, for instance, the mandate M/491 for bio-surfactants and bio-solvents and M/430 for biopolymers. These mandates led, for instance, to the development of standards that specifies a procedure for determining the bio-based content of a product. Such standards could also contribute to the acceleration of niches by specifying characteristics of bio-based products, potentially creating trust among consumers and industry stakeholders. Examples are EN 13432 for biodegradability and composability of packaging or EN 17228 for bio-based polymers, plastics, and plastic products. Furthermore, we identified a case where new standards potentially support regime destabilization. Likewise, adjusting biofuel standards in compliance with the RED fulfil a supportive function. In this sense, it supports the technically implement of the legislation. In addition, some standards facilitate the large-scale application of biotechnological processes. Other standards potentially foster coordination of multi-regime interaction by replacing, combining, and merging existing standards. For example, the

previously mentioned standard for bio-based polymers and plastic contains a set of standards that existed separately before. In addition, the previously mentioned biofuel standards also contribute to multi-regime interaction coordination by modifying its content along with regulations. Namely, along with an amendment of the RED (EU Directive 2015/1513), which addresses land use change, sustainability criteria for biomass were integrated. Finally, the reference to the United Nations Convention on Biological Diversity and other overarching strategies shows a tendency to align standardisation with strategic goals.

5. Discussion

5.1. Knowledge utilization in bioeconomy-related standardisation processes

Our study provides insight into the use of scientific knowledge in the standardisation process by applying the concept of standard-relevant publications introduced by [Blind and Fenton \(2022\)](#) for bioeconomy-related standards. The approach offers a basic understanding of the role of standard-relevant publications in general. Subsequently, it paves the way to systematically assess the scientific knowledge base of standards in other standardisation fields. In this sense, comparing our findings with the results from [Blind and Fenton \(2022\)](#) allows a deeper understanding of the particularities of knowledge use in bioeconomy-related standardisation activities.

This comparison reveals a more vital use of scientific references in bioeconomy-related standards. According to our findings, 44% of the bioeconomy-related standards refer to at least one scientific publication. In contrast, [Blind and Fenton \(2022\)](#) found scientific references only in one-quarter of the standards. These results indicate a more intensive use of scientific knowledge in the field of bioeconomy.

In addition, our results indicate that the percentage of standards referring to scientific literature has increased during the last decades. Such a trend of ‘scientisation’ of standardisation is also identified [Blind and Fenton \(2022\)](#). Additionally, our results show that the years between the publications of relevant scientific findings and its up take in the standard development process diminish overtime. This indicates that the knowledge flow from science to standardisation became faster over time. Furthermore, at least 13% of the standards that use scientific literature updated their references by adding new scientific knowledge in a revised version of the standards document. The utilization of new scientific knowledge underlines the willingness to integrate novel academic findings into the standardisation process. Notably, our findings indicate that new scientific publications often enrich standards

Table 4
The role of standardisation for the bioeconomy transition along with different policy interventions points (Kanger et al., 2020) adopted from Blind (2022).

Intervention point	Role of standardisation	Examples related to bioeconomy
Stimulation of different niches	Promote the development of standards on harmonized terminology, measurement and testing (e.g., via programmes, like Horizon 2020)	Mandates to CEN to develop and adopt European standards for bio-based products (CEN/TC411): M/491 Bio-surfactants and bio-solvents M/430 Biopolymers
Acceleration of the niches	Standards allowing the exploitation of economies of scale and reducing transaction costs Use standards to create trust among consumers/customers and increase network effects	Standards to facilitate large scale biotechnological processes (e.g., control procedures for raw materials for biotechnological processes DIN EN 1826) Standards to specify characteristics of bio-based products (e.g. EN 13432 for packaging recoverable through composting and biodegradation; DIN EN 17228 for bio-based polymers, plastics, and plastic products; or DIN EN 17399 for algae and algae products)
Destabilization of the regimes	Promote the application of new standards to substitute the application of existing standards	Replacement of existing standards with new ones (e.g., DIN V 51606 Standard for biofuels, withdrawn in 2003, replaced by DIN EN 14214). Here the update supports legislation that aims at fostering regime change (e.g., RED: DIN CEN/TS 16214-1; DIN EN 15940; DIN EN 16709)
Addressing the broader repercussions of regime destabilization	Allow the coexistence of standards Expand the transition period to a new generation of standards (e.g., mobile communication)	
Coordination of multi regime interaction	Check the consistency of stock of standards Use standardisation to promote technology convergence Coordinate standards with regulations (NLF), including using standards as regulations	Combination of two existing standards (e.g., DIN EN 15935 combines DIN EN 15169:2007–05 and DIN EN 15935:2012–11) Merging of technological content of different standards (e.g. bioplastics: DIN EN 17228 merges CEN/TS 16137:2011, CEN/TS 16295:2012, CEN/TS 16398:2012, and CEN/TR 15932) Modification along with regulations (e.g. sustainability criteria for biofuels: DIN CEN/TS 16214-2 in response to the EU Directive 2015/1513)
Tilting the landscape	Alignment of international standardisation along SDGs, in particular, climate change, European (technological sovereignty) and national standardisation strategies roadmaps	Standards referring to global agreements and guidelines (e.g., DIN EN 16214-4 Sustainability criteria for biofuels and bioliquids refers to IPCC guidelines or DIN EN 16751 Sustainability criteria bio-

Table 4 (continued)

Intervention point	Role of standardisation	Examples related to bioeconomy
		based products refers to United Nations Convention on Biological Diversity)

documents related to Environment, Health Protection, and Safety. This standardization field generally belongs to the fields where standards often refer to scientific publications (Blind and Fenton, 2022).

At this point, it is also worth mentioning that academic literature critically discusses and assesses the environmental impact of the bioeconomy (D'Amato et al., 2019; Gawel et al., 2019; Bergamo et al., 2022). In general, there is no consensus on the relationship between the bioeconomy and sustainability among researchers (Pfau et al., 2014; Priefer et al., 2017). In addition, there is a critical discourse within society on these issues and concerns on the consumers' side (Sijtsema et al., 2016). The fierce controversy in the academic discourse and societal concerns indicate a high degree of issue polarization. Consequently, it is likely that the experts participating in the standardisation also tend to disagree on specific issues. As outlined in the theoretical background, in polarized contexts, the willingness to take the cost of knowledge exchange tends to be higher and political use of knowledge driven by the users is more likely (Weiss, 1979; Contandriopoulos et al., 2010). Hence, the observed intense knowledge use might be interpreted as a strategy to deal with the uncertainty by increasing input and output legitimacy in the formative phases of standardisation (Botzem and Dobusch, 2012). Another example of the intense use of scientific knowledge standardisation in a highly polarized context are standards related to GMO regulations. Here, the underlining policy-making process was shaped by considerable scientific uncertainty (Lake, 1991) and negative mass media (Vigani and Olper, 2013). Likewise, the standard-setting is potentially also accompanied by a certain level of disagreement, which triggers knowledge use. However, an alternative interpretation would be that regulations-driven standards rely stronger on scientific inputs (see chapter 5.2).

Blind and Fenton (2022) argue that although the citation in standard documents does not necessarily imply the authors' involvement in the standardisation meetings, the likelihood of participating in standards development is still higher for the cited scientists. Therefore, observing affiliated organizations allows for discussing the potential involvement of actors with different organisational backgrounds providing inputs for the standardisation. In addition, it enables exploring the origins of scientific knowledge utilized to increase standards' output legitimacy (Botzem and Dobusch, 2012). Similar to the findings of Blind and Fenton (2022), our results demonstrate a strong involvement of university researchers. However, in the bioeconomy case, a comparatively higher percentage of standard-relevant publications were published with the involvement of private enterprises and public research institutes. These findings highlight the importance of bioeconomy-related standardisation for the private and public sector. However, the strong involvement of private enterprises in shaping the knowledge foundation also affects the legitimacy of standards, considering the firm-specific interests of industrial stakeholders (Blind et al., 2022). Transparency and openness are needed to mitigate the risks that the content of the standards merely favours the industry's interests. The World Trade Organization also underlines this requirement in their formulation of the Principles for the Development of International Standards (WTO, 2000).

Our findings also demonstrated that many of the forerunners in the field, namely the organizations that push knowledge creation forward, are not cited in the standard documents. This phenomenon might be explained by the tension between basic research and standardisation observed by Zi and Blind (2015), and to some extent, by Blind et al. (2018). Furthermore, we identified an intense activity of scientists from European, particularly French organisations. Comparing our results

against the findings of [Blind and Fenton \(2022\)](#) shows that the leading countries engaged in research that builds the scientific foundation for bioeconomy-related standards are also those countries intensely involved in publishing standard-relevant publications in general (see [Table 2](#)). However, in the case of the studied bioeconomy-related standards, we identified Finland as an additional country with substantial publishing activities. By this means, our result shows that some countries are more engaged in publications in some specific knowledge fields.

5.2. Standardisation between science and regulation

Our study also provides insights into bioeconomy-related standardisation activities associated with climate and environmental regulations. In this sense, our analysis shows that one of the drivers for standardisation activities around the bioeconomy is the emanation of European legislation, such as the RED, REACH, or the EU ETS. Again, observing specific cases reveals insights that contribute to a better understanding of the link between science, regulation, and standardisation.

Namely, the above-average referencing of research finding in standardisation around controversially discussed GMO regulations ([Bauer et al., 2001](#)) also underlines the importance of considering interactions between science, regulations and standardisation. In this sense, a possible interpretation of the relation between the role of scientific knowledge and regulations is that standards referring to regulations strongly depend on scientific evidence. In other words, standardisation work driven by regulations might need a solid scientific base and crucially rely on the input of scientists during the standardisation process. Consequently, standardisation bodies reach out to researchers. A further possibility is that the knowledge producers mainly drive the integration of scientific knowledge in these contexts. Likewise, in situations where controversial legislation plays a role, stakeholders might compensate the perceived lack of options to influence regulations by trying to integrate their stances in the standardisation process where they expect a higher impact ([Heß and Blind, 2019](#)).

Standards related to biofuels represent another case that underlines the complex relationship between standardisation, regulations, and research, such as the case of biofuels. The RED was established in 2009 and aimed at promoting the use of energy from renewable sources by setting mandatory national targets. For instance, the RED set a target of 20% share of energy from renewable sources by 2020. In this regard, our analysis shows that one third of the biofuel standards published during the first half of the last decade directly refer to the Renewable Energy Directive 2009/28/EC (RED). The increasing number of bioeconomy-related standards in the ICS group ‘Petroleum and related technologies’ during the 2010 decade can be seen as a response to legislation supporting the use of renewable energy, which requires standardisation work to realize its implementation ([Ladu and Blind, 2017](#)). Still, on the one hand, the standardisation activities could be interpreted as an outcome of the technological development that provoked the need for standards. In this sense, other scholars demonstrated a substantial increase in biofuels patents between 2005 and 2010 ([Grubb et al., 2021](#); [Guillouzoic-Le Corff, 2018](#)), while 91% of the standards in this field were published in 2010 or later. This chronology suggests that standardisation activities related to biofuels increased after technological development peaked. Such a time gap between R&D outputs and standardisation activities in Germany was also identified in the case of nanotechnology ([Blind and Gauch, 2009](#)).

To sum up, our results indicate that knowledge utilization in standard-setting tends to depend on its context. In the case of biofuel, technological development occurred before the implementation of regulation and standardisation. This situation suggests that regulation and standardisation follow the logic of Knowledge-Driven Model, where the availability of new technologies offers opportunities for new policies ([Weiss, 1979](#)). Simultaneously, the new EU regulations that take upon the novel technological solutions also required standardisation. GMO

standards are closely linked to EU regulations as well. However, this legislation does not consider technological development as a solution but aims to strictly regulate it and ban its use in an early stage ([Lieberman and Gray, 2006](#)). In the uncertain and polarized context of GMO regulations ([Lake, 1991](#)), it is likely that both, the standard-setters and researchers from different organisations, might have higher incentives to foster knowledge utilization. In turn, broad knowledge use fosters the legitimacy of standards through the associated increase of scientific and technical rationality, which is particularly relevant for standard-setting, where the public sector defines its outcome’s objective ([Borraz, 2007](#)). However, creating legitimated standards requires the balanced participation of state actors, business actors, and civil society organisations ([Fuchs et al., 2011](#)). Hence, the observation of scientific knowledge entering the standard-setting process reflects only a partial source of legitimacy.

5.3. Understanding the role of bioeconomy-related standards in socio-technical transition

Our analysis illustrates how standards potentially support the bioeconomy. Therefore, we explored the possible contribution of the identified bioeconomy-related standards following the conceptual framework developed by [Blind \(2022\)](#) that links standardisation to the six policy intervention points proposed by [Kanger et al. \(2020\)](#). At this point, it is important to note, that our study does not assess the impact of standards or the quality of the standardisation outcome. However, observing specific examples allows discussing the potentials of standards to guide the transition towards a sustainable bioeconomy. More precisely, we argue that observing links between standardisation, science and regulations helps to gain insights on the role of standards within socio-technical transitions. Comparing the function of biofuel standards with standards addressing the material use of biomass in other fields underlines this claim.

In the case of biofuels, it is argued that the RED and other climate-related policies implemented between 2005 and 2010 increased the pressure on the fossil fuel regime and created a certain momentum for renewable energy, particularly for biofuels niches ([Vieira et al., 2022](#)). Hence, the regulatory framework fulfils two basic functions of supportive policy mixes to foster sustainability transitions: niche creation and regime destabilization ([Kivimaa and Kern, 2016](#)). In turn, the standards for biofuels in compliance with the RED fulfil a supportive function of co-regulation ([Moosmann et al., 2020](#)). Consequently, one could argue that the standards that translate these regulations in practice execute the destabilization function of regulations and therefore support the transition in a distributive way.

In contrast, standardisation work for the material use of biomass (e.g., ICS group ‘Rubber and Plastic industry’ or ‘Packaging and Distribution of Goods’) lacks behind the biofuel standards. Notably, in these fields, policy support is mainly limited to R&D subsidies, while unlike in the case of biofuels, no strong measures stimulate the market ([Philp, 2015](#)). However, mandated by the European Commission, CEN/TC 411 developed standards for bio-based products to support the bio-based niche market, for instance, by increasing visibility and awareness ([NEN, 2021](#)). The published terminology, measurement, and testing standards potentially contribute to niche stimulation ([Blind, 2022](#)). These standards are often additionally allocated in the ICS group ‘Environment. Health Protection. Safety’. This overlapping indicates that the standards in this field often aim to ensure the safety of these products and, therefore, contribute to the need to develop applicable standards to set guidelines as an orientation for companies and customers ([Bhagwat et al., 2020](#)). Hence, such standards foster consumer trust, which supports the acceleration of niches ([Blind, 2022](#)). Consequently, these standards could contribute to socio-technical transition by shaping niches.

This overview indicates that standards fulfil different transformative functions. Our examples also demonstrate that an isolated content

analysis of standards might fall short in explaining its role as ‘socio-technical actor’ (Goulden et al., 2015). Moreover, the observation requires a reflection on the standards embeddedness within the regulatory framework and the R&D activities in the field.

6. Conclusions

Exploring standard-relevant publications in combination with references to regulations allows for assessing the role of science and the regulatory framework. As demonstrated, the regulatory framework played a crucial role at the beginning of our observation period. However, later on, the science base became more relevant (see Fig. 4). In addition, we found a reduction in the delay between the publication of relevant scientific literature and the publication of the standard citing these findings. Our analysis also highlights the willingness to integrate new scientific findings during the standards update process. We also show that knowledge use in standard-setting is context-specific and tends to be more intense in polarized contexts.

From a methodological perspective, our study contributes to a more profound understanding of the role of scientific knowledge in standardisation by applying and expanding the work of Blind and Fenton (2022). In this sense, our analysis of standard-relevant publications successfully demonstrated how the concept could be used to study the role of science in standardisation processes in a specific field. Combining the concept with an analysis of references to regulations enriches the approach and enables assessing the links between science, regulation, and standardisation.

Finally, we discussed how standards potentially shape the transition towards a bioeconomy. In this context, our findings illustrates that the identified standards could influence the socio-technical transition in multiple ways (see Table 4). The results illustrate the role of standards in fostering transitions and its embeddings in the broader regulatory framework and technological development.

Limitations and Outlook

The application and extension of the concept of standard-relevant publications (Blind and Fenton, 2022) reveal some entry points for further research. First, the combination allows quantitatively identifying cases with intensive use of scientific knowledge, for instance, for GMO-related standards. Such cases, in turn, offer a chance to explore drivers of knowledge utilization. Further investigations in this direction would also address one major shortcoming of our study: the missing consideration of the broader contexts of the standardisation process, including the specific interests of different stakeholder groups. In this sense, Blind et al. (2022) findings on the motivation of researchers for participating in standardisation processes could serve as a starting point to frame drivers for integrating scientific inputs in the standardisation process. Likewise, they demonstrate that industrial researchers participating in standardisation processes tend to represent companies’ interests, including the motivation to prevent standards with content contradicting their interests. This factor could explain the use of scientific references published by industrial researchers in standards related to controversial regulations. Furthermore, preventing regulations is another motivation factor (Blind et al., 2022). This calls for future research to explore knowledge utilization in weakly regulated areas or fields where regulations are rather unspecific. Further research is needed to understand the motivation of knowledge producers and users in general and specific cases. Understanding the underlying motivations would also help to sense in which cases knowledge utilization in standardisation processes tends to contain characteristics indicating a Knowledge-Driven or Problem-Solving Model (Weiss, 1979). Furthermore, we have not assessed the functional role of the reference to regulations and scientific literature within the standards documents and its position in the text (e.g., citation used in the introduction; or scientific findings used as a reference to update the technical content of the

standards). However, research on the interplay of standardisation, regulations, and science is essential to gain insights into the transformative role of standards.

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Alexandra Gottingen: Data collection, Formal analysis, Writing – original draft. **Luana Ladu:** Validation, Writing – review & editing. **Knut Blind:** Idea, Conceptualization, Methodology, Supervision.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Data Availability

Data will be made available on request.

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