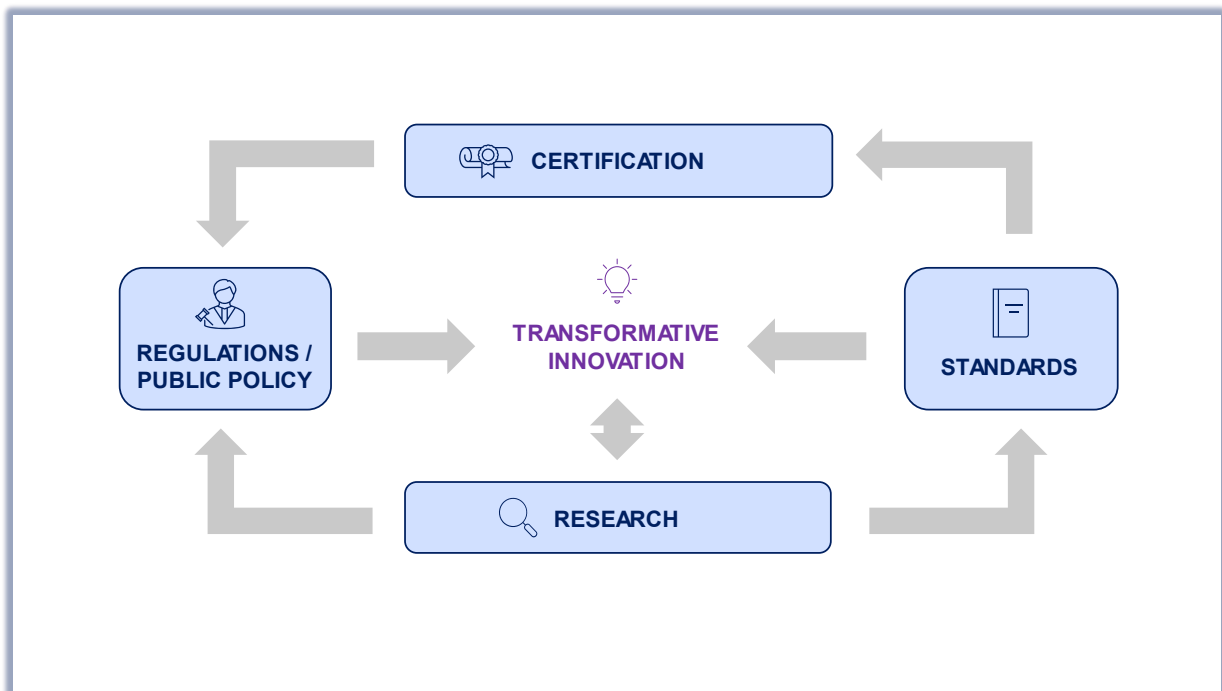


Maximizing the impact of standards and regulation to drive transformative innovation: a new approach



Place: Karlsruhe, Berlin

Status: Final Version

Date: July 2023

Imprint

Maximizing the impact of standards and regulation to drive transformative innovation: a new approach

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Acknowledgments

First, the author appreciates the funding of the performed research by Our 2050 World (commissioned by BSI). Many thanks go to Virginia Newton-Lewis, who accompanied and supported the project from the beginning to the final draft of the report. She helped to make contact with many of the interviewees and shared valuable background information. Further thanks go to the interviewees, who spent their time for the interviews but also provided further helpful background material. Finally, Joel Chapman took over and provided as well as Emily Faint valuable comments to the draft reports.

Recommended citation

Blind, Knut (2023): Maximizing the impact of standards and regulation to drive transformative innovation: a new approach. Karlsruhe, Berlin: Fraunhofer Institute of Systems and Innovation Research, Report produced on behalf of Our 2050 World (commissioned by BSI).

Published

July 2023

Notes

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0 Executive Summary

Action to address climate change, including fast progress towards net zero and other global challenges, requires transformative innovation. It means moving beyond incremental innovation to complete systems change, including consumers' behaviour and the governance of the framework conditions. Consequently, innovation policies are needed. However, the relationship between standardization and innovation policy must be better documented and explained. Although ideas for transformative innovation policy have been developed and first initiatives have been evaluated, the potential role of standardization and its relevance within the regulatory framework needs to be better addressed. Therefore, our contribution is focused on the following research question:

- What role can standardization and standards - together with their interplay with regulatory frameworks - play in promoting transformative innovation?

We performed a literature review, stakeholder interviews, and case studies to answer this question. The literature review showed that, despite the availability of several review papers on transformative innovation policy, more work needs to be done to define transformative innovation. At its core, transformative innovation is about disruptive or radical innovation, in which significant changes should accompany both the regulatory framework and consumers' behaviour. The literature on the impact of standards (e.g. Blind, 2022, Blind et al. 2023) and regulation on innovation and recently published reports has been considered.

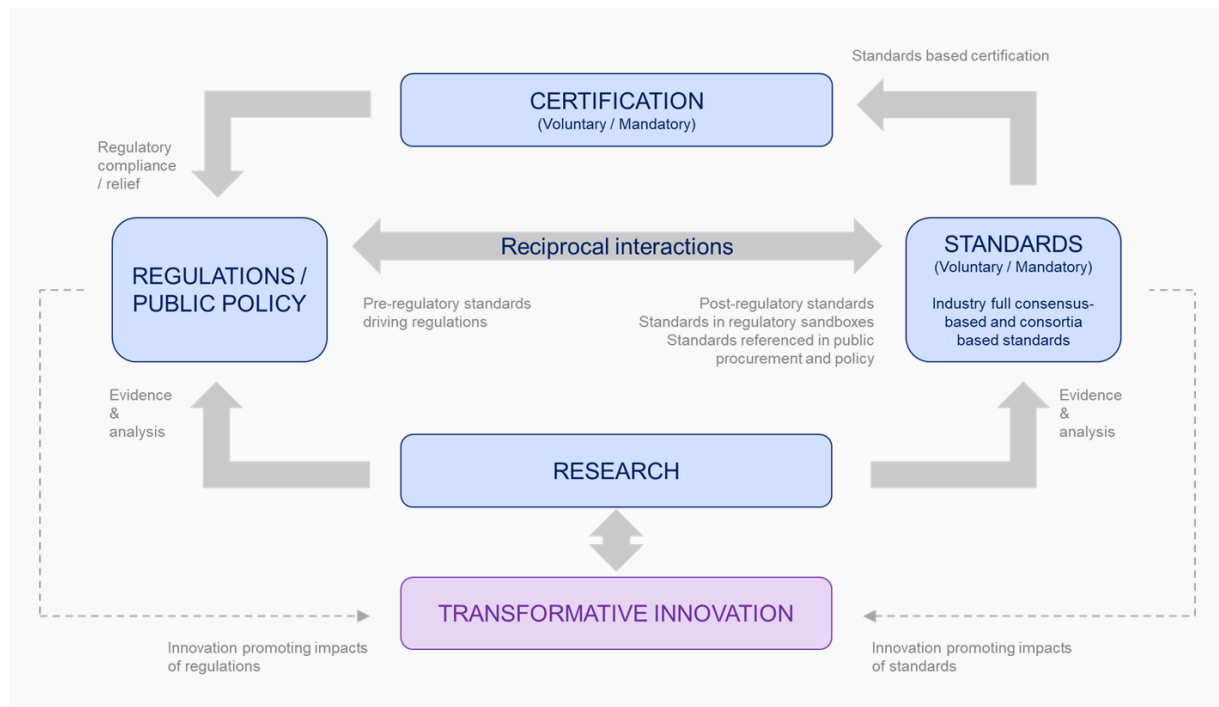
In parallel, we conducted interviews with stakeholders from standardization bodies, regulators, voluntary initiatives, industry, and academics. Thirdly, we performed three case studies of the international standard ISO 30500 on non-sewered sanitation systems, the ISO Net Zero Guidelines (IWA 42:2022) (ISO 2022), and the corporate net zero standards released by Science Based Target Initiative (SBTi). The first case is a rare but successful example of a standard initially asking for technologically unfeasible solutions. The ISO Net Zero Guidelines (IWA 42:2022) and the net zero standards released by SBTi have been selected because they are also driven by the objective and need to achieve net zero and propose specific requirements or solutions to get there.

The insights from the literature, the interviews, and the case studies have been used to develop a conceptual governance model of standardization and regulation promoting transformative innovation. It combines previous work, e.g. by Tait et al. (2017) and Hale (2021). However, it also derives from the experiences from the implementation of the Porter Hypothesis (Porter and van der Linde, 1995), i.e. the establishment of ambitious regulations to trigger radical innovation. Finally, it considers in particular the interactions between standardization and regulation.

Whereas recent approaches highlight standards as inputs for regulations, in the European Union and other countries, standards are also used to specify the - rather generic - governmental regulation. Furthermore, reciprocal relations between standards and regulation exist. In addition, other public policies, like public procurement referencing standards, can promote innovation and have to be considered as does the vital role of certifications in contributing to regulatory relief and compliance.

An immediate finding from the research is that there is an obvious need to improve the scientific evidence about the impact of these various interactions on innovation. Moreover, complementary, conceptual considerations, e.g. about the potential role of standards in regulatory sandboxes (a limited form of regulatory waiver or flexibility for firms enabling them to test new business models with reduced regulatory requirements), still need to be addressed.

Figure 1: How standards and regulations can interact to drive transformative innovation



Insights from our research can be used to develop more comprehensive and effective transformative innovation policies. We derive the following policy implications from the complete governance model based on the existing literature, the insights from the interviews, and the case studies.

“Impossible” standards, as well as regulations, can enable transformative innovation.

Standards should not only focus on their compliance facilitating function, i.e. guiding to compliance with standards, but also to regulations. Furthermore, their vital innovation enhancing capacity, e.g. in improving their innovation management, has to be better understood. In general, awareness of the critical role that standardization plays in transformative innovation policy has to be raised. Standardization will require more resources for proactive initiatives. Following the logic claimed by the Porter Hypothesis which states that environmental regulations can stimulate innovation and increase a firm's competitiveness (Porter and van der Linde, 1995), the establishment of ambitious regulations to trigger radical innovation and standards specifying radical requirements derived from needs (such as climate change) instead of the technological feasibility perspective, can trigger disruptive innovations.

Global challenges require standards to be mandated by internationally active bodies.

In case of market failures, like climate change, standards are not only market-driven. Indeed, they can also be initiated via the regulators, e.g. the European Commission mandating and financing the development of European standards by the European standards-setting organizations to specify their European regulations and directives. This effective division of work might also be implemented in other countries. Global challenges or objectives, like net zero, cannot be reached alone by market-led policy and voluntary standards. Therefore, the United Nations or other international organizations may mandate international standardization organizations with the development of ambitious international standards guiding and promoting transformative innovation, leveraging the mechanisms of the Porter Hypothesis at a global level to encourage transformative innovation.

Increasing and diversifying participation in standards drives innovation.

To increase the legitimacy and, ultimately, the diffusion of standards aiming to promote transformative innovation, stakeholders' involvement in standardization processes, which industry representatives generally dominate, should become more inclusive. It should include policymakers, particularly regulators, to promote the linkages of standards to regulations. Inclusiveness can also encourage the development of needs-driven standards. Here, the established practice of remote meetings facilitates the participation of stakeholders with limited resources. Finally, the engagement of both multinational enterprises and internationally organized non-governmental organizations can push the implementation of standards at a global level.

The timing of standardization is essential for innovation.

The international standardization system follows a bottom-up principle of initially national initiatives. However, standards addressing global challenges and triggering the required transformative innovation can already be developed at the international level in due course. In general, science- and innovation-based standardization processes should be initiated well ahead of policy and industry initiatives to help shape follow-up activities. In addition, the opportunities presented by digitalization can speed up the development process via remote sessions.

When it comes to standard-setting processes, there is an understandable tension between reaching consensus and delivering against objectives and the inclusivity and diversity of stakeholders involved. But this can be resolved by majority-based decision processes in not completely open consortia, which might then be transferred in a second stage to standard development organizations' open and consensus-based processes.

Finally, public funding could be provided to develop the required ambitious standards for two reasons - first, we have a market failure legitimizing the intervention by policymakers and second, these standards might complement governmental regulations.

Implementation can be enhanced through open access, digitization, and timely updates.

When standards are eventually published, they only become effective in promoting transformative innovation if implemented. Initially, standards aiming to contribute to transformative innovation should be available for free pushing their diffusion as we know from open accessible scientific publications. However, this is in contrast to the status quo of paying fees for standards. Further, their diffusion can be driven via the opportunities of digitalization. In addition, implementing international standards, e.g. proven via third-party certifications, could indicate regulatory compliance.

The dynamics in science, technology, and markets, but also needs, like climate change, are challenging both the speed of standardization processes and the timeliness of released standards. Therefore, the relevant standards should be updated in a timely manner to minimize their potentially limiting effect on innovation. In addition, establishing regulatory sandboxes suggested in recent policy initiatives should be aligned with complementary standardization activities to harness possible synergies and promote transformative innovations.

Furthermore, it has to be ensured that standards are eventually used by the regulatory bodies and public procurers linked to different ministries supporting key government objectives. Finally, the trade-enhancing impact of international standards for the global diffusion of transformative innovations, e.g. environmental technologies to combat climate change, should be considered in trade policy initiatives.

1 Introduction

1.1 Background

To achieve the goals of the Paris Agreement and limit global temperature rises to 1.5 degrees, the global economy should seek to have almost halved emissions by 2030 to reach net zero by mid-century. However, the reality is that global emissions are increasing year on year.¹ Therefore, action to address climate change, including speedy progress towards carbon neutrality and net zero, and other global challenges cannot be delivered by current technologies and solutions alone. Incremental improvements will be not sufficient.

Transformative innovation is needed. This means moving beyond incremental innovation to complete systems change, including consumers' behaviour and the governance of the framework conditions. Consequently, comprehensive innovation policy measures are required, which have also to consider the role of standards and regulation. However, the relationship between standardization and innovation policy must be better documented and explained. Whilst numerous ideas and initiatives for transformative innovation policy have been developed, the potential role for standardization and its relevance within the regulatory framework needs to be better addressed, a consideration highlighted in the recent report by Steen et al. (2022), which illustrates how standards can help accelerate the transition to net zero. Following the conveyor belt model introduced by Hale (2021), which claims that voluntary and mainly bottom-up initiatives are likely to be weak and not particularly effective due to the limits of voluntarism, globally aligned regulation promoting actions towards net zero are needed to achieve the goals of the Paris Agreement. Therefore, the research specifically focuses on regulation and how voluntary standards generated bottom-up by a broad variety of stakeholders can be orchestrated at an international level to eventually underpin regulation.

It should be noted that the relationship between innovation, on the one hand, and standards and regulation, on the other, is ambivalent. The latter can limit innovation, particularly radical changes outside the current frameworks. However, complying with them is crucial to achieving societal objectives such as protecting the environment or achieving net zero to combat climate change. In particular, standards and regulations are required to prevent greenwashing and raise the integrity of net zero action by non-state "actors". Against this backdrop, this report aims to provide more insight into how to balance the trade-off - within the current national and international governance system of regulation and standardization - between the innovation-promoting and potentially innovation-limiting impact of standards and regulations with suggested actions to help organizations walk this delicate tightrope. Therefore, our contribution is focused on the following research question:

- What role can standardization and standards - together with their interplay with regulatory frameworks - play in promoting transformative innovation?

We performed a literature review, stakeholder interviews, and case study research to answer this question. The literature review showed that, despite the availability of several review papers on transformative innovation policy, more work needs to be done to define transformative innovation. At its core, transformative innovation is about disruptive or radical innovation, which should be accompanied by significant changes in the regulatory framework and consumers' behaviour. The

¹ See, for example, the CO2 emission tracker of the International Energy Agency <https://www.iea.org/>.

literature on the impact of standards (e.g. Blind, 2022, Blind et al., 2023) and regulation on innovation and recently published reports have all been considered.

In parallel, we interviewed stakeholders from standardization bodies, regulators, voluntary initiatives, industry, and academics. Thirdly, we performed three case studies of the international standard ISO 30500 on non-sewered sanitation systems, the ISO Net Zero Guidelines (IWA 42:2022), and the Science Based Target Initiative (SBTi).

Insights from the literature, the interviews, and the case studies have been used to develop a conceptual governance model of standardization and regulation promoting transformative innovation. The model combines previous work, e.g. by Tait et al. (2017) and Hale (2021) and draws on the experiences of implementing the Porter Hypothesis (Porter and van der Linde, 1995), i.e. the establishment of ambitious regulations to trigger radical innovation, and considers, in particular, the interactions between standardization and regulation.

Whereas recent approaches highlight standards as inputs for regulations, in the European Union and other countries, standards are also used to specify the - often generic - governmental regulation. Furthermore, reciprocal relations between standards and regulation exist. In addition, other public policies, like public procurement referencing standards, can promote innovation. Finally, the vital role of certifications in contributing to regulatory relief and compliance is explored.

An immediate finding from the research is that there is a clear need to improve the scientific evidence about the impact of these various interactions on innovation. In addition, further conceptual explanations, e.g. about the potential role of standards in regulatory sandboxes, still need to be factored into the mix.

1.2 Research objectives

The objective of the performed research is to understand the relationship between standards (broadly conceptualized) and transformative innovation.² In general, but also in the context of the need to address climate change, it explores and clarifies how standards, particularly those with “impossible” targets, can drive transformative innovation.

The primary outcomes of the work are to:

- 1) Provide a foundational evidence base on which we can better understand the conditions under which standards enable transformative innovation of the type demanded, e.g. by net zero objectives, compared to incremental innovation.
- 2) Better understand the trade-off between ambitious targets as demanded by science, e.g. to achieve net zero, and stakeholders agreeing in a consensual way to the specifications of standards and eventually implementing them.
- 3) Set out key recommendations and challenges for a consistent and coordinated effort that centres standards to achieve the transformational change needed.

1.3 Limitations

The literature review was designed to quickly uncover and synthesize a large amount of highly relevant information. This means that the documents reviewed were selected systematically based on the existence and frequency of the keywords, standards, and regulations in papers on transformative innovation. It is possible that relevant evidence was excluded or not identified through the keyword-based search. Though the scope of the evidence search was global, only the evidence

² See examples of transformative innovation in the concept note of the UNFCCC GLOBAL INNOVATION HUB <https://unfccc.int/topics/un-climate-change-global-innovation-hub>.

in English was reviewed, potentially excluding specific perspectives relevant outside English-speaking parts of the world.

Similarly, though an effort was made to include a diverse range of stakeholders in the interviews, the sample only necessarily reflects some eligible professionals working in relevant fields. For example, experts from standardization bodies and European countries are prominent in the sample, as those were the groups that were easiest to contact during a short fieldwork period. Further research should seek to better represent the perspectives of those in low-and-middle-income countries. Additionally, only some people we sought to interview were available. As such, this report only claims to summarize some relevant evidence on the topic.

1.4 Structure of this report

This report combines the insights from the literature review, the stakeholder interviews, and three case studies. It includes findings based on all data and evidence mainly collected between October 2022 and January 2023.

The report is structured as follows:

- Chapter 1 presents the background, the objective, and an overview of the methodology.
- Chapter 2 displays some basic definitions.
- Chapter 3 presents insights from the literature.
- Chapter 4 presents the case studies.
- Chapter 5 displays a comprehensive conceptual framework of the interplay between standardization and regulation to promote transformative innovation.
- Chapter 6 presents recommendations addressing different stakeholders.
- Chapter 7 presents existing gaps and recommendations for future research.

2 Definitions

The first section is devoted to definitions of the key terms the report seeks to address – namely, innovation, the standards and regulations which surround it, and net zero. A clearer understanding of both will help organizations better navigate the road to net zero.

2.1 Innovation

Innovation, in general, has been well defined by the Organization for Economic Co-operation and Development (OECD) since 1992 within the so-called Oslo Manual. Its fourth edition was published in 2018 (OECD/Eurostat 2018), which provides guidelines for collecting and interpreting data on innovation. It defines innovation as:

“a new or improved product or process (or combination thereof) that differs significantly from the unit’s previous products or processes and that has been made available to potential users (product) or brought into use by the unit (process).”

The OECD collaborated with ISO’s technical committee on innovation management (ISO/TC 279) to exchange perspectives on the definition of innovation. It resulted in greater alignment between the two organizations’ definitions, considering the different objectives of the Oslo Manual and the ISO 56000. The OECD shaped its definitions to suit innovation measurement, while ISO considered the requirements for standardization. As a result, the definition of innovation given in ISO 56000 on innovation management is:

A “new or changed entity, realizing or redistributing value”.

The ISO definition is narrower because it requires innovation to be the creation, or at least the redistribution, of value.

The essential requirement for an innovation to be significantly different from a company’s previous products or business processes is often subjective and depends on the company’s capabilities and context. In addition, the OECD addresses the significance of innovations in terms of their ‘newness’ or economic impacts. In particular, disruptive or radical innovations and their economic impacts are interesting but difficult to identify and measure. One approach proposed by the OECD, which can be based on objective information, is to define whether an innovation is new to the company only, new to the company’s market, or new to the world. However, the degree of “novelty” will not necessarily determine whether it has the potential to become a radical or disruptive innovation. Another approach is to ask companies themselves for their expectation of the potential to transform the whole market in which it operates, but also to improve its competitiveness. But of course, their answers may be biased. Furthermore, the OECD argues that innovation’s potential to transform (or create) a market can provide a possible indicator for the rare incidence of radical or disruptive innovation. According to the OECD, following Christensen (1997), radical innovations are considered to transform the status quo, while disruptive innovation has its root in simple applications offered in niche market segments and then diffuses throughout the market, eventually displacing established competitors.

ISO 56000 defines radical or breakthrough innovation in contrast to incremental innovation as innovation with a high degree of change, which can relate to the entity or its impact. In contrast, disruptive innovation, according to ISO and similar to the understanding of the OECD, initially addresses less-demanding needs and the capacity to displace established offerings by being generally more cost-effective, requiring fewer resources, and offered at a lower price.

Whereas the OECD does not address transformative innovation, ISO 56000 mentions that innovations can be transformative in their impacts on all interested parties involved without further explanation, like the UNFCCC (2022) asking for transformative climate solutions without adequately defining them.

Whereas transformative innovation policy has been established in the academic literature and confirmed in the review conducted by Haddad et al. (2022), transformative innovation itself needs to be better defined.³ Therefore, Xu et al. (2021) address this ambiguity based on a broad review of the existing literature. In particular, they reveal that breakthrough and radical innovation following Christensen (1997) can be integrated into the concept of transformative innovation, focusing on significant, impactful technological changes.⁴ However, for our study, we need more than this rather technology-oriented approach.⁵ And we have to consider also the literature on transformative innovation policy, because we focus explicitly on standardization and standards as one specific policy instrument, but also its links to other policies, particularly regulation.⁶

Ultimately, we rely on the insights of the review performed by Haddad et al. (2022) on transformative innovation policy, a relatively novel approach (Grillitsch et al., 2021) mainly applied in Europe (Casula, 2022). Without explicitly defining transformative innovation, they conclude that transformative innovation policy as an umbrella of transition- and mission-oriented policies can be characterized by addressing grand challenges and inclusive growth, the need for directionality, multi-faceted policy intervention, multiple actors, global networks, and multi-level governance. These characteristics are appropriate for our analysis because achieving net zero can be considered a grand challenge, which needs radical technological innovation and behavioural and social change at the system level (e.g. Schot and Steinmueller, 2018). Net zero can be understood as a targeted, measurable and time-bound mission defining a clear direction of change related to innovation activities and not just their simple expansion (Diercks et al., 2019; Grillitsch et al., 2019). With the ISO Net Zero Guidelines (IWA 42:2022), a top-down approach in defining the mission towards net zero has been realized, which is often a challenge (Weber and Rohrer, 2012).

In contrast, now bottom-up initiatives are needed in developing and selecting solutions. Although we focus on standardization as a policy instrument, we must also consider that it plays an essential role in a multi-faceted policy intervention, particularly in OECD countries (Diercks, 2019), based on a complex mix of policy instruments to achieve net zero. Furthermore, standardization activities are driven by multiple "actors" (Kattel and Mazzucato, 2018), often within global networks confirmed by the more than one thousand participants from different countries and institutions having a diversity of opinions in the development of ISO Net Zero Guidelines (IWA 42:2022).⁷ Finally, the standardization system is characterized by multi-level governance, i.e. national, regional, and international standardization bodies, which are often embedded or linked with regulatory bodies.

³ The interviews with the stakeholders reveal that the term transformative innovation needs to be more well-known and established. For example, one interviewee mentioned Fred Steward (Steward 2012), who first mentioned the term transformative innovation in a sectoral context. Another interviewee highlighted that transformative innovation could be much easier achieved in the energy than in the water sector based on costly and difficult-to-change infrastructures.

⁴ De los Reyes and Scholz (2019) require innovation to be transformative and not only radical but also designed for long-term environmental sustainability.

⁵ More appropriate - also according to one academic interviewed - could be the term system innovation (OECD, 2015), covering not only corporate but also social "circular" practices involving multiple actors, including civil society and users (Schot and Steinmueller, 2018). However, the concept of system innovation published by the OECD has yet to take off in the scientific literature, which has not been further investigated.

⁶ On the one hand, regulations can, however, be understood also as innovation in governance (De Vries et al., 2016), but are, on the other hand, a complex tool to promote innovation (Borras and Edquist, 2013, 2019). Here, transformative innovation in governance is characterized by high novelty and high adoption, according to Valdivieso et al. (2021).

⁷ Find more information here: <https://www.iso.org/netzero>.

2.2 Standards and regulation

Since we consider not only standardization, but also regulation in the literature review, the interviews with stakeholders, and finally the conceptual model, it's important to provide a proper definition. According to the OECD (2021), "regulation includes all laws, formal and informal orders, subordinate rules, administrative formalities, and rules issued by non-governmental or self-regulatory bodies to whom governments have delegated regulatory power." However, since we want to make the distinction between regulation and standardization, we consider the second part of the definition as standardization.⁸ ISO/IEC (2004) defines standardization as an "activity of establishing, concerning actual or potential problems, provisions for common and repeated use, aimed at achieving the optimum degree of order in a given context".⁹

In contrast, Tait and Banda (2016, p. 2) consider regulation "as legally based instrument, backed up and enforced by a government authority". In addition, they define guidelines as being "issued under the aegis of a regulatory system to help those being regulated to understand what is expected of them by the regulator". However, we consider the latter an element of regulation to simplify the dichotomy between regulation and standard.

Unfortunately, there is no official definition of a standard by the OECD. However, it states that "standards [are] often defined by consensus and approved by a recognized body that provides, for common and repeated use, rules or guidelines for the characteristics of products, processes and organizations" in the 4th edition of the Oslo Manual (OECD/Eurostat, 2018). The perception is close to the simplified ISO understanding of standards¹⁰ as "a formula that describes the best way of doing something", i.e. producing products, managing processes, delivering services or supplying materials. However, the more detailed definition in the ISO/IEC guideline from 2004 defines a standard as "a document, established by consensus and approved by a recognized body, that provides, for common and repeated use, rules, guidelines or characteristics for activities or their results, aimed at the achievement of the optimum degree of order in a given context."¹¹ Standards are the condensed knowledge of experts being aware of the needs of the organizations they represent, e.g. manufacturers, sellers, buyers, customers, trade associations, users, or regulators (see also Tait and Banda, 2016, p. 2.).

In addition to the standards released by ISO itself or its members, defined as committee-based standardization following a consensual approach¹², Wiegmann et al. (2017) differentiate market-based standardization leading mostly to one de-facto standard within a competitive process between different solutions.¹³ However, in addition to the formal organizations, like ISO and its national members, there are quasi-formal standard-setting organizations, like IEEE, and several industry consortia and even open source foundations developing standards. Based on more than one hundred organizations, Teubner et al. (2021) present in their - focused on mobile communication - taxonomy of industry consortia other categories, i.e. large industry and technology influencers,

⁸ Wiegmann et al. (2017) name regulation as government-based standardization.

⁹ See <https://www.iso.org/standard/39976.html>

¹⁰ See <https://www.iso.org/standards.html>

¹¹ See <https://www.iso.org/standard/39976.html>

¹² ISO understands consensus as having a general agreement, characterized by the absence of sustained opposition to substantial issues by any significant part of the concerned interests and by a process that involves seeking to take into account the views of all parties involved and to reconcile any conflicting arguments, i.e. consensus need not imply unanimity. See <https://www.iso.org/glossary.html>. Since consensus needs time, the formal standard development organizations allow a closed group of interested parties to develop in a short time the development of workshop agreements.

¹³ Vollebergh and van der Werf (2014) mention, in addition, unsponsored standards without an identified source that holds a proprietary right, like in the case of the QWERTY standard for keyboards.

high-level concept developers, young technology specialists, small industry and technology influencers. Finally, companies, particularly multinational enterprises, produce standards for their internal and external use, so-called private standards (Blind and Müller, 2020).

Table 1 provides an overview of the differences in setting standards and legislative processes to develop regulations structured by phases.

Table 1: Phases of standardization and legislative processes

	Standards	Legislation
Initiation	Identification of the need for standardization, submission of standardization applications	Perception and addressing of problems
Development Consultation	Commenting on standardization applications, formulation of draft standards, commenting on draft standards	Policy-forming (consultations and discussions), development of draft laws, the proposal of amendments
Decision	Consultation on draft standards	Parliamentary debate and voting
Implementation	Implementation of standards in company/products	Implementation of legal requirements in company/products
Monitoring	Sanctioning non-compliance by other market players	Sanctions (negotiation of fines etc.)
Adjustment	Updating or withdrawal of standards	Adapting existing laws

Source: Heß and Blind (2019).

The following Tables 2 and 3, based on Tait and Banda (2016), summarize the differences between standards and regulations, but also their relative advantages, which will be unlocked to promote transformative innovation by their sophisticated combination in the framework presented in Chapter 5.

Table 2: Differences between standards and regulations

	Standards	Regulations
Type	Based on recommendations	Based on legislation
Voluntariness vs. obligation	Adoption is usually voluntary	Adoption is mandatory to protect citizens' health and safety
Development process	Established by consensus of all parties concerned and interested, including relevant industry representatives but the risk of the dominance of large companies	Developed by a regulatory authority, usually involving consultation but the risk of regulatory capture
Base	More dynamic development processes and, in principle, regular updates	Long development cycles and limited updates
Approval	Based on consolidated results of science, technology, and experience in practice	Provide technical specifications either directly or by reference, e.g. to standards.
Over-sights	Approved and published by a recognized standardization body or informal consortia	Adopted by a legal authority
Coverage	Oversight by independent third-party certification, second party or self-declaration	Oversight by formal government-appointed regulatory bodies
	National but increasingly international	Mostly national

Source: consolidation of Tait and Banda (2016, p. 3) based on Allen and Sriram (2000), Langlois and Savage (2001), Blind et al. (2017), Hale (2021), and Zhang et al. (2023) differentiating between market- and government-led standardization.

Table 3: Relative advantages of standards and regulations

Standards	Regulations
Standards can act as infrastructures for coordination and a common language for interoperability and compatibility.	Regulations have the force of law, and compliance is compulsory and enforceable.
<p>Standards as routines (usually internal standards) can govern behaviour required for certain activities/routines.</p> <p>International standards reflect current views of a wide range of interests, including incumbent industries.</p> <p>International standards can influence international trade</p>	Easier to diffuse through inter-country, regional, or international treaties and conventions
Standards as technology can reduce the variety and enhance economies of scale, thereby reducing transaction costs	Regulations are prescriptive and sometimes are linked to specific standards which, if adhered to, constitute compliance
Standards can be an innovation to achieve market dominance	Regulations have to be implemented by all regulated organizations

Source: consolidation of Tait and Banda (2016, p. 3) based on Allen and Sriram (2000), Langlois and Savage (2001), Blind et al. (2017), Hale (2021), and Zhang et al. (2023) differentiating between market- and government-led standardization.¹⁴

¹⁴ Allen and Sriram (2000) categorize government-led standards as regulatory standards.

2.3 Net zero

Reaching net zero emissions is an urgent global goal that will require transformative innovation and robust standards to deliver.

Net zero as a concept can be traced back to the paper by Allen et al. (2009), which highlighted the impact of cumulative CO₂ emissions on global warming. The IPCC Fifth Assessment AR5 report published in 2013 went on to state that limiting global temperature rises meant limiting the cumulative CO₂ emissions in the atmosphere and, to do so, additional anthropogenic (i.e. human-caused) CO₂ emissions into the atmosphere would need to reach zero.

The landmark 2015 Paris Agreement Article 4.1 stated: 'Parties aim to reach global peaking of greenhouse gas emissions as soon as possible...so as to achieve a balance between anthropogenic emissions by sources and removals by sinks of greenhouse gases...'.

The concept of removals is integral to the definition of net zero.

It is important to note that the IPCC defines net zero emissions and net zero CO₂ emissions separately (IPCC 2018). According to the IPCC, 'net zero carbon dioxide emissions are achieved when *anthropogenic* CO₂ emissions are balanced globally by anthropogenic CO₂ removals over a specified period.' The definition notes that 'Net zero CO₂ emissions are also referred to as carbon neutrality.'

In comparison, the IPCC (2018) defines net zero emissions as 'achieved when *anthropogenic emissions* of *greenhouse gases* to the *atmosphere* are balanced by *anthropogenic removals* over a specified period.'

The IPCC definition forms the basis of the definition agreed upon in ISO's Net Zero Guidelines (ISO 2022), which defines net zero as the 'condition in which human-caused residual GHG emissions are balanced by human-led removals over a specified period and within specified boundaries'. The ISO definition includes a note that 'The words "human-caused" and "human-led" are intended to be understood as synonymous with the word "anthropogenic" in IPCC definitions.'

2.4 The Porter Hypothesis

The Porter Hypothesis states that environmental regulations can stimulate innovation and increase a firm's competitiveness (Porter and van der Linde, 1995). In particular, firms facing ambitious environmental regulatory framework conditions are forced to adopt new technologies and processes to comply with the regulations. These innovations can lead to cost savings, improved efficiency, and even new market opportunities. Therefore, firms that are early adopters of environmentally friendly practices required may gain a competitive advantage over their rivals. The Porter Hypothesis challenges the traditional view that environmental regulations burden businesses and suggests they can drive innovation and economic growth. The hypothesis remains a topic of debate among economists and policymakers. However, the review of empirical studies by Ambec et al. (2013) confirms the "weak" version of the Porter Hypothesis, i.e. that stricter environmental regulation leads to more innovation. In contrast, the evidence about its strong version of stricter regulation promoting companies' economic performance remains mixed.

3 Summary of the literature review

Based on a long tradition of discussion and adjustments, innovation has been defined by the OECD (OECD/Eurostat 2018) as a "new or improved product or process". In contrast, ISO 56000 on innovation management defines a "new or changed entity, realizing or redistributing value". In contrast, the literature on transformative innovation is quite limited, although transformative innovation policy is gaining increasing attention among policymakers. Still, there needs to be an established definition of transformative innovation. Xu et al. (2021) address this ambiguity based on a broad review of the existing literature. In particular, they reveal that breakthrough and radical innovation following Christensen (1997) can be integrated into the concept of transformative innovation, focusing on significant, impactful technological changes.¹⁵ Eventually, we define it as a combination of disruptive innovation from a technological or commercial perspective needing significant changes in consumer or societal behaviour and regulatory frameworks. Therefore, it can be considered as a system innovation, a term that has yet to be widely accepted. In contrast, a definition of transformative innovation policy has been established in the academic literature, confirmed in the review conducted by Haddad et al. (2022).

Since we consider not only standardization but also regulation in the literature review, the interviews with stakeholders, and finally the conceptual model, we had to provide a proper definition following the OECD (2021) and ISO/IEC (2004).

In the limited number of academic papers about transformative innovation, standardization and standards as possible instruments to achieve it are only sometimes addressed, and if so, then in combination with regulations. According to Tait et al. (2017), pre-regulatory standards are needed when there is no pre-existing regulatory framework to ensure the effective development of technologies in their early stages unless the new technologies threaten public interests, like health and safety concerns. In that case, the development and implementation of regulations are needed to complement the already existing pre-regulatory standards. In addition, there might be a need to set up post-regulatory standards, which are proportionate but also adaptive to the properties of the new technology and their products. Related to transformative innovation, it has to be highlighted that the existing literature does not fully consider the Porter Hypothesis (Porter and van der Linde, 1995). It claims that stringent and ambitious environmental regulation can stimulate companies to generate transformative innovations, which in turn might increase both their productivity and, ultimately, their competitiveness and the sustainability of their products. All the insights from the literature are ultimately integrated into the new conceptual framework of the role of standardization and regulation in promoting transformative innovation.

¹⁵ De los Reyes and Scholz (2019) require an innovation to be transformative, not only to be radical but also designed for long-term environmental sustainability.

4 Case studies

Three relevant examples of standardization processes have been selected to complement the limited literature. The cases are based on documents provided by the case owners, interviews with the case owners, stakeholders, and experts, and scientific literature, as in the case of ISO 30500 (Miöner and Binz 2021). The case selection is motivated by looking at detail at the rare case of initially “impossible” standards, i.e. standards defining a solution that does not yet exist. This is true for ISO 30500 on non-sewered sanitation systems, a standard based on needs rather than technological feasibility.¹⁶ However, the Corporate Net-Zero Standard released by the Science Based Target Initiative (SBTi) and the ISO Net Zero Guidelines (IWA 42:2022) are driven by the urgent requirements to speed up and, crucially, operationalize the efforts towards net zero.

The case descriptions briefly elaborate on the topic and objective, the stakeholders involved, the process, and in the first case also, the impacts to be observed so far. For the other two examples, we can indicate their potential diffusion, but not the consequences of their yet to be realized implementation.

4.1 A global approach to “impossible” standard setting that drives innovation: ISO 30500 Non-sewered sanitation systems

ISO 30500 provides a unique insight into the role that “impossible” standards defining requirements for a technology that doesn’t currently exist can play in driving transformative innovation and highlights how a global approach to initiating and formulating a standard enables its dissemination and implementation. The process holds many lessons for those seeking to replicate this success, particularly concerning funding modalities and coordination.

In 2018, ISO published ISO 30500 specifying general safety and performance requirements for the design and testing and sustainability issues for non-sewered sanitation systems (NSSS). An NSSS is defined within ISO 30500 as a prefabricated integrated treatment unit comprising frontend (toilet facility) and backend (treatment facility) components. They collect, convey, and thoroughly treat the specific input within the system. This allows for the safe reuse or disposal of the generated solid, liquid, and gaseous output. It is not connected to a networked sewer or drainage system.

Based on interviews and documents (Miöner and Binz 2021), we analyzed the development of the ISO 30500 standard structured into three phases.¹⁷ In the first phase, the Bill and Melinda Gates Foundation (BMGF) decided to support small-scale, non-sewered sanitation, particularly in Africa.¹⁸ One of their first initiatives was the Reinvent the Toilet Challenge (RTTC). It explicitly aimed to develop a toilet that operates “off the grid” without connections to water, sewer, or power outlets. Within the RTTC, research organizations received grants for developing innovative non-sewered sanitation technologies with specific health, resource, and cost requirements. In contrast to previous approaches focusing on water-sensitive, community-based, and low-tech solutions, it emphasized financial profitability, economic efficiency, and the fulfilment of consumer preferences. In particular, the BMGF pushed for ambitious high-tech solutions to the sanitation problem applicable as transformative innovation globally for all non-sewered sanitation systems.

¹⁶ Interviewees from the industry contest that standards should set goals. They prefer the regulator to set the goals.

¹⁷ See a more detailed description of the development of ISO 30500 in Miöner and Binz (2021, p. 180-184).

¹⁸ The BMGF also supported the development of ISO 24521 on activities relating to drinking water and wastewater services and ISO 31800 on fecal sludge treatment units.

The RTTC revealed that a critical barrier to the diffusion of on-site sanitation was the lack of internationally agreed specifications or standards of on-site systems and the fragmentation by differing national solutions, ultimately leading to decisions against non-sewered toilets (Starkl et al., 2015). Consequently, the development of ISO 30500 was initiated by a network of “actors” around RTTC. In contrast to other ISO initiatives, it was a global approach from the beginning driven by the BMGF, the German-based but globally acting certification body TÜV SÜD, supported by the American National Standards Institute (ANSI) as secretary. TÜV Süd drafted a technical specification based on a review of existing technologies and standards of non-sewered sanitation to understand the requirements for its diffusion on a global level. Furthermore, health and safety guidelines by the United States Environmental Protection Agency (EPA) were considered.

Parallel to drafting the technical specification, BMGF and ANSI initiated the development of an International Workshop Agreement IWA, which was published as IWA 24 in 2016. Following the publication of IWA 24, an ISO Project Committee 305 with a large BMGF-sponsored number of participants from low-income countries and a handful of technology providers, was established to start a consensus-based process involving all interested stakeholders.¹⁹

In contrast to traditional standardization processes, ISO 30500 defined the requirements for a technology that did not exist and, therefore, was not unduly influenced by the vested interests of incumbents. However, there was an intense debate around the requirements which were considered too low by stakeholders of higher-income countries but too high by representatives of emerging economies. Nevertheless, the active participation of representatives from developing countries in the standardization process ultimately ensured that the standard could be effectively implemented there.

ISO 30500 was published in 2018 but a year earlier prototypes were already being tested according to the draft standard in South Africa, followed by initiatives in other emerging economies, like China and India. Shortly after this, Sando et al. (2020) reported that pilot implementations of non-sewered sanitation systems in South Africa almost complied with the requirements of ISO 30500. Overall, ISO 30500 is one of the rare cases of an initially “impossible” standard that specified the requirements for a not-yet-existing technology. However, such an approach requires significant external funding and coordination.

4.2 SBTi Corporate Net-Zero Standard

SBTi Corporate Net-Zero Standard is an example of a standard developed within a private voluntary initiative (Hale 2021) via an open and transparent stakeholder process to define net zero to guide firms’ efforts toward the net zero objective. It is complementary to the more general ISO Net Zero Guidelines (IWA 42: 2022).

The Science Based Target Initiative (SBTi) observed that companies are increasingly trying to reach net zero targets. However, the need for a common definition has also been observed²⁰, because a missing common definition and approach reduces the impact of the efforts to reach net zero targets.

The SBTi is a global non-governmental organization that tries to enable companies to set emissions reduction targets that align with climate science's evidence. The initiative is a collaboration between the Carbon Disclosure Project (CDP), the United Nations Global Compact, the World Resources Institute (WRI), the World Wide Fund for Nature (WWF), and the We Mean Business Coalition.

¹⁹ In the past, countries from the Global South implemented water sanitary standards developed in Germany. To create specifications for a radically new solution, i.e. a transformative innovation, the contributors of these previous standards have not been involved,

²⁰ See the review by Hale et al. (2022) of many net zero targets.

Following a 2019 scoping phase of work, a multi-stakeholder process was initiated by the SBTi with the publication of a Net Zero Foundation Paper in early 2020. Then, an expert advisory group of 42 experts from civil society, academia, and industry was established as the main consensus-building body of the process. In Spring 2021, almost 400 participants from various sectors across 37 countries joined a public consultation related to a criteria draft. The following summer, nearly one hundred companies tested the target-setting tool and provided feedback. Consequently, a second consultation, now with less participants, was performed in early autumn before the SBTi published in late October 2021 a global science-based standard for companies to set their net zero targets. The Net-Zero Standard of SBTi aims to provide managers with a science-based approach to align their targets with the need to achieve net zero. Explicitly, the Net-Zero standards target large companies with more than 500 employees, whereas SMEs could use this document to understand the elements of SBTi's recommended target and target-setting process. For SMEs, the SBTi offers a FAQ page for more information. Furthermore, the standards do not cover net-zero targets for financial institutions, for which SBTi has set up a separate net-zero framework to develop a different standard. However, it can also generate more transparency for further stakeholders.

The Net-Zero Standard contains four key elements comprising a corporate net-zero target. The first of these elements is a near-term science-based target, the second is a long-term science-based target, the third is mitigation beyond the value chain, and the final element is neutralizing residual emissions.

The SBTi recommends a five-step approach to setting science-based targets. First, after establishing a base year to track emissions performance consistently and meaningfully, the emission of companies have to be calculated, target boundaries and years have to be set before the near-term and long-term science-based targets can be calculated.

In addition to the pilots conducted before the final SBTi corporate net-zero standard was published, no further adoptions or information about its diffusion have been reported. Therefore, it is too early to assess its impact on innovations contributing to the progress toward net zero.

4.3 ISO Net Zero Guidelines

The ISO Net Zero Guidelines (IWA 42: 2022) provide guiding principles and recommendations to enable a common approach to drive organizations to achieve net zero as soon as possible and by 2050 at the latest. It is intended to be a common reference not only for companies, but also for governance organizations, including voluntary initiatives like SBTi, policy, and national and international regulators. It can help organizations take action to contribute to achieving global net zero, covering all seven stages from preparation, measurement, target-setting, reduction, offsetting, reporting to impact, and interconnection (see more details in McGivern et al., 2022).

The ISO Net Zero Guidelines (IWA 42: 2022) were only published in late 2022. Therefore, we focus again on the ambitions of the stakeholders and institutions involved and the standardization process, but not on their realized impact.

As part of Our 2050 World²¹, a collaboration to help accelerate the transition to achieve net zero by 2050 supported by the UN Race to Zero campaign²² and the UNFCCC Global Innovation Hub²³,

²¹ Our 2050 World is an open collaboration between international organizations and standards bodies to drive transformational collective action to achieve net zero. See more details here <https://our2050.world/>.

²² <https://unfccc.int/climate-action/race-to-zero-campaign>

²³ The Global Innovation Hub claims to promote transformative innovations for a low-emission and climate-resilient future. It aims to expand the global innovation space by facilitating solutions that support the climate-related Sustainable Development Goals (SDGs) and that address core

the development of the ISO Net Zero Guidelines (IWA 42: 2022) was initiated at the beginning of 2022. The first seed document was published in May 2022, the base for a series of workshops which took place between July and September 2022. More than 1,200 participants from over 100 countries contributed to the Net Zero Guidelines through the International Workshop Agreement (IWA) process. This approach facilitated the broad and direct participation of experts and practitioners. They eventually generated a practical common consensus-based international reference point with the IWA to reduce variation and complexity in targets, measurement, assessment methodologies, reporting requirements, and considerations of broader impact. It was developed to harmonize the increasing number of initiatives, frameworks, and concepts in net zero action. ISO published the ISO Net Zero Guidelines (IWA 42: 2022) at COP27 in November 2022. Up to February 2023, almost ten thousand copies have been downloaded by interested parties located in over 140 countries, which also reflects the large number of experts involved in its development.

ISO Net Zero Guidelines (IWA 42: 2022) entail recommendations to enable a common, global approach to achieve net zero greenhouse gas emissions through aligning voluntary initiatives and adopting standards, policies, and national and international regulations. They make the distinction between 'governance organizations'²⁴ (effectively, those that create rules and guidance on net zero for others to follow) and organizations that use and implement this guidance. On the one hand, they provide assistance reflecting their specific capabilities on what institutions are responsible for setting framework conditions. On the other, they also consider what other organizations can do to effectively contribute to efforts to limit global warming by reaching net zero no later than 2050. Overall, in combination with applicable science-based pathways, the ISO Net Zero Guidelines (IWA 42: 2022) guide organizations interested in developing and implementing climate strategies.²⁵

ISO Net Zero Guidelines (IWA 42: 2022) provide a common reference for collective efforts, offering a global basis for harmonizing, understanding, and planning for net zero for actors at the state, regional, city, and organizational levels. They provide an agreed direction to support national objectives, corporate goals, and societal expectations. Moreover, Our 2050 World stresses that the ISO Net Zero Guidelines (IWA 42: 2022) will support the real economy and play a critical role in harnessing voluntary commitments from non-state actors, eventually motivating national governments to strengthen their commitments and ambitions.²⁶ In summary, the expectation is that the more intensive use of standards generates a framework of voluntary compliance tools. They can be used by states and market actors and support an accelerated transition to net zero of global, national, and regional market frameworks by triggering a virtuous cycle between non-state actors and national or regional governments.

4.4 Case comparison

Although the three cases are quite different, they have the common characteristic of coming from a global need perspective, such as addressing sanitation problems or the challenges of climate change. This approach is quite different from the traditional standardization approach, which is

human needs via alternative value chains. The Innovation Hub aims to complement the current incremental, sector-based, and problem-oriented approach to innovation for climate solutions with a transformative, need-based, and solution-oriented one. See <https://unfccc.int/top-ics/un-climate-change-global-innovation-hub>

²⁴ These are so-called governance organizations covering national and sub-national (e.g. regional, local, municipal) governments, regulators, voluntary initiatives, intergovernmental bodies, and international and national non-governmental organizations.

²⁵ It has to be noted that the ISO Net Zero Guidelines (IWA 42: 2022) do not guide carbon neutrality for organizations or for products and services, which will be provided in the forthcoming ISO 14068 is currently under development. However, a first comparison of the two documents can be found in Radunsky (2022).

²⁶ One interviewee sees the limited involvement of regulators as a problem for referencing the ISO Net Zero Guidelines (IWA 42: 2022) in future regulations.

based on existing technologies and practices already successfully implemented in specific companies, regions, or countries.

In the first case of ISO 30500, the starting point was the development of an International Workshop Agreement (IWA 24) two years before being initiated by the BMGF with a smaller number of stakeholders. This document was then the base for ISO 30500, going through the complete standardization process at ISO, beginning with the development of a draft, which was then shared for commenting and further discussion. The voting process is crucial for reaching a consensus. If consensus is achieved, then the draft will become an ISO standard. If an agreement is not reached, the draft has to be modified further and voted on again. However, BMGF sponsored participants from across the African continent to join, who eventually supported the standard, whereas there were severe concerns from members of developed countries. Nevertheless, first assessments of the pilots or prototypes of solutions reveal that compliance with the initially “impossible” standard is possible. This evidence is similar to the innovations triggered by the mechanism of the Porter Hypothesis based on ambitious regulations.

In contrast to IWA 24, ISO Net Zero Guidelines (IWA 42: 2022) were developed with a much larger group of experts worldwide.²⁷ A further difference between IWA 24, respective ISO 30500, and ISO Net Zero Guidelines (IWA 42: 2022) is not only that in the former case, only a few stakeholders have been involved, but also that in the latter case, universities and research institutes made significant contributions. The involvement of academia has also been highlighted in the SBTi Corporate Net-Zero Standard case and it’s important that participation of scientific stakeholders is determined not solely on commercial opportunity but also on delivering critical scientific objectives, for example, making fast progress towards net zero can be crucial for specifying “impossible” standards.²⁸

There are similarities in processes between ISO 30500, particularly its predecessor of IWA 24 and ISO Net Zero Guidelines (IWA 42: 2022), and the SBTi Corporate Net-Zero Standard. In addition, openness and transparency of standardization processes outside the established international and national standardization bodies following the WTO guidelines have been found.

Finally, ISO Net Zero Guidelines (IWA 42: 2022) and SBTi Corporate Net-Zero Standard are complementary, with the former recommending science based targets, whereas the latter helps large companies to set them and verifies if they have set these targets.²⁹ The initiators of the ISO Net Zero Guidelines (IWA 42: 2022) claim to have developed a baseline document considering the views of all stakeholders, which is complementary to standards or guidelines released by SBTi.

So far, we only have proof for ISO 30500 that the specification of a standard with requirements for which solutions have initially not been developed ultimately triggered research and development activities generating the first transformative innovations. In summary, it is too early to observe which of the three approaches by ISO and SBTi will be successful.

²⁷ However, it must be pointed to the forthcoming ISO 14068 on carbon neutrality. Despite the differences between carbon neutrality and net zero, these two approaches might challenge the principle of ISO not having a competition between standards. See Blind (2011) for an economic analysis of competition between standards.

²⁸ See Blind et al. (2018b) for the motivation of researchers to participate in standardization processes.

²⁹ Interviewees have mentioned that the accreditation of ISO by the WTO might be an advantage for implementing the ISO Net Zero Guidelines (IWA 42: 2022) compared to the standard released by SBTi.

5 Conceptual framework of standardization and regulation promoting transformative innovation

5.1 Gaps in existing frameworks

The literature review, case studies, and insights from the interviews reveal several gaps in previous approaches and policies. To address these, we propose a comprehensive framework that goes beyond Blind and Gauch (2009), Tait et al. (2017), and Hale (2021) to unlock the potential of standardization and regulation and their various interactions to enable transformative innovation.

Differentiating between standards, regulations, and their interaction is critical for innovation.

Since standards and regulations complement each other in promoting innovation, they must be carefully differentiated and considered through a holistic lens. In addition, their relationship is, over time, non-linear, including several reciprocal feedback loops (e.g. Gottinger et al., 2023).

More than two decades ago, Allen and Sriram (2000) addressed the role of standards in innovation for the first time. Still, they need to differentiate between different types of innovation and manage the relationship between standards and regulation.

In his conveyor belt model, Hale (2021) explains that in addition to regulation private voluntary initiatives, orchestrated campaigns, and standards have to be considered as governance approaches to achieve net zero in particular. However, he does not elaborate on their impact on innovation in general.³⁰ However, he perceives standards based on voluntary initiatives and orchestrated campaigns as input to regulation.³¹ Regulations could be general framework conditions, which are detailed in a second stage by specific standards (see examples of standards related to emission regulations provided by Vollebergh and van der Werf, 2014) as in the case of the New Legislative Framework established within the European Union since decades.³² Similarly, Blind et al. (2017) differentiate in their analysis based on a large-scale company survey of the impact on innovation between standards and regulation. Still, they do not consider their interaction as well as Blind and Münch (2021) in their investigation at the level of OECD countries.

The interaction between standardization and regulation has been explicitly explained by Tait and Banda (2016) and Tait et al. (2017), which distinguish between pre- and post-regulatory standardization and put them into the context of incremental vs. radical innovation. In contrast to other work, this approach is quite comprehensive. Some interviewees point to the development of innovation ecosystems which follow non-linear innovation processes requiring a continuous adaptation of standards and regulations, which goes beyond the simplified approach by Tait et al. (2017).

Therefore, there are still several significant areas for improvement in their framework. First, they distinguish between pre- and post-regulatory standards. Although putting standards into the context of different technology readiness levels (TRLs), they do not use the empirically validated taxonomy of Blind and Gauch (2009) about the role of different types of standards along the research and innovation life cycle.

³⁰ McGivern et al. (2022) have analyzed more than 30 voluntary initiatives related to net zero, but only four are related to standards.

³¹ Blind and Mangelsdorf (2016) show that firms in sectors framed by a rather generic regulatory framework try to influence or even avoid specific regulations via their involvement in standardization.

³² https://single-market-economy.ec.europa.eu/single-market/goods/new-legislative-framework_en

In addition, the success and impact of standards depend on their implementation, which is in contrast to regulation, voluntary. Unfortunately, the implementation of standards has yet to be broadly investigated due to a lack of data.³³ The exception is international management system standards, i.e. ISO 9001 on quality management, ISO 14001 focusing on environmental management, ISO 27001 on IT security management, and ISO 50001 on energy efficiency. Whereas the impact of ISO 9001 on innovation is ambivalent (Manders et al., 2016) and more closely associated with incremental than radical innovation (see also Clougherty and Grajek, 2023), ISO 14001 certification contributes to environmental innovation (Lim and Prakash, 2014). Recently, Mirtsch et al. (2021a) revealed a positive correlation between German companies' probability of introducing product innovation and their likelihood to be certified according to ISO/IEC 27001.

Consider the different impacts of international and national standards on innovation in the context of the regulatory framework.

When it comes to addressing global challenges such as climate change, national standards are insufficient, and international standards are needed to promote transformative innovations. However, the latter have to be embedded in the general national regulatory framework. The distinction between the national and the international level of standardization has been referenced (e.g. By Tait et al., 2017), but its implication for innovation has yet to be fully explained. However, the Porter Hypothesis (Porter and van der Linde 1995) needs to be considered. It claims that an ambitious national regulatory framework can promote both innovations and the affected companies' economic performance. Furthermore, the role of international standards within such ambitious - mostly national - regulatory frameworks needs to be clarified in more detail beyond the concept of post-regulatory standards helping companies comply with the regulation (Tait et al., 2017). In addition, international standards might be linked to other national innovation policies, like public procurement, to promote innovation (Blind, 2008).

Unlock the opportunities of developing standards without full consensus.

Within standardization, we can differentiate between fully consensual and open processes implemented for the development of formal standards released by national, regional, or European standard development organizations. In addition, these organizations, like BSI, but also more informal consortia offer sponsored standards developed quickly without requiring full consensus (see also Tait et al., 2017), so-called publicly available specifications, or workshop agreements. However, the latter's role for promoting innovation needs to be better understood because they are largely ignored in most previous studies. However, they can help to speed up the generation of specifications guiding innovation activities.

Beyond standards and regulation, market-based solutions contribute to forming new markets.

The coordination of market- with committee-based standardization and governmental regulation, often needed for emerging new industries and markets (Wiegmann et al., 2017), needs to be developed further. Furthermore, Tait et al. (2017) highlight the role of multinational enterprises (MNEs) in developing emerging markets. Still, their influence on generating market-based standards is not discussed (Blind and Müller, 2020). However, MNEs use global standards to govern global value chains (see the examples already presented by Nadvi, 2008). In addition to MNEs, other types of companies are the main drivers of standardization processes.

³³ In the context of the German Standardization Panel, which addresses organizations active in standardization, data about the number of standards implemented is collected. See, for example, Blind and Müller (2020).

Consider the impacts of international standards and certifications on trade and, ultimately, innovation.

International standards and certifications are essential drivers for international trade (see the review by Swann, 2010). Internationally traded goods are often based on standards, which is often a factor for their success in trade.³⁴ However, international trade is also promoting innovation in the target countries via increased import competition, new export opportunities, access to further imported intermediates, and foreign input competition (Shu and Steinwender, 2019, Melitz and Redding, 2021). These drivers of innovation still have to be connected to standards.³⁵ In addition, the effects of standards on trade can be pushed further by the implementation of certification schemes, e.g. ISO 9001 related to quality management (Clougherty and Grajek, 2008, 2014), particularly by accredited certification bodies (Blind et al., 2018b). In addition to standards, certification and accreditation complemented by metrology and market surveillance are essential elements of the so-called quality infrastructure (Guasch et al., 2007), more recently also including the regulatory framework (UNIDO, 2018).

Both standards and regulations should be science-based.

Finally, the role of science as input into standardization has thus far not been examined in depth or even properly quantified (see the exception by Blind and Fenton, 2022). Even so, it plays a vital role in transformative innovation. Hale (2021) highlights the relevance of science-based targets related to net zero but does not elaborate on their explicit links to standardization processes and standards. Tait and Banda (2016, p. 2) claim that standards should be based on “consolidated results of science, technology and experience”, but do not explain it further, and it’s similar with Tait et al. (2017) who put the case for a science-based regulatory system without developing the argument fully.

³⁴ Regarding lead markets originating in one country, standards can help them succeed globally (Beise, 2004; Beise and Rennings, 2005).

³⁵ In most studies about the trade-promoting role of standards, the latter are considered exogenous. However, Blind and von Laer (2021) show that international standards are influenced by national research and innovation activities and should, therefore, be considered endogenous.

5.2 A governance system of standardization and regulation promoting transformative innovation

In this section, we propose a revised governance system for transformative innovation that focuses on the differentiation between standards and regulation and the different types of standards in the governance ecosystem. It reflects the previously identified gaps and the insights from the interviews and case studies. This system expands Hale's (2021) model and the approach presented by Tait et al. (2017).

As pointed out by Hale (2021), single governance instruments, i.e. regulations or standards, are unlikely to deliver transformative innovations, like progress towards net zero on the required time-scale. Instead, he proposes a governance "ecosystem" combining voluntary initiatives, international orchestration efforts, standardizations, and regulations. However, we focus on the latter two because they are within the scope of our literature review and the stakeholder interviews. Moreover, the interactions between standards and regulations have been identified as insufficiently investigated and explored. Finally, voluntary initiatives are likely to be weak and not particularly effective due to the limits of voluntarism because of the lack of power to ensure compliance from those who are not involved and of limited reputational pressure (Hale, 2021). In contrast, standards have a de facto market, economic or legal power to compel organizations to comply with them.

Broader than the conveyor belt model introduced by Hale (2021) and the simple distinction between pre- and post-regulatory standards by Tait et al. (2017), we further differentiate the relationship between standards and regulation and different types of standards in our governance ecosystem.

Different standardization processes have other impacts on innovation.

Starting with standardization, we have to consider different types of processes and standards because they have implications for the relation to regulation and ultimately for their impact on transformative innovation. As Hale (2021) has already explained, with support from interviews, consensually developed standards still have to acknowledge the interest of incumbents in the industry. They are interested in something other than radical changes having the potential to be enablers for transformative innovation or solutions to achieve net zero (e.g. Steen et al., 2022). Nevertheless, standards can be the basis for regulations, as suggested by Hale (2021), but also Tait and Banda (2016).³⁶ However, both do not consider the power of regulations to trigger radical innovation according to the Porter Hypothesis. Instead, these regulations force companies to develop new technologies, products, and processes, which comply with more ambitious requirements. Within the framework of this kind of regulation, new standards might also have to be developed, which help companies comply with the new rules as a strong driver for their participation in standardization (Blind and Mangelsdorf, 2016). However, it's not just the affected companies who might consider the development of standards following new regulatory initiatives. The regulators themselves, like the European Commission, might mandate the standardization bodies to develop standards complementing or specifying often more generic regulations.

Nevertheless, these standards still have a voluntary character from a legal perspective, whereas they might be mandatory from an economic perspective. This approach is slightly different from countries having mandatory standards in contrast to voluntary standards, like China (see Zhang et al., 2023). However, the impact of this interaction between regulation and standards³⁷ Innovation has

³⁶ For example, South Korea even implemented ISO/IEC 27018 for data protection in cloud computing as a national regulation (Löhe and Blind, 2015).

³⁷ According to Heß and Blind (2019), German companies perceive a frequent reciprocal interaction between regulation and standards with even more impulses from the side of regulators.

not yet been analyzed, although it could, in theory, be quite effective in promoting transformative innovation following the logic of the Porter Hypothesis.

The role of “impossible” standards

In accordance with the Porter Hypothesis, interviewees suggest considering the development of challenging or even “impossible” standards, which do not reflect the state of science and technology, or the current practice. They propose to specify objectives requiring currently not yet feasible solutions, also called “impossible” standards. They could then trigger - in the case of success related to ISO 30500 - the development of transformative innovations. This procedure contradicts the current principle that standards should be based on established technical solutions used in the current practice. Furthermore, standardization processes follow the consensual principle, which challenges finding an agreement on a specific future technology. Overall, the mechanisms of the Porter Hypothesis can also work for initially “impossible” standards, for example, if around five years after its release, a company claimed to have developed a solution that ultimately complied with ISO 30500. However, for the proof of the functioning of the Porter Hypothesis related to the SBTi Corporate Net-Zero Standard or the ISO Net Zero Guidelines (IWA 42: 2022), we still need time to make an assessment.

The ISO 35000 case mentioned above is a rare exception. Therefore, interviewees suggested considering the development of standards or specifications by smaller, often closed consortia, which do not necessarily rely on the consensus principle. Since smaller consortia with a common objective, which has been de facto the case in the development of ISO 30500, have a higher likelihood of finding an agreement, there is the option to consider a two-step approach. As a first step, consortia³⁸ can exclude participants with diverging interests and speed up the standardization process. Therefore, these consortia might be forerunners in creating these “impossible” standards specifying ambitious objectives triggering transformative innovations. In a second step, these workshop agreements and publicly available specifications could be the foundation for developing a completely international, regional, or national standard following the consensual principle.³⁹ Some interviewees go even one step further, claiming that voluntary standardization processes, even based on full consensus, can compete with the lengthier processes to release governmental regulations. Therefore, regulations might be forced to speed up to avoid being restricted by stakeholders pointing to already set and established standards.⁴⁰

Like some types of standards being mandatory, for example, in China (Zhang et al., 2023), and therefore being an element of the framework of obligatory regulations, interviewees mentioned that certifications could also be distinguished between the majority of voluntary and some mandatory schemes. Generally, quality and environmental management system standards are voluntary in most countries. Nevertheless, certifications based on them can generate regulatory relief, i.e. their implementation indicates compliance with a related governmental regulation.⁴¹ However, companies might also be forced to be certified based on standards, e.g. the ISO/IEC 27001 series on IT security.⁴² In consequence, not only the standard itself has been developed by interested

³⁸ These consortia could be established or new organizations having the objectives of creating standards (see Teubner et al., 2021 for an overview of different types), but also working groups within formal standardization bodies dedicated to producing international, regional, or national workshop agreements or publicly available specifications.

³⁹ There is no empirical evidence about this possible transition. However, newly formed working groups often create workshop agreements and publicly available specifications because the responsible technical committee needs to endorse their relevance or content.

⁴⁰ In addition, the World Business Council for Sustainable Development (2021) argues that companies can use minimum standards to demonstrate to regulators what is feasible related to regulations to be strengthened without putting further compliance costs on businesses.

⁴¹ See, for example, the discussion of Testa et al. (2016) on companies' perception of the regulatory relief initiatives provided by public administrations in the EU for organizations based on Environmental Management Systems relying, e.g. on ISO 14001.

⁴² Mirtsch et al. (2021b) point to the requirement for German energy providers to be certified according to ISO/IEC 27001.

stakeholders, but also its implementation is surveyed by non-governmental organizations, i.e. certification becoming a substitute for regulatory inspection.⁴³ Since compliance with regulations is considered to create a higher burden than standards, the former are less supportive of innovation (e.g. Blind et al., 2017). Therefore, the substitution of regulatory compliance by certification schemes might have a positive impact on innovation. However, empirical proof still needs to be generated.

The role of regulatory sandboxes

Since the regulatory frameworks are increasingly challenged by the progressing dynamics in science and research, but also market developments and grand challenges such as climate change, there is pressure for faster progress. However, the normal processes of releasing new or updated laws and regulations are instead time-consuming. One way to increase flexibility beyond relying on more flexible standards complementing rather generic regulations is to consider regulatory sandboxes.⁴⁴ They have their origin in the financial sector (Allen, 2019). According to the OECD (2020), regulatory sandboxes refer to “a limited form of regulatory waiver or flexibility for firms, enabling them to test new business models [or innovations] with reduced regulatory requirements”. Sandboxes often include mechanisms intended to ensure overarching regulatory objectives, including consumer protection. Regulatory sandboxes are typically organized and administered on a case-by-case basis by the relevant regulatory authorities.” Although the OECD (2021) suggests increasing the use of both regulatory sandboxes and standardization to face the increasing demand for flexibility, they do not consider their combination, which is also not yet addressed in the academic literature, e.g. in the survey by Allen (2019).

Finally, not only might regulation interact with standardization and standards, but also other instruments of innovation policy (see Edler and Fagerberg, 2017 for an overview). However, so far, mainly public procurement as a demand-side policy instrument (Edler et al., 2012) makes an explicit link to standards (Blind, 2008), e.g. related to solar plants in India (Marian et al., 2022).⁴⁵ In addition, the impact of their combination on transformative innovation has yet to be empirically investigated. Furthermore, there are possible opportunities for policies supporting clusters and networks focused on innovation to consider the standardization of commonly developed technologies. Overall, a systematic review of the potential synergies between innovation policy instruments and standardization to promote transformative innovation still needs to be generated. This observation is also endorsed by the interviewed academics.

Science-based standards as an enabler of transformative innovation

Although we have already considered the innovation-promoting impacts of regulation and standardization, a further reciprocal relationship must be explored. Innovation, in general, and transformative innovation, in particular, rely on breakthroughs in science and research. However, to unlock the innovation-promoting and reduce the innovation-limiting impact of both regulation and standards (see Blind 2016a, b for previous overviews)⁴⁶, they need to be science- and evidence-based. Currently, this is not always the case for standards as revealed by Blind and Fenton (2022) for all standards released by ISO, Gottinger et al. (2023) for the bioeconomy or Asna Ashari et al. (2023) for the emerging hydrogen technology. The interviewed experts highlighted that up-to-date, science-based standards do not present a barrier but can be an effective enabler or a prerequisite for

⁴³ The certification bodies might be surveyed by accreditation bodies appointed by the national governments or ministries.

⁴⁴ For example, in partnership with the UK's FCA regulator, the UK Transition Plan Taskforce is trialing its disclosure framework and implementation guidance as the “gold standard” for corporate net zero transition plans. See <https://transitiontaskforce.net/get-involved/>.

⁴⁵ However, some interviewees underline that despite referencing standards, not enough companies might join public tenders to have a sufficient level of competition eventually.

⁴⁶ Some interviewees suggest considering the impact of the innovation management series ISO 56000 separately. However, there needs to be more anecdotal and broad empirical evidence about its potential impact on innovation.

transformative innovation. The same requirement is also valid for regulation. However, very few empirical studies about scientific references cited in policy-related documents (Bornmann et al., 2016, Haunschild and Bornmann, 2017, Youtie et al., 2017) reveal that policy documents need to exploit the available scientific evidence. Therefore, it is suggested to increase the incentives for universities and research organizations to get actively involved in standardization processes and be consulted by regulatory bodies.

We must return to their functions to complete the conceptual model of standards and regulations promoting transformative innovation. Starting with standards, the recent review by Blind (2022) reveals that standards codify first knowledge and are, therefore, also a source for researchers and innovators promoting in particular companies' success with market novelties (Blind et al., 2022), a type of innovation being the core of transformative innovation. Secondly, standards reduce variety, which allows the leverage of economies of scale or scaling processes, i.e. reducing the cost per unit, but also contributes to building critical mass, a requirement for forming new markets. Thirdly, compliance with standards can promote trust among the users and consumers of new technologies and products. Trust itself increases their willingness to pay and, therefore, is a further requirement for forming new markets, e.g. for transformative innovations. Interviewees also mentioned the role of standards in building trust among investors⁴⁷, e.g. standards for giving carbon credits for greenhouse gas reductions released by the Integrity Council for the Voluntary Carbon Market.⁴⁸ Finally, standards can be the base for the interoperability between products and their components, which is also a general requirement for the formation of markets in network industries like information and communication technologies. Reidenbach et al. (2022) already highlight the need for interoperability of technologies to transform the energy system towards net zero. Gregoire-Zawilski and Popp (2023) can even prove that interoperability standards related to smart grids promote entry by companies new to this market, whereas the innovation of incumbents is reduced. Overall, interoperability standards increase the diversity of innovating firms in this market, which can contribute to transformative innovation in general, but via innovations in smart grids also net zero.⁴⁹

Governmental regulations have similar characteristics as standards and contribute to innovation (see, e.g. Tait et al., 2017). However, the balance between their different functions has slightly shifted. First, standards are a richer source of knowledge for potential innovators than regulations, which is particularly effective for emerging technologies (see Blind et al., 2017). Second, regulations should generally be technology neutral and not reduce variety. Therefore, they contribute only to the formation of new markets if specific technologies and related products are not anymore allowed or mainly selected, like renewable energy sources for combating climate change. Here, the innovation-triggering effect claimed by the Porter Hypothesis has to be mentioned. Thirdly, regulation might be better suited than standards because of their mandatory character to create trust and reduce uncertainties. This holds both for the demand side, e.g. via product safety regulations, and the supply side, e.g. via limiting liability claims in case of accidents related to innovative technologies. Finally, whereas standards generally solve interoperability challenges, regulations can also define interfaces between different components of new technologies, e.g. plugs of electric vehicles, if standardization does not generate a common solution (Wiegmann et al., 2017).⁵⁰

⁴⁷ Deng et al. (2022) reveal that companies' involvement in standardization reduces their implied cost of equity.

⁴⁸ See here for more details on the Integrity Council for the Voluntary Carbon Market (2022) <https://icvcm.org/the-core-carbon-principles/>.

⁴⁹ Foucart and Li (2021) introduce insurance against risky research and development activities as a further function of standards. However, this function mainly triggers incremental at the cost of radical innovation, eventually not benefitting transformative innovation. The new ISO 56000 on innovation management could also promote the effectiveness and efficiency of companies' innovation activities. However, an assessment can only be provided if information about its diffusion and efficacy is available.

⁵⁰ Some standards create specific incentives for companies to innovate, like intellectual property rights. However, these are so generic or are part of the institutional framework that they are not explicitly considered, as well as all the competition enhancing or securing regulations have an indirect positive impact on innovation.

Table 4: Relative relevance of standards and regulation for innovation

	Standards	Regulations
Source of knowledge	very relevant	limited relevance
Variety reduction	very relevant	limited relevance
Trust building	relevant	very relevant
Interoperability	very relevant	limited relevance

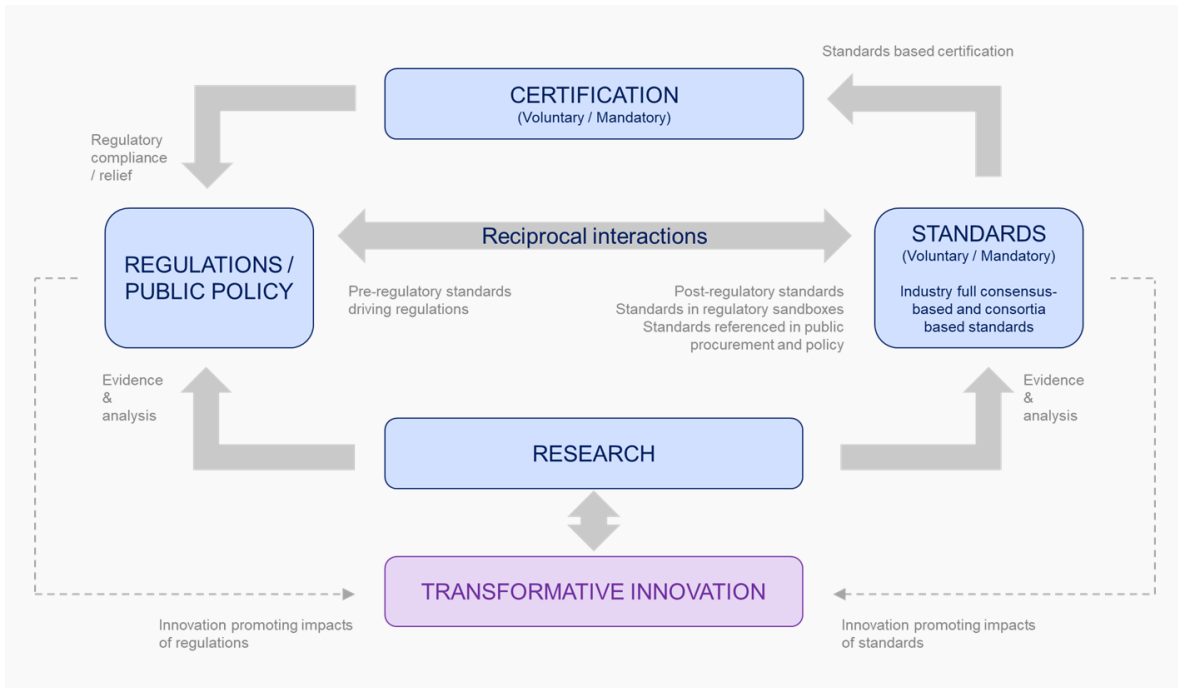
Taking the innovation-promoting impacts of both standards and regulation together, their functions can effectively complement each other in promoting transformative innovations.⁵¹ First, standards are certainly a better source of knowledge for innovators, mainly if they are already involved in their creation in the emerging stage of new and transformative technologies (Blind et al., 2017). Second, whereas both regulators and standard setters should focus on defining performance requirements and not on selecting or specifying technologies in a prescriptive way, regulations can, along with the Porter Hypothesis, better trigger transformative innovations in contrast to the consensus-based standards. Thirdly, regulations are more effective in generating trust in emerging technologies than standards, but the latter are also needed to help companies introduce their innovations into the market. As several interviewees mentioned, certification schemes based on voluntary standards are not only used to promote regulatory relief but could also prove regulatory compliance. Finally, interoperability should be achieved via standards. If the voluntary standard-setting processes eventually do not lead to a common solution because of company- or country-specific interest, supra-national coordination by regulatory bodies or other institutions can intervene to generate supra- or international framework conditions for transformative innovations.⁵²

In Figure 1, we display the elements of the expanded governance system and its various links. On the left-hand side, we have regulation but also other public policy instruments relevant to innovation. We find standardization, its different types, and outputs on the right-hand side. Their various linkages connect both. In addition, we explicitly present the role of certifications and research in producing scientific evidence of regulations and standards.

⁵¹ It must be mentioned that the interviewees' views differ regarding the relative advantage of standards vs. regulations, i.e. academics and NGOs focusing on environmental concerns favor regulation. In contrast, standard-setting organizations, other NGOs developing standards, and specific industry representatives have a strong preference for standards.

⁵² There is a further reciprocal virtuous triangle cycle to be mentioned, which could eventually be exploited to promote innovation. In addition to the innovation-promoting role of standards, the latter, particularly international standards, can promote the global trade of environmental technologies contributing to combatting climate change. These trade flows can further push innovation (see Shu and Steinwender, 2019 or Melitz and Redding, 2021), eventually leading to a virtuous triangle cycle if we consider the positive impact of innovation on standards (Blind and van Laer, 2021) and trade (see already Wakelin, 1997).

Figure 1: **How standards and regulations can interact to drive transformative innovation**



Source: own development

6 Implications

These new insights can be harnessed for more comprehensive and effective transformative innovation policies. We derive the following implications from the complete governance model, mainly the interviews.

6.1 Implications for the standardization process

6.1.1 Topics

First, we focus on the standardization process. In general, the relevance of standardization for transformative innovation policy has to be raised, which consequently requires more resources for proactive initiatives. Standardization should follow the logic of the Porter Hypothesis related to regulation. The example of ISO 30500 as a kind of “impossible” standard has specified radical requirements from a needs rather than technological feasibility perspective triggering disruptive innovations. This approach should be further pursued as an alternative to the consensus-driven standardization processes which have the tendency of triggering incremental than radical innovation. In addition, standards should not only focus on their compliance facilitating function (Tait et al., 2017), but also on their innovation-enhancing capacity, e.g. ISO 56000 on innovation management, to support transformative innovation.⁵³ Therefore, closer coordination with research institutes might contribute to a more innovation focused agenda-setting in standardization.

Standards do not only become regulations according to the conveyor belt approach presented by Hale (2021).⁵⁴ Standardization processes can also be initiated via regulators, e.g. the European Commission mandating the development of European standards by the European standards-setting organizations to specify their European regulations and directives.⁵⁵ This practical and efficient division of work is also implemented in China via so-called governmental standards (Zhang et al., 2023) and might also be implemented in other countries. However, countries’ institutional context has to be considered, at least in the short term. In the long term, this established division of work between regulation and standards might be implemented in other world regions, like the United States. The approach might increase the role of international standards to harmonize national regulatory framework conditions.

Global challenges or objectives, like net zero, cannot be reached alone by market-led policy and voluntary standards. Therefore, the United Nations or other international organizations should take the opportunity to embrace a more proactive role. They should use the possibilities of standards by mandating international standardization organizations, i.e. ISO and IEC, with the development of ambitious international standards guiding and promoting transformative innovation. This approach can be perceived as harnessing the mechanisms of the Porter Hypothesis at global level to encourage innovation of companies in general, but not necessarily the competitiveness of specific countries.

⁵³ Here, the general focus on performance instead of prescriptive standards has to be mentioned. Related to climate change, the successful implementation of ISO’s London Declaration to ensure its standards contribute to achieving the Paris Agreement, the United Nations Sustainable Development Goals, and the United Nations Call for Action on Adaptation and Resilience is essential.

⁵⁴ See also the understanding in the United Nations’ High-Level Expert Group on the Net Zero Emissions Commitments of Non-State Entities (McKenna et al., 2022).

⁵⁵ Interviewees mentioned some room for improvement in the development of the mandated standards of the European Commission, e.g. by more specific requirements.

6.1.2 Stakeholders, participation, and inclusion

The legitimacy and, ultimately, diffusion of standards aiming to promote transformative innovation have to be promoted. Therefore, the stakeholder base involved in standardization processes should be broadened towards non-governmental organizations, universities, and research organizations. Here, additional incentives, including funding for research institutes and innovative start-ups, might be required. Furthermore, related to the challenges of climate change, it has to be pointed out that the involvement of participants from low- and middle-income countries in the global south needs to be strengthened (Prosser and Whitmarsh, 2022), as has been the case in the development of ISO 30500.

The explicit addition of inclusiveness into the set of WTO criteria required for standardization processes should be considered in the future. The greater inclusiveness and diversity challenge the industry's internal consensus-finding processes and inclination towards incremental instead of radical innovation. In addition, the increased involvement of policymakers, particularly regulators, in standardization processes boosts the chances of standards becoming mandatory or referenced in regulations. Eventually, the engagement of both multinational enterprises and internationally organized non-governmental organizations can push the implementation of standards at a global level.

6.1.3 Processes of standardization: A new blueprint for global challenges?

The international standardization system follows a bottom-up principle of initially national initiatives. Therefore, the rare example of the development of ISO 30500 and ISO Net Zero Guidelines (IWA 42: 2022) could be considered a blueprint for the joint development of new standards addressing global challenges and triggering the required transformative innovations already at the international but not national level. Following the development of a standard, a top-down approach could be started, eventually leading to its faster and broader implementation at global level. Another interesting approach is IWA 37 on the safety, security, and sustainability of cannabis facilities and operations, initiated by Canada, a country liberalizing its national cannabis market. This example starts not from the global level, but it is driven by implementing a new regulatory framework at the national level. However, in the case of its broad implementation, it can lead to an alignment of the regulatory framework related to cannabis at the global level, which is also the objective of the ISO Net Zero Guidelines (IWA 42: 2022).

The speed of standardization is vital for innovation. Therefore, in addition to the mainly market- and industry-driven standardization processes, further initiatives should be introduced ahead of policy and industry initiatives. Their results, workshop agreements or complete standards, will allow for guiding follow-up activities, which might now be driven by stakeholders from the industry interested in shaping new markets.⁵⁶ Relevant scientific insights, including from basic research and input from start-ups (generally ahead of the mainstream and industry incumbents), should be included in these initiatives. Finally, digitalization via remote sessions of technical committees and working groups can also speed the development process despite the broader involvement of stakeholders.

The tension between reaching a consensus in due time and high ambition, inclusiveness, and stakeholder diversity might be addressed through a stepwise approach: First, majority-based decision processes might be used in closed consortia, which are either part of formal standardization bodies

⁵⁶ Interviewees also mentioned that standardization processes could be too early, leading to inferior standards, see the examples in Cabral and Salant (2014).

or independent institutions having liaisons with the former. These workshop agreements, specifications, or consortia standards might then be transferred - as in the case of ISO 30500 - to a second stage to standard development organizations' open and consensus-based processes. Therefore, there should still be a diversity of standard-setting bodies, which assures sufficient competition to find timely solutions addressing the above mentioned requirement for speed.⁵⁷

Finally, public funding has to be provided to develop the required ambitious standards, because the incumbents in the industry with the necessary resources might not be interested due to possible threats to their successful business models. In contrast, private stakeholders or NGOs aiming for these standards need the required resources and capacities. Overall, we have a market failure legitimizing the intervention by policymakers, which is additionally justified if these standards complement governmental regulations.

6.2 Implications related to standards

When standards are eventually published, they enable transformative innovation most effectively if they are timely and broadly implemented. Here, different options could be employed. At first, it should be considered - as in the case of ISO Net Zero Guidelines (IWA 42: 2022) - to make standards aiming to contribute to transformative innovation available through open access (see Steen et al., 2022). Although this approach threatens the business model of many established standard-developing organizations, the loss in revenues from the sale of these standards can be compensated by follow-up sales of complementary standards. Even the ISO Net Zero Guidelines (IWA 42: 2022) are an excellent example because they recommend the use of several ISO standards as a way to fulfil some of its recommendations.

In addition, their diffusion can be pushed even further by reducing the price. Via the opportunities of digitalization, companies with flat-rate contracts with standard-setting organizations might be pointed to these standards. In addition, compliance with international standards, e.g. proven via third-party certifications, could be used to indicate compliance with regulations, i.e. regulatory relief. Suppose international standards, e.g. post-regulatory standards, in particular related to ambitious regulations in the sense of the Porter Hypothesis, are implemented as national regulations. In that case, such certificates can even be used to show regulatory compliance.

As outlined above, the dynamics in science, technology, and markets, but also needs or challenges such as climate change, are challenging standardization processes and particularly released standards. To unlock the economic functions to promote transformative innovation and minimize their potential innovation-limiting effects, the relevant standards have to be updated much faster than the current five year cycle.

6.2.1 Implications for policymakers

Since regulators are pressured to be ahead of future technologies, they might make wrong decisions, e.g. by forbidding innovative but risky technologies following the precautionary principle instead of the innovation principle. However, by making use of the insights of standardization processes and even standards created by stakeholders being closer to the technological frontier (see also Blind et al., 2017), regulators are gaining time, but also knowledge, which can be eventually integrated into the following regulations (see Tait et al., 2017).

⁵⁷ Some interviewees also mentioned that timely standardization processes could put competitive pressure on regulatory bodies.

In this line, policymakers and regulatory bodies are also considering the increasing use of regulatory sandboxes, especially in highly dynamic areas, including net zero, with the potential to create transformative innovations. However, there needs to be more experience with regulatory sandboxes outside the financial sector. In the future, the establishment of regulatory sandboxes, which increasingly focus on energy systems (Gangale et al., 2023), should be aligned with complementary standardization activities to exploit possible synergies of these two instruments to promote transformative innovations.

As recommended above, standardization processes should involve representatives of regulatory bodies to reflect their preferences and ensure that the produced standards are eventually compatible and aligned with the regulatory framework. Only a few of these organizations can join the standardization processes. Therefore, it has to be ensured that the produced standards are eventually used by the much larger group of regulatory bodies linked to different ministries supporting government objectives. The same argument is true of public procurers, who should be involved in standardization processes to contribute to specifications driving the development of transformative innovations. This approach could be accommodated by a strong signal from the demand side via budgets available for transformative innovation via public procurement. It requires the standards developed explicitly to trigger transformative innovation to be distributed to and eventually implemented by public procurement agencies. Furthermore, the same recommendations apply to other areas of public policy, mainly research and innovation policies promoting transformative innovations, which might benefit from standardization and standards.

Finally, the trade-enhancing impact of international standards for the global diffusion of transformative innovations, e.g. environmental technologies for combating climate change, should be considered in trade policies such as trade agreements. Here, the reciprocal mechanism of trade pushing innovation is a long-term strategy to be embraced for transformative innovations.

7 Gaps and future research agenda

The findings from our research reveal several research gaps and directions for future exploration. Although the literature review was extensive and interviews were conducted with a broad range of stakeholders, any future research should first identify whether there is additional already published literature on the topic.

- Firstly, the term transformative innovation has yet to be fully defined. A definition of transformative innovation has to be developed to set the basis for future research, which can then help to promote the role of standardization and standards within innovation research and policy.
- The Porter Hypothesis has been conceptually and empirically investigated in depth based on several environmental regulations established in several countries. However, the number of “impossible” standards cases is still somewhat limited. Therefore, only anecdotal evidence about their impacts exists, e.g. related to ISO 30500 (Miörner and Binz, 2021, Sakhondo et al., 2020).⁵⁸ To test the applicability of the Porter Hypothesis to this type of standard, more cases and more time are required to investigate the true impact on transformative innovation.
- When it comes to innovation, some studies about the impacts of standards on the one hand and the effects of regulation on the other already exist. However, the influence of their interaction on innovation in general and transformative innovation has yet to be investigated. Here, the interaction between regulation and standardization has only been anecdotally investigated – what is required is a long-term and broadened approach to reveal its possible virtuous cycles to ultimately promote transformative innovation.
- In the future, the role of standardization and standards for implementing regulatory sandboxes could be analyzed empirically if this innovation policy is implemented further in practice. However, today, conceptual developments might help to unlock the opportunities of this relationship in the future.
- Not only has the relationship between standards and regulation not been investigated in depth, but the same applies to the links between consortia standards, workshop agreements, like the ISO Net Zero Guidelines (IWA 42: 2022), and complete standards. Overall, the full set of options from the company, consortia, full consensual based standards, and regulation and their various interactions relevant for transformative innovations has not been analyzed at all.
- In addition, the impact of voluntary initiatives, e.g. defining net zero collected in McGivern et al. (2022), on innovation has not yet been addressed in previous research and explicitly excluded in the performed analysis.
- Certifications based on standards are necessary as a signal for companies’ customers, but also of presumption of conformity, e.g. with environmental regulation as in the case of ISO 14001 on environmental management. Therefore, they deserve further research not only related to generating compliance with the law, but also as drivers for transformative innovation. In particular, several certification schemes related to implementing actions towards net zero and carbon neutrality have been established in parallel in the context of financial reporting to increase the efficiency of investments into organizations potentially impacted

⁵⁸ The innovation-enabling impact of ISO 56000 on innovation management can only be analyzed in a few years when its adoption has reached a broader base.

by climate change. So far, their impact on transformative innovation remains vague and needs further time to collect data for empirical investigations.

- Due to the critical role of trade for innovation, certifications' role in international business and their impact on innovation, particularly in clean technologies, deserve further attention.
- In addition to certification, accreditation is a further element of the quality infrastructure promoting trust, an essential characteristic of a successful innovation system. However, the research on quality infrastructure still needs to be expanded, and investigations about its impact on innovation in general are at their very beginning and on transformative innovation is nonexistent.
- Furthermore, transformative innovation needs a coordinated approach, including all innovation policy instruments. The interaction of standardization with other innovation policy instruments beyond public procurement and investments in research has yet to be addressed. However, a comprehensive, effective, and efficient transformative innovation policy has to leverage their synergies, considering the different institutional contexts and countries' levels of development.
- Finally, the analysis and recommendations in this report have been based on the current national and international governance system of regulation and standardization. As such, it did not consider any completely new system of governance. A new system of governance may be needed to tackle the challenges of climate change and could be an area of future research.

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A.1 Methodology

The research comprises a literature review, qualitative research with stakeholders, and where relevant, case studies that can support thinking for net zero.

Literature review

A focused literature review was undertaken to cover relevant academic publications and grey literature. The key areas we explored as they relate to transformative innovation and “impossible” standards are:

- The role of the enabling environment/market framework in shaping the relationship between standards and transformative innovation.
- The process of standardization, including the role of science/experts in standards making.
- The specifications of standards being able to drive transformative innovation.

For the literature review, databases, like Google Scholar, Scopus, and Web of Science (WoS), have been used. Searches using the combination of “standard”, “innovation” and “net zero” have revealed 6550 papers, using “standardization” instead of “standard” only 930 papers. In Scopus, the combination of “net zero”, “standard*” and “innovation” led to 20 papers (standardization 2) (WoS 46 / 1). In parallel, searching for “transformative innovation” generated 197 papers in Scopus (WoS 122), but in combination with “standard” only seven papers (WoS 3), which eventually turned out not to be relevant. Therefore, all 197 papers identified via the search term “transformative innovation” in Scopus have been the base for the literature review to identify the potential of standards, but also regulation to contribute to transformative innovation. Then, all the abstracts have been read to classify whether the papers are eventually relevant to address our research questions. Eventually, 65 papers have been selected to be relevant. And fortunately, the full text of all papers could be accessed. However, 24 out of the 65 papers had neither links to standardization or standards nor to regulation. Therefore, we have analyzed in depth the remaining 41 papers. However, it turned out that most of these papers provided only limited additional insights. Therefore, relevant reviews about standards, but also regulation as well and innovation have been considered (Blind 2016a; Blind 2016b; Blind 2022; Blind 2023), because performing a more generic systematic literature review of almost 40,000 papers about innovation and standards would have been too time-consuming and ultimately inefficient.

Among the grey literature, the concept note of the UNFCCC (2022) has been considered as well as the Policy Memo by Hale (2021) and the report by Steen et al. (2022) about accelerating the transition to net zero also addressing the role of standards. Further papers on the role of standardization and regulation (e.g. Tait and Banda, 2016; Tait et al., 2017 or Hale, 2021) are also reflected. The OECD published a report on the required interoperability of technologies to transform the energy system towards net zero (Reidenbach et al., 2022). On behalf of the German standardization bodies DIN and DKE conducted Blind et al. (2022), a survey among stakeholders involved in standardization to identify the current role and the potential of standards to address the challenges of climate change. However, also more generic policy documents, like the strategy on standardization of the European Union released in February 2022 claiming that “EU’s ambitions towards a climate neutral, resilient and circular economy cannot be delivered without European standards”. Even the European Green deal includes explicitly CO₂ emissions standards for cars and vans within its targets for 2030 (European Commission, 2019) reconfirmed in the Green Deal Industrial Plan for the Net-Zero Age (European Commission, 2023) pointing to the role of standards for promoting the roll-out of clean and digital technologies. However, this is just a first brief selection of the most relevant sources

confirming the intensive discussion among policy makers about the role of standards for transformative innovation in general and achieving net zero in particular.

Stakeholder interviews

Since the insights from the literature have been limited, expert knowledge is important to update and expand the previous perspectives. Therefore, stakeholders not only from academia, but also governmental organizations, like the OECD and UNFCC, but also national regulators, non-governmental organizations and eventually standardization bodies including their participating organizations, e.g. industry or environmental or climate protection groups, were interviewed.

In total, a total number of 26 interviews with 30 interviewees were conducted. In order to reach a high diversity among the stakeholders, we addressed organizations or individuals from all over the world to ensure we included voices from lower, middle, and higher-income countries and to strike a fair gender balance. Despite the focus on Europe, experts from Asia, South and North America plus representatives from international organizations were interviewed.⁵⁹

Table A5: Overview of stakeholders interviewed

Stakeholder type	Number of interviewees
Academics	7
SDOs	10
NGOs	7
Industry	2
National Governments	2
International Institutions	2
Total	30

The interviews were conducted following the interview guideline displayed in the Annex. In general, the interviews have been recorded and automatically transcribed.

Case studies

Based on documents, scientific papers, and insights from some interviews, three case studies have been produced focusing on standardization processes with the potential to contribute to transformative innovation. In particular, ISO 30500 on non-sewered sanitation systems, the SBTi Corporate Net-Zero Standard, and ISO Net Zero Guidelines (IWA 42: 2022) are presented and assessed.

⁵⁹ Our 2050 World (commissioned by BSI) facilitated some of these interviews by providing contact details of stakeholders and circulating an invitation email.

A.2 Interview Guideline

Introduction

- Introduction to researcher. Thank you for agreeing to take part
- Introduction to Fraunhofer ISI – independent research organization, on behalf of Our 2050 World (commissioned by BSI) to carry out this study
- Explanation of research:
 - Carrying out ca. 20 interviews with a range of stakeholders, including academics, government, standardization bodies, businesses, NGOs around the world.
 - Interviews will explore the potential of standards to foster transformative innovation in general and contributing to achieve net zero in particular.
 - The findings will be used to help Our 2050 World build the Standards Pace to Net Zero initiative and place standards at the heart of the transition to net zero.
- About the discussion
 - Participation is voluntary - there are no right or wrong answers, you can choose not to discuss any issue
 - What you say is confidential and your participation is anonymous.
 - We will write a report of our findings, but no names or personal details will be included.
 - You will not be identifiable to anyone else in the report
- We will be recording the interview, so we have an accurate record of what is said
 - Recorder is encrypted and files stored securely on Fraunhofer ISI's computer system in line with General Data Protection Regulation (GDPR) 2018
 - Only the research team will have access to the recordings
 - Data will be deleted at the end of the project
- The interview will last 45 minutes/Questions/Ask for permission to start recording

NB. For some interviewees, it will be appropriate to ask about how their organization is achieving transformative innovation in general and progressing towards net zero (i.e. businesses, charities, regions/cities) in particular. However, for others it is more about how they are helping to generate transformative innovation in general and to drive others towards net zero (i.e. standards bodies, international organizations, etc.).

START RECORDING

Background

- Role title and length of time in role
- Personal remit and responsibilities
 - Generally
 - In relation to innovation and sustainability, and net zero if applicable
- The nature of the organization
 - Primary activities / business
 - Size and geographical scope
 - It's role in relation to innovation and sustainability, and net zero (if applicable)

Understanding of (transformative) innovation

- Personal understanding of the term
- Official definition in use within organization
- Other definitions used by other organizations or individuals they engage with

Current actions towards transformative innovation (net zero)

- The benefits of transformative innovation for their organization in general and of achieving net zero in particular
- The specific actions are they taking
- Do they feel like there is coordinated action and collaboration?
- What else do they think their organization (or organizations within their sphere of influence) should be doing to contribute to transformative innovation in general and to achieve net zero in particular?

The role of international standards

What are standards? [INTERVIEWER – READ OUT IF ASKED] A standard is an agreed way of doing something, such as making a product, managing a process, delivering a service, supplying materials, or simply using a term. Standards are designed by subject matter experts and aim to define the best way of doing something. Standards are voluntary – organizations are not forced to follow standards, they choose to do so. Some standards set out absolute requirements that must be met if a user wants to make a claim about their compliance with the standard. The British Standards Institution (BSI) is the national standards body for the UK – they maintain the catalogue of standards and develop new ones. BSI have several standards related to sustainability, including standards for energy and environmental management systems, amongst many others.

Role of standards related to (transformative) innovation in general and in particular related to net zero

- How can standards support transformative innovation?
- Do you have an example of where standards supported innovation in general? And what could have been changed about that example so that the innovation was more transformative?
- How have standardization processes to be reshaped to support transformative innovation contribution net zero related to?
 - Stakeholders to involve
 - Processes, e.g. voting rules
 - Outputs
 - Etc.
- How can the trade-off between ambitious targets needed for transformative innovation and the consensus process in standardization be relieved?
- What is specific about standards contributing to net zero?

Current barriers for transformative innovation in general and net zero in particular created by standards

- How do standards in general hinder progress towards transformative innovation in general?
- How do standards hinder in particular innovation relevant for the progress towards net zero?
- etc.

Interplay between standardization and regulation on related to transformative innovation in general and innovation contributing to net zero in particular

- Views on voluntary initiatives, such as standardization, as opposed to mandatory initiatives, such as government legislation to promote transformative innovation
 - Are there some areas or issues where voluntary measures are more likely to be effective in delivering transformative innovation in general and innovations related to net zero in particular?
 - Areas or issues where they are less likely to be effective?
 - How should the interplay between regulation and standardization be organized to support effectively transformative innovation in general and innovation driving net zero in particular?
- What specific role could standard setting organizations play in supporting transformative innovation in general and driving specifically to net zero?
-

Conclusion

- Overall views on transformative innovation and net zero:
 - What is the overall role of standardization and standards in supporting transformative innovation and what lessons can be learned for net zero?
 - How might framework conditions be shaped to increase their enabling impact for transformative innovation in general and innovation relevant for net zero in particular?
 - Are further instruments beyond standards and regulation to be considered?
- Anything else you would like to add?
- Explain that we are looking for literature that will help us to:
 - Understand the opportunities of standardization and standards promoting innovation driving net zero
 - Understand the interplay between regulation and standards promoting innovation driving net zero
- Can you provide any further literature recommendations or further interview partners?
- Thank and end.

END RECORDING