Developments in demonstrations, tests and standardization
Executive summary report



On 21-22 November 2024, the IEA Experts Group on R&D Priority-setting and Evaluation (EGRD) organized a hybrid workshop on developments in demonstrations, tests and standardization in cooperation with the Technical University of Denmark.

The workshop raised three questions:

1. How can standards support and accelerate technological development and vice versa, in particular in the demonstration and deployment stages?
2. What lessons can be learned from different examples of technology, and can such lessons be transferred to other technological areas?
3. What can the IEA's Technology Cooperation Programmes do to strengthen the necessary knowledge creation from reference cases and recommended practices to the international standardization committees and vice versa?

The energy transition relies on widely accepted international standardization systems that adequately reflect countries' policy priorities and values regarding the creation of affordable, secure and safe energy systems. International standards play a crucial role in an interconnected world and help make the development, manufacture and supply of goods and services safer, reliable, more efficient, cost-competitive and sustainable.

Standards are ideally based on sound knowledge-creation processes and quality assurance throughout the entire innovation system, from research to commercialization. Standards help researchers and innovators bring their research closer to the market and spread technological advances by establishing uniform criteria and by developing methods, practices and procedures. Standards offer a basis for the

integration of diverse technologies into complex, innovative systems and solutions, and enable interoperability between components, products and services. Standards ensure that products and services meet safety, reliability and quality criteria, setting minimum safety requirements to the development, transport and use of technologies and services, and protecting the public and workers. By harmonizing technical specifications, standards make industries more efficient and make trade between countries easier and more competitive because the same specifications are adopted for use in different countries as national or regional standards. Standards contribute by promoting good regulatory practices and reducing the technical barriers to open up international trade.

In the IEA's technology cooperation programmes, experts work to advance the research, development and commercialization of energy technologies by sharing knowledge, identifying best practises and developing recommended practices in new technology areas in which international standards have not yet been developed. In the many international standardization committees such as the ISO or IEC, experts from industry and academia work collectively to develop standards in rapidly developing areas of technology that rely on state of the art knowledge on demonstrations, tests and measurements. These two communities do not necessarily have well-aligned interests, possibly leaving overlaps or gaps in knowledge.

Key observations and recommendations from workshop presentations and discussions:

Standards matter, but are challenging to develop. The experts emphasized the importance of knowledge-based international standards for new energy technologies that represents state of the art. However, they also observed the challenges of developing stackable standards for technologies and integrated energy systems characterized by complexity, interoperability, connectivity and competition. Third-party certification based on assessments of compliance with international standards is an indispensable part of the overall international quality-assurance process. It is based on transparency, stakeholder involvement, rigorous processes and peer assessment.

Pre-normative research a prerequisite for standards. The experts noticed the strong relationship between pre-normative research and standards. Standards are the result of negotiations among different interests – technological, industrial and national – in which pre-normative research provides widely acknowledged scientific advice to the standardization process. The acceleration of technological development may surpass the standards, but proper tests, demonstrations and standards for these steps help compensate for possible disproportionalities.

Standards take time, requiring resources and incentives. The development of standards and the work of international standardization committees take time, much time, and resources. Some researchers are involved in standardization work, but in general recognition and more incentives, including financial incentives to cover fees, travel and working hours, are needed to engage more researchers in this work. While some experts hold that the most interested industry or other body should pay for such engagement, other experts considered that research impacts should be integrated into funding schemes. A combination of various funding streams seems to be an obvious route in this respect.

The different technology readiness levels and standards. A variety of energy technologies were presented and discussed at the workshop, including wind energy and other variable energy sources, CCS, electrolyzers, storage, and smart and hybrid energy systems. Common to all these technologies is the fact that standards play a role in their development and implementation and that these standards are developed in international committees governed by communities of the willing, consensus and agreed processes and procedures. Some are well founded in a set of standards that are regularly updated, while others – especially integrated systems – are exploring which standards to adopt and which to develop.

Robust governance structure for complex systems. The experts observed that the increasing complexity of the energy system, the need for interoperability, the combination of new and existing standards, and the engagement of highly specialized experts require robust governance arrangements beyond international standardization committees and bodies.

IEA TCPs provide an ideal framework for pre-normative research. The experts found that the IEA, with its well-established and legally strong framework, is an ideal platform for joint research and pre-standardization work. Some excellent examples were mentioned, such as ISGAN SIRFN, IEA Wind TCP and IEA Storage TCP. Collaboration in this framework needs to be strengthened and adequately valorised.

Several TCP tasks include activities on market uptake and providing input to international standards, often as open access recommended practices, reference cases or guidelines. The experts recommended the that TCPs continue to concentrate on developing best practises and reference cases and provide this knowledge to international standardization and certification bodies. In this respect, the IEA's Recommended Practices may also need a general re-definition to serve officially as both pre-standard aids and implementation aids for standards.

Better liaison mechanisms between IEA TCPS and international standardization committees. Today there is some liaison between TCPs and the IEC (e.g. solar, wind and marine), as well as ISO (e.g. CCS), but better mechanisms are needed that go beyond the IEC list (IEC Organizations with TC/SC liaisons > IEA: List of TC/SCs Liaisons). The liaisons should not only be extended to take place on the Technical Committee level, but also be used to invite TCP experts to participate in working groups and project teams. The experts recommended the TCPs exchange lessons learned and best practices within their TCPs and across the TCPs concerning interfaces, interactions and cooperation with international standardization committees. The IEA Wind TCP task 51 Forecasting had developed such good practice with IEC SC8A.

The workshop was organized into **four distinct sessions**, together with an **introductory session** and a **concluding session**. All presentations are available at: IEA Experts Group on R&D Priority-setting and Evaluation Workshop - Event - IEA.

In the **introductory session**, **Ignacio Martí**, Head of the wind energy materials and components division, DTU Wind, welcomed the participants to the DTU Risø Campus. He stressed the significance of standards in technological development and the energy transition and mentioned that the participants would visit DTU facilities and highlighted the role of these facilities in enabling knowledge transfer and the development of standards. He explained the essential role of standards in ensuring reliable, safe, secure, affordable and sustainable energy systems and helping to reduce risks and signal market readiness, thus facilitating quicker adoption of innovations. The presenter highlighted the significant role of the IEA Wind TCP in developing standards through international collaboration and consensus. He mentioned that recommended practices developed by the IEA Wind TCP have influenced the development of standards globally and emphasized the importance of knowledge transfer within the IEA family of TCPs, which includes many technologies, in order to speed up learning processes and facilitate the adoption of best practices across different areas of technology.

Christian Bay-Andersen, Deputy Director, Danish Ministry of Climate, Energy and Utilities, gave a speech about the role of technologies in the Danish energy transition. He presented Denmark's approach to achieving its climate targets, focusing on strategic planning, technology identification and overcoming barriers. He outlined Denmark's ambitious goals, including a 70% reduction in emissions by 2030 compared to 1990 levels, and an indicative target of a 50-54% reduction by 2025. He emphasized the importance of forward planning to ensure timely sectoral decisions and the implementation of appropriate solutions. He also highlighted the need to identify relevant technologies for each sector, assess their potential to reduce greenhouse gas emissions, and address implementation barriers. Finally, he listed the priorities for renewable energy, comprising increased electrification, supplying Europe with green and secure energy, and ensuring security of supply.

Session 1. Setting the scene

Maria Skou, Director, Dansk Standard, talked about why standards matter for the energy transition. She described getting started with a standardization process and emphasized that standards are essential for ensuring market access by helping products meet regulatory requirements and gain market acceptance. Additionally, she underscored the importance of standards in ensuring interoperability between different systems and technologies, which is crucial for the successful implementation of new solutions in the energy sector. The presenter highlighted the significant growth and integration of the wind industry with other energy sources and new technologies and emphasized the increasing complexity and the importance of standards in this sector, especially with rising sustainability considerations and European legislation. She noted that research and innovation, coupled with standardization, are crucial for market access and expressed hopes of seeing similar advances in the future in quantum computing technology, space technology and bio-solutions.

The following discussion touched upon the problem of researchers often lacking the incentive to engage in standardization because it does not advance their academic careers. However, close collaboration

with industry and having dedicated personnel working on innovation and standardization may help bridge this gap. Compromises are often necessary in standardization. Standards are developed through a coalition of willing participants, and if key stakeholders are not involved, the resulting standards may not be ideal. The process can be slow and sometimes results in substandard outcomes. However, there are mechanisms for reviewing and revising standards when necessary. Increasing resources, especially for research input, and ensuring balanced stakeholder involvement can help improve the process. The discussion concluded with an acknowledgement of the importance of careful standard development and the role of both legislation and standardization in achieving energy and environmental goals.

Prof. Ryuji Matsuhashi, University of Tokyo, talked about international standardization policy and new energy technologies. As a Japanese representative of ISO standards in the energy and environmental fields, he shared his insights into the role of ISO and IEC in standardizing energy-related issues, which included environmental performance, carbon neutrality, energy security and resilience. He also explained the development of financial standards like green bonds, climate finance and sustainable finance, and the importance of maintaining consistency across these standards. Additionally, the presentation addressed the development of ISO 22366, which aimed to promote resilient energy systems. The discussion concluded with mutual acknowledgement of the importance of careful standard development and the role of both legislation and standardization in achieving energy and environmental goals.

Federica Baldan, DG Research and Innovation, talked about the role of standardization in the valorization of knowledge. She emphasized how standards, together with research and innovation, may derisk and accelerate the development, adoption and scaling of technology on global markets. She introduced the Code of Practice on standardization in the European Research Area, offering flexible and inclusive recommendations to and addressing higher education institutions, research and innovation organizations, project partners and policy actors. These included the need to develop standardization policies within organizations, integrating standardization activities into career development plans, providing education and training on standardization, and considering long-term standardization involvement beyond one single project. Policy-makers and stakeholders were encouraged to promote standardization as a means of knowledge valorization, support start-ups and SMEs, and develop service portfolios aligned with research and innovation activities. Furthermore, member states were urged to share best practices and collaborate with SME associations and start-up incubators.

Session 2. Accelerating technology development

Michele de Nigris, Director, Department Sustainable Development and Energy Sources at RSE, talked about international collaboration in the pre-standardization phase: the scientific foundation of normative documents. He gave an overview of the main advantages of standards for products and services such as higher quality, safety and cost reduction through economies of scale and the use of standardized components, and went on to describe the typical phases of the knowledge cycle, from research to pre-standards to standards. The need for an interoperable IT framework for multi-lateral and cross-sector data exchange was highlighted as a means to enable energy-system integration, and several initiatives at European level were listed. The ISGAN SIRFN was described as an example of excellence in

the IEA community. The collaboration project brings together more than 20 research communities from 15 countries involved in smart-grid testing facilities to identify collaboration opportunities, exchange state of the art testing practices and test protocols. Finally, the presenter stressed the increasing complexity of the energy system and the need for an integrated approach involving specialized stakeholders. Pre-standardization activities, supported by strong scientific research, can lead to smoother and more market-ready standardization procedures. The IEA's established framework provides an ideal platform for joint research and pre-standardization work, which has proven effective in various sectors, including networks, wind and solar energy.

Dipl.-Ing. Dr. Gerald Franzl, Center for Distributed Systems and Sensor Networks at the University for Continuing Education Krems (Donau-Universität Krems), gave a presentation with examples from R&D on inter-operation demands beyond connectivity. Interoperability is required to network independent systems and requires mutual technical, syntactic, semantic and operational understanding. The actual information exchange among systems depends on the specific use. In demonstration projects, a prototype integration and/or a sandbox environment is developed to showcase the implementation and the practically achievable benefits of a novel technology. Experience, in particular of the issues encountered, leads to “recommended practices”, i.e., indicators of integration, from which integration profiles can be derived. Profiles specify how to use and stack different standards to achieve normatively what a specific use needs. The presenter gave examples from recent and ongoing R&D projects that specify integration profiles top-down, i.e. in controlling the assets of a virtual power plant, applying IEC 61850-7-420:2021 to manage a battery energy storage system, using multi-tier signalling to utilize implicit demand flexibilities, linking EV charging management (CSMS) with home/building EMS, and lastly the coordination of BEV-recharging with shared mobility-booking. He recommended resorting to stacks of widely used standards to mitigate difficult integration and the costly replacement of existing infrastructure and to enable rapid diffusion. Summarizing, sector-coupling is challenging with domain-centric standards, norms and definitions of terms. It would therefore benefit from a common language and mutual understanding.

Kim Branner, Head of Section, DTU Wind, talked about developments in blade tests and the work in IEC 61400-23. He began with examples of recent wind turbine failures and the lessons learned from these incidents and emphasized the need for the industry to learn from these failures and improve standards accordingly. The current standards may be outdated, as they were developed when turbine blades were much shorter. The presentation included details of a project focused on improving fatigue-testing methods for blades, aiming to make the tests more representative of real-world conditions and faster to conduct. He highlighted ongoing research in the lab aimed at developing better and faster testing methods for wind-turbine blades, which are being incorporated into new versions of relevant standards. The new testing methods included the use of digital-twin technology to enhance the reliability of wind-turbine blades. The technical aspects of blade-testing were explained, including the limitations of current standards that only test in two directions, missing many potential failure modes. The presenter advocated adopting a more comprehensive approach to testing that considers the complex loads experienced by blades in operation. In conclusion, the presenter called for a more structured approach to learning from failures, similar to practices in the space industry, to accelerate improvements in wind-turbine technology.

Session 3. Navigating and managing the vectors in technology development: practices and lessons learned from different examples of use

Geert Tjarks, EWE- Energy Provider, talked about standardization of the integration of electrolysis plants into the hydrogen and electricity grid. The presentation focused on EWE's approach to developing the hydrogen economy, starting from renewable energy production to setting up large-scale hydrogen production facilities using electrolyzers. EWE leverages existing pipeline infrastructure and underground salt caverns for hydrogen storage, aiming to supply large-scale industrial customers like steel works and refineries. The presenter explained the concept of systemic integration, which involves locating electrolyzers strategically near electricity hubs to utilize existing infrastructure and reduce costs. Large-scale storage facilities are integrated to ensure continuous hydrogen supply to industries. EWE is a partner in the Hy2Infra regional hydrogen cluster that is contributing to the emergence of an EU hydrogen network. This cluster also aims at facilitating future interconnections, mainly by developing common agreements on interoperability and recommendations on operational rules, hence indirectly contributing to standards. Multiple standards are needed for the hydrogen economy. For some production technologies, standards are being developed, but others such as power-to-x and gas purity are still at an early stage. Also, certification of low-carbon and green hydrogen are lacking. In conclusion, he emphasized the need for coordination across the value chain and alignment of European and international standards to facilitate global technology deployment. See also the European Hydrogen Roadmap on Standardisation (DocsRoom - European Commission).

Dr. Masahiro Nishio, AIST Department of Energy and Environment, talked about standards for energy conservation management and CCS. The presenter first gave an overview of ISO/TC301 Energy management and energy savings, its 51 member countries and 43 observing members, active working groups and a list of standards already developed. He continued to discuss the development and standardization of carbon capture and storage (CCS) technologies, focusing on ISO TC-265. This technical committee, proposed by Canada in 2011, aims to capture and transport large amounts of CO_2 emitted from power generation and industrial processes, storing it underground to prevent atmospheric release. ISO TC-265 comprises 28 participating countries and 17 observing countries, organized into working groups for each CCS process: capture, transportation, storage and cross-cutting issues. The committee often produces technical reports to aggregate relevant information before creating formal standards, reflecting the evolving nature of CCS technology. In conclusion, the presenter underscored the importance of international collaboration and standardization in advancing CCS technologies, committing to continued efforts in these areas.

Poul E. Sørensen, Professor, DTU Wind, talked about hybrid power plants, best practice and international standards. The presenter discussed the evolution of standards for wind-energy grid connections based on his research on wind energy and its impact on grid stability. He has been involved in international standardization since 1997 and is a leading expert in IEC 61400-27 on wind-energy generation systems. He provided insight into IEC 61400-27-3 on frequency domain modelling complexity and 61400-27-4 on validation cases for time series simulations and gave an overview of IEC 61400 standards supporting grid connection for solar, storage and other inverter-based resources as well. The presentation emphasized the importance of hybrid power plants, which combine multiple renewable-

energy sources to optimize the use of transmission lines. The presenter illustrated a typical scenario where renewable energy development areas are far from load centres, leading to limitations in transfer capacity. By controlling the entire renewable generation area collectively, rather than the individual plant, it is possible to avoid exceeding transmission capacity and to make better use of the infrastructure. The presenter addressed concerns about curtailing potential renewable generation, noting that, while this was a significant issue 20 years ago, advances in technology and control strategies have mitigated these concerns. The presentation concluded with a discussion of the importance of standardization and grid codes in facilitating the integration of hybrid power plants.

Session 4. International cooperation, TCPs and technology standards and certification

Dipl.-Ing. Michael Moltinger, Department Green Engineering & Circular Design, Salzburg University of Applied Sciences, talked about the IEA's TCP Energy Storage Task 43 Status Report: Standardized Use of Building Mass as Storage for Renewables and Grid Flexibility. The presenter provided an update on the ongoing IEA TCP storage project in Task 43. This included new guidance on Near Field Communication (NFC) performance certificates, which are designed to standardize performance metrics across different countries, and the creation of a one-stop shop to simplify processes and extend market reach. The presenter also mentioned several ongoing demonstration projects and the collection of initial monitoring data, which will be crucial for informing future work and refining the processes involved. A detailed comparison of concrete versus wooden constructions for energy storage was provided, highlighting the higher temperature requirements for wooden constructions and their differences in storage potential. Furthermore, the presenter addressed the challenges of implementing these systems in existing buildings, particularly regarding weight and moisture management. The importance of regulatory compliance, especially for fire safety and structural integrity, was also discussed. The presenter shared insights from a recent demo project in Austria, where a wooden house with 12 flats was built using the TAP system as a single heating and cooling unit. This project aims to provide practical data on the effectiveness of wooden constructions in real-world applications. The presenter expressed optimism about the future of these systems and the ongoing research efforts, highlighting the benefits of standardization in streamlining industry processes and improving collaboration between providers and end users.

Maria Moser, Solid Solar Energy Systems GmbH, talked about IEA TCP Energy Storage Task 45: Accelerating the uptake of Large Thermal Energy Storages. The presenter discussed the critical need for standards in storage systems, emphasizing the importance of material test standards to ensure the longevity and reliability of large-scale storage solutions. She highlighted that the task involves various types of storage materials and processes, each requiring specific standards. The presenter noted that one of the key goals is to define these standards in collaboration with industrial partners, aiming for publication by the end of the next year. This process includes developing test standards for materials used in large-scale storage systems, such as liners for thermal energy storage pits, to ensure they meet durability and performance requirements. The presenter stressed the importance of collaboration among international partners to develop effective and widely applicable standards. In conclusion, she expressed optimism about the progress being made and the potential for these standards to streamline

processes, improve reliability in advanced storage solutions, and foster innovation in the renewable energy sector.

Corinna Möhrlen, WEPROG (substitution for Gregor Giebel), talked about the IEA Wind Recommended Practice (RP) for the Implementation of Renewable Energy Forecasting Solutions. The presentation covered the four main parts of the RP: the selection of forecasting solutions, the design and execution of benchmarks and trials, the evaluation of forecasts and forecast solutions, and data requirements for real-time applications. The presenter emphasized the critical importance of data quality in real-time applications, noting that the industry often lacks proper data quality control measures. The publication of an Open Access book on these recommendations has started to gain traction in the industry, providing practical guidelines and recommendations (LINK). The presenter also highlighted ongoing collaborations with the IEC SC8A (Grid integration of renewable energy sources) Working Group 2 on a standard for renewable energy forecast evaluation, particularly for the integration and operation of wind and solar forecasting. The goal of the collaboration is to develop a comprehensive standard alongside the recommended practices that have already been adopted for renewable energy forecasting. There is already some liaison between the IEA and the IEC's technical committees TC8 (System aspects of electricity energy supply), TC82 (Solar PV), TC88 (Wind energy) and TC114 (Marine energy), but there is little institutional knowledge about exchanges of knowledge, lessons learned etc. Therefore, there is a need for better mechanisms and procedures regarding how to establish or officially adopt work between organizations like the IEA and IEC to ensure effective collaboration on the development of standards and fair and efficient influences in the decision-making for acceptance.

Anthony Fraisse, Head of section, DTU Wind, presented the key messages from IEA TCP Wind Task 45, Recycling of wind turbine blades. The presenter described the task objective as being dedicated to the recycling of wind-turbine blades, as well as reaching the objectives of identifying knowledge gaps and sharing common challenges, and creating a consensus and recommended practices for the management of end-of-life wind-turbine blades. Key topics included robust predictions of wind-turbine blade waste, the economic viability of scaling recycling solutions, and the need for reliable wind- turbine data to support recycling. The presenter noted that current waste volumes are insufficient to support a reliable recycling business, as they only total about 0.1% of plastic waste produced annually. The presentation emphasized the importance of harmonizing policies at the European and global levels to facilitate recycling efforts. One proposed solution is coupling pyrolysis with the remelting of glass fibre to introduce recycled content into new materials, which is increasingly demanded by manufacturers. This approach aims to create a closed-loop system where materials from decommissioned blades are reused in new products. The ambition is to develop a recommended practice for wind-turbine blades in designing recyclable blades, repurposing and recycling blades, and providing this practice to IEC 61400-28-2 Decommissioning and preparation for recycling. The presenter proposed to establish a stronger link between IEA TCP Wind Task 45 and IEC TC 88 to exchange knowledge and viewpoints, organize joint events and plan future joint discussion groups.

David Robert Verelst, Senior Scientist, DTU Wind, talked about standards and certification. The presenter emphasized the political nature of standards development, with different stakeholders having varying agendas. Some prefer detailed handbooks, while others advocate general principles. The

presenter stressed the importance of being involved in committees and understanding the dynamics to influence standards effectively. He pointed out that being a member of these committees requires a long-term commitment and strategic consideration, as it involves navigating complex political landscapes and interests. A key point was the balance between making standards specific enough to ensure safety and reliability and not hindering innovation. The presenter acknowledged that standards often lag behind technological advances due to the lengthy and complex process of approval. This delay can be frustrating for those in the industry who need to implement new standards while managing their existing operations. He noted that standards need to be stable enough for the industry to adapt them but flexible enough to incorporate new knowledge and innovations. In conclusion, the presenter highlighted the importance of continued engagement and collaboration to create a level playing field and support the development of standards. He called for academics and industry professionals to work together to bring new knowledge to the surface and ensure that standards evolve in a way that supports both safety and innovation.

Simon Pansart, RWE, talked about relying on third-party certification. The presenter explained the rational for third-party certification as a means of managing the conflicting interests between the OEMs having an interest in protecting their property right, and technology users/owners and operators having an interest in assessing certain technical details to make sure that the design is correct and the manufacturing is done properly. Based on two extreme cases, he illustrated his message that third-party certification can effectively mitigate the risk of something going wrong and that independent international schemes such as IECRE aim for further improvement. This includes the systematic involvement of all stakeholders when developing certification rules, detailed and rigorous rules for manufacturing inspection, the transparency of reporting and exchanges of information among actors, and transparent rules for becoming an accepted certification body based on peer assessment.

In the **concluding session**, the moderators of the four sessions summarized the key messages from each session. Each session moderator invited the participants to express their views and develop recommendations to the IEA community on developments in demonstrations, testing and standardization. Key messages and recommendations are described above.