



Standardization and Standards: Safeguards of Technological Sovereignty?

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ABSTRACT

Technological sovereignty has gained significant relevance for the geopolitical relations during the Covid-19 pandemic, initially triggered by the trade conflicts in particular between the U.S. and China and now even further fired by the Russian attack of the Ukraine. Consequently, policy measures have been discussed to achieve technological sovereignty. Despite the growing relevance of standardization, their opportunities have only to a limited extent been considered an effective policy instrument to secure or even achieve technological sovereignty. Based on a review of the literature, the mechanism of standardization and standards as safeguards for technological sovereignty are elaborated. We offer a list of propositions to be tested in future studies. Using mobile communication standardization to illustrate its specific characteristics including its development process, we elaborate on the effectiveness of the various safeguard mechanism. Finally, policy implications are derived for the various mechanisms. The paper ends with challenges for standardization and standards to achieve or assure technological sovereignty in the future geopolitical contexts.

1. Introduction

There is an increasing focus on technological sovereignty in geopolitical relations originally initiated by geopolitical uncertainties, e.g., trade conflicts between China and the United States, but further triggered by the Covid-19 pandemic, the Russian aggression on Ukraine and related massive frictions in the global supply chains (Schwellnus et al., 2023). Meanwhile, technological sovereignty is entering the portfolio of policy goals related to research and innovation (Edler et al., 2023), but also supply chains (Weyerstrass et al., 2021) and trade (e.g., March and Schieferdecker, 2023). Kar and Thapa (2020) even distinguish between knowledge, research, development, production, operation, usage, and transparency sovereignty. The complementary approach of open strategic autonomy (Cagnin et al., 2021 or Amaral-Garcia et al., 2023) claims to encompass a wide range of policies from geopolitics and economics (i.e., critical raw materials and supply chains) to the law (i.e., regulation and standards), technology, environment, and climate, and data governance (i.e., manipulation of data and misinformation).

Consequently, there is also a discussion about which means can contribute to reaching these different policy goals, pointing more towards assuring autonomy (e.g., Cagnin et al., 2021) than achieving autarky (March and Schieferdecker, 2023) or protectionism. Several papers highlight the relevance of research and innovation (Edler et al.,

2023; March and Schieferdecker, 2023) to secure their technological sovereignty. Others also point to supply chain sovereignty (Weyerstrass et al., 2021), e.g., in the case of photovoltaics (Caravella et al., 2024). Although most studies address the need to follow a collaborative approach, only a few studies explicitly point to the opportunity for standardization and other ways to develop technologies commonly, even the few contributions focusing on technological sovereignty, e.g., Maurer et al. (2015) or Crespi et al. (2021).

Furthermore, in the Communication of the European Commission “Shaping Europe's Digital Future,” the importance of “European technological sovereignty” is highlighted to enhance Europe's position digitally and subsequently geopolitically, and to protect European values (European Commission, 2020). Here, compliance with European standards is a requirement to gain access to the European Union (EU) single market. The EU government's internal interoperability strategy ensures common standards for secure and borderless public sector data flows and services.

Referring to the leading role in setting global standards for 5G and the Internet of Things by the European Telecommunication Standards Institute (ETSI) (see also Madiaga, 2020),¹ it is claimed to extrapolate this position also in the standardization of future technologies, like blockchain, supercomputing, quantum technologies, or artificial intelligence. In contrast, the review of EU strategic dependencies (European

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¹ However, EU's leading position is questioned by Da Ponte et al. (2023).

Commission, 2022b) reveals several of them eventually leading to vulnerabilities, that cannot be immediately reduced. For example, it is proposed to establish standards to improve the recycling of materials needed for photovoltaics (Caravella et al., 2024). Another suggestion is to increase the effort of standardization in cybersecurity to ensure a rollout of the related technologies responding to EU policy needs despite the decreasing influence of the EU in standardization at the international level. The recently published “European Standardisation Strategy” (European Commission, 2022a) states that Europe’s technological sovereignty and ability to reduce dependencies rely on the success of European actors in international standardization activities. However, this requires strong standardization skills in industry and academia and agile, flexible, and future-oriented processes in standard-setting organizations (SSOs).

Although in the literature, standards are often used in the context of regulation, e.g., as environmental standards or data, privacy, and cybersecurity standards (e.g., Madiega, 2020), we focus explicitly on standards released by SSOs, like the International Organization for Standardization (ISO) or International Electrotechnical Commission (IEC) and their national member bodies. They are accredited by national governments or international organizations following the principles of the World Trade Organization required for international standardization, i.e., transparency, openness, impartiality and consensus, effectiveness and relevance, coherence, and addressing the concerns of developing countries. The first three principles are relevant for standards to unfold their safeguarding mechanism related to technological sovereignty. Furthermore, it has to be highlighted that in these organization the national delegation principle is applied, which requires that delegated experts represent their countries’ and not their organizations’ interest. The other types of standards (see Wiegmann et al., 2017), i.e. market-based standards, often controlled by a single or few companies, or government-based standards released by specific countries, are even less effective in securing technological sovereignty of countries.

The basic definition of technology sovereignty we rely on is “the ability of a state or a federation of states to provide the technologies it deems critical for its welfare, competitiveness, and ability to act and to be able to develop these or source them from other economic areas without one-sided structural dependency” (Edler et al., 2023).² Therefore, in our definition digital sovereignty is a subcategory and in contrast to Floridi (2020). He argues that digital sovereignty relevant for data, software, hardware, and infrastructure is not about replacing the increasingly insufficient analog sovereignty but complementing it with a supranational, contemporary-digital one, providing to all stakeholders more comprehensive benefits of harmonization and coordination, but also leveled playing fields. Furthermore, he argues that digital sovereignty is about controlling the digital, i.e., influencing its occurrence, creation, or destruction and its dynamics, including options to check and correct for any deviation.

EU’s technological sovereignty is increasingly under pressure. First, external shocks, like pandemics, but also frictions of trade flows, are crucial challenges, which might become more relevant in the future. Second, internal economic weaknesses is triggered by suffering innovativeness and competitiveness, pushed by a lack of R&D personnel and investments, but also the foundation of start-ups.

Whereas previous studies focus on whether trade and innovation policy instruments can relieve this pressure, our contribution is analyzing the potential of standardization and standards, which are relevant for trade and innovation policy, for securing and strengthening

EU’s technological sovereignty.

Although we are not explicitly considering the role of standardization and standards for the different dimensions describing geopolitics, we elaborate on them related to standards, because they provide the general context for technological sovereignty and referred to in our analysis when appropriate. At first and most obvious is the geographical dimension, which describes the physical location of states. At first glance, standards do not play a role regarding this exogenous dimension. However, standards can be a backbone for the transport infrastructure, e.g., railways, which has implications for the geopolitical dimension, e.g., travel time. Within the Belt and Road Initiative, China also aims to implement its standards in the countries integrated into the initiative. The addressed standards are not only focused on the infrastructure but also cover product standards. A further rather exogenous dimension of geopolitics is culture, i.e., national identity, language, and religion, but also ethical values. Here, standards do not play a relevant role, at least in the short run. However, the European Commission claims in its standardization strategy (European Commission, 2022a) that standards should also incorporate core European democratic values.

Geopolitics also has an environmental dimension. On the one hand, many natural resources, i.e., raw materials, depend on the geographical context. Here, standards, in general, do not play a role. However, specific mining technologies are crucial for harvesting raw materials, and standards may foster performance. On the other hand, climate change has important implications for the environmental dimension of geopolitics. Here, numerous standards exist being relevant for the reduction of greenhouse gas emissions (see the role of standards for the SDGs in general and climate change in particular Blind and Heß, 2023) or for increasing energy efficiency are important and supported by empirical evidence (e.g., Prakash and Potoski, 2014). This dimension is obviously significantly impacted by standards, not necessarily in the short, but in the medium and long run. Especially in the last few years, the military dimension of geopolitics has gained significant attention again also in Europe triggered by the Russian attack on Ukraine. However, weapons-related standards are crucial for this dimension; for example, NATO has specific standards that are particularly relevant for procurement and ICT networks because cyberattacks are becoming increasingly elementary in military conflicts. Therefore, standards, like the popular information security management series ISO 27001, are immediately relevant not only for companies, but also for whole countries and, therefore, the military dimension of geopolitics. In this context, the different generations of mobile communication standards, are important and intensively discussed because of their relevance for a country’s information system infrastructure. This example immediately leads us to the technological dimension of geopolitics because technologies have implications for global power dynamics. Here, standards can leverage countries’ technological capacities to exert power in global relations via exploiting economies of scale and, increasingly more importantly, the generation of network externalities. Finally, the economic dimension is crucial for geopolitics. It relies certainly closely on the technological dimension and the technology-specific role of standards (e.g., Blind and Gauch, 2009). In addition, economic power is based on the size of economies because large domestic markets support the development of large companies, which are in a better position to enter foreign markets and govern global value chains. Consequently, they can also influence the specifications of national but particular international standards, which are crucial for trade flows (e.g., Swann, 2010) and global value chains (Blind et al., 2018c).

Based on this background, we elaborate on the role of standardization and standards for technological sovereignty and try to answer whether and under which conditions they can serve as its safeguards in general and illustrated by the specific characteristics of the mobile communication standardization process and its implication.

The contribution of our paper is trifold. First, we elaborate and present the mechanisms of how standardization and standards can help secure or achieve technological sovereignty, an important objective in

² Floridi (2020) also focuses much more on legitimizing of digital sovereignty, which is outside the scope of our definition and elaboration of the safeguard mechanisms of standardization and standards. However, since the legitimization of standardization in contrast to governmental regulation has been debated in the last few years, this dimension could be integrated into follow-up research.

geopolitics, eventually considering different context factors. Answers to this question help policymakers responsible for technological sovereignty, e.g., ministries funding research and innovation,³ and those responsible for trade, to shape and implement effective policies. Various mechanisms are underpinned by the specific characteristics of the mobile communication standardization including its development process. Secondly, we derive policy recommendations to promote standardization as a safeguard of technological sovereignty. Thirdly, we identify challenges for fulfilling this role within the geopolitical context.

Consequently, the remainder of the paper is structured as follows. First, we review the limited literature about the role of standardization in securing or achieving technological or digital sovereignty. Secondly, we present the various safeguard mechanisms of standardization and standards, concluding with some propositions addressing different context factors, followed by the elaboration of the specific characteristics of the mobile communication standardization including its development process framework. Thirdly, following our conclusions, policy recommendations are derived, and a list of challenges for standardization fulfilling this role is presented.

2. Literature review

Reviewing the few but growing number of studies that address technological or digital sovereignty or open strategic autonomy in combination with “standard” by searching the databases Scopus and Web of Science, reveals that several publications mention standardization and standards, but only a few explicitly elaborate on the link to technological and digital sovereignty.

Most elaborated is the study by JRC on open strategic autonomy (Cagnin et al., 2021), which claims that the increasing global competition in standardization generates opportunities for strengthening countries' competitiveness. On the one hand, the large EU market contributes to its standard-setting power in international standardization processes, which eventually influences via the Brussels effect (Bradford, 2012) foreign governments and multinational or EU-oriented exporting enterprises to comply with European standards and ethical values. In particular, Europe's technological sovereignty benefits from its leading position in mobile communication standardization, e.g., 5G, the Internet of Things, cloud technologies, and artificial intelligence⁴ (Theben et al., 2021), to level the playing field in global markets. In addition, Madiaga (2020) highlights the EU approach to the security of 5G networks supported by a toolbox on 5G cybersecurity based on European standards and certification schemes, which are eventually relevant for public procurement. Furthermore, this power in standardization, backed by significant investments into research and development, allows the dissemination of the objectives of the green, digital, and social transition into international standards. Overall, Cagnin et al. (2021) categorize standardization as a proactive and not defensive instrument to promote Europe's open strategic autonomy.

On the other hand, new stakeholders, like China following its standardization strategy 2035,⁵ but also the U.S.-based bigtechs endorsed by a recently released governmental standardization strategy (White House, 2023), are entering the scene of international standardization and are challenging Europe's previous position and future ambitions not

only in standardization but also in global value chains coordinated by international standards (Blind et al., 2018b). For example, in technologies relevant to Radio Access Networks (RAN), numerous patents claimed to be essential for implementing standards, e.g., 5G, and lock-ins create high dependencies for the European industry (e.g., ZEW, 2021). Consequently, mobile communication network operators founded the Open RAN to establish open source based solutions, that allow more competition and innovation. However, there is still a high uncertainty about the possible success of this initiative for the EU (e.g., Dinges et al., 2021), particularly since Kim et al. (2023) reveal a strong strategic engagement of the U.S. government (White House, 2023). Finally, Nordhaug and Harris (2021) claim that standards are essential for the digital public infrastructure, which eventually can enable digital sovereignty.

The economic impact of standards is not only relevant for GDP (Blind et al., 2021b) but, in particular, international standards also foster trade, i.e. exports but also imports (Swann, 2010). Therefore, they can contribute to independence and greater diversity in the supply chain, e.g., for 5G (Dinges et al., 2021). However, Blind and von Laer (2021) reveal that international standards released by ISO cannot necessarily be treated as exogenous parameters for global trade flows but can be influenced by participating countries' technological profiles contributing proactively to their technological sovereignty.

Complementary to the few macroeconomic considerations about the role of standardization and standards for technological sovereignty in general and digital sovereignty in particular, there is also an argument at the micro level, which has to be mentioned. Foucart and Li (2021) analyze firms' decisions to invest in radical product innovation under the assumption that using standards is a strategy to hedge against the risk of failure in R&D. Consequently, companies using standards are more likely to deliver only incremental innovations because of the reduced incentives and lower efficiency related to their investments in radical innovation. The major shortcoming of the approach by Foucart and Li (2021) is taking the standards as exogenous parameters. However, we know from several studies (e.g., Blind et al., 2021a; Wakke et al., 2015) that more R&D-intensive and innovative companies are entering SSOs and contributing to standards development. Therefore, standards are not an exogenous fallback option for R&D active companies but a complementary approach. In addition, Riillo et al. (2022) reveal based on the Luxembourgish Community Innovation Survey that firms facing technological uncertainty either exclusively standardize internally or follow a cooperative strategy by combining standardization within the firm and in SSOs. In summary, with increasing internal R&D risk and external technological uncertainty, companies tend to get involved in standardization or using standards as a hedging strategy. This confirms their potential contributions not only to their own but also to their countries' technological sovereignty.

Consequently, involvement in standardization can be considered as an additional strategy to hedge against the risk of failure in the developing and marketing radical innovations. Moreover, since this is a joint effort of all involved companies and other engaged stakeholders, it can be perceived as insurance for the whole domestic industry in setting national standards and even for the global industry in the context of international standardization. The bigger this joint effort, which can be nevertheless hampered by free riders (see Blind and Mangelsdorf, 2016 on the high relevance of knowledge sourcing as a motive to join standardization for SMEs), the more international standardization contributes not only to one country's but to all countries' technological sovereignty.

So far, few studies examining standardization in the context of technological sovereignty have addressed the macroeconomic level. However, the country-level considerations can be complemented by companies' standardization strategies related to performing R&D and hedging related risks. Eventually, we will concentrate on the macroeconomic level in analyzing standardization's and standards' roles as safeguards of technological sovereignty, which still requires to consider

³ For example, the German Federal Ministry of Education and Research (BMBF) had a department for research on technological sovereignty and innovation.

⁴ The role of standardization will be further promoted by the Artificial Intelligence Act in the European Union (Council of the European Union, 2024) to provide standards to ensure compliance in line with the state of the art, to promote innovation, competitiveness, and economic growth in the Single Market.

⁵ The Chinese standardization strategy can be found here https://www.gov.cn/zhengce/2021-10/10/content_5641727.htm.

companies, e.g. national champions having a strong market power even within the global context.

3. Standardization and standards as safeguarding mechanisms for technological sovereignty

Based on the above-presented definition of technological sovereignty by [Edler et al. \(2023\)](#) and the relevant functions of standardization known from literature reviews, we elaborate on how standardization and standards can be considered safeguards related to technological sovereignty. Since there is no established conceptual framework, our approach focuses on research, innovation, trade, and public policies, particularly the regulatory framework, as essential instruments to assure technological sovereignty (e.g., [Edler et al., 2023](#)), because they can immediately be supported by standardization and standards.

Baseline for standardization being an effective instrument for safeguarding technological sovereignty are sufficient human resources, i.e. experts⁶ being involved in standardization processes defending national interests related to technological sovereignty, which has also implications for the technological dimension of geopolitics. In particular, researchers have to be involved in standardization in order to exploit the successful and efficient transfer of knowledge particularly from publicly funded research into standards.

Therefore, our considerations start from standardization as a knowledge and technology transfer channel ([Blind and Gauch, 2009](#)), and its interlinkages to other channels, because it has an essential role in innovation (see the reviews by [Blind, 2016, 2022](#)). In addition to standards' indirect influence via innovation on trade, standards influence directly trade flows ([Swann, 2010](#)) and, therefore, technological sovereignty. These two perspectives have to be complemented by the fact that standards play, at least in the context of the European Union (EU), an essential role in the specification and eventually the implementation of regulations, in particular, to generate an innovation-fostering framework (e.g., [Blind, 2023](#)) or to contribute to the transformation of the economy ([Blind, 2024](#)). According to the recent EU standardization strategy ([European Commission, 2022a](#)), standardization for shaping technical regulations will play an even more critical role, including for the protection of European values, another dimension of geopolitics.

3.1. Standardization, research, and innovation

The critical base of technological sovereignty is certainly research and development (R&D) (see also [Edler et al., 2020, 2023](#)). Furthermore, it has to be pointed out that skilled labor forces are needed for conducting R&D, and for countries' involvement in standardization processes. Not only R&D, but also researchers' involvement in standardization, particularly on the international level, can be a strategy to achieve or secure technological sovereignty. However, researchers' motivations have to be considered, as well as the obstacles they face ([Blind and Gauch, 2009](#); [Blind et al., 2018a](#)).

Since the direct engagement of researchers in standardization is often not possible or not realized, the stakeholders involved in standardization processes have to rely on the different forms of codified outputs of R&D projects.

First, scientific publications can immediately prohibit proprietary claims, e.g., patents, owned by foreign companies. Therefore, they can contribute to domestic companies' access and their country's technological sovereignty. Whereas scientific publications are systematically referenced as prior art in patents, standards are only an emerging source

for documenting prior art ([Bekkers et al., 2020c](#)). Indirectly, scientific publications are - still limited - but increasingly cited by international standards ([Blind and Fenton, 2022](#)). Related to the standards published by ISO, these publications cover a broad range of scientific areas and originate in various countries, and institutions. Standards have a multiplier function for the diffusion of these standard-relevant publications and eventually to innovation as a driver for technological sovereignty in the context of the technological dimension of geopolitics. In addition to this indirect contribution via innovation, these publications by domestic researchers shape the specifications of international standards and contribute to technological sovereignty, but not necessarily to foster competitive advantage due to the missing appropriability of contents published in scientific papers.

Second, intellectual property rights (IPRs) can be used to protect the results of R&D activities and projects. Regarding inputs into standardization, patents are the most relevant IPRs, particularly standard essential patents. However, they are still both technologically concentrated in information and communication technologies, particularly mobile communication, and dominated by a few leading countries and companies (e.g., see the recent landscape report by [Bekkers et al., 2020a](#)). Furthermore, since the declaration of these standard-essential patents (SEPs) requires their licensing according to Fair, Reasonable, and Non-Discriminatory (FRAND) conditions, these patents are accessible for all companies and, therefore, countries interested in implementing the referenced standards. In theory, SEPs allow - like scientific publications - domestic companies to implement the protected technologies and contribute to their and other countries' technological sovereignty. However, in practice, there are intensive but contradicting discussions about both the essentiality of patents ([Bekkers et al., 2020b](#)) and the determination of the FRAND conditions ([Heiden and Baron, 2021](#)), e.g., about the hold-out and hold-up by SEPs owners ([Contreras, 2019](#)) due to excessive licensing fees related to the latter ([Galetovic et al., 2015](#)). Therefore, the massive number of declarations of SEPs associated with the various generations of mobile communication standards might create an accumulation of licensing fees, making the implementation of the standards costly and eventually allowing to exclude potential implementers. Therefore, such royalty stacking could endanger technological sovereignty as objective in geopolitical power games. However, the existence of this phenomenon is not decisively proven (e.g., [Elhauge, 2008](#)).

Triggered by the massive increase in the declaration of SEPs, straightforward licensing and even cross-licensing deals have no longer been sufficient. Therefore, patent pools have been formed to commercialize the portfolios of SEPs owned by numerous patentees collectively. In addition to the transaction cost-saving function of patent pools, which are of minor importance for technological sovereignty, [Vakili \(2016\)](#) reveals that large patent pools did succeed in establishing dominant standards and promoted the rate of follow-on innovations. Moreover, they facilitated shifts towards vertical disintegration in the affected industries, where upstream technology-focused organizations contributed to the development of follow-on complementary technologies. Therefore, specialized start-ups had the chance to enter the market. Consequently, patent pools related to important standards reduce the price for the bundle of a large number of patents and multiple negotiations of licensing. This eventually increases the supply chain's diversity and contributes to technological sovereignty.

Finally, not only hard- but more and more software is the result of R&D activities. Consequently, software, in general, is becoming increasingly relevant for today's economies, supported by the famous quote "software is eating the world" ([Andresen, 2011](#)), but also for the military dimension of geopolitics due to the increasing relevance of cyberattacks. However, proprietary software mainly dominated by U.S. big tech companies is not necessarily beneficial for other countries' and companies' technological or digital sovereignty. In contrast, Open Source Software (OSS) is accessible to all interested stakeholders, depending on the licensing type, to different degrees (e.g., [Almeida](#)

⁶ Here, two challenges have to be mentioned particularly for Europe. First, the current age structure of the experts active in standardization will lead to one quarter to retire in the next ten years. Second, research results are significantly relevant as input for standardization processes requiring the active involvement of researchers. See [Blind et al. \(2024\)](#).

et al., 2011) and, therefore, directly contributes to countries' technological or digital sovereignty. Influencing the development of OSS is becoming increasingly relevant in geopolitical relations, exemplified by China's initiative to establish an own OSS repository to become independent from Microsoft's owned GitHub. In addition, according to Biddle (2019), Open Source foundations claim not only to organize the development of OSS but also to set standards by themselves, which can be used without facing major restrictions created by licenses.

Furthermore, there are also indirect implications via standardization and standards. Böhm and Eisape (2021) compare Open Source communities and SSOs and reveal the cost of changing technology, i.e., hardware vs. software, as a critical determinant for the comparative advantage of each approach. Both types of organizations create complementary products, but compete in the efficiency of the standardization process. Eventually, they release independent and complementary standards available to industry and policymakers. In addition to the competition between Open Source communities and SSOs, Blind and Böhm (2019) analyzed the knowledge flows between them. There is indeed the intention of SSOs to integrate OSS in their standardization processes and standards, e.g., IEEE starting to include references to GitHub repositories in some of their standards and ISO includes Open Source foundations in the list of submitters of publicly available specifications. However, legal and other incentives still prohibit a closer integration of OSS into the standards released by SSOs. In summary, OSS certainly contributes directly by making software code accessible and even by setting standards for technological and digital sovereignty. However, the potential of integrating OSS in standards could be an indirect channel, which has not yet been exploited.

In addition to the indirect impact of OSS via setting standards or standardization on technological sovereignty, there is a potential second indirect impact, which goes back on insights on OSS. For example, Wright et al. (2023) reveal that OSS contributes to the growth of the number of start-ups, increasing the diversity in the supply chains and contributing to technological sovereignty. Therefore, OSS communities' standard setting activities as mentioned above might also contribute to this start-up growth and technological sovereignty. Böhm and Eisape (2021) display the similarities between OSS communities and standardization, which can lead to the conclusion that OSS and standards might promote entrepreneurship. Finally, the first evidence provided by Funk and Luo (2015) shows how the emergence of open standards created entrepreneurial opportunities for start-ups in the semiconductor industry. They argue that the standards reduced transaction costs and fostered firms' specialization, thus facilitating the entry of vertically-specialized new ventures enriching the portfolio of companies.

3.2. Standardization, trade, and global value chains

Whereas the literature on the trade impacts of standards focuses on their competitiveness-promoting role and, consequently, on exports (starting with Swann et al., 1996), their import-enhancing function must also be considered related to technological sovereignty in the context of the economic dimension of geopolitics. The review of existing studies by Swann (2010) reveals that most of them show positive impacts of international and national standards on exports. However, in most studies, imports are found to be hindered by national standards, whereas international standards play a promoting role. Therefore, to promote their competitive advantage and technological sovereignty, it has to be concluded that countries should implement international standards. In addition, it has to be noted that international standards are not necessarily for all countries' exogenous parameters but can be influenced by their R&D performance and technological profile (Blind and von Laer, 2021), which eventually promote their technological sovereignty, but also economic power in the context of geopolitics. This link underlines the complexity of the relationships of the different standardization- and standards-related drivers for technological sovereignty.

In addition, to consider the stock of international standards as drivers

of trade and securing technological sovereignty, certificates on quality management systems drive international trade (Clougherty and Grajek, 2008, 2014) and, therefore, contribute to technological sovereignty. Furthermore, accreditation promotes trade, particularly between partners in the global south (Blind et al., 2018c). In this context, it must be mentioned that quality (Manders et al., 2016) and environmental management standards (Lim and Prakash, 2014) might also affect countries' innovation performance and, consequently, eventually, their technological sovereignty.

3.3. Standardization and other policy areas

Complementary to the embeddedness of standardization and standards in R&D and their different output forms, they are also linked to other public policies. First, standards can specify national regulations, like in the European Union (Blind, 2024), but also make them completely redundant. This link can contribute to technological sovereignty if national regulations are specified or even substituted by supranational, e.g., via European standards or even better international standards. Then, international standards reduce the fragmentation of markets and contribute to the harmonization of the regulatory landscape, which eventually promotes the technological sovereignty of all countries implementing these standards, because their industries comply with the same portfolio of identical standards and this increases the diversity in the global supply chains and consequently these countries' technological sovereignty. Finally, it has to be noted that the rapid internationalization of national regulations, as recently suggested by the OECD (2021), also promotes the technological sovereignty of the supporting countries. In addition to these direct links to technological sovereignty, international standards harmonizing national regulations or making them even superfluous are pushing innovation (Blind and Münch, 2024), particularly in emerging areas (Blind et al., 2017), and trade, both securing technological sovereignty.

In addition to this regulatory approach, demand-side policies, like public procurement, can promote technological sovereignty, e.g. by pushing the diversity of suppliers of critical technologies (e.g., Edler et al., 2020). However, public procurers can rely on standards and certifications in their tender specifications. This allows them to reduce their risks in basic requirements and then enables them to increase their flexibility in other innovative dimensions. Overall, relying on standards can push the innovation promoting impact of public procurement (Blind, 2008).

Table 1 summarizes the most relevant drivers influencing countries' technological sovereignty influenced or moderated by standardization and standards.

To safeguard technological sovereignty, standardization processes should follow the WTO principles for the development of international standards,⁷ i.e., transparency, openness, impartiality and consensus, effectiveness, relevance, and coherence.

Based on the drivers for technology sovereignty listed in Table 1 and references to already available empirical evidence, we derive the following propositions related to standardization's and standards' role as safeguards for technological sovereignty:

- R&D active countries can influence the trajectories in standardization processes to secure their technological sovereignty (Blind and von Laer, 2021).
- Standards can serve as a backup for technological sovereignty for those countries that do not invest heavily in R&D, similar to their hedging function for companies (Foucart and Li, 2021). However, a minimum level of R&D is necessary to ensure countries' absorptive

⁷ https://www.wto.org/english/tratop_e/tbt_e/principles_standards_tbt_e.htm

Table 1
Standardization and standards as safeguarding mechanisms for technological sovereignty

Driver	Description	Safeguarding mechanism related to technological sovereignty
Human Resources	Involvement of researchers and experts in standardization processes Indirectly, HR are the essential requirement for R&D and innovation activities	by integrating own contents, preventing other countries' content and keep technology use open
R&D	Implicit and proprietary R&D results as input in standardization processes	by integrating own contents, preventing other countries' content and keep technology use open
Publications	Publications can be the base for standards	by diffusing their contents broadly and in general without limitations
Patents	Patents declared to be standard-essential	by being available for all companies world-wide and, therefore, countries interested in implementing the standards
Software	Software, particularly Open Source Software, can be the base for standards	by being available according to the applicable Open Source licenses for all companies and countries interested in implementing the standards
Innovation	Involvement in standardization and the implementation of standards can promote the innovation capabilities of companies and countries	by generating product innovation expanding the already existing products and set of suppliers
Trade	Involvement in standardization and the implementation of standards can promote the capabilities of companies and companies to trade goods and services	by promoting export and import of goods for a larger group of companies and countries
Policy/Regulation	Policy initiatives, like public procurement referring to international standards or referencing standards in regulations	by expanding the number of companies being able to deliver products to public tenders and by harmonizing the regulatory frameworks across countries

capacity (Cohen and Levinthal, 1990) to implement them, e.g., in developing countries (Zoo et al., 2017).

- Patent-active countries can influence both the direction of standardization processes (Buggenhagen and Blind, 2022) and the implementation of standards, e.g., via economically feasible licensing conditions (FRAND) and, therefore, technological sovereignty.
- Standardization and standards are more critical for assuring technological sovereignty related to hardware, whereas OSS is more relevant for software and digital sovereignty.
- Public procurement can promote the implementation of international standards to increase the diversity in the supply chain, e.g., supporting innovative start-ups and SMEs to secure countries' technological sovereignty.
- International standards are crucial for supporting domestic exporters' competitive advantage and promoting imports (Swann, 2010), which is even more relevant for technological sovereignty.
- In particular, international standards can complement the primarily nationally specified regulations in heavily regulated sectors to secure technological sovereignty by promoting innovation (Blind and Münch, 2024) and a broad portfolio of suppliers.
- If governmental regulations are not necessarily needed, international standards can provide an open, innovation-friendly framework for emerging technologies, securing countries' technological sovereignty (Blind et al., 2017).

4. Mobile communication standardization as an illustration

Although these propositions related to standardization and standards as safeguards for standard setters and implementers are only a starting point for further research, we will illustrate and specify them first related to 5G mobile communication technology based on existing evidence and some of our investigations. Furthermore, we elaborate on the geopolitics and technological sovereignty related to the follow-up generation of 6G.

The following arguments motivate the selection of 5G and its following generation 6G for elaborating our lines of argument. First, 5G is a technology and critical infrastructure mentioned in the literature about technological sovereignty (e.g., Edler et al., 2020) or open strategic autonomy (e.g., Cagnin et al., 2021), but also related to the military dimension of geopolitics due to possible vulnerability for cyberattacks. Second, standardization and standards are crucial in establishing and rolling out 5G infrastructure and applications. Third, there is empirical evidence about factors influencing countries' technological sovereignty related to 5G (e.g., Da Ponte et al., 2023), but also first information related to 6G, which can help to illustrate our line of argument.

Since human capital is the base for research and innovation, R&D personnel focusing on 5G or 6G must be able to keep track of the research developments and join standardization committees dealing with 5G. Since detailed information about the specialization of R&D personnel is generally unavailable on an international level (see, e.g., Da Ponte et al., 2023), scientific publications allow much more topic-related analysis focusing on 5G (e.g., Buggenhagen and Blind, 2022) or 6G.

Although scientific publications - in contrast to patents - are not the focus of investigations related to 5G or 6G, they prohibit the proprietary appropriation of the disclosed research findings and technologies and contribute to the freedom to operate for all companies and countries in producing components of 5G technologies currently and 6G technologies in the future.

Similarly, OSS played a minor role for a long time related to 5G in general and 5G standardization in particular. However, it is becoming more critical to implement the 5G network (Lando et al., 2023) and help strengthen all countries' 5G-related technological sovereignty. Furthermore, even in 5G standardization, the U.S. promotion of Open Radio Access Network (Open RAN) is an OSS-based reaction to the so far dominating Chinese providers' patent-based proprietary solutions, i.e., an example of standardization being used to secure technological sovereignty.

5G related patents contribute to the technological sovereignty of the country hosting the applicants, i.e., companies and research organizations (Da Ponte et al., 2023). In contrast standard-essential patents (SEPs) give all companies and, therefore, also countries interested in using the protected 5G technologies the opportunity to receive a license according to Fair, Reasonable And Non-Discriminatory (FRAND) requirements. However, Bekkers et al. (2023) reveal that in addition to royalty-free licensing offers to strengthen the technological sovereignty of all affected countries, SEPs are more likely to be in the focus of litigations. This is an indication that licensing agreements have been difficult or not at all being achieved. Patent pools are an opportunity to collect license fees from numerous patentees effectively and license them efficiently to interested licensees as a package. Despite the expected efficiency gains, e.g., via lower transaction costs and higher predictability of the expected licensing fees, pools failed to take successfully off for previous mobile communication standards. However, Nikolic and Galli (2022) elaborate on why, for 5G, the formation of patent pools might work in the future, making licensing feasible, easier, and cheaper and, therefore, contributing to the licensees' technological sovereignty.

Testbeds and demonstrator projects are essential to the roll-out of 5G. Wadatkar et al. (2023) provide an overview of 5G testbeds for V2X

applications and reveal the important role of 5G standards in their realization. Due to their openness to all interested companies, they help countries to achieve technological sovereignty by promoting 5G applications, which are more effective and efficient if closely coordinated with standardization activities and the released standards (see Koch and Blind, 2021 for IIoT).

Whereas small and particularly young companies are less likely to be involved in standardization, for 5G, a search in the database, Crunchbase reveals more than one thousand start-ups founded since 2000 mentioned in their description 5G and standardization. This evidence indicates that their business model relates to 5G standards. However, further investigations are necessary. Surprisingly, a search in the literature database Scopus does not reveal any scientific paper about start-ups and 5G standards. In addition, the role of start-ups has not been addressed in the study by Da Ponte et al. (2023) about technological sovereignty related to 5G. There is a research gap that needs to be closed in the future.

Finally, innovations related to 5G depend on standards and standardization. Unfortunately, there are no comprehensive scientific studies about 5G based innovations, which are also explained by their complexity based on multiple components and infrastructure (e.g., Bauer and Bohlin, 2022) and the lack of databases. Therefore, Da Ponte et al. (2023) and others rely on 5G patent families to describe countries' innovation potential and the subgroup of 5G related SEPs to reveal the links to standardization. These indicators also play a major role in calculating technological sovereignty related to 5G.

Regulation also influences innovation in 5G, as displayed by Bauer and Bohlin (2022). They focus on regulating bottlenecks, coverage, Mobile Virtual Network Enabler and Aggregator access, and neutrality. However, they elaborate little on reference to standardization activities and standards. Within the European Union (EU), there is a close link between regulations and harmonized European standards specifying the former (see Blind, 2024). Therefore, standards influence innovation not only in a direct way but also indirectly via regulation in the EU and other countries, like China. However, related to 5G, this link is currently not so relevant and, therefore, contributes not to technological sovereignty (see also Da Ponte et al., 2023). Furthermore, certification schemes can promote the rigorousness of the implementation of standards, and the accreditation of the certification bodies can increase their credibility. However, certification schemes based on 5G standards do not play an important role, as the missing scientific publications in Scopus indicate.

Another innovation policy instrument is public procurement, and referencing standards in the specifications of tenders can contribute to innovation (Blind, 2008) and technological sovereignty because it can increase competition between existing suppliers and even in the long run on the number of potential suppliers. In the European procurement database TED (Tenders Electronic Daily), there are currently no tenders related to 5G standards. However, Blind and Niebel (2022) reveal that security issues also addressed in 5G standards play an important role in procuring 5G technologies in the Member States of the European Union.

Finally, standards are essential in trade and global value chains and mainly related to 5G components. Therefore, Da Ponte et al. (2023) use several trade-related indicators based on ICT to calculate the indicator of technological sovereignty related to 5G. Unfortunately, 5G-specific trade data is not easily available. Therefore, there is limited research on this linkage so far (see only the analysis of trade impacts of SEPs on ICT global value chains by Von Laer et al., 2022). This research gap must be closed to get more empirical evidence on 5G standards' critical role for trade flows and technological sovereignty.

To summarize the insights from this elaboration on 5G (see Table 2), we observe that we have first empirical evidence about the linkages between the drivers for technological sovereignty and the safeguard mechanism of standardization and standards. However, this evidence does not exist for all of them and is often not always 5G-specific. Furthermore, the limited evidence represents just a snapshot, i.e., correlations, and does not allow the derivation of causal relationships.

Table 2

Standardization and standards as safeguarding mechanisms for technological sovereignty related to 5G (Sources in brackets).

Driver	Indicator (Source)	Empirical evidence (Source)
Human Resources	Involvement of researchers and experts in standardization processes (Da Ponte et al., 2023)	Individuals' ascension to 3GPP leadership positions primarily driven by their individual achievements (Baron and Kanevskaia, 2023).
R&D	Share of 5G R&D investment over total R&D investment within top 2500 companies worldwide (EU Industrial R&D Scoreboard)	Contribution to 5G TS (Da Ponte et al., 2023)
Publications	5G related publications listed in the Web of Science (WoS).	Positive correlation with contributions to 5G standardization (Buggenhagen and Blind, 2022)
Patents	Declared patents to the 5G standard, disclosed by the declaring organization (ETSI database)	Contribution to 5G TS (Da Ponte et al., 2023) Positive correlation with contributions to 5G standardization (Buggenhagen and Blind, 2022)
Software	Open RAN enables interoperability among the RAN components and interfaces and. It increases the flexibility of network deployment through the development and use of open interfaces and open hardware/software (O-RAN Alliance, 2020)	Open RAN as open source initiative reacting to China's lead in 5G standardization via patents (Kim et al., 2023)
Innovation	Share of 5G related firms over total firms (EU Industrial R&D Scoreboard)	Domestic innovation capabilities contribute to 5G TS (Da Ponte et al., 2023)
Trade	Stock of SEPs in ICT (ETSI database)	SEPs related to ICT mainly, i.e. the predecessors of 5G, promote exports and reduce import pressure (Von Laer et al., 2022)
Policy/Regulation	The EU toolbox for 5G cybersecurity was outlined to guide Member States in tackling the main 5G-related cybersecurity risks, incl. Suggestions ensuring a diverse supply chain of vetting equipment suppliers. (NIS, 2020)	Securing TS by expanding number of companies being able to deliver products to public tenders and by harmonizing the regulatory frameworks incl. For public procurement across countries

Finally, 5G is a very advantageous example for analyzing technological sovereignty, which has to be complemented by further examples of other technologies, e.g., blockchain or artificial intelligence. Despite these limitations, we have presented a preliminary proof of the relevance of the various drivers and the safeguard mechanisms of standardization and standards, which have to be enriched by further empirical evidence and elaborated to be applicable to other technologies.

Whereas Table 2 summarizes the indicators and the empirical evidence assessing standardization and standards as safeguarding mechanisms for technological sovereignty related to 5G, we provide further evidence that 6G and related standardization activities are in the focus of geopolitical tensions and, therefore, still relevant for technological sovereignty. First studies show that China's good positioning in 5G publications and patents has been leveraged to a dominance in 6G.⁸ For example, over 40 % of the scientific publications listed in the Web of Science have been coauthored by scientists having an affiliation in

⁸ See <http://afdip.com/index.php?ac=article&at=read&did=3953>. However, own searches in the database ESP@CENET reveal that applicants from the United States of America are almost 40 %, still ahead of those from China and Europe with nearly 20 %.

China. In contrast, only 15 % are originated by researchers from the U.S. On the same level, with 40 % of the patent applications, China is ahead of the U.S. and Japan despite the sanctions against Huawei Technologies first by the U.S. government and meanwhile also by several European countries.⁹ On the contrary, the U.S. sanctions have hampered the influence of U.S. stakeholders in the 3GPP standardization (Chen, 2024). China was obviously able to mobilize in particular state-owned companies, but also research organizations and universities to file patents.¹⁰ It is expected the commercial roll-out will be in 2030, whereas Europe is still struggling to push the commercial implementation of 5G (Blind and Niebel, 2022), which calls for an integrated framework for developing European 6G innovation according to Ahokangas et al. (2023). Due to the increased speed of 6G compared to 5G, it is expected to be the infrastructure e.g. for autonomous driving. In contrast to the state-driven approach by China, the Next G Alliance in the U.S. is driven by its large big-techs, like Google and Apple. Complementary, IBM holds a significant number of 6G patents. Finally, the European Union has established a research group focusing on 6G in the European Telecommunications Standards Institute (ETSI) and expects to deliver first 6G standards by 2029 or 2030. Based on these developments, the scenarios “States support global standards amidst rising tensions, but may limit 6G development” and even the worst case scenario “Failure of global collaboration leads to fragmented 6G systems” presented by Timmers and Serentschy (2024)¹¹ are becoming more likely. This is confirming the relevance of mobile communication standardization will be a topic for geopolitics also in the future, i.e. 6G standardization.

5. Conclusions, policy recommendations and challenges

We come to the following conclusions based on our conceptual analysis of standardization and standards securing technological sovereignty underpinned by an explorative empirical analysis of 5G standardization.

First, experts, particularly researchers, who are actively involved in standardization promote the integration of domestic technologies in future standards and help to reduce the influence of technologies generated abroad while keeping the use of standardized technologies generally open. Secondly, R&D activities related to standardization topics generate implicit and explicit technological knowledge. The former can help researchers actively involved in standardization to shape specifications of standards securing their own organizations', particularly companies, and, therefore, countries' technological sovereignty. The latter can lead to scientific publications, patents, or even software. Scientific publications can serve as foundations for the specifications of standards, particularly in science-based areas. Since they do not restrict the use of the documented scientific knowledge and technologies, they promote the openness of the eventually developed standards and, therefore, to the technological sovereignty of the own country in the short run due to the time advantage (Wakke et al., 2016), but in the long run for all countries, but they cannot serve as barter chips in technology-oriented geopolitical power games. Here, patents due to their proprietary character have a long term effect, at maximum 20 years of the patent protection. Patented technologies can only be integrated into standards, if they are declared to be essential for the implementation of the linked standards offering them for licensing

under FRAND. Eventually, the protected technology is available for all interested companies, which contributes to technological sovereignty for all countries, but the generated licensing revenues strengthen not only the economic, but due to the opportunity to reinvest them into the next generation of technology also to the technological power in geopolitical relations. Since R&D investments can also contribute to the development of software, the increasing relevance of OSS for standards has implications for technological sovereignty. In theory, OSS can be used by all interested companies and organizations. In practice, the contributors to the OSS repositories shape the future development, which fosters their own, but to a lesser extent, others' technological sovereignty. Standardization is only partly driven by research but also by market needs. Whereas standardization in leading-edge research areas cannot rely on many alternative solutions, the choice among market-driven standards might be much larger. In order to successfully influence international standard-setting strategic alliances (see Blind and Mangelsdorf, 2013, about standardization as formation of strategic alliances) between different countries might be necessary to reflect not only common technological capabilities but also economic interests, and cultural identities and values, a further dimension of geopolitics, which goes beyond pure technological sovereignty.

Not only does providing input into standardization strengthen a country's technological sovereignty, but also participating is beneficial because the participating companies' and therefore countries' innovation performance benefits from the knowledge exchange (Blind, 2022). However, increased innovation performance via standardization contributes to technological sovereignty by shaping future technological and innovation trajectories and the technological and economic positioning within geopolitical relationships. Here, the innovation-enhanced trade performance of countries has also to be mentioned, which is beneficial for their technological sovereignty by relying on leading-edge innovations and using them as barter chips against weaker performance in other technologies or product domains. In geopolitical relations, innovation contributes to countries' technological and economic positioning.

Finally, international standards can be a powerful tool in public policies to promote countries' technological sovereignty. First, public procurement can reference international standards, thereby increasing the number of potentially supplying companies eligible for public tenders and reducing the dependency on very few suppliers. Second, international standards can substitute or specify national regulations, contributing to the harmonization of regulatory frameworks across countries. This harmonization can help to level the playing field, strengthening technological sovereignty in general and potentially leading to a more equitable global technological landscape, but not necessarily promotes the power position of single countries in geopolitical relationships.

In summary, international standardization and standards can serve as crucial instruments for maintaining and enhancing technological sovereignty via different dimensions. However, international standards are not necessarily able to push the positioning of specific countries in geopolitical technological and economic power relations.

Although the above-derived mechanisms and propositions are not yet or only to a limited extent empirically tested (e.g. Da Ponte et al., 2023) and only illustrated by the example of 5G, we suggest some policy recommendations to strengthen the safeguarding role of standardization and standards related to technological sovereignty.

As human resources are the basis for R&D, the development of standards requires not only technologically skilled engineers but also complementary economic and strategic knowledge, for which there is already a shortage (Blind and Drechsler, 2020), which is growing shortly in Europe (Blind et al., 2024). Therefore, Higher Education Institutes should expand their portfolios and programs to teach these skills, as recently confirmed in the EU standardization strategy (European Commission, 2022a) but also the U.S. strategy (White House, 2023). Of course, a direct link to technology or digital sovereignty does not exist in

⁹ Information about standard-essential patents does not exist yet because 6G standards are not yet published.

¹⁰ Compared to the more than one thousand start-ups listed in Crunchbase mentioning 5G, only some more than thirty mention 6G in a search conducted in October 2024.

¹¹ In the same direction, Rossi (2024) elaborates on the attempts of the European Commission to reduce the influence of large bigtechs by changing the governance of ETSI but increasing the risk of fragmentation of 5G and 6G at the global level.

the education strategies, but the students might be sensitized to the topic in the future.

Continuous investment in research and development is a key factor in securing and achieving technological or digital sovereignty. To strengthen the role of standardization and standards as safeguards, the interfaces of existing publicly funded programs need to be extended. This necessity has been recognized and addressed in the recently published standardization strategy of the European Union.

In addition to the incentives to be provided for researchers to make them participate in standardization, Nagle (2021) recommends reducing their participation costs, which, according to Blind et al. (2018a), is a significant barrier.

Furthermore, increasing the diversity in supply chains is a different strategy to assure technological sovereignty. In addition to strengthening companies already in the market against foreign competitors, which their national governments might financially support, standardization might also provide another opportunity. Since Funk and Luo (2015) show that patent pools related to standards contribute to the market entry of start-ups, their further promotion can help to contribute to technological sovereignty. Even more generally, aligning SSOs to the needs of start-ups might be an indirect approach to push the variety of the supply chain, particularly in ICT markets, and towards technological sovereignty.

Standards not only play a crucial role in the technology or supply-side aspects of standardization but also on the demand side. In particular, public procurement that relies on international standards can directly enhance a country's technological and digital sovereignty. By fostering a diverse range of potential bidding companies, this approach can also address security issues, such as those related to critical 5G infrastructure (Dinges et al., 2021).

Finally, Europe already has a robust standardization system with established governance and rules attracting international contributors and allowing the development of worldwide accepted standards, e.g., by ETSI. In other areas, more active involvement in international standardization bodies might be needed in the long run, e.g., as claimed by the European Commission in its new standardization strategy (European Commission, 2022a). In addition, Weyerstrass et al. (2021) point to Europe's regulatory power and market size, which creates strong incentives for multinational enterprises to comply with European regulations and standards. Following the successes in imposing European standards on a global scale in mobile communication, Europe's ambition is to extrapolate them, e.g., in AI and other areas, to keep its role as a global standard setter.

Standards also play an essential role in infrastructure projects, like GAIA-X, a platform to promote a secure pan-European data collection, processing, and sharing mechanism for different but interoperable cloud service providers. GAIA-X is not intended to compete against current offers but focuses on linking different elements through open interfaces and standards to create an innovative aggregation platform.

However, the recommendations mentioned above are facing different challenges. On the one hand, we have to clarify that standardization might be also barrier to achieve technological sovereignty. In general, setting standards is reducing the variety of technologies, in particular, if they are recommending specific technologies and are not specifying general performance criteria. This reduced variety might increase the dependency on one specific technology and on the companies being its leaders. For a country, this might be even more detrimental, if all of these companies concentrated in another country, like we observe for 5G. Network effects might aggravate this dominance over several generations of technologies, as in mobile communication. Therefore, such standards challenge the technology sovereignty for all countries having little influence on their development. However, if the WTO principles related to the development of international standardization, i. e. transparency, openness, and impartiality and consensus, are fulfilled the above elaborated cases should be very limited.

On the other hand, the effectiveness of standardization as a safeguard

is contingent on several factors. First, despite the financial opportunities to promote standardization, both researchers and their institutions' incentives, which are dominated by scientific excellence and reputation (Blind et al., 2018a) or intrinsic motivations (Blind et al., 2022b) have to be considered and shaped towards standardization in the long run. Complementary, standardization is dominated by companies' interests (Blind et al., 2022a), which might disincentive researchers. Second, in those technological areas, where patents also play an important role in the funding of R&D, e.g., via licensing revenues, their integration into standardization is still - despite licensing regimes under FRAND conditions - also challenged by an increase of relevant patent applications and the extension towards numerous new players. Third, standards are still not well established as a knowledge source for new product development in the industry (Großmann et al., 2016). Fourth, international standards are the best option to foster international trade (Swann, 2010) and global value chains (Blind et al., 2018b) and are the preferred option within trade agreements (Blind and Müller, 2018). However, deviations from international standards have been recently used to pursue the protection of domestic industries. In this context, fifth, it has to be noted that international standards compete with policymakers' preferred national regulations (OECD, 2021), another option to implement protectionist trade policies. Sixth, complementary to the system of accredited national, European, and international SSOs, several international standardization consortia and Open Source communities are responsible for setting global standards, providing the backbone of the IT infrastructure and the internet. Since they are not necessarily closely embedded into or linked to the national regulatory frameworks (see e.g. Lee et al., 2024), exploiting their potential for technological sovereignty is challenging. In particular, Open Source and standards can contribute to technological and digital sovereignty, with the former being more relevant for software and the latter for hardware. However, their interfaces are still challenged by frictions and somewhat different types of governance (Blind and Böhm, 2019), e.g., due to their various relations to patents. Seventh, large, primarily U.S.-based bigtechs have the power to set de facto standards within global value chains (Dinges et al., 2021). Still, they cannot easily be geared to contribute to all countries' technological sovereignty.

CRedit authorship contribution statement

Knut Blind: Writing – review & editing, Writing – original draft, Validation, Supervision, Resources, Project administration, Methodology, Investigation, Funding acquisition, Data curation, Conceptualization.

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