Report on Standardization of Artificial Intelligence for Industrie 4.0

Intelligent Manufacturing in Germany and China

IMS 国家智能制造标准化总体组 智能制造标准化 National Intelligent Manufacturing Standardisation Administration Group

STANDARDIZATION COUNCIL INDUSTRIE 4.0

GPQI Dialogues for Innovation and Trade

Publiziert durch
Deutsche Gesellschaft für Internationale Zusammenarbeit (GIZ) GmbH

Eingetragener Firmensitz
Bonn and Eschborn, Germany

Globalprojekt Qualitätsinfrastruktur
Tayuan Diplomatic Office Building
No. 14, Liangmahe Nanlu, Chaoyang
100600 Peking, VR China
info@gpqi.org I www.gpqi.org

Design
Oliver Hick-Schulz

Fotos
Cover: gesrey/iStock

Im Auftrag
Bundesministerium für Wirtschaft und Klimaschutz (BMWK)
Berlin, Deutschland 2023
Peking, VR China 2023

Text
Global Project Quality Infrastructure

Autor:innen und Expert:innen
Dr. Qi Wu, Siemens Ltd., China, **Ruiqi Li**, China Electronics Standardization Institute, **LI Han**, China Electronics Standardization Institute, **Lan Zhuo**, China Electronics Standardization Institute, **Jia Li** China Electronics Standardization Institute, **Xiaofei An**, Siemens Ltd., China, **Liwu Zhou**, Easycare Intelligence Tech. Inc., **Pengda Hong**, SIHERIA TECHNOLOGIES Co., Ltd., **Baoxuan Hong**, SIHERIA TECHNOLOGIES Co., Ltd., **Penghui Hong**, SIHERIA TECHNOLOGIES Co., Ltd., **Chenwei Tang**, Sichuan University, **Zheyi Wang**, Insightverse Ltd., **Xiaohu Wang**, GYMD Digital Technology Co. Ltd., **Guangrui Zhang**, Ocean University of China, **Jun Zhang**, Siemens Ltd., China, **Xiao Fei**, Siemens Ltd., China, **Dominik Rohrmus**, Labs Network Industrie 4.0 (LNI4.0), **Christoph Legat**, Technische Hochschule Augsburg (THA),

Das Bundesministerium für Wirtschaft und Klimaschutz (BMWK) hat die Deutsche Gesellschaft für Internationale Zusammenarbeit damit beauftragt, das Globalprojekt Qualitätsinfrastruktur zu implementieren.

Implemented by

Federal Ministry for Economic Affairs and Climate Action

Deutsche Gesellschaft für Internationale Zusammenarbeit (GIZ) GmbH

Diese Publikation ist das Ergebnis der Arbeit der Deutschen Akkreditierungsstelle (DAkkS) mit der freundlichen Unterstützung des Staatlichen Amtes für Zertifizierung und Akkreditierung (CNCA) und des Staatlichen Akkreditierungsdienstes für Konformitätsbewertung der VR China (CNAS).

DAkkS Deutsche Akkreditierungsstelle

Besonderer Dank für die maßgeblichen Beiträge an der Publikation gilt Frau Sabine Reinkober (Dipl.-Pol., Master Sciences Po) und Herrn Ing. Prof. Dr. iur. Raoul Kirmes von der Deutschen Akkreditierungsstelle (DAkkS).

CONTRIBUTORS

国家智能制造标准化总体组
National Intelligent Manufacturing Standardisation Administration Group

NATIONAL INTELLIGENT MANUFACTURING STANDARDISATION ADMINISTRATION GROUP

The National Intelligent Manufacturing Standardisation Administration Group (IMSG) was established to promote and accelerate the progress of intelligent manufacturing in China under the leadership of the Standardisation Administration of China (SAC) and Ministry of Industry and Information Technology (MIIT). It is responsible for carrying out practical work on intelligent manufacturing standardisation, including participation in international standard-setting on intelligent manufacturing as well as organising exchange and cooperation on international standards.

STANDARDIZATION COUNCIL INDUSTRIE 4.0

STANDARDIZATION COUNCIL INDUSTRIE 4.0

The Standardization Council Industrie 4.0 (SCI 4.0) was founded at the Hannover Messe 2016 as a German standardisation hub by Bitkom, DIN, DKE, VDMA and ZVEI. The initiative aims to initiate standards for digital production and to coordinate these standards nationally and internationally. SCI 4.0 orchestrates implementation of the standardisation strategy of the German Platform Industrie 4.0, which includes coordination with standardisation organisations (SDOs) and international partners as well as interlocking with pilot projects. The aim of this coordinated approach is to ensure that standards exploiting the potential of Industrie 4.0 are developed in a coordinated manner. SCI 4.0 is supported by DKE and the German Federal Ministry for Economic Affairs and Energy (BMWi).

GPQI

GLOBAL PROJECT QUALITY INFRASTRUCTURE

The German Federal Ministry for Economic Affairs and Energy (BMWi) established the Global Project Quality Infrastructure (GPQI) to promote the development of well-functioning and internationally coherent quality infrastructures. GPQI supports political and technical dialogue and implements bilaterally agreed activities in collaboration with all relevant stakeholders. The project aims to reduce technical barriers to trade and enhance product safety through bilateral political and technical dialogue on quality infrastructure (QI) with some of Germany's key trading partners.

CONTENTS

1. INTRODUCTION

Artificial intelligence (AI) has been ubiquitous for several years, and now it is impossible to imagine today's digital world without it. It is increasingly permeating more and more areas of social and economic life and is already changing the way we work, learn, communicate, and consume. There are already numerous, existing application examples for AI today. In industry, the importance of AI is also increasing rapidly. Experts believe that AI will have such an impact on industrial value creation in the future that companies will hardly be able to resist using it. The possibilities are manifold: voice assistants and chatbots are among them, programs for document research, systems for image generation and recognition, industrial robots that naturally interact and cooperate with humans on the factory floor, or autonomously driving logistics systems. AI is already being used in many companies to optimize processes and ensure their stability, increase productivity, ensure continuous quality of production, and reduce energy costs. These are mainly analytical activities that support decision-making processes. In this context, the use of artificial intelligence enables adaptation based on observations and existing (background) knowledge instead of rigid, predefined patterns. AI is thus a technology that drives progress and secures the economic power, and ultimately ensures the prosperity of society in its entirety.

The translation of new knowledge and new ideas into products and services is crucial for the competitiveness of companies. Standardization can serve as a catalyst for innovation and help anchor solutions on the market in the long term. Norms and standards define requirements for products, services, and processes. They can form the basis for technical procurement and product development. At the same time, norms and standards ensure interoperability and serve to protect people, the environment, and property, as well as to improve quality in all areas of work and life. In this way, standardization can create transparency and trust in the application of technologies and support communication between all stakeholders through uniform terms and concepts.

Germany and China have been working together since 2008 to increase product safety, reduce technical barriers to trade, and promote the development of a bilateral and internationally harmonized quality infrastructure. Areas of cooperation include Industry 4.0, machine safety, medical devices, e-commerce, IT security, and mobility solutions. This exchange is supported by the governments of both countries, which are represented by the German Federal Ministry for Economic Affairs and Climate Action (BMWK) and the Chinese State Administration for Market Regulation (SAMR). In turn, this serves as the basis for further cooperation, including in the field of standardization within the Sino-German Standardization Cooperation Commission (SGSCC). SGSCC and its sub-working groups also function as a platform for experts to discuss and exchange views on bilateral and international cooperation in the field of standardization, develop a framework for common positions, and promote coordinated standardization proposals in international bodies. The sub-working group Industrie 4.0 / Intelligent Manufacturing focuses on the development of automation in the manufacturing industry using information technology and novel information and communications technology (ICT) and thus addresses the digital transformation of the manufacturing industry. The technical expert group on "Artificial Intelligence Applications in Industrie 4.0 / Intelligent Manufacturing" has set itself the task of looking at the mutual understanding of the standardization mechanisms of both countries in the context of artificial intelligence and, in doing so, identifying fundamental potentials and insights for joint activities. The present report summarizes exchanged information and gains insights.

Various standards have been published or are under development in the context of AI – on national and international levels, consortial and full consensual. Nevertheless, due to the disruptive nature of AI, also regulatory and legislative bodies across the world are increasingly considering artificial intelligence and its impact, e.g., on the correct interpretation and validity of the set legal framework when applying artificial intelligence. The sheer volume of publications (norms, standards, and scientific publications) relating to artificial intelligence across the globe presents a significant challenge in terms of processing the vast amount of information in an appropriate manner. Furthermore, the role of norms and standards differs from region to region, with several systemic differences. Therefore, the aim of this publication is to strengthen the understanding by comparing the role of standardization in China and Germany/Europe and to summarize the general objectives and roadmaps of the two economic areas regarding the standardization of artificial intelligence to derive communalities and differences.

Prior to embarking upon a comprehensive discourse about artificial intelligence, it is imperative to establish a definition of what is meant. A variety of definitions, even in a normative context, still exist. As of 2022, a normative definition of artificial intelligence now exists after hard work and intensive discussions worldwide: An AI system is an "engineered system that generates output such as content, forecasts, recommendations, or decisions for a given set of human-defined objectives" [1]. Problematically, the definition is still rather weak and will not tackle the existing challenge of diverging definitions. Nevertheless, we rely on this definition to define the scope of this document and will highlight the challenge of (partially contradictory) definitions hindering the comparability, harmonization, and integration of existing works. In addition to the aforementioned objectives, this report aims to provide further insights into the current situation of a lack of clear terminology systems.

The remainder of this report is structured as follows: In Section 2, the Chinese standardization landscape is described. Thereby, it is presented how standardization processes work in China, which committees are working on norms and standards related to AI, and how they are related to international committees. Similarly in Section 3, the standardization environment, its committees, and objectives in Germany are described together with interrelation to European and international committees. The key findings of the report are summarized in Section 4 based upon these perspectives, similarities, and differences, where the opportunities for leveraging AI in manufacturing through standardization are described in terms of a series of common challenges to be addressed. Finally, in Section 5 an outlook is given on how these challenges might be addressed and facilitated by future joint cooperation between China and Germany/Europe in the field of standardization in general, and artificial intelligence standardization in particular. Thereby, future prospects within the Sino-German cooperation on standardization of artificial intelligence in Industrie 4.0 / Intelligent Manufacturing is given and collaboration on various levels – standardization, research, and enterprise – is suggested.

2. STANDARDISATION LANDSCAPE IN CHINA

Several committees and groups in China are currently developing international and national standards for artificial intelligence. Standardization roadmaps have been researched and released to coordinate national standardization activities. In addition, industry alliances exist that focus on developing urgently needed consortia standards to meet their individual demands.

2.1 Political and Regulatory Environment in China

The Standardization Law of the People's Republic of China was revised at the 30th Meeting of the Standing Committee of the Twelfth National People's Congress on November 4, 2017. This law stipulates the organization and implementation of standardization work, the formulation of standards, the supervision and management of standardization, and other related contents. According to the law, the standards of China include national standards, industry standards, local standards, association standards, and enterprise standards. National standards are divided into mandatory standards and voluntary standards. Both industry standards and local standards are voluntary standards. Mandatory standards must be implemented. The state shall encourage the adoption of voluntary standards. Mandatory national standards shall be developed to address technical requirements for ensuring people's health and the security of their lives and property, safeguarding national and eco-environmental security, and meeting the basic needs of economic and social management. Relevant administrative departments under the State Council shall, according to their duties and responsibilities, propose mandatory national standards and organize drafts, solicit opinions, and conduct technical reviews thereof. The administrative department in charge of standardization under the State Council shall be responsible for proposal approval and the numbering and notification of mandatory national standards. The administrative department in charge of standardization under the State Council shall assess whether proposed mandatory national standards conform with the provisions in the preceding paragraph and grant approval for proposals found to conform with the provisions. Mandatory national standards shall be approved and published, or authorized for approval and publication, by the State Council. Products and services that do not meet mandatory standards shall not be manufactured, sold, imported, or provided. At the same time, a statistical analysis and report mechanism is established to monitor the implementation of mandatory standards. In terms of AI, there is one mandatory standard proposed under the topic of generative AI service that is under development in China named *Cybersecurity technology Labeling method for content generated by artificial intelligence (20241842-Q-252)* [2].

In addition, voluntary national standards may be developed to address technical requirements that are needed to serve basic and generic purposes, support mandatory national standards, or play a leading role in relevant industries. Voluntary national standards shall be developed by the administrative department in charge of standardization under the State Council. There are ten voluntary national standards about AI that have been published, including terminology, data labeling, key technology, computing resource, etc.

In terms of AI-related regulations or laws in China, *Interim Measures for the Administration of Generative Artificial Intelligence Services* was issued on July 10, 2023, by the Cyberspace Administration of China, National Development & Reform Commission, Ministry of Education, Ministry of Science & Technology, Ministry of Industry & Information Technology, Ministry of Public Security, and the National Radio and Television Administration. These measures apply to the provision of generated texts, pictures, audio and video, and other content to the public in the People's Republic of China (hereinafter referred to as "generative AI services") using generative AI technology. For example, in the process of algorithm design, training selection, model generation and optimization, and service provision, effective shall be taken to prevent measures discrimination based on ethnicity, religious belief, region, sex, age, occupation, or health. Effective measures shall be taken based on the characteristics of service types to make generative AI services more transparent and generated content more accurate and reliable. A provider shall label the generated contents such as pictures and videos in accordance with the Provisions on the Administration of Deep Synthesis of Internet-based Information Services [3].

The Position Paper of the People's Republic of China on Strengthening Ethical Governance of Artificial Intelligence (AI) released on November 16, 2022, highlights China's vision, practices, and views for ethical governance of the technology from the perspective of global cooperation and coordination. It calls for global consensus with mutual respect, and actions for the good of humanity [4].

State Council 2023 Legislation Work Plan [5] was issued on June 15, 2023, by the State Council. The draft revision of the draft Artificial Intelligence Law will be prepared and be submitted to the Standing Committee of the National People's Congress for review.

Two major documents related to the Chinese standardization strategies on AI have been issued. The State Council released the *Development Plan of the New Generation Artificial Intelligence* [6] in July 2017 as the first of its kind to be formulated with the rationale to address the emergence of AI as the latest focus of global competition. The goal is to spur China to take a stronger hold of AI development at the next level and keep pace with AI technology advancements. To further implement this development plan, the Chinese Ministry of Industry and Information Technology (MIIT) issued the *Three-Year Action Plan for Promoting the Development of Next Generation of Artificial Intelligence Industry (2018–2020)* [7] in December 2017. The document focuses on the integration of AI and manufacturing and aims to implement the first phase of the development plan for the next generation of artificial intelligence. The action plan laid out an implementation plan and goals to be achieved by 2020 [8]. The action plan laid out an implementation plan and goals for four areas to be achieved by 2020, initiatives included the development of smart manufacturing, in particular, key technical equipment and new manufacturing models incorporated with AI; and building a comprehensive AI support system, including setting up an industry training data pool, covering industry, healthcare, finance, transportation, etc.

To strengthen the top-level design of standardization in the field of intelligent manufacturing and artificial intelligence, promote research of key technologies develop standards, and standards system construction, guidelines of AI and intelligent manufacturing are published. The important standardization demands and the relationship between the demands are discussed in the guidelines, which give a picture of the whole standardization system. The guidelines also suggest deepening international exchanges and cooperation on AI and intelligent manufacturing standards, as well as paying attention to the synergy of international standards and domestic standards. In terms of the international standards and standardization, according to Article 8 of the Standardization *Law of the People's Republic of China* [9], China promotes participation in international standardization activities, engagement in international cooperation and exchanges on standardization, participation in the development of international standards, adoption of international standards in the Chinese context, and harmonization of Chinese and foreign standards. Details of the guidelines are given in Section 2.3.

2.2 Standardization Landscape in China

2.2.1 Standardization Framework in China

In China, Standardization Administration of China (SAC) established a series of corresponding standards committees to adapt to international committees of ISO, IEC, and ITU or develop standards in some new technologies. These standardization committees are responsible for communicating international and domestic standardization work and organizing experts to participate in the development of relevant international standards. In addition, since artificial intelligence, smart manufacturing, and other fields involve many existing industries or technologies, government departments such as SAC and MIIT have jointly formed a standardization overall group (**National Intelligent Manufacturing Standardization Group (IMSG) & National AI Standardization Group (AISG)**) to coordinate and promote standard project establishment and development among various standardization technical committees, improve the efficiency of standard development, and reduce cross-duplication.

Within many social groups and enterprises, due to the existence of targeted standardization needs, they will also initiate the development of group standards and enterprise standards to fill the standard gaps in addition to national standards and industry standards, thereby forming a more complete standard layout.

2.2.2 Standardization Actors for Artificial Intelligence in China

The standardization actors for AI in intelligent manufacturing in China are shown in Figure X, including standardization committees as well as coordination groups at national level. At the same time, the mirror relationship between the standardization committees in China with the international standardization committees is shown in the figure.

2.2.2.1 Coordination Groups at National Level

In China, two coordination committees pertinent to the context of artificial intelligence deserve a mention. Firstly, the **National Intelligent Manufacturing Standardization Group (IMSG)** is responsible for carrying out intelligent manufacturing standardization work under the guid-

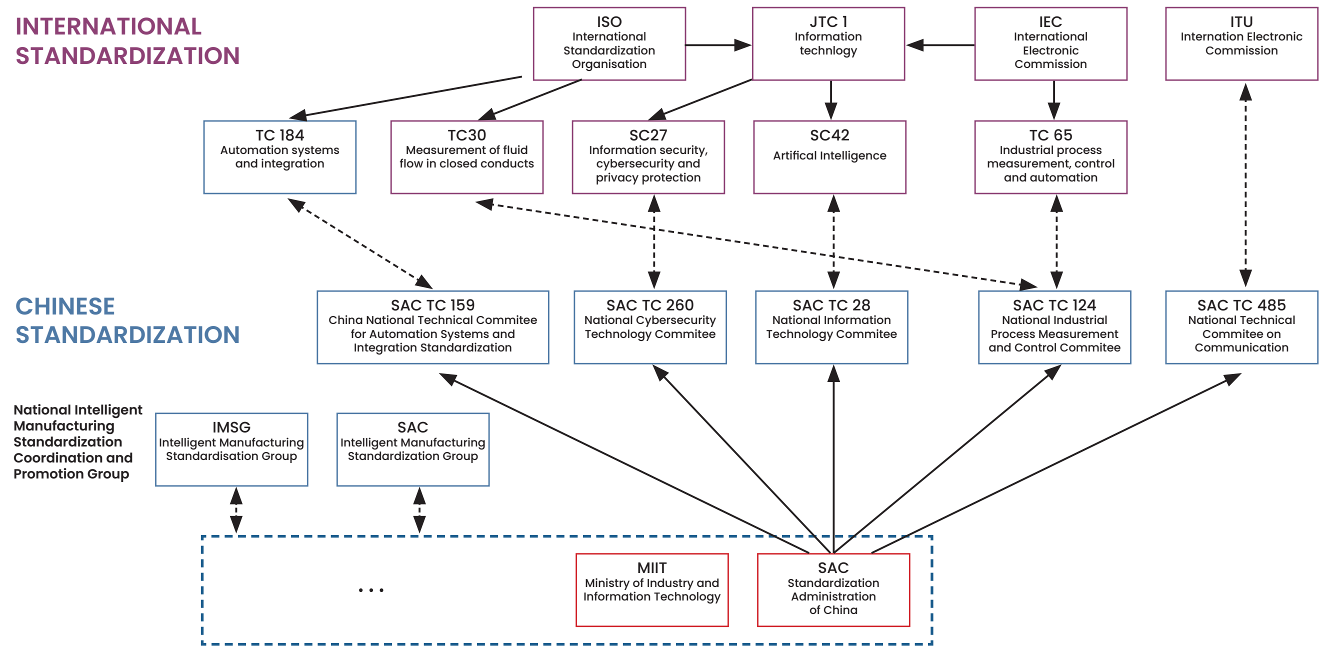


Figure 1: Standardization Actors for Artificial Intelligence in China

ance of the National Intelligent Manufacturing Standardization Coordination and Promotion Group. Topics of interest include (but are not limited to) developing plans for standardizing intelligent manufacturing, coordinating the technical aspects of the relevant national standards, conducting pilot demonstrations, and providing training for respective standards. Additionally, IMSG is responsible for organizing participation in international standardization efforts related to intelligent manufacturing and for carrying out international standardization exchanges and cooperation [10].

Secondly, the **National AI Standardization Group (AISG)** is responsible for coordinating and planning AI standardization efforts. Its responsibilities include international and national standardization work for AI, such as creating plans and policies for standardized AI practices in China, coordinating technical aspects of related national standards, and establishing mechanisms for spreading AI basic standards and industrial application standards [11].

2.2.2.2 Standards Committee at National Level or Industrial Level

The National Information Technology Committee (SAC/TC 28) was established in 1983 and is a technical organization engaged in standardization in the field of information technology under the joint leadership of the National Standardization Management Committee and the Ministry of Industry and Information Technology. It is the mirror committee of ISO/IEC JTC 1 (Joint Technical Committee on Information Technology) in China. The scope is standardization in the field of information technology, which covers the design, development, and management of technologies, systems, and tools for information collection, representation, processing, transmission, exchange, presentation, management, organization, storage, and retrieval. The subcommittee of AI **(SAC/TC 28/SC 42)** [12] is mainly responsible for the revision of national standards in the field of artificial intelligence foundation, technology, risk management, trustworthiness, governance, products and applications, etc., international counterpart ISO/IEC JTC 1/SC 42. The subcommittee is responsible for the major basis for technology, risk management, trust, areas of governance, and products and applications of artificial intelligence. In August 2020, the subcommittee was established on the foundation of four working groups: (a) on the foundation, models, and algorithms, (b) chips and systems, (c) products and services, and (d) trustworthy. By August 2024, it had expanded to include twelve extra working groups: knowledge graph, open source, computer vision, embodied intelligence, medical applications, smart living, steel applications, intelligent computing, financial applications, logistics applications, grid applications, and mining applications.

The National Cybersecurity Standardization Technical Committee (SAC TC 260) is engaged in the standardization of cybersecurity and is the mirror committee of ISO/IEC/JTC 1/SC 27. The committee is responsible for organizing and carrying out standardized technical work related to cybersecurity in China, and the main work areas of the committee include standardization of technical work in the areas of security technology, security mechanisms, security services, security management, security assessment, and so on. The report of AI Practical Guide to Network Security Standards – Guidelines for Ethics for Artificial Intelligence was developed in China [13].

The **Technical Committee for Measurement Control and Automation of Industrial Processes (SAC/TC 124)** is the industrial process measurement control and automation of national standards and industry standards of the system revision work in China. It is the mirror committee of IEC/TC 65 and ISO/TC 30. The main works include: the development of industrial process measurement and control communication network protocol standards, various types of instrumentation, implementation agencies, control equipment standards, and safety standards [14]. The **Technical Committee for Industrial Automation Systems and Integration (SAC/ TC 159)** is responsible for the standardization of automation systems and integration for product design, procurement, manufacturing and transportation, support, maintenance, sales processes, and related services. These include information systems, fixed and mobile robotics in industrial and specific non-industrial environments, automation technology, control software technology, and system integration technology [15].

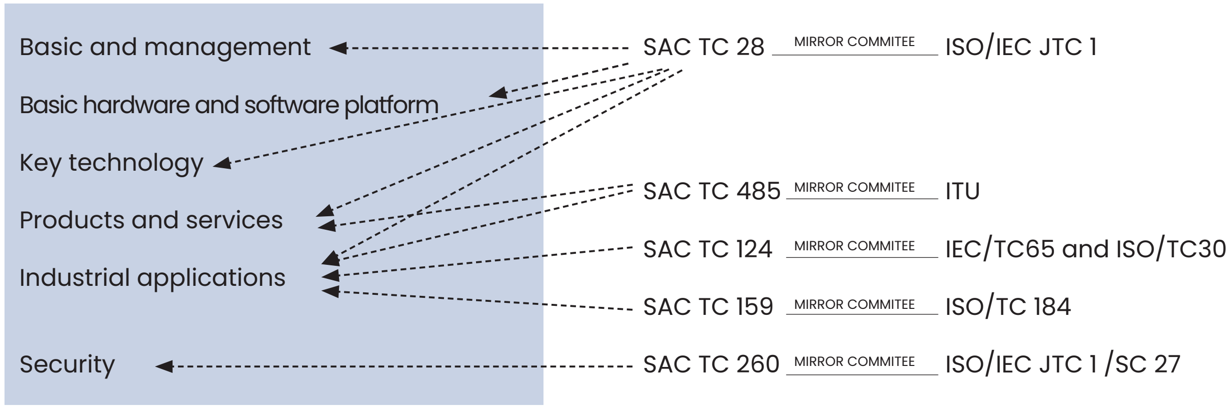


Figure 2: Standardization directions at National standard levels of the TCs

The **National Technical Committee for Communication Standardization (SAC/TC 485)** is mainly responsible for the development and revision of national standards on communication networks, systems and equipment performance requirements, communication basic protocols and related test methods, and other areas [16].

Figure 2 provides a summary of the previously introduced technical committees and relates them to both the respective international TCs as well as the national Chinese AI standardization directions. More standards will be developed in the future.

2.2.2.3 Association or Alliance at Society Level

The **China Electronics Standardization Association (CESA)** [17] carries out research and discussion on some common problems in the standardization work of the electronic information industry, promotes the results of standardization, and organizes the academic and technical exchange of standardization of the electronic information industry.

The **China Communications Standards Association (CCSA)** [18] carries out research and technical investigation of communication standards system and puts forward proposals for the project of formulating and revising communication standards.

The **Artificial Intelligence Industry Development Alliance (AIIA)** [19] builds a cooperative platform for production, research, and development, promotes the research and development, design, production, integration, and service levels of alliance members, builds the ecology of China's artificial intelligence industry, enhances the competitiveness of China's artificial intelligence industry, strengthens the deep integration of artificial intelligence and economic and social fields, promotes technological progress, improves productivity, promotes the digital transformation of traditional industries, and supports the accelerated development of new technologies, new industries, new industries, and new models.

The **Intelligent Manufacturing System Integrator Consortium (CIMSIC)** [20] is mainly responsible for building intelligent manufacturing system integration technology research and development, industry applications, supply and demand docking, and marketing of integrated public service platforms, to promote intelligent manufacturing system integration common technology and core technology exchange and research. This consortium is developing the standards related to smart factories, etc., which involve the elements of AI.

Others: There are also other social organizations that are focused on the research or application of AI, such as the Shanghai Artificial Intelligence Standards Committee (ASIS), Chinese Association for Artificial Intelligence (CAAI), China Computer Users Association (CCUA), Shenzhen Artificial Intelligence Industry Association (ASIIA), and the Zhongguancun Shuzhi Artificial Intelligence Industry Alliance (ZAI). For example, CCUA published the group standard on AI: Vocational Skill Requirements and Evaluation for Artificial Intelligence Engineers Part 1: Computer Vision [21].

- **Shanghai Artificial Intelligence Standards Committee** [22] is responsible for carrying out the centralized management of local standardization technologies in the field of artificial intelligence in Shanghai; proposing the plan for AI standardization in Shanghai; establishing an AI standard technology route suitable for the development of Shanghai's AI industry; technological innovation and cross-border integration; establishing and improving the Shanghai AI technology standards system by comparing with the international advanced level; organizing and carrying out research and revision of local standards in this professional field; organizing and carrying out the publicity; and training and consultation of local standards in this professional field.

- **Chinese Association for Artificial Intelligence** [23] was established in 1981. At present, it has 49 branches, including 41 professional committees and 8 working committees, covering the field of intelligent science and technology. The academic field of the society's activities is intelligent science and technology. The basic task is to unite national intelligent science and technology workers and activists to promote the development of intelligent science and technology in China through, among other things, academic research, domestic and foreign academic exchanges, scientific popularization, academic education, scientific and technological exhibitions, academic publications, talent recommendation, academic evaluation, academic consultation, technical review, and awards.

- **Zhongguancun Shuzhi Artificial Intelligence Industry Alliance** [24] is voluntarily jointly initiated and established by enterprises in the field of artificial intelligence in Beijing and aims to build a platform for innovation cooperation and exchange in the artificial intelligence industry in Beijing.

In addition, national occupational and technical skills standards on AI were published in 2021 by the Ministry of Human Resources and Social Security, the Ministry of Industry and Information Technology, including artificial intelligence engineering technicians and artificial intelligence trainers.

2.3 Standardization Strategy / Reports on Context of Artificial Intelligence in China

2.3.1 National Guideline on AI Standardization

The **National Guideline on AI standardization** [25] was developed by Standardization Administration of the PRC, Office of the Central Cyberspace Affairs Commission, National Development and Reform Commission, Ministry of Science and Technology of the PRC, Ministry of Industry and Information Technology of the PRC. This guideline defines a framework for the AI standard system in China published in 2020. The Administrations for Market Regulation of each province, autonomous region, municipality, and the Xinjiang Production and Construction Corps, along with the Cyberspace Administration, the Development and Reform Commission, the Science and Technology Department, and the competent Department of Industry and Information Technology, as well as the relevant national standardization technical committees, are responsible for the implementation of this plan. The top-level design of this standard system is depicted in Figure 3. The guideline analyzes the overall rules of standard system construction and standard development and, thereby, clarifies the relationship between standards. The guiding ideology of this guideline includes: "Strengthen the top-level design and macro guidance of standards. Accelerate the transformation of innovative technologies and applications into standards, strengthen the implementation and supervision of standards, and promote the deep integration of innovation achievements and industries. Pay attention to the coordination and matching with intelligent manufacturing, industrial Internet, robots, Internet of vehicles, and other related standard systems. Deepen international exchanges and cooperation on AI standards, pay attention to the synergy of international and domestic standards, give full play to the supporting and leading role of standards in the development of AI, and escort high-quality development."

Figure 3: Framework of AI standard system in China [25]

At the same time, it has guided the orderly development of AI standardization in China and completed the pre-research work on more than 20 important standards, such as key general technologies, key areas of technology, and ethics.

A **Basic and common standards** include terminology, reference architecture, and test evaluation, which are located on the far-left side of the AI standard architecture and support other parts of the standard system structure;

B **Supporting technologies and product** standards provide basic support for the construction of AI software and hardware platforms, the development of algorithm models, and the application of AI;

C **Basic software and hardware platform** standards mainly focus on intelligent chips, system software, development frameworks, etc., to provide infrastructure support for artificial intelligence;

D **Key general technology standards** mainly focus on machine learning, knowledge graphs, brain-like intelligent computing, quantum intelligent computing, pattern recognition, etc., to provide general technical support for AI applications;

E **Standards in key technology areas** mainly focus on natural language processing, intelligent speech, computer vision, biometrics, virtual reality/augmented reality, human-computer interaction, etc., to provide technical support for artificial intelligence applications;

F **Product and service standards** include the relevant standards for intelligent products and new service models formed in the field of artificial intelligence technology;

G **Industry application standards** are located at the top of the AI standard architecture, facing the specific needs of the industry, refining other parts of the standards to support the development of various industries;

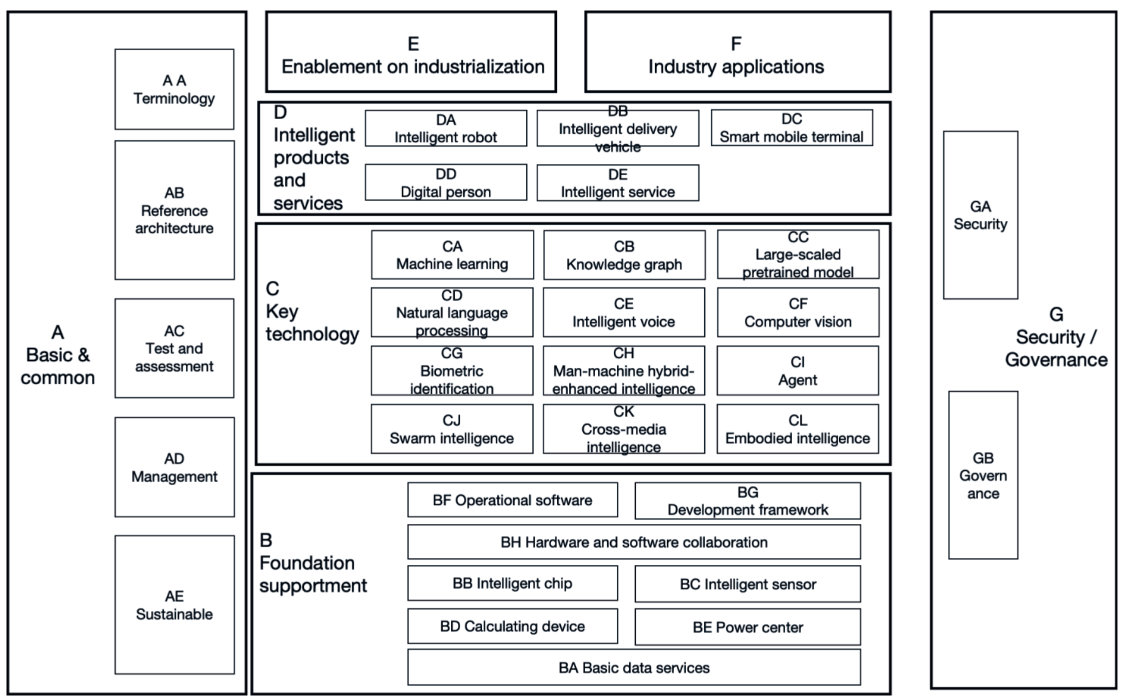
H **The safety/ethics standard** is located on the far-right side of the AI standards architecture and runs through the other parts to establish a compliance system for AI.

This guideline also gives some standardization direction in intelligent manufacturing, including mass customization, predictive maintenance (including the application of VR/AR technology), process optimization, manufacturing process flow optimization, operation management optimization, and other standards. As the technologies related to AI develop quickly, this guideline will continue to be revised in the next step. Guidelines for the Construction of a Comprehensive Standardization System for the National Artificial Intelligence Industry was issued on June 6, 2024. The framework of the AI standard system is updated as the following Figure 4.

2.3.2 National Guideline on Intelligent Manufacturing Standardization

The **National Guideline on Intelligent Manufacturing Standardization** has been published in 2018 [27] and 2021 [28]. The guideline proposes the Framework of the IM Standard System in China and proposes the AI application standardization direction in intelligent manufacturing as shown in Figure 5. The comparison between version of 2018 and version of 2021 is shown in the following figure. The new version of the guide updated the

Figure 4: Updated Framework of AI standard system in China [26]



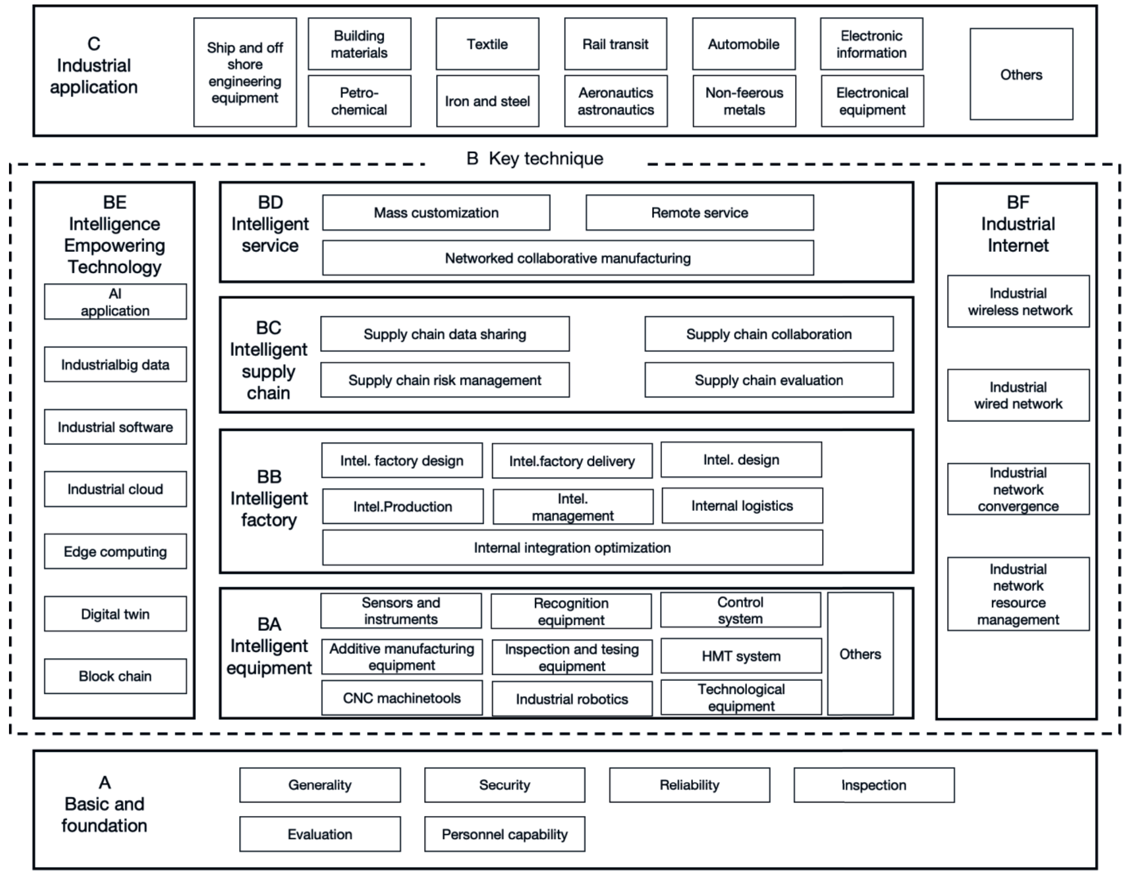


Figure 5: Structural Diagram of Intelligent Manufacturing Standard [28]

framework of IM standard system in China, and revised the AI application standardization direction in IM as follows: "Artificial intelligence standards: These mainly include knowledge service standards such as machine learning, knowledge representation, knowledge modeling, knowledge fusion, and knowledge computing; platform and support standards such as application platform architecture and integration requirements; performance evaluation standards such as training data requirements, testing instructions, and evaluation principles; and application management standards for the whole life cycle of products, such as intelligent online testing and operation management optimization."

At present, the second revision of the guideline has been initiated and will be published in the next few years. The intelligent manufacturing standardization will be updated according to new technologies, models, and standardization demands.

2.3.3 Other Related Standardization Roadmaps or Reports at the Association Level

2.3.3.1. Artificial Intelligence Standardization Whitepaper (2018 Edition)

The Artificial Intelligence Standardization White Paper (2018 Edition) [29] aimed to stress the importance of establishing standards for the rapid development of AI: "At present while China's deployment of AI-related products and services is expanding, there also exists the issue of a lack of standards. AI is promoting into many areas, and while some sub-fields are standardized, their dispersed one have not formed systemic standards yet." The white paper analyzed the standard demands of AI:

- **Define the scope of AI research. AI has shifted from laboratory research to applications.** The practical system of the domain shows the trend of rapid growth, which needs to be defined by unified terminology, clear the core concept of artificial intelligence connotation, extension, and demand, guide the industry to correctly understand and understand artificial intelligence technology, and facilitate the widespread use of artificial intelligence technology by the public.

- **Describe the framework of AI systems. Users and developers are facing the power of artificial intelligence systems.** And when implemented, AI systems are generally seen as a "black box," but it is necessary to go through the technical framework. Specifications to enhance the transparency of artificial intelligence systems. Because of the wide range of applications of AI systems, it may be difficult to give a common AI framework, and a more realistic way is to give a specific framework in a particular scope and problem. For example, machine learning-based AI systems are currently mainstream technologies and rely on technical resources, including cloud computing and big data, on which to build a framework of machine learning-based AI systems and define the capabilities of their components.

- **Evaluate the intelligence level of AI systems. AI systems are divided by intelligence.** It has always been controversy, and giving a benchmark to measure its intelligence level is a difficult and challenging task. The different applications of intelligent grade evaluation need to be further clarified, and the need for standardization work to gradually solve the problem.

- **Promote the interoperability of AI systems.** Different scenarios involve different AI systems and components. Information interaction and sharing between systems and components need to be guaranteed through interoperability. Artificial intelligence interoperability also involves the interoperability between different intelligent module products to achieve data interoperability, that is, different intelligent products need standardized interfaces. Standardization ensures that the application interface, service, and data format of the AI system define interchangeable components, data, and transaction models through standard and compatible interfaces.

- **Evaluate AI products.** Artificial intelligence systems, as industrial products, require performance, security, compatibility, and interoperability, and more can be evaluated to ensure the quality and availability of products and to ensure the sustainability of the industry. The evaluation work generally includes a series of activities such as testing and evaluation, the evaluation object can be a self-driving system, service robot, and other products, in accordance with standardized procedures and means, through measurable indicators and a quantifiable evaluation system to obtain scientific evaluation results, while with training, communication, and other means to promote the implementation of standards.

- **Standardization of key technologies.** Key technologies that have developed patterns and are widely used should be standardized in a timely manner to prevent version fragmentation and independence, and to ensure interoperability and continuity. For example, the user data bounded by the deep learning framework should ensure data exchange and not be bounded by the platform by clarifying the data display method and compression algorithm of the neural network and protect the user's rights and interests in the data, and other basic standards such as human-computer interaction technology, sensor interface, and basic algorithm need to be formulated as soon as possible.

- **Ensure safety and ethics.** Artificial intelligence collects a large amount of personal, biological, or other characteristic data from a variety of devices, applications, and networks that are not readily well organized and managed from the beginning of the system's design and take appropriate privacy measures. Artificial intelligence systems, which have a direct impact on human safety and life safety, may pose a threat to human beings and need to be standardized and evaluated to ensure safety before such artificial intelligence systems are widely used.

- **Standardization of industry application characteristics.** In addition to common technology, the implementation of artificial intelligence in specific industries also has personalized needs and technical characteristics, such as home applications, medical applications, transportation applications, etc., that need to consider the functional performance characteristics of specific devices, system composition structure, and interrelations.

2.3.3.2. Artificial Intelligence Standardization White Paper (2021 Edition)

By comparison with the version of 2018, the 2021 edition [30] provides novel content on the following aspects:

- First, from the perspective of the industrial chain, the current situation and development trend of the artificial intelligence industry are analyzed;

- The second is to introduce the current internationally recognized AI system life cycle model, AI ecosystem framework, and machine learning technology framework;

- The third is to sort out the key works of major AI standardization organizations at home and abroad;

- The fourth is to form an AI standard system framework and a detailed list of standard systems;

- Fifth, it puts forward suggestions for key work of artificial intelligence standardization in China by combining work with the progress of standardization works and the construction of standards system.

2.3.3.3. Artificial Intelligence Safety Standardization White Paper (2023)

This white paper [29] investigated the development of AI, sorted out the regulatory policies and standardization status of AI security at China and overseas, and analyzed the risk challenges and connotations of AI security. In addition, it gave the framework of AI security standardization system and put forward suggestions for AI security standardization. Based on the analysis of risk challenges, such as attack modes and impacts, the white paper gave the rules of AI security: human orientation, parity of authority and responsibility, and classification.

Standardization in Europe and Germany is solely driven by industrial interests and follows a decentralized approach. Standards serve as non-binding guidance for the industry with regard to market regulation and are therefore beneficial for ensuring compliance with regulatory requirements. The market authorities' regulatory interventions lead to normative requirements handled by well-defined processes within the European Union. These aspects are detailed in Section 3.1.

Drivers or initiators of normative projects are the industry representatives organized in technical bodies. The federal structure of Europe, the requirement for consistent standards throughout the single European market, and the decentralized approach to standards development at national level, as well as cooperation between nations on an international level, lead to a complex organizational network. This network is formed through specific agreements on adoption and cooperation between institutions and is further expounded upon in Section 3.2.

Standardization roadmaps survey future requirements for normative or scientific activities to adapt the existing normative framework to changing boundary conditions underlying the roadmap within a transformative perspective. The published contents are informative but do not establish a binding framework for action in Europe. Section 3.3 presents a concise overview of selected roadmaps on artificial intelligence related to Industry 4.0 / Intelligent Manufacturing.

3. STANDARDISATION LANDSCAPE IN GERMANY AND EUROPE

3.1 Political and Regulatory Environment in Germany and Europe

Europe and most European countries have a legal system that follows the basic structure described in this section. In the following, the German and European systems are used as examples without loss of generality. Figure 6 provides an overview.

Norms and standards are closely linked to the legal system. Therefore, it is necessary to take a detailed look at legislation and its mechanisms to gain a fundamental understanding of the role of norms and standards within the legal system. In Germany, the constitution, known as the Basic Law, is at the top. This is followed by formal laws, which are passed by the parliamentary legislature in accordance with the procedure laid down in the Basic Law of the Federal Republic of Germany [31, Acts 76–82]. Ordinances, on the other hand, are issued by the executive, i.e., the government, based on an authorization granted by formal law [31, Act 80.1]. The content, scope, and purpose of the authorization granted must be sufficiently defined in the corresponding formal law, so that no ordinance is possible without a basis of authorization by a higher law. This should be distinguished from general administrative regulations, which are not legal acts addressed to citizens, but administrative acts addressed to the administration and issued by higher bodies within the administrative hierarchy.

The central political institution in Europe is the European Union (EU), which is an independent legal entity. The EU is an association of (currently) 27 European states. The political system of the EU contains both supranational and intergovernmental elements. This is reflected in the organization of the organs of the European Union: The European Council and the Council of the European Union represent individual states through their governments; the European Parliament, as the legislative body of the EU, directly represents the citizens of the European Union. The European Commission represents the executive body, and the EU Court of Justice represents the judicial authority in the form of supranational institutions. In European law, a distinction is made between directives and regulations. **Regulations** are a legal act of the European Union with general validity and direct effectiveness in the member states. An example is the EU regulation 2017/745 [32] on the clinical investigation and sale of medical devices for human use. In the context of AI, the so-called AI Act of the European Commission is a regulation [33], too. **Directives** are legal acts of the European Union. They are not directly applicable but must be transposed into national law by the member states. Directives are usually adopted jointly by the Council of the European Union and the European Parliament in accordance with the ordinary legislative procedure on a proposal from the European Commission. One example is the so-called Machinery Directive, EU directive 2006/42/EC [34], which regulates a uniform level of protection for accident prevention for machines and partly completed machines when they are placed on the market. EU law can be accessed via EUR-Lex.[1]

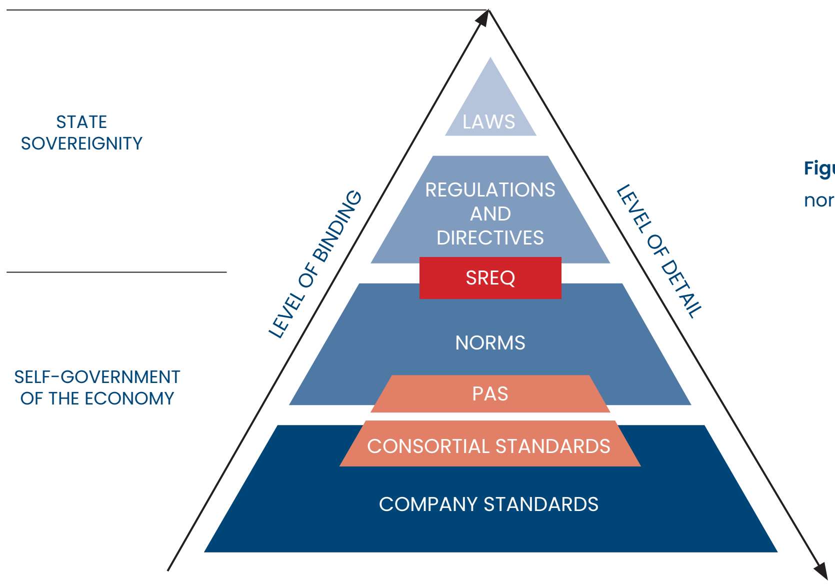


Figure 6: Standards and norms in the legal system

In summary, when products are marketed or services are provided in Europe, they must comply with both European Union regulations and national laws – e.g., German law. These laws can either be of national origin or designed to implement European directives. Together they are known as the regulatory framework. The legal framework usually outlines specific objectives or necessary general measures but does not prescribe the exact methods for achieving these objectives. This is because necessary and appropriate measures, especially in technical contexts, depend heavily on the current state of the art. If these measures were to be included in legislation, the legislation would need to be regularly updated to reflect changes in the state of the art. Therefore, legislation continues to focus on technology-independent objectives and requirements, while full-consensus standardization defines the current state of the art to be used in this context. Full-consensus standardization is the only body capable of fulfilling this role because of the broad consensus of all relevant parties on which it is based.

[1] https://eur-lex.europa.eu

[2] European standards are identified by the letters "EN" (European Norm) in their name.

3.2 Standardization Landscape in Germany and Europe

3.2.1 Standardization Framework in Germany and Europe

In accordance with the federated nature of Europe, national standardization bodies (NSBs) and their respective mirror committees represent country-specific activities and interests of the European Standardization Organizations (ESOs), namely CEN, CENELEC and ETSI. Similarly, the national bodies of the European countries mirror the international committees of the ISO, IEC, and ITU. The communication channels in Europe are currently exclusively via the national mirror committees – not least because of the voting rights for consensus building of standards on the international level. For this reason, both international and (if existing) corresponding European committees are often mirrored by the same national technical committee; there is no consolidated European perspective, voting, and direct communication from European levels to international standardization bodies and committees. However, work at the European level, mostly in the form of publications, represents important signposts for national work; in some cases, there is also an orchestrating exchange and formation of opinion at the European level with feedback to the national level.

European Standards[2] are developed within CEN (electrotechnical sector), CENELEC (general standards), and ETSI (telecommunications sector). CEN and CENELEC have adopted the vote weighting system specified for the European Union in the Nice Treaty, which is based on the population of each country. All CEN members are obliged to adopt European Standards, unchanged, as national standards, and to withdraw any conflicting national standards. Accordingly, all CEN/CENELEC members apply the same European Standards. This is one of the foundations of the European internal market. The use of European Standards is voluntary. With increasing globalization, experts are developing standards at international level. International standards can also be adopted as European Standards. According to the Vienna Agreement [35], a standard can also be developed either on international (e.g., ISO) or European (e.g., CEN) level and then adopted simultaneously as both an international and a European Standard by means of parallel voting. Similarly, the Frankfurt Agreement [36] between IEC and CENELEC defines simultaneous adoption of IEC international standards on a European level by CENELEC. The European standardization organizations are officially recognized by EU regulation 1025/2012 [37] as providers of European standards. CEN, CENELEC, and ETSI have been working with the European Commission since 1984, when a cooperation agreement was signed.

DIN and DKE, which are the German NSBs, are one of the CEN and CENELEC members with the greatest voting weight. DIN, the German Institute for Standardization, is an independent platform for standardization in Germany with more than 36,000 experts from industry, research, consumer protection, and the public sector bringing their expertise to work on standardization projects. DKE, the German Commission for Electrical, Electronic & Information Technologies of DIN and VDE, is the German standardization organization responsible for the development and adoption of standards and safety specifications in the areas of electrical engineering, electronics, and information technologies. DKE constitutes a joint organization of DIN and VDE (a technical-scientific association), the operative and juridical responsibility for running the DKE being in the hands of VDE.

3.2.2 Standardization Actors for Artificial Intelligence in Germany and Europe

The foundational framework delineated in the preceding section for standard setting in the field of artificial intelligence is also apparent in Germany and Europe. This section delves deeper into the primary levers and their interplay. Figure 7 provides a concise summary.

DIN/DKE/NA 043-01-42 GA, the DIN/DKE joint working committee artificial intelligence, is a subcommittee of DIN NIA], the DIN Standards Committee on Information Technology and selected IT applications which develops standards in the IT sector. This German JWG on artificial intelligence mirrors on a German national level the CEN/CLC JTC 21 (European level) as well ISO/IEC JTC 1/SC 42 (international level). **CEN-CLC/JTC 21** [38] shall produce standardization deliverables in the field of artificial intelligence and related use of data, as well as provide guidance to other technical committees concerned with artificial intelligence. The JTC 21 shall also consider the adoption of relevant international standards and standards from other relevant organizations, like ISO/IEC/JTC 1 and its subcommittees, such as SC 42 Artificial Intelligence. Furthermore, the JTC shall produce standardization deliverables to address European market and societal needs and to underpin primarily EU legislation, policies, principles, and values – in this context the currently open standardization requests from the European Commission towards implementing standards for the upcoming European Artificial Intelligence Act. **ISO/IEC/JTC 1/SC 42** [39] serves as the focus and proponent for JTC 1's standardization program on artificial intelligence and provides guidance to JTC 1, IEC, and ISO committees developing artificial intelligence applications.

The **Standardization Council Industrie 4.0 (SCI4.0)** [40] pursues the goal of initiating digital production standards in Germany and coordinating them nationally and internationally. In 2016, the German industry announced the founding of the Standardization Council Industrie 4.0, an initiative originating from Bitkom[3], DIN, DKE/VDE, VDMA[4], and ZVEI[5], with the aim of initiating standards for digital production and coordinating them nationally and internationally. Nowadays, SCI4.0 serves as a neutral coordination, orchestration, and consultancy body for industry, academia, and politics regarding strategies and the operational execution of innovation processes and standardization activities on national and international levels. The **STD 1941.0.8 Expert Board on Artificial intelligence in Industrial Applications hosted by SCI4.0** serves as a coordinative technical committee to identify needs on future standardization activities on artificial intelligence in IM/I4.0. By that, the technical committee contributed to various national standardization roadmaps, e.g., on Industrie 4.0 or on artificial intelligence. Furthermore, implementing, following up, and initiating essential activities and projects for the implementation of the AI strategy, as described in the national standardization roadmaps, is a critical mission of this organization.

[3] Bitkom e.V. is the industry association for the German information and telecommunications sector.
[4] VDMA e.V. is an industry association of the German and European machinery and plant manufacturers.
[5] The ZVEI is an industry association of the German electrical and digital industries.

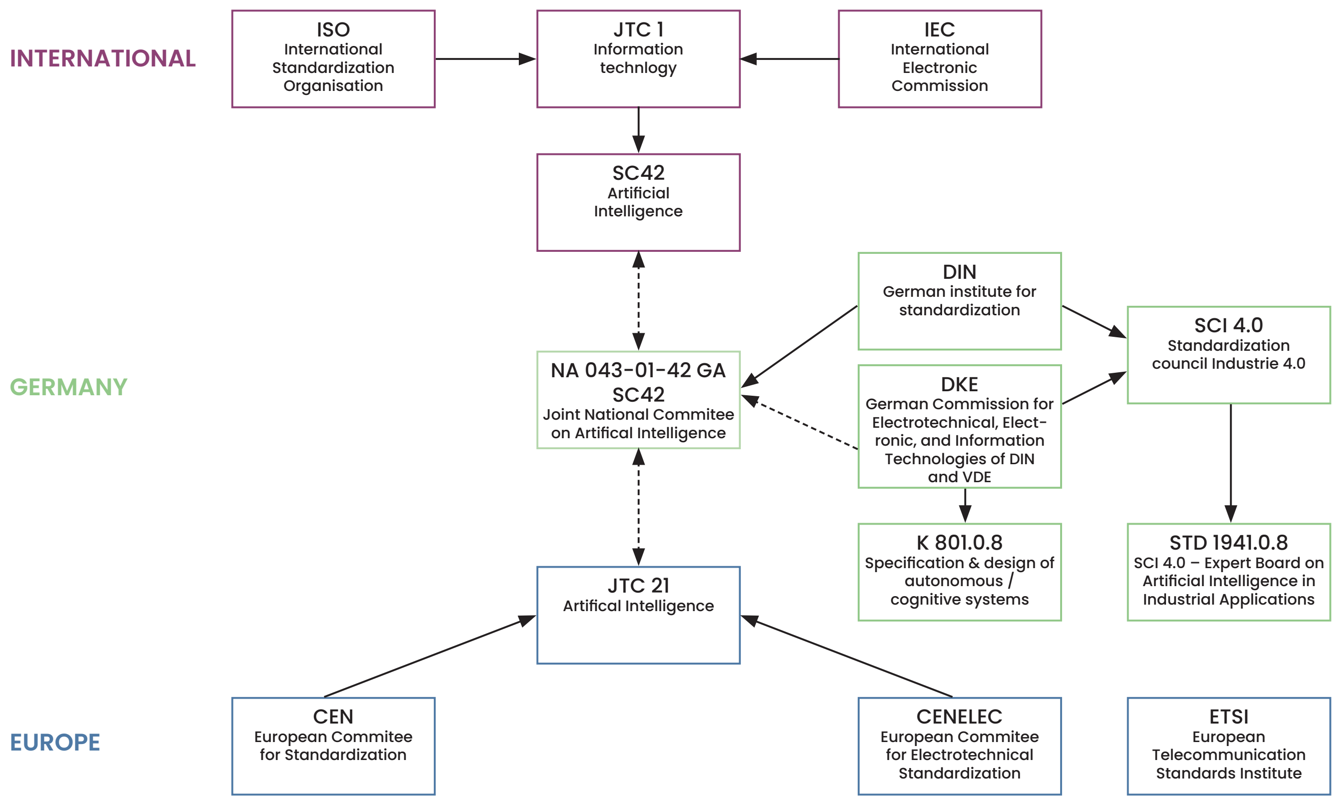


Figure 7: Relationship between European and German (national) committees on Artificial Intelligence Standardization

Beyond these committees focusing exclusively on AI, various further standardization groups are addressing aspects of artificial intelligence within the respective area of interest, e.g., the specification and design of autonomous/cognitive systems (**DKE/AK 801.0.8**) or functional safety of electrical, electronic, and programmable electronic systems (**DKE/GK 914**). A huge variety of further standardization committees dealing with aspects of artificial intelligence in their respective scopes exist but a comprehensive overview of them is beyond the scope of this report.

Additionally, various industrial consortia, associations, and societies deal with selected aspects on artificial intelligence, e.g., digital twins for data provisioning, simulation models for data synthesis, etc., and develop and publish specifications and consortia standards. An overview of these activities is left for future work.

3.3 Standardization Strategy on Artificial Intelligence in Germany and Europe

Due to the highly distributed nature of standardization activities in Europe and Germany, various stakeholders, e.g., industrial experts and political and regulatory bodies, demand a structured overview of current (development and standardization) activities with a focus on specific applications, topics, methodologies, and challenges. Accordingly, some standardization roadmaps with different focuses have been developed and revised frequently by industrial and academic experts. Most of these standardization roadmaps exhibit an intersection of their contents. This is obvious because, not least, these standardization roadmaps ultimately investigate the identical reality from different perspectives and different viewpoints.

The aim of the standardization roadmaps is to describe at an early stage a framework for action that will strengthen the national industry and science in the competition between the best solutions and products and create innovation-friendly conditions for the technology of the future. From the European and German perspective, norms form the basis for technical sovereignty, create a framework that promotes transparency, and provide orientation. Thus, they ensure security, quality, and reliability.

In the remainder of this section, a brief overview of selected standardization roadmaps on German and European levels in the context of Industry 4.0 / Intelligent Manufacturing and artificial intelligence are presented briefly and some major outcomes are summarized, without claim to completeness.

3.3.1 German Standardization Roadmap on Industrie 4.0

The Industrie 4.0 standardization roadmap is one of the central Industrie 4.0 communication media for national and international exchange between standardization, industry, associations, research, and politics. The document serves as a guide for all stakeholders from the various technological sectors and presents the current work and discussion results as well as relevant standards and norms in the field of Industrie 4.0. It outlines the requirements for standardization and provides impetus for successful implementation.

The standardization roadmap Industrie 4.0 is developed by the national technical committee STD 1941.0.1 operated by the Standardization Council Industrie 4.0 (cf. Section 3.2, Figure 7) and jointly published by DIN and DKE. Each new edition builds upon the previous one, using its contents as the foundation. Results from previous iterations are also taken into consideration. Requirements for the future standardization framework are updated based on current developments and findings. Consequently, new requirements and recommendations for action, both short and long term, are derived and described. The recent 5th edition of the Industry 4.0 standardization roadmap [41] was published in 2023 and focuses on achieving interoperability and thus standardized machine-to-machine and human-to-machine communication in networked digital ecosystems. Other key topics are sovereignty as well as environmental and social sustainability.

Artificial intelligence was integrated for the first time in the 4th Edition of the German Standardization Roadmap Industrie 4.0 focusing on the use of AI in industrial applications. The Expert Board on Artificial Intelligence in Industrial Applications (STD 1941.0.8, cf. Section 3.2) takes a central role in developing standardization roadmaps and their continuous monitoring in the context of artificial intelligence in Industrie 4.0. Alongside its coordination and orchestration responsibilities, STD 1941.0.8 also oversees the development of the normative framework for AI in Industrie 4.0. Content-related and strategic considerations for AI in industrial applications are contributed to national standardization roadmaps, including the Industrie 4.0 standardization roadmap in collaboration with experts from STD 1941.0.1.

The development of the fundamental concept of Industrie 4.0 is evident in the multiple iterations of the standardization roadmap because it reflects the current state of knowledge and aims to provide suggestions for the suitable transformation of the Industrie 4.0 standardization framework. The recent, fifth edition of the Industry 4.0 standardization roadmap strives to establish a digital industrial ecosystem and address the corresponding normative obligations. Thereby, three major objectives – in accordance with the Vision 2030 for Industry 4.0 – are identified, namely interoperability, autonomy, and sustainability. They are detailed in the following.

- **Semantics as a foundation of interoperable digital ecosystems:** Investigations in the context of Industrie 4.0 and the digital transformation of industries have shown that achieving a shared understanding regarding the notion of semantics is challenging due to varying perspectives. These disparities occur because of several factors, such as the distinct contributions of diversified disciplines, including linguistics, philosophy, and computer science, to the comprehension of semantics. Achieving interoperability is a key objective of standardization strategies, requiring a uniform understanding of the role of semantics. This is especially important for efficiently establishing interoperability in digital ecosystems, which provide the foundation for a vast range of data-driven services and functionalities in various industries. In the realm of Industrie 4.0, a plethora of standards exist to facilitate interoperability among systems. Therefore, it is crucial to establish a means by which knowledge can be conveyed, exchanged, comprehended, or processed, utilizing objective and unambiguous descriptors. To achieve this end, a unifying framework of standards for knowledge sharing is imperative.

- **Autonomy of industrial data spaces:** Data spaces are considered a significant driver for the objective of generating additional value from data, while simultaneously ensuring data autonomy, data security, and data integrity for stakeholders. To achieve this aim, data spaces provide participants with secure, trusted transaction zones (security domains), through which data can be accessed, evaluated, and managed collaboratively. Data spaces provide a way to deliver specific value consistently across different examples by offering common technical, legal, and business principles. There are numerous examples in the manufacturing industry where companies are creating additional value through data analysis. Nevertheless, these solutions are forming islands on a data and application level – not yet supporting pervasive data accessibility and a full range of data space characteristics. Achieving this objective on an industrial level requires applying appropriate standards and norms.

- **Social, ecological, and technical sustainability:** Adhering to the socio-technical approach, work systems' design and standardization consider interactions between social and technical components. Such a perspective that is focused on human-centeredness can prevent "technical constraints" that may surface when elements of Industrie 4.0 are introduced without considering standardized aspects and defined specifications of human-centric work design. Fundamental principles of occupational health and safety law must be objectively considered alongside standards for operating, implementing, and evaluating Industrie 4.0 systems centered on human needs. Ecological sustainability and digital transformation are often referred to together as a "double transformation" or "twin transformation," but subjectivity should be avoided when discussing their impact. The European Union and its member states can establish standards for global value chains and digital ecosystems. To effectively carry out the "twin transformation," sustainability components should be digitally documented and accessible as data and information. As a result, there are multiple connections to interoperability and industrial autonomy aspects.

Methods and algorithms from the field of AI are employed for both semantic data modeling and processing. Furthermore, AI autonomy is a crucial component regarding AI regulation. In Industry 4.0, socio-technical considerations play a significant role, highlighting the importance of human oversight and human-centric AI (also in the context of the upcoming AI regulation in Europe). Generally, artificial intelligence plays an important role in facilitating and achieving all three objectives. Thereby, norms and standards are enablers for the trustworthy and beneficial use of AI in industrial automation.

3.3.2 German Standardization Roadmap on Artificial Intelligence

On behalf of the German Federal Ministry of Economic Affairs and Climate Action, DIN and DKE began work on the second edition of the German Standardization Roadmap on Artificial Intelligence in January 2022 and published it in December 2022. More than 570 experts from various fields,

including industry, science, the public sector, and civil society, participated in and contributed to the refinement of the strategic roadmap for AI standardization. This project was led and supported by a specialized, high-level coordination group on AI standardization and conformity.
The standardization roadmap on AI highlights the necessary requirements, provides specific recommendations, and establishes the groundwork for initiating standardization efforts on a national, European, and international level at an early stage. The roadmap significantly contributes to the European Commission's Artificial Intelligence Act by supporting its implementation. The second edition of the German standardization roadmap on AI [42] investigates in detail requirements and necessary actions in the following fields: basic topics, ethics / responsible AI, quality, conformity assessment and certification, IT security and safety in AI systems, industrial automation, mobility and logistics, and AI in medicine. Accordingly, this roadmap covers various topics related to Industrie 4.0 / Intelligent Manufacturing, including security and safety, testing and certification, socio-technical systems, and industrial automation. To ensure consistency among different German roadmaps and avoid duplicating efforts, STD 1941.0.8 (SCI4.0 Expert Board on Artificial Intelligence in Industrial Applications) has been assigned responsibility for all topics related to industrial automation within this standardization roadmap. Additionally, the board is responsible for implementing identified recommendations for action, which can be clustered into five major action fields described in the following:

- **Data reference models for the interoperability of AI systems** Many actors participate in value chains, and for their AI systems to work together automatically, a secure, reliable, and flexible data exchange model is necessary. A comprehensive data exchange is established through data reference model standards from various fields, which guarantee the worldwide interoperability of AI systems.

- **Horizontal AI basic security standard**: AI systems are essentially IT systems. There are already many standards and specifications for IT systems from various application areas. To ensure uniform IT security for AI applications, an overarching "umbrella standard" that combines existing IT standards and test procedures and adds AI-related aspects would be beneficial. Subordinate standards on other topics can supplement this basic security standard.

- **Practical criticality checks of AI systems** When self-learning AI systems make decisions that affect people, their possessions, or access to scarce resources, unintended AI errors can jeopardize fundamental individual rights or democratic values. Thus, to ensure that AI systems can be developed freely in ethically non-controversial fields, designers must create an initial criticality test using established standards and specifications to quickly and legally determine whether an AI system has the potential to cause such conflicts.

- **Strengthen the European quality infrastructure by "Trusted AI":** The absence of dependable quality standards and test protocols for AI systems results in the risk of negatively influencing economic growth and competitiveness. The implementation of a program on "Trusted AI," is an important building block to establish a consistent and reproducible framework for testing AI systems' properties, including reliability, robustness, performance, and functional safety, and make trustworthy assessments. Standards and specifications outline the necessary properties for the certification and conformity assessment of AI systems, without subjective evaluations.
- **Use cases for identification of standardization needs:** AI research as well as the industrial development and application of AI systems are rapidly evolving. Currently, there are numerous AI applications across different fields. The need for standardization in AI applications suitable for industrial use can be identified from use cases specific to each application and industry. It is crucial to integrate reciprocal impulses from research, industry, society, and regulation to shape standards and specifications. Standards that have been developed must be tested and refined using use cases. This approach enables the identification of application-specific requirements at an early stage and the realization of commercially viable AI standards.

The outcome of the Standardization Roadmap AI serves as a precursor to future work and sets the foundation for standardizing artificial intelligence – both on cross-domain-spanning as well as domain-specific standardization (vertical standardization) like industrial automation, energy, and mobility. Implementing these results will aid the support of industry and science, while creating innovation-conducive circumstances for future technologies. These outcomes will notably contribute to the socio-political dialogue on the prospects and use of AI at a European level – especially also in context of the upcoming AI regulation in Europe.

3.3.3 CEN-CENELEC Focus Group Report: Road Map on Artificial Intelligence

As regulatory activities at the European level emerged and the importance of AI in standardization increased, the Focus Group on AI launched in April 2019 as part of European efforts to support CEN and CENELEC in finding ways to develop and diffuse AI in Europe. The group aims to facilitate the process. A significant result of the Focus Group was the publication of the Roadmap on Artificial Intelligence[6] [43] in September 2020 as a component of an outcome report and the first of its kind in Europe.
The Focus Group discussed the following seven themes that have been addressed for European standardization, which are described in detail in the roadmap: accountability, quality, data for AI, security and privacy, ethics, engineering of AI systems, and safety of AI systems.

Based on an analysis of these themes, it was concluded that there is a strong necessity for establishing a dedicated European standardization working group – which has already been implemented by setting up CEN-CLC/JTC 21 (cp. Section 3.2.2). Beyond this organizational aspect, the roadmap highlights that "the physical world is governed by mechanisms that have evolved over centuries" [43, p. 3] which should also be used for the digital world (e.g., data, information, behavior, etc.). Moreover, the implementation of AI standards can aid economic and social stakeholders in facilitating, bolstering, and enhancing such systems in the digital realm. It is critical that ESOs and European NSBs ensure the advantageous impact of AI on citizens and society through standardization. In principle, adhering to and upholding the fundamental values and human rights recognized in Europe and establishing suitable governance of AI throughout the entire system life cycle will help to ensure reliable (strong, safe, secure, etc.) AI to enhance European competitiveness and provide benefits for society.

[6] The area of responsibility of Focus Group on AI was transferred to the newly established standardization committee CEN-CLC JTC 21. With the establishment of this committee, the Focus Group on AI ceased its work.

4. OPPORTUNITIES FOR LEVERAGING AI IN MANUFACTURING THROUGH STRATEGIC INTERNATIONAL STANDARDIZATION

Comparing AI standardization activities on IM/I4.0 in Germany and China, most committees and (technical) groups concentrate their standardization activities primarily on general topics of AI, i.e., horizontal standardization. Therefore, minor activities address the development of specific standards for IM/I4.0. As a result, manufacturing-specific requirements are not adequately addressed due to the necessary abstraction of horizontal standardization. Current white papers and guidelines fail to provide a clear direction for standardizing AI in manufacturing.

Current white papers and guidelines do not provide a clear direction for the standardization of AI in manufacturing, although international standardization can act as a lever for a variety of current challenges. Therefore, based on the Chinese and German perspectives presented earlier in this report, this section describes current and common challenges in the application and use of AI in manufacturing that can benefit from international collaboration in standardization.

4.1 General and fundamental challenges

The previous sections of this report provided an overview of technical bodies that are involved in the standardization of AI in China, Germany, and Europe, but also which regulatory frameworks need to be considered when offering products and services in these markets. Thereby, it was particularly important to understand the terms and their meaning to be able to classify the scope. However, as mentioned already in the introduction, there are some challenges regarding a common and uniform definition of artificial intelligence. Therefore, this chapter summarizes general, fundamental challenges related to the consistency of terminology and the regulatory/legal framework. If a common definition and understanding of AI remains an unresolved challenge, standardizing the regulatory framework or at least sharing common ideas is even more difficult. And if a common definition and understanding of AI remains an unresolved challenge, standardizing the regulatory framework will be even more difficult. This can also be seen in a global historical perspective, in a world where tolls and artificial trade barriers are an essential element of doing business and boost local trade.

Challenge 1:
Lack of a widely accepted definition of Artificial Intelligence.

The ISO/IEC 22989 definition of artificial intelligence lacks (up to now) widespread acceptance due to its limited significance and specificity. Multiple normative documents on AI are in development, partly utilizing various alternative definitions of AI resulting in varying scopes. This leads to opaque and partially contradictory definitions, causing inconsistencies between standards. Although there is no universally accepted definition of AI, progress in methods, technologies, and aspects greatly impacts the discussion, definition, and standardization of AI. Nevertheless, the distinct separation and relationship between these constituent aspects of AI remains indistinct and occasionally unclear, resulting in divergent interpretations and applications. Varying definitions used in documents, which might be used in conjunction, result in high levels of complexity when comparing definitions, reason about their relationship, and in case of contradiction and ultimately lead to insurmountable problems.

Challenge 2:
Lack of a unified understanding and definitions of AI systems in manufacturing.

Although ISO/IEC 22989 provides a standardized definition for AI systems, it lacks specific evaluative criteria for their implementation in verticals like manufacturing. This leads to confusion as traditional software systems might be mistakenly classified as AI, despite not employing AI-specific methods like machine learning or natural language processing. Further standardization efforts can help solve this problem by establishing clear criteria and benchmarks, ensuring a consistent understanding and proper classification of AI systems within the manufacturing industry.

Challenge 3:
Government policymaking, regulation, and innovation of artificial intelligence

Due to the rapid progress in the development and application of AI, people may become more and more concerned about human safety and property security. Some countries may issue policies/regulations to limit the development of AI instead of intensifying the crackdown on crimes committed by using AI, and industries will be adversely impacted. The European Union follows a stringent regulation regarding AI, emphasizing trust, transparency, and ethical considerations. German and European standardization is challenged in aligning these regulations while trying to internationally standardize. Despite significant investments in AI research and development, German companies express some concerns that the EU's AI regulation might hinder innovation by imposing restrictive standards that are difficult to meet [44]. In contrast, China's overall direction and the government implementing policies focus on fostering AI development and application while managing risks and a reduced notion of privacy. China's AI standards are designed to support rapid innovation and economic growth trying to balance data security and transparency to mitigate political and social risks. Germany's AI strategy, which includes substantial funding and infrastructure investments, aims to achieve technological sovereignty and reduce dependence on external powers. However, the stringent regulatory environment may impede the effective transfer of research findings into practical applications, which is a critical weakness identified by industry associations. China has implemented robust and strict regulations to control the use of AI, but these are primarily focused on political stability and social control rather than economic restrictions. The Chinese regulatory framework allows Chinese companies to innovate rapidly and compete effectively on the global stage. However, it also raises concerns about privacy, surveillance, and the ethical implications of AI deployment. In a nutshell, the heterogeneity of regulatory frameworks and varying opportunities for the research, development, and use of AI poses a global challenge. The need for a deep, fundamental understanding of the regulations and protection goals of different economic areas makes international exchange, common rules, and standards difficult. This may result in unequal opportunities for AI development across the globe, a lack of equality, and disadvantage in global competition in international markets.

4.2 Availability of AI-ready data in manufacturing

In the rapidly evolving landscape of industrial AI, the challenges surrounding data availability, quality, and sharing present significant hurdles that hinder the widespread application and effectiveness of AI technologies in manufacturing. These challenges stem from the inherent complexities in collecting and managing data from diverse manufacturing environments, where inconsistencies in data formats and security concerns can severely limit the potential of AI. Addressing these issues through international standardization offers a promising avenue to enhance the reliability, security, and utility of industrial data, thereby supporting the broader integration of AI into manufacturing processes.
Data sharing within the industry can be leveraged to solve these challenges, and facilitate the availability of adequate and qualitative data, but concerns over enterprise data security which restrict the sharing of data. Standardization can help by creating frameworks for secure data sharing and collaboration among orga-

nizations. Initiatives like digital twins / AAS [45], [46] industrial cloud federation [47], industrial data spaces, GAIA-X, manufacturing-X, and approaches like federated learning aim to address privacy and scalability concerns by allowing collaborative model training while preserving data security. Effective AI standardization can facilitate these efforts and accelerate the adoption of AI in manufacturing by resolving data sharing and security issues.

Challenge 4:
Lack of availability and quality of industrial data

For a single manufacturing process, devices from different manufacturers typically produce disparate or inconsistent data. The structure of this data often does not meet the requirements of most AI algorithms, restricting data availability. As a result, extensive data pre-processing is necessary to ensure the quality of sample data for model training. Labeling raw data requires expert understanding of the manufacturing scenario, as it can be difficult to differentiate between condition and defect data. This complexity poses a challenge for AI standardization in regulating human input. Standardization must incorporate various dimensions of data quality monitoring and optimization to enhance the performance of industrial AI applications. Thus, the availability, quality, and quantity of industrial data become fundamental obstacles, and standardization can help mitigate these issues to support the pervasive application of AI in the industry.

Challenge 5:
Insufficient data for model training

Training machine learning and deep learning models requires extensive and varied datasets to ensure accurate results and avoid overfitting. However, in manufacturing settings, collecting sufficient data on rare events, such as equipment malfunctions or product defects, is often challenging. Gathering comprehensive data across different parameters and conditions within a limited time frame would be difficult, too.

4.3 Core technologies for AI in manufacturing

The integration of AI in manufacturing holds great promise for improving operational efficiency and innovation. However, several challenges must be addressed to fully realize this potential. Deploying AI across distributed environments and ensuring consistent quality of AI systems are significant obstacles. These challenges are compounded by the need for seamless interoperability between cloud and edge systems, as well as the difficulty of establishing clear and universal testing standards for AI performance. International standardization is emerging as a critical solution to overcome these barriers, enabling more effective and reliable deployment of AI technologies across the manufacturing sector.

Challenge 6:
Lack of flexible, interoperable distributed deployment of AI in manufacturing

In manufacturing, many devices are deployed in the field or on the edge, while machine learning models are typically generated and trained in the cloud due to extensive computational needs. The challenge is to scale down these models for effective edge deployment and maintain synchronization between edge and central models. Cloud-edge collaboration and distributed AI systems face hurdles due to immature technology, a lack of standardized protocols, and security concerns. Additionally, current systems are not scalable enough to handle large-scale AI applications across multiple platforms.

Standardization can help to address these challenges by ensuring compatibility and interoperability between diverse systems and components. Developing standards for distributed AI deployment and security protocols will facilitate seamless cloud-edge integration, protect data, and mitigate security risks. This will enable more efficient and scalable AI systems, fostering innovation and improving operational efficiency in the manufacturing sector.

Challenge 7:
Unclear quality requirements and testing methods of AI systems in manufacturing

In manufacturing, AI systems must integrate with various operational systems, such as enterprise resource planning and manufacturing execution systems, supervisory, process and line management systems, or quality management systems, which require compliance with accuracy, recall, interoperability, integration, and interconnection standards. Furthermore, many AI systems feature customized modules based on specific customer needs, complicating performance testing for both suppliers and customers. The rapid evolution of AI technology often outpaces the development of standardized testing methods and legal frameworks, making it difficult to create consistent quality and testing standards across diverse applications.

Standardization can address these issues by establishing clear quality requirements and standardized testing methods for AI systems in manufacturing. By developing universal benchmarks for accuracy, recall, and interoperability, standardization can help ensure that AI systems meet consistent performance criteria. Additionally, creating standardized testing protocols will assist suppliers and customers in evaluating AI system performance effectively. Harmonizing these standards across regions can also facilitate the development of a cohesive legal and regulatory framework, enabling more reliable and widespread adoption of AI in manufacturing.

4.4 Challenges related to industrial application of AI

As AI becomes increasingly integral and pervasive in manufacturing processes, the industry faces several challenges that hinder its full potential. These challenges stem from the high reliability requirements and the difficulty of adapting AI models to diverse and complex industrial scenarios, which can cover any aspect of continuous processes, vision systems, robotics, automation science, sensor and actuator technology, etc. Uncertainty about the benefits of AI due to stringent requirements and complex, heterogeneous scenarios, and the limited ability to reuse and generalize AI models across (mostly heterogeneous) systems, processes, and scenarios, are particularly pressing issues. Addressing these barriers through international standardization offers a way to unlock the true value of AI in manufacturing, ensuring that AI systems are both effective and adaptable across different applications.

Challenge 8:
Undetermined benefit due to high requirements

The potential benefits of AI for productivity, efficiency, and cost savings in manufacturing are not fully understood due to the significant demands for reliability and safety. High variation and complexity in automation systems, coupled with frequent human intervention, result in stringent requirements for resilience. These requirements are often unmet by current technologies, especially in the absence of sufficient qualitative and quantitative training data. Manufacturing companies aim to enhance core KPIs to maintain competitiveness, often relying on traditional control and sensor systems for their robust performance in critical scenarios. However, non-significant scenarios may not derive enough benefits from implementing an AI system. Standardization can help by clarifying and verifying the fundamental issues across sub-verticals, enabling a more accurate assessment of AI's benefits.

Challenge 9:
Difficulty reusing AI models and insufficient generalization ability of AI systems.

In the manufacturing sector, the complexity and variety of industrial scenarios make it challenging to reuse AI models. Even within the same industry and process, external environmental factors like temperature and humidity can affect the accuracy of AI models, necessitating customization for each specific scenario. This limits the ability to reuse standardized AI models. Additionally, different algorithm engineers may propose varying solutions based on their experience, further complicating standardization. Industrial AI demands high stability and accuracy, as errors can impact the entire production line, making it difficult to establish fixed model selection guidelines.

Standardization can mitigate these challenges by promoting the development of modular and interoperable AI components that can be easily customized and integrated into diverse industrial applications. Standardizing data formats, structures, and vocabularies across industries will facilitate the reuse of AI models, enhancing their generalizability and reliability. This approach will support the creation of robust AI solutions that maintain high accuracy and stability, regardless of varying external conditions.

4.5 Data security and application of generative AI

In the manufacturing sector, the integration of advanced industrial AI faces significant hurdles, particularly in areas such as data security, data sharing, and the deployment of generative AI. These challenges are compounded by the need for robust datasets to train AI models, the complexity of integrating AI with existing manufacturing systems, and the reluctance of companies to adopt new technologies due to concerns about cost, security, and compatibility. Addressing these issues is crucial for harnessing the full potential of AI in manufacturing, and international standardization offers a strategic path forward. By establishing clear guidelines and frameworks, standardization can facilitate secure data sharing, enhance the interoperability of AI systems, and promote the widespread application of AI technologies across the industry.

Challenge 10:
Industrial data security and sharing of production data

The model training process of both machine learning and deep learning requires large amounts of diverse data to ensure proper generalization and avoid overfitting. However, a common problem in real-world manufacturing environments is the lack of sufficient low-frequency event data, such as equipment failures and product defects. In these scenarios, it is difficult to collect data under different settings, conditions, and configurations in a short period of time. Sharing data within the same industry is the first choice to improve model performance. However, corporate data security as well as reservations due to intellectual property protection prevents data from leaving the private domain for global model training.

AI standardization must not only focus on a single organization, but also consider the specifications of cooperation between multiple organizations. How to promote data sharing under the different security regulations of different enterprises is a major challenge. Recently, federated learning has been proposed to alleviate privacy and scalability issues by distributing the model training process among multiple industry nodes. Through this novel technique, these cooperative parties only need to share local model parameters with each other to jointly build the model, instead of exposing sensitive private data samples.

Challenge 11:
Lack of a widespread application of generative AI in manufacturing

Despite the rapid advancement and widespread adoption of generative AI in fields such as marketing, sales, and creative industries, its application in manufacturing remains limited. While generative AI has significant potential to transform manufacturing processes, several challenges have hindered its widespread adoption. Integrating generative AI into manufacturing systems presents complex technical and organizational barriers that many companies, especially small and medium-sized enterprises (SMEs), struggle to overcome. One of the primary challenges is the complexity of integrating AI technologies with existing manufacturing infrastructure and organizational processes. Many manufacturing plants operate with legacy systems that are not easily compatible with modern AI. Upgrading or replacing these systems can be costly and time-consuming, creating a significant barrier to adoption. In addition, the traditional nature of many manufacturing organizations often leads to resistance to change. Entrenched practices and skepticism about the tangible benefits of AI contribute to slow adoption, especially in industries where precision and reliability are paramount. Generative AI models face unique challenges related to accuracy and reliability. In manufacturing, where precision and quality are critical, any errors or unexpected results generated by AI models can lead to significant operational problems or even safety hazards. This risk is particularly concerning for manufacturers in regions such as Germany, where stringent quality standards are a priority. In addition, the development and deployment of generative AI requires significant computing resources, which is another challenge, especially in areas where energy consumption and data center regulations are stringent.

International standardization offers a promising way to address these challenges by providing a framework that can facilitate the broader adoption of generative AI in manufacturing. Standardization can help bridge the compatibility gaps between legacy systems and new AI technologies, making integration more feasible and cost-effective. It can also encourage the development of interoperable AI tools and systems, ensuring that different AI applications can work together seamlessly across different manufacturing processes. In addition, establishing standardized data formats and structures would improve data quality and accessibility, increasing the reliability and accuracy of AI models. By addressing these challenges through standardization, the manufacturing industry can unlock the full potential of generative AI to drive innovation, efficiency, and competitiveness.

5. SUMMARY

Both China and Germany are striving for the technological development and application of AI, with each nation pursuing ambitious goals to establish itself as a global leader in the field. China's strategic plans aim to position the country as a global AI innovation hub by 2030. Similarly, Germany's AI Action Plan, backed by significant investments in research and infrastructure, aims to elevate the country's status as an AI leader within the EU and globally. However, Germany faces challenges due to the slow implementation of its AI strategies and a restrictive regulatory environment.

The inherently global nature of AI underscores the need for international collaboration and harmonization of standards, typically achieved through international standardization. It's critical to recognize the different legal and regulatory frameworks that influence AI and their impact on global standardization efforts. These differences can lead to fragmented standards in different countries and markets. It is therefore essential that these standards are concrete iterations of international agreements, aiming for the broadest possible consensus. This approach will strengthen economic and scientific cooperation and prevent unnecessary barriers to the exchange of goods, services, and knowledge.

To address these challenges, China and Germany can work together in several key areas:

- **Joint research initiatives:** By establishing joint research programs, both countries can leverage their strengths. Germany's emphasis on ethical AI can complement China's rapid innovation capabilities, leading to advances that are both cutting-edge and ethically responsible.

- **International standards development:** Collaborating on the development of international AI standards can help harmonize regulations and reduce barriers to innovation. Joint participation in international AI governance forums and standard-setting bodies can ensure that both nations contribute to shaping a consistent regulatory framework.

- **Data-sharing agreements:** Developing secure and ethical data-sharing frameworks can greatly enhance AI research and development. By pooling their data resources, China and Germany can improve the quality and accuracy of AI models to the benefit of both countries.

In the context of AI integration in manufacturing, China and Germany can maximize their strengths through strategic cooperation. Joint research and development initiatives can accelerate the development of AI applications in manufacturing. Germany's strong engineering and manufacturing expertise can benefit from China's rapid technological progress, while China can leverage Germany's deep knowledge of manufacturing. In addition, collaboration on international AI standards specific to manufacturing can create a unified framework that ensures easier integration and interoperability of AI systems across borders. This will allow technologies to be applied consistently and effectively in different manufacturing environments. Addressing the AI skills gap is another area where collaboration can be beneficial. Co-sponsored training programs and exchange initiatives can provide manufacturing professionals in both countries with the education and hands-on experience needed to effectively implement and manage AI systems. This collaborative approach will help develop a skilled workforce proficient in the latest AI technologies, and drive innovation and competitiveness in the manufacturing sector.

Finally, creating secure and ethical data-sharing agreements is critical to advancing AI research and development. By establishing frameworks that facilitate the secure sharing of data, China and Germany can accelerate the development of robust AI models that benefit both nations, and lead to greater efficiency, innovation, and global competitiveness in manufacturing.

6. BIBLIOGRAPHY

[1] ISO/IEC 22989:2022 - Artificial intelligence – Artificial intelligence concepts and terminology, 2022

[2] Cybersecurity technology labeling method for content generated by artificial intelligence, 20241842-Q-252, Jun. 2024. [Online]. Available: https://bit.ly/3zLj0gK

[3] Interim Measures for the Management of Generative Artificial Intelligence Services. Cyberspace Administration of China, National Development and Reform Commission, Ministry of Education, Ministry of Science and Technology, Ministry of Industry and Information Technology, Ministry of Public Security, National Radio and Television Administration, 2023. [Online]. Available: https://bit.ly/3ZS3Pgc

[4] The Position Paper of the People's Republic of China on Strengthening Ethical Governance of Artificial Intelligence (AI). Ministry of Foreign Affairs, 2022. [Online]. Available: https://bit.ly/3zCnuX3

[5] "State Council 2023 Legislation Work Plan." [Online]. Available: https://bit.ly/4h51btU

[6] "Circular of the State Council on Printing and Issuing the Plan for Development of the New Generation of Artificial Intelligence." [Online]. Available: https://bit.ly/4gRpZ8t

[7] Three-Year Action Plan for Promoting the Development of Next Generation of Artificial Intelligence Industry (2018-2020). MIIT, 2017. [Online]. Available: https://bit.ly/3ZZRlxA

[8] Interpretation of the Three-Year Action Plan for Promoting Development of a New Generation Artificial Intelligence Industry (2018-2020). MIIT, 2017. [Online]. Available: https://bit.ly/3Ycz4Bp

[9] "Standardization Law of the People's Republic of China." [Online]. Available: https://bit.ly/3TUcBqg

[10] "Introduction of the National Intelligent Manufacturing Standardization Group." [Online]. Available: https://bit.ly/4dDoEPV

[11] "The National Artificial Intelligence Standardization General Group and the Expert Advisory Group were established." [Online]. Available: https://bit.ly/3BsACOM

[12] "Introduction of subcommittee of AI SAC/TC 28/SC 42." [Online]. Available: https://bit.ly/3ZSKBY3

[13] "Cybersecurity Standards Practice Guidelines -Guidelines for the Prevention of Ethical Security Risks of Artificial Intelligence," Jan. 2021. [Online]. Available: https://bit.ly/4exngj5

[14] "Introduction of Technical Committee for Measurement Control and Automation of Industrial Processes (SAC/TC124)." [Online]. Available: https://bit.ly/4dF365g

[15] "Introduction of Technical Committee for Industrial Automation Systems and Integration (SAC/ TC159)." [Online]. Available: https://bit.ly/3BvxySf

[16] "Introduction of National Technical Committee for Communication Standardization (SAC/TC 485)." [Online]. Available: https://bit.ly/47UFcBy

[17] "Introduction to China Electronics Industry Standardization Technology Association." [Online]. Available: https://bit.ly/3TUcYRG

[18] "CCSA (China Communications Standards Association)." [Online]. Available: https://www.ccsa.org.cn/english/

[19] "Implement the government's strategic deployment and accumulate high-energy for industrial development The preparatory meeting of the Chinese Artificial Intelligence Industry Development Alliance was successfully held." [Online]. Available: https://bit.ly/3BxdqPH

[20] "CIMSIC (Intelligent Manufacturing System Integrator Consortium)." [Online]. Available: https://bit.ly/4eR9esh

[21] Vocational Skill Requirements and Evaluation for Artificial Intelligence Engineers Part 1: Computer Vision, T/CCUA 009-2020, Nov. 2020. [Online]. Available: https://bit.ly/3NciFXx

[22] "Shanghai Artificial Intelligence Standards Committee." [Online]. Available: http://www.sh-ais.com

[23] "Chinese Association for Artificial Intelligence." [Online]. Available: https://bit.ly/3Ya5j4a

[24] "Zhongguancun Shuzhi Artificial Intelligence Industry Alliance." [Online]. Available: https://bit.ly/4h8aFoj

[25] National Guideline on AI Standardization. 2020. [Online]. Available: https://bit.ly/3NhTMcZ

[26] "Notice of the four departments on printing and distributing the guidelines for the construction of a comprehensive standardization system for the national artificial intelligence industry (2024 edition)." [Online]. Available: https://bit.ly/3NaYAkm

[27] National Guideline on Intelligent Manufacturing Standardization (2018). MIIT, SAC, 2018. [Online]. Available: https://bit.ly/3TZCCEz

[28] National Guideline on Intelligent Manufacturing Standardization (2021). MIIT, SAC, 2021. [Online]. Available: https://bit.ly/3YgdH2o

[29] Artificial Intelligence Safety Standardization White Paper (2023). SAC TC 260, 2023. [Online]. Available: https://bit.ly/3Ya79lJ

[30] Artificial Intelligence Standardization White Paper (2021 Edition). China Electronics Standardization Institute, 2021. [Online]. Available: https://bit.ly/3NbNdZv

[31] Basic Law for the Federal Republic of Germany. Accessed: Aug. 30, 2024. [Online]. Available: https://bit.ly/3NeOz5B

[32] "REGULATION (EU) 2017/ 745 OF THE EUROPEAN PARLIAMENT AND OF THE COUNCIL - of 5 April 2017 - on medical devices, amending Directive 2001/ 83/ EC, Regulation (EC) No 178/ 2002 and Regulation (EC) No 1223/ 2009 and repealing Council Directives 90/ 385/ EEC and 93/ 42/ EEC," vol. 60, no. L 117, pp. 1–175, May 2017.

[33] "REGULATION (EU) 2024/1689 OF THE EUROPEAN PARLIAMENT AND OF THE COUNCIL of 13 June 2024 laying down harmonised rules on artificial intelligence and amending Regulations (EC) No 300/2008, (EU) No 167/2013, (EU) No 168/2013, (EU) 2018/858, (EU) 2018/1139 and (EU) 2019/2144 and Directives 2014/90/EU, (EU) 2016/797 and (EU) 2020/1828 (Artificial Intelligence Act)," no. 1/144, Jul. 2024, Accessed: Aug. 30, 2024. [Online]. Available:https://bit.ly/3YaQ9vG

[34] "DIRECTIVE 2006/42/EC OF THE EUROPEAN PARLIAMENT AND OF THE COUNCIL of 17 May 2006 on machinery, and amending Directive 95/16/EC," no. L 157/24, Jun. 2006, [Online]. Available: https://bit.ly/4gQVCiz

[35] "Vienna Agreement Establishing an International Classification of the Figurative Elements of Marks," Accessed: Aug. 30, 2024. [Online]. Available: https://bit.ly/3zJzLZJ

[36] IEC - CENELEC Agreement on Common planning of new work and parallel voting: IEC-CENELEC Frankfurt Agreement, Oct. 2016. Accessed: Aug. 30, 2024. [Online]. Available: https://bit.ly/3zJzOon

[37] "REGULATION (EU) No 1025/2012 OF THE EUROPEAN PARLIAMENT AND OF THE COUNCIL of 25 October 2012 on European standardisation, amending Council Directives 89/686/EEC and 93/15/EEC and Directives 94/9/EC, 94/25/EC, 95/16/EC, 97/23/EC, 98/34/EC, 2004/22/EC, 2007/23/EC, 2009/23/EC and 2009/105/EC of the European Parliament and of the Council and repealing Council Decision 87/95/EEC and Decision No 1673/2006/EC of the European Parliament and of the Council," Nov. 2012, [Online]. Available: https://bit.ly/3ZUguzb

[38] "CEN/CLC/JTC 21 'Artificial Intelligence' Work Programme." Accessed: Aug. 30, 2024. [Online]. Available: https://bit.ly/4dCYb50

[39] "ISO/IEC JTC 1/SC 42 'Artificial intelligence.'" [Online]. Available: https://bit.ly/4dF3r82

[40] "Standardization Council Industrie 4.0: The Address for future of standardization." [Online]. Available: https://www.sci40.com/english/

[41] German Standardization Roadmap Industrie 4.0, 5th ed. DIN e.V. & DKE German Commission for Electrical, Electronic & Information Technologies. Accessed: Aug. 30, 2024. [Online]. Available: https://bit.ly/4dARNeg

[42] W. Wahlster and C. Winterhalter, Eds., German Standardization Roadmap on Artificial Intelligence, 2nd ed. DIN e.V. & DKE German Commission for Electrical, Electronic & Information Technologies.

[43] "Road Map on Artificial Intelligence (AI)," CEN-CENELEC Focus Group, Sep. 2020. Accessed: Aug. 30, 2024. [Online]. Available: https://bit.ly/3zCor1z

[44] "The EU AI Act - Towards the finish line: Key issues and proposals for the trilogue negotiations," German AI Association, Position Paper, Jul. 2023. Accessed: Aug. 30, 2024. [Online]. Available: https://bit.ly/3ZQ2o1N

[45] Asset Administration Shell for industrial applications, international standard 63278 series, Dec. 2023.

[46] "ISO/IEC JTC 1/SC 41 'Internet of Things and Digital Twin' - Convenor & Members." Accessed: Aug. 30, 2024. [Online]. Available: https://bit.ly/4dzuqlE

[47] Reference architecture for Industrial Cloud Federation, SPEC 92222, Dec. 2021. Accessed: Aug. 30, 2024. [Online]. Available: https://bit.ly/4dvlKvm