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D8.6 – Education & Training materials/handbook

Project contract n:	101135417 — Stan4SWAP — HORIZON-CL4-2023-HUMAN-01	
Work package, WP title	WP8, Communication Dissemination, Training and Education	
Task, task title:	T8.4, Education and Training content	
Deliverable nr:	D8.6	
Deliverable title:	Education & Training materials/handbook	
Deliverable type:	PU – PUBLIC	
Document preparation date:	2025-09-30 (M22)	
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This project has received funding from the European Union's Horizon Europe research and innovation programme under grant agreement No 101135417
This Work has received funding from the Swiss State Secretariat for Education, Research and Innovation (SERI) for its Associate Partner

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Revision History

Deliverable Title: D8.6 – Education & Training Materials/Handbook
Filename: Stan4SWAP Deliverable 8.6_v1

Version	Date	Action	Partner
V1.0	2025-09-30	Final version	Fraunhofer ISI

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Abbreviations List

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AFNOR	Association Française de Normalisation
BMS	Battery Management System
BT	Technical Board
CCMC	CEN-CENELEC Management Centre
CD	Committee Draft
CEN	Comité Européen de Normalisation
CENELEC, CLC	Comité Européen de Normalisation Electrotechnique
CWA	CEN Workshop Agreement
D	Deliverable
DC	Direct current
DIN	Deutsches Institut für Normung
DIS	Draft International Standard
EN	European Norm
ETSI	European Telecommunications Standards Institute
EU	European Union
EV	Electric Vehicle
FDIS	Final Draft International Standard
HBS	Handheld Swappable Battery Systems
IDV	Individualism Index
IEC	International Electrotechnical Commission
IPC	International Patent Classification
IPR	Intellectual Property Rights
ISO	International Organisation for Standardisation
IT	Information Technology
ITU	International Telecommunication Union
IWA	International Workshop Agreement
L-cat	light-category
LTO	Long-term Orientation
NP	New (Work ITEM) Proposal
MAS	Motivations Towards Achievement and Success
NWI	New Work Item
NWIP	New Work Item Proposal
OCA	Open Traffic Systems City Association e.V.
OCPP	Open Charge Point Protocol
OEM	Original Equipment Manufacturer
OJEU	Official Journal of the European Union
P-Member	Participant members
PAS	Publicly Available Specification
PDI	Power Distance Index
prEN	Preliminary European Norm
PT	Project Team

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R&D	Research and Development
SC	Sub Committee
SDO	Standard Development Organization
SME	Small and medium-sized enterprises
SoA	Service oriented Architecture
SPEC	Specification
TC	Technical Committee
TCF	The Culture Factor
TR	Technical Report
TS	Technical Specification
TU	Technical University
UAI	Uncertainty Avoidance Index
UK	United Kingdom
UN	United Nations
UNE	Asociación Española de Normalización
UNI	Ente Italiano di Normazione
US	United States
WD	Working Draft
WG	Working Group
WLTP	Worldwide Harmonized Light Vehicles Test Procedure
WP	Work package

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Executive Summary

Stan4SWAP is a Horizon Europe CSA (Coordination and Support Action) project to boost standardisation for swappable batteries of light-category (L-cat) electric vehicles (EVs) in support of a quick, effective, and performant mobility scheme.

The project aims to contribute to the European regulatory, standardisation, competitiveness, and excellence by disseminating its results to a wide audience and enhancing cooperation and engagement with international standardisation organisations through the whole project duration.

This deliverable summarises the work done as part of the project's task T8.4: Education and Training content which provides education and training materials for standardisation in the mobility and transport ecosystem of swappable batteries within the scope of Stan4SWAP. In particular, it presents four outputs:

- The Handbook, on "Standardisation and Standards for Mobility and Transport in the Ecosystem of Swappable Batteries" with six specific case studies
- A learning video, "Standardisation and standards for mobility and transport in the ecosystem of swappable batteries – basic topics"
- A learning video, "Standardisation and standards for mobility and transport in the ecosystem of swappable batteries – advanced topics"
- Interesting additional material on standardisation, including the Stan4SWAP factsheets

The material will be made widely available throughout Stan4SWAP channels and platforms, as well as through relevant additional initiatives of partners and stakeholders.

Several university lecturers also expressed interest in the output of Stan4SWAP's education task and confirmed that the 'topic is of central importance in (their) teaching'. In addition, various discussions took place with the training unit of a European network of battery companies that showed great interest in future joint training activities.

Stan4SWAP's final event will highlight the work of T8.4. Additional strategies for distributing the task's outputs will also include the integration into resource collections such as those of the European projects EDU4Standards.eu and SEEBLOCKS.eu.[1] An exchange of information with both initiatives has already taken place.

Details on various additional measures will be provided in Stan4SWAP's work package eight's final dissemination report (D8.7 Report on Communication, Dissemination, and Exploitation activities) in M24 (November 2025).

[1] See https://edu4standards.eu/ and https://seeblocks.eu/

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1. Introduction

Standardisation and standards are regarded as vital catalysts for the economic development of the European Union (EU) and its green transition and play a significant role in achieving the United Nations' Sustainable Development Goals. Moreover, collaborative efforts in developing international standards empower the EU to effectively navigate the escalating economic and systemic competition. In this context, knowledgeable experts are indispensable. However, the demand for standardisation specialists across the EU and its industries is steadily rising, driven by the increasing relevance of standards in increasingly complex domains. Stan4SWAP's task T8.4 aims to address this gap in the context of swappable batteries.

Stan4SWAP is a Horizon Europe CSA (Coordination and Support Action) project to boost standardisation for swappable batteries of light-category (L-cat) electric vehicles (EVs) in support of a quick, effective, and performant mobility scheme. It aims to contribute to the European regulatory, standardisation, competitiveness, and excellence by disseminating its results to a wide audience and enhancing cooperation and engagement with international standardisation organisations through the whole project duration.

Stan4SWAP's task T8.4, whose work is presented in this report, was dedicated to the development of education and training content for various stakeholder groups of swappable batteries' standardisation. Specifically, it collected and produced education and training materials about standardisation and standards in the mobility and transport ecosystem of swappable batteries and related topics, resulting in a handbook, two training videos and a collection of additional helpful materials.

How to Read this Document

This document is structured as follows: Section 2 describes the method to create Stan4SWAP's education and training materials, followed by section 3, which presents the task's key outputs:

- The Handbook, on "Standardisation and Standards for Mobility and Transport in the Ecosystem of Swappable Batteries"
- The learning video "Standardisation and standards for mobility and transport in the ecosystem of swappable batteries – basic topics"
- The learning video "Standardisation and standards for mobility and transport in the ecosystem of swappable batteries – advanced topics"
- A collection of 20 additional helpful sources.

Section 4 gives an outlook, followed by four annexes with the handbook, the slides shown in the two learning videos and the additional material collection.

The materials will be made widely available throughout Stan4SWAP channels, platform and relevant existing external initiatives of partners and stakeholders.

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2. Methodology of Stan4SWAP Task 8.4

STAN4SWAP's task T8.4 developed education and training content for standardisation in the mobility and transport industrial ecosystem of swappable batteries. Its specific focus was on the seven stakeholder groups specified in the project's task T8.3, see Stan4SWAP (2024a) and Table 1.

# of Task 8.4	# of the project in general	Target Group	Role as Stan4SWAP's target group in general	Consideration in this deliverable
TG1	**TG5**	**Universities and Higher Education Institutions**	Professors and students of relevant curricula (e.g. engineering courses)	Key target group; as direct user and multiplier channel
TG2	**TG1**	**Standardisation experts**	Specific technical bodies such as CLC/TC 21X 'Secondary cells and batteries' which develops European standards for electric vehicle batteries and its international counterpart, IEC/TC 21, CLC/TC 69X and its WG 06 'Battery swap systems'	Further training for beginners in the different areas of the battery value chain
TG3	**TG2**	**Policy Makers**	European Commission Services in particular EC DG GROW and DG MOVE, governments, local authorities, in particular cities and municipalities, but also authorities managing R&I funds.	Additional knowledge important for the interplay between standards and regulation
TG4	**TG3**	**Vehicle Industry**	L-cat equivalent vehicles industry. Both individual companies as well as industry associations.	To train standardisation experts
TG5	**TG4**	**Research & Innovation community**	RD&I projects, innovation initiatives, startups, and organizations providing funding for R&I activities	To train standardisation experts
	TG6	**Scientific Community**	Scientific associations, publication panels, scientific consortia, scientific networks.	
TG6	**TG8**	**Municipalities**	Local authorities of cities and municipalities that have a key role in encouraging a user-friendliness and accessibility of battery swapping stations.	To consider standards appropriately in strategic decisions
	TG9	**Project developers**	Actors with the capacity to build finance and operate the infrastructure, ie. investors, insurances, electricity providers, among others	
TG7	**TG7**	**General Public**	Wider audience will be reached by communication and dissemination activities to ensure good visibility of the project and its expected scientific, societal and environmental impact.	To address their individual standardisation interest

Table 1: Target Groups of Stan4SWAP's education and training measures

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The development of the materials in this task considers the regulatory framework conditions analysed in Stan4SWAP's work package (WP) 3, as well as six case studies performed in T8.4. Based on this, a handbook and two educational videos were produced.

In addition to the new educational content developed for task T8.4, the preparation of the handbook also incorporated external references and findings from other Stan4SWAP tasks, in particular:

- Material from CEN, CENELEC, ISO and other Standard Development Organizations (SDOs)
- Material of various standardisation educators and the EU projects SEEBLOCKS.eu and EDU4Standards.eu
- Material from Stan4SWAP experts prepared for Technische Universität Berlin and the EURAS network
- Descriptions of the swappable batteries' market based on Stan4SWAP's work in WP4
- Overview of relevant standards and regulations in the context of swappable batteries developed for Stan4SWAP's deliverable D3.1 (Stan4SWAP, 2024b)
- Stan4SWAP contributions reflecting the partners' experiences with the standardisation of swappable batteries and the lessons learned
- Six case studies, created by Stan4SWAP partners in collaboration with various European and international standardisation experts and group leaders (chair persons, leaders of working groups, etc.)

The work on the case studies included six steps:

- The creation of a case study template
- The selection of cases
- The identification and contacting of appropriate experts
- Case study development
- Clarification of additional questions
- Case study editing and integration in the handbook.

The following case studies were created:

- Case study IEC 62840 Standards Series
- Case study ISO 18243 – Electrically propelled mopeds and motorcycles
- Case study ISO 19453-6 Road vehicles – Environmental conditions and testing for electrical and electronic equipment for drive system of electric propulsion vehicles. Part 6: Traction battery packs and systems
- Case study ISO 23625 – Lithium-Ion Batteries for Small Craft Development and insight
- Case study IEC 61851-25 – Electric vehicle conductive charging system
- Case study DIN SPEC 91533 – Battery swap systems for heavy electric commercial vehicles to extend range

The details and outcome are shown in the handbook and presented in annex 1 of this report. Monthly discussions between the project partners on the handbook in WP8 were another important component in the successful completion of the document.

The two education videos with basic and advanced content rely on material from SDOs, material from EDU4Standards.eu experts, material from the former SEEBLOCKS.eu project and the content of the handbook. The collection of additional study materials for Stan4SWAP's target groups is described in Chapter 3.

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3. Stan4SWAP Handbook, Education Videos and Additional Materials

The task's output, the manual, the slides of the two education videos and the additional material are provided in the annex.

The handbook which can be found in annex 1, is divided into 11 chapters.

Chapter 1 sets the stage for standardisation in the ecosystem of swappable batteries and explains the purpose and scope of the handbook, followed by the description of core concepts of standards and standardisation in Chapter 2.

Chapter 3 and 4 provide introductions to the European standardisation landscape and the ecosystem of swappable batteries. They are followed by Chapter 5, which brings the areas of standardisation and swappable batteries together by describing the importance of standardisation for the swappable batteries' ecosystem, for example to ensure security and compatibility.

Chapter 6 explains the characteristics and creation of European and international standards and specifications such as EN Standards from CEN and CENELEC, CEN Workshop Agreements, ISO and IEC Standards, Technical Reports and Technical Specifications. Chapter 7 provides insights in the policy landscape and presents three key regulations in the context of swappable batteries. Afterwards, it reviews current standards activities and ongoing initiatives in the context of swappable batteries.

Chapter 8 presents standardisation strategies for the ecosystem's stakeholders, followed by Chapter 9 which provides recommendations to connect research in this area and standardisation.

Chapter 10 explores six real-world applications and outcomes of standardisation efforts, followed by the summary in Chapter 11.

In total, 62 slides were created for the videos. The first video includes introductory topics such as:

- Acquiring fundamental knowledge of standards
- Understanding the effects of standards
- Exploring the connections between research and development and standardisation
- Identifying the various roles of different standards
- Understanding the impacts of standards for appropriate use

while the second video includes specific strategies and one of the handbook's case studies.

The first video has a duration of 36 minutes and the second one of 29 minutes. Figures 1 and 2 show screenshots of both videos. Further information is provided in annex 2 and annex 3.

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Figure 1: Screenshot of the learning video "Standardisation and standards for mobility and transport in the ecosystem of swappable batteries – basic topics"

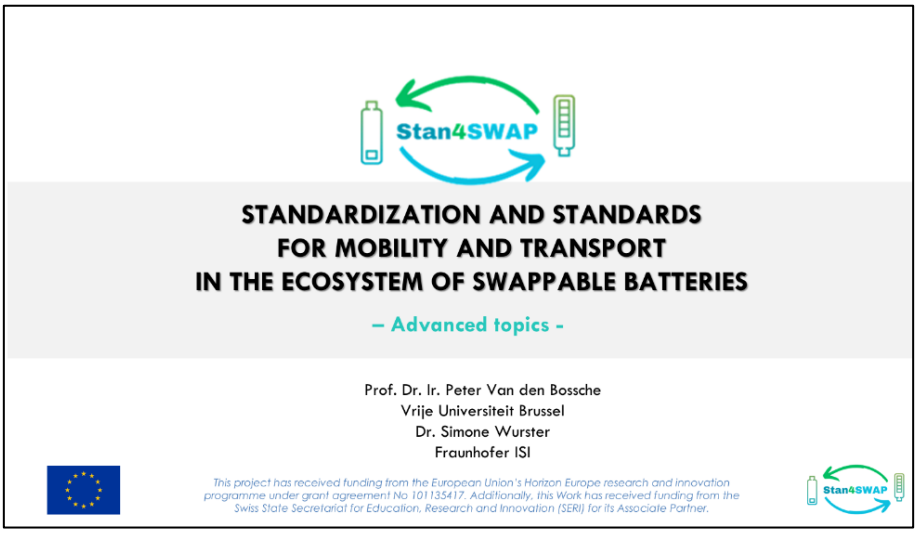

Figure 2: Screenshot of the learning video Standardisation and standards for mobility and transport in the ecosystem of swappable batteries – advanced topics"

The standardisation and standards topic have various additional general dimensions, for which helpful guidance exists already. This includes, for example, more detailed descriptions on the interplay between standards and law and standards and intellectual property rights, particularly related to Standard Essential Patents (SEP).

Based on analyses in the SEEBLOCKS.eu database[2] provided by the EDU4Standards.eu project, 20 additional sources were selected as additional helpful material for Stan4SWAP's target groups and presented in Annex 4. They were also integrated in the handbook's annex.

[2] Link: https://seeblocks.eu/visualisation-tool

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4. Outlook

Stan4SWAP's work in the area of educational and training content resulted in a 95-page manual and two videos based education material presented on 62 slides.

The materials will be made widely available throughout Stan4SWAP channels and relevant additional initiatives of partners and stakeholders including the Advisory Committee on Research & Innovation (replacing the former working group on STAndards, Innovation and Research (STAIR) of CEN-CENELEC which will launch in October 2025).

Further dissemination of the material is planned. Several university lecturers also expressed interest in the output of Stan4SWAP's education task and confirmed that the 'topic is of central importance in (their) teaching'. In addition, various discussions took place with the training unit of a European network of battery companies that showed great interest in future joint training activities.

Stan4SWAP's final event will highlight the work carried out in T8.4. Additional strategies for distributing the task's outputs will also include the integration into resource collections, such as EDU4Standards.eu and SEEBLOCKS.eu. An exchange of information with both initiatives has already taken place.

Details on various additional measures will be provided in Stan4SWAP's WP8's final dissemination report (D8.7 Report on Communication, Dissemination, and Exploitation activities) in November 2025.

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Stan4SWAP (2024c). Stan4SWAP on the agenda of the CEN-CENELEC working group STAIR https://stan4swap.standards.eu/news/stan4swap-on-the-agenda-of-the-cen-cenelec-working-group-stair

All other references are included in annex 1 of this report.

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ANNEXES

Annex 1: Handbook on standardisation and standards for mobility and transport in the ecosystem of swappable batteries

Annex 2: Slides of the learning video “Standardisation and standards for mobility and transport in the ecosystem of swappable batteries – basic topics”

Annex 3: Slides of the learning video “Standardisation and standards for mobility and transport in the ecosystem of swappable batteries – advanced topics”

Annex 4: Interesting additional external links on standards and standardisation

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Annex 1

Handbook on standardization and standards for mobility and transport in the ecosystem of swappable batteries

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Co-authors:

Peter van den Bossche, Vrije Universiteit Brussel, Kirsten Glennung, CENELEC, Karl-Maria Grugl, KTM Forschungs & Entwicklungs GmbH, Arne Hameister, Swobbee GmbH, Enrico Maria Mayrhofer, Piaggio & C. SPA

This **handbook** was developed in the **EU project Stan4SWAP**. Stan4SWAP is a Horizon Europe project to boost standardisation for swappable batteries of light-category (L-cat) electric vehicles (EVs) in support of a quick, effective, and performant mobility scheme. In this context, the project aims to provide appropriate contributions to Europe's regulatory framework, standardisation, competitiveness, and excellence.

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We thank various experts involved in the creation of the following standards and specifications for their valuable contributions to our case study series:

- IEC 62840 Standards Series
- ISO 18243 – Electrically propelled mopeds and motorcycles
- ISO 19453-6 Road vehicles — Environmental conditions and testing for electrical and electronic equipment for drive system of electric propulsion vehicles. Part 6: Traction battery packs and systems
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OCPP	Open Charge Point Protocol
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OJEU	Official Journal of the European Union
P-Member	Participant members
PAS	Publicly Available Specification
PDI	Power Distance Index
prEN	Preliminary European Norm
PT	Project Team
R&D	Research and Development

SBMC	Swappable Batteries Motorcycle Consortium
SC	Sub Committee
SDO	Standard Development Organisation
SME	Small and medium-sized enterprises
SoA	Service oriented Architecture
SPEC	Specification
TC	Technical Committee
TCF	The Culture Factor
TR	Technical Report
TS	Technical Specification
UAI	Uncertainty Avoidance Index
UK	United Kingdom
UN	United Nations
UNE	Asociación Española de Normalización
UNI	Ente Italiano di Normazione
US	United States
WD	Working Draft
WG	Working Group
WLTP	Worldwide Harmonized Light Vehicles Test Procedure

1. Introduction

Standards are the hidden forces that shape the world around us, from the smartphones in our pockets, to the various means of transportation we use every day. They are everywhere and provide multiple advantages … but rarely noticed.

Think for example of standards for charging connectors for electric vehicles (EV). At present, approximately four different types of EV charging connectors are in use, complemented by two additional combined variants for fast charging. The distribution of these connectors is largely regional. Within the European Union, however, the IEC 62196 Type 2 connector, based on standard IEC 62196 (International Electrotechnical Commission - IEC) has been established as a common vehicle connector. This development was reinforced by the European Directive 2014/94/EU on the deployment of alternative fuels infrastructure, which mandates that all newly installed public charging points be equipped with Type 2 interfaces. As a result, most charging stations across Europe now follow this standard, ensuring interoperability, lowering costs, and supporting the broader adoption of electric mobility (see European Parliament and the Council, 2014a and Saraswathi and Ramachandran, 2024).

Interested to learn more about standards, these invisible rules behind our modern technology in the e-mobility context and the ecosystem of swappable batteries?

This book invites you to explore the fascinating world of standards and specific aspects of the ecosystem's application areas. Let's dive in and discover how standards quietly drive progress using the example of swappable batteries in light category (L-cat) EVs – two wheelers and light 3-4 wheelers for passengers and goods.

Why the focus on swappable batteries and batteries for L-cat EVs specifically?

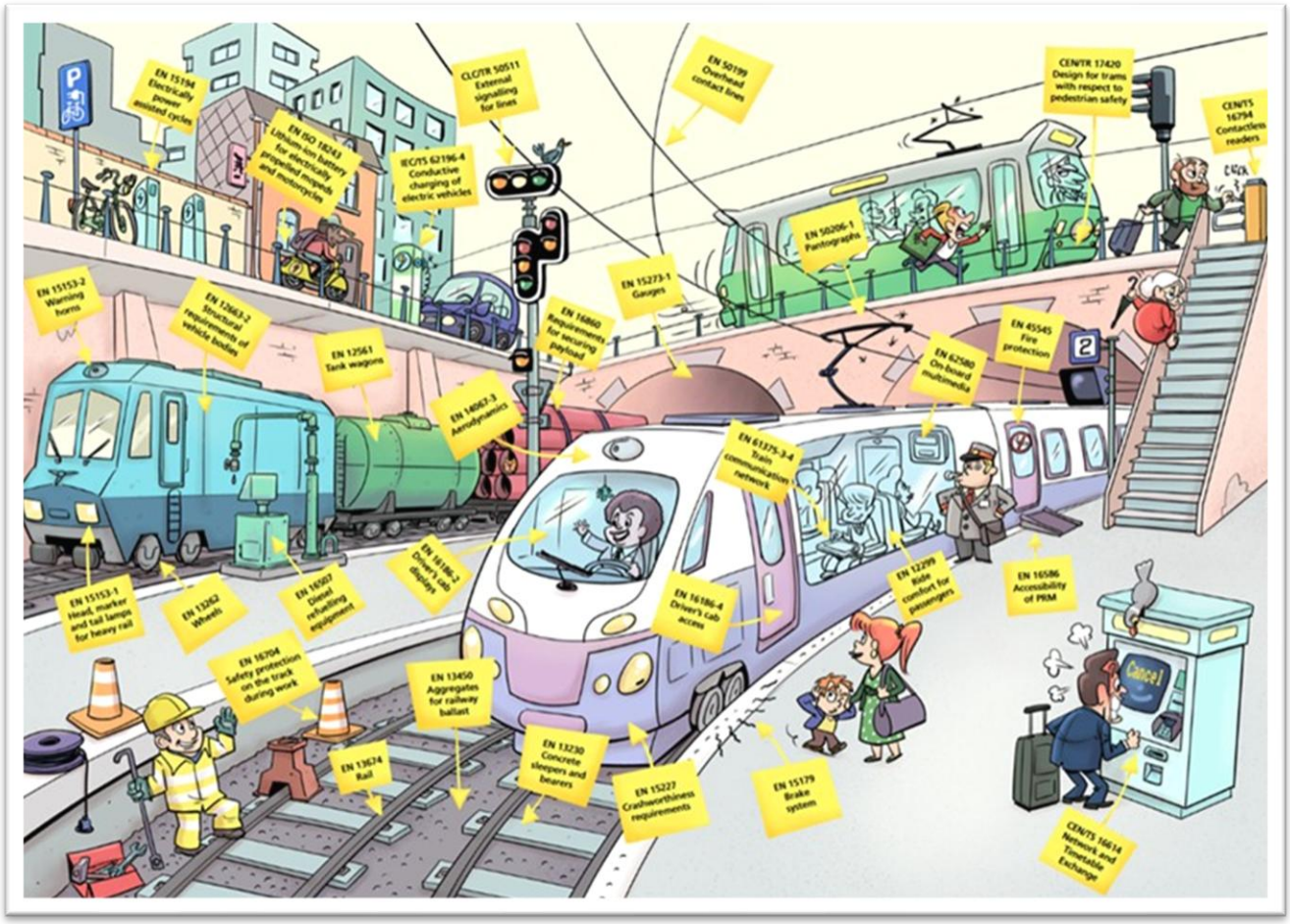
The key benefit of battery swapping is related to the charging time of batteries. Swappable battery solutions were tested for various vehicles but seem to be specifically applicable for L-cat EVs, which due to their light weight require less power than bigger vehicles such as trucks and cars. As a specific e-mobility application, swappable battery systems also help to decarbonise micro mobility.

Both in Europe and internationally, there is a great need for standards and specifications to support the ecosystem of swappable batteries.

Therefore, this handbook is designed to offer guidance on standardisation for individuals of the various stakeholder groups interested in contributing to, or better understanding how standardisation works in this specific area. With a particular European focus, it wants to help European organisations to successfully develop standards and specifications specifically.

Besides the vehicle industry, battery producers, infrastructure providers and standards developers in general, it addresses also universities and Higher Education Institutions with their

students and lecturers, policy makers, scientific and innovation communities, municipalities, project developers, and individuals from additional areas interested in standardisation.



Source: CEN and CENELEC (2021 - Design: www.mazygraphic.be - Illustrations: Marco Paulo)
Figure 1: Examples for the importance of mobility standards

The manual is divided into 11 chapters. Chapter 1 sets the stage for standardisation in the ecosystem of swappable batteries and explains the purpose and scope of this handbook, followed by the description of core concepts of standards and standardisation in Chapter 2.

Chapters 3 and 4 provide introductions to the European standardisation landscape and the ecosystem of swappable batteries. They are followed by Chapter 5, which explores the relationship between standardisation and swappable batteries by outlining the importance of standardisation for the ecosystem of swappable batteries, ensuring security and compatibility, for example.

Chapter 6 explains the characteristics and creation of European and international standards and specifications such as EN Standards from CEN and CENELEC, CEN Workshop Agreements, ISO and IEC Standards, Technical Reports and Technical Specifications. Chapter 7 provides insight into the policy landscape and presents three key regulations in the context of swappable batteries. Afterwards, it reviews current standards activities and ongoing initiatives in the context of swappable batteries.

Chapter 8 presents standardisation strategies for the ecosystem's stakeholders, followed by Chapter 9, which provides particular recommendations to connect research in this area and standardisation.

Chapter 10 explores six real-world applications and outcomes of standardisation efforts, followed by the summary in Chapter 11.

The standardisation and standards topics have various additional general dimensions, for which helpful guidance already exists. This includes, in particular, more detailed descriptions on the interplay between standards and law and standards and intellectual property rights, particularly related to Standard Essential Patents (SEP). The Annex provides links to useful additional materials in this context.

2. Principles of Standards and Standardisation

Standards play a critical role in fostering economic efficiency, particularly in the context of industrial production, technological innovation, and market expansion. When all conditions are met, standards create a robust framework that enhances productivity, minimizes costs, and accelerates market access. Before coming to the benefits of standardisation, in general, and for the mobility ecosystem, in particular, we want to answer four fundamental questions:

What is a standard? How are standards created?
Who creates standards? and Which types of standards are distinguished?

What is a standard?

A standard is a technical document which is designed to be used as a rule, guideline or definition.

It is a "document, established by consensus and approved by a recognized body that provides, for common and repeated use, rules, guidelines or characteristics for activities or their results, aimed at the achievement of the optimum degree of order in a given context. Standards should be based on consolidated results of science, technology and experience, and aimed at the promotion of optimum community benefits" (CEN-CENELEC, 2025a).

Standards are grounded in the consensus of a broad spectrum of stakeholders, with an emphasis on wide applicability. They must be both practical and reflective of the current state of scientific and technological advancements in the area where they apply. Simultaneously, many standards specifically consider environmental, social and economically sustainability.[1]

How are standards created?

There are various methods for the creation of new standards across different organisational levels, each serving distinct purposes and applications.

At the most basic level, a **company or sector** may develop a standard tailored specifically to its own operations or industry requirements. These standards are typically intended for internal

[1] Standards developed at the European Committee for Standardisation (CEN), the European Committee for Electrotechnical Standardisation (CENELEC), the European Telecommunications Standards Institute (ETSI), the International Organisation for Standardisation (ISO), the International Electrotechnical Commission (IEC) and the International Telecommunication Union (ITU) for example have a specific focus on the United Nation's sustainability goals. At CEN and CENELC, for example, environmental considerations are based on the mandatory involvement of so-called Annex 3 organisations in standardisation. These organisations represent not only environmental interests, but also, for example, the interests of small and medium-sized enterprises (SMEs) and consumers. See https://boss.cen.eu/reference-material/guidancedoc/pages/opinion/ for further information.

use, addressing particular needs within the organisation or sector. For example, the automotive industry uses car platforms to reduce the development costs by joint production of bigger quantities. On this basis, outwardly distinct models and even types of cars from different brands may contain the same major components.

Other standards are developed with a **broader scope**, aiming to address issues that extend beyond individual companies or sectors. In such cases, the standards development is typically facilitated through a **Standards Development Organisation (SDO)**. An SDO is an entity where multiple stakeholders - such as government bodies, industry representatives, academic institutions, and other relevant parties - convene to develop standards through a collaborative process.

These stakeholders work together to ensure that the standard reflects a broad consensus, balancing the interests of various groups and ensuring its applicability and relevance on a national, regional, or even international scale depending on the scope of the SDO where it is being developed. The development of standards through this consensus-based approach helps ensure that the standards are widely accepted, feasible, and beneficial across industries and sectors. This handbook is dedicated to the development of such standards. More details will be provided in Chapter 6.

Who creates standards?

As previously stated, individual companies have the capacity to establish standards. However, such standards are typically confined in scope, applicability, and right of use.

To achieve a broader and more significant impact, it is necessary for a national, or, ideally, transnational, or international organisation to be involved. Numerous SDOs exist globally.

On a pan-European level, CEN, CENELEC and ETSI are the key players. They have national member organisations such as AFNOR, DIN, UNE, UNI, presented at CEN (2025a) and CENELEC (2025). On the international stage, organisations such as ISO, IEC and ITU are also central to the development of global standards (see Chapters 3 and 6 for more details).

In line with their specific standardisation topics, many SDOs are divided into specific units, such as technical committees (TCs) and, more specifically, subcommittees (SCs) and working groups (WGs).

Which types of standards are distinguished?

Standards and specifications can be classified according to different criteria. The following sections present three classifications which are relevant in the mobility context.

Classification based on economic effects

David (1987) classifies specifications and standards according to the economic problems that they solve. He distinguishes between compatibility, reference, and quality aspects. Information

in the original categories was expanded later (see Swann, 2000). Table 1 shows the characteristics of each category. The relevance for Stan4SWAP is described in section 5.2.

Task	Characteristics
Compatibility and Interoperability	• Description of required product characteristics for interaction in a technical system • Favouring of component innovations
Quality and Security	• Definition of set points, e.g. function level, performance and efficiency variance • Reduction of the users' transaction costs
Reduction of variants	• Limiting the characteristic attributes of a product / system, e.g. in terms of size and quality • Favouring of economies of scale • Reduction of investment risks
Provision of information and measured values	• Provision of information to describe, quantify and evaluate (product) characteristics • Reduction of transaction costs between suppliers and buyers

Source: own research based on Tassey (1982, 2000) and Swann (2000)
Table 1: Classification of specifications and standards based on economic effects

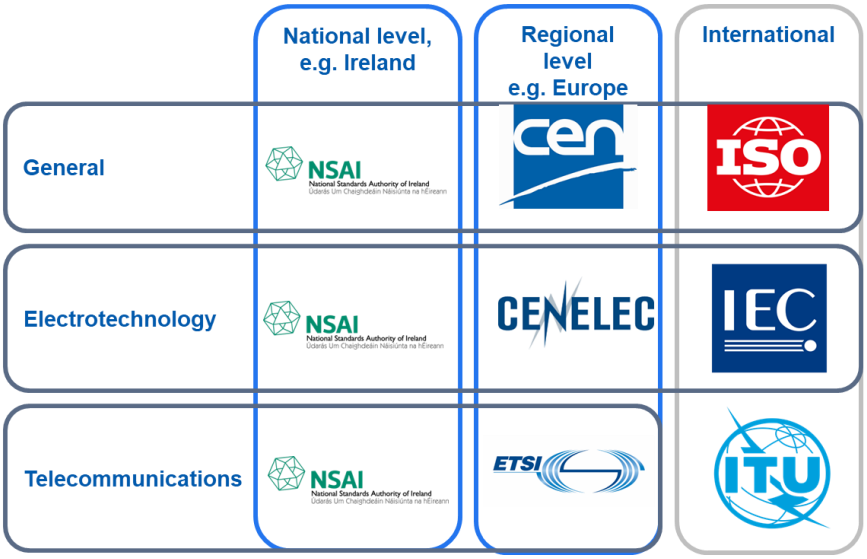
Classification based on the development phase

From the perspective of the development phase, Sherif (2001) developed another typology. The starting point is the time of introduction of the standard, compared to the relevant technology life cycle. Three characteristics can be distinguished: "anticipatory" (in advance), "participatory" (simultaneously), and "responsive" (reactive).

Anticipatory specifications and standards enable the development of new markets when individual companies do not have the necessary resources or are prevented by regulations. Participatory specifications and standards are created together with the prototype of a new product in the implementation and test phase, and allow for compatibility. Responsive standards serve to officially declare a specification or a standard when a product or service has been successfully marketed (see Sherif, 2001).

Classification according to the geographical level

According to the following figure, standardisation can take place on national, regional and international levels, while various interrelations exist. The example below departs from the Irish context, where the national standardisation body (NSB) participates in all 3 ESOs, however, in other countries there may be different national actors according to the domain.



Source: Blind (2025)

Figure 2: Links between standard development organisations

It shows national and European SDOs such as CEN, CENELEC, and ETSI, as well as the international SDOs: ISO, IEC, and ITU, of which CEN, CENELEC, ISO, and IEC are the key international players in the context of swappable batteries and their ecosystem. More information on the standards developed in these organisations is given in Chapters 3 and 6.

3. Introduction to the European Standardisation Landscape

The last section briefly introduced the three European Standardisation Organisations: CEN, CENELEC, and ETSI, as part of the international standardisation landscape. All these organisations are recognised as the European Standards Organisations (ESOs) by the European Union (EU).[2]

As we will see in Chapter 7, standardisation in the field of swappable batteries mainly takes place at CEN and CENELEC, while ETSI, the European Telecommunications Standards Institute, focuses on ICT. Therefore, this section focuses on these organisations, both headquartered together in Brussels, Belgium.

CEN is an association that brings together the National Standardization Bodies of 34 European countries. Likewise, CENELEC is an association that brings together the National Electrotechnical Committees of 34 European countries. The following figure gives an overview on their fields of activities, also showing that e-mobility belongs to their core topics.

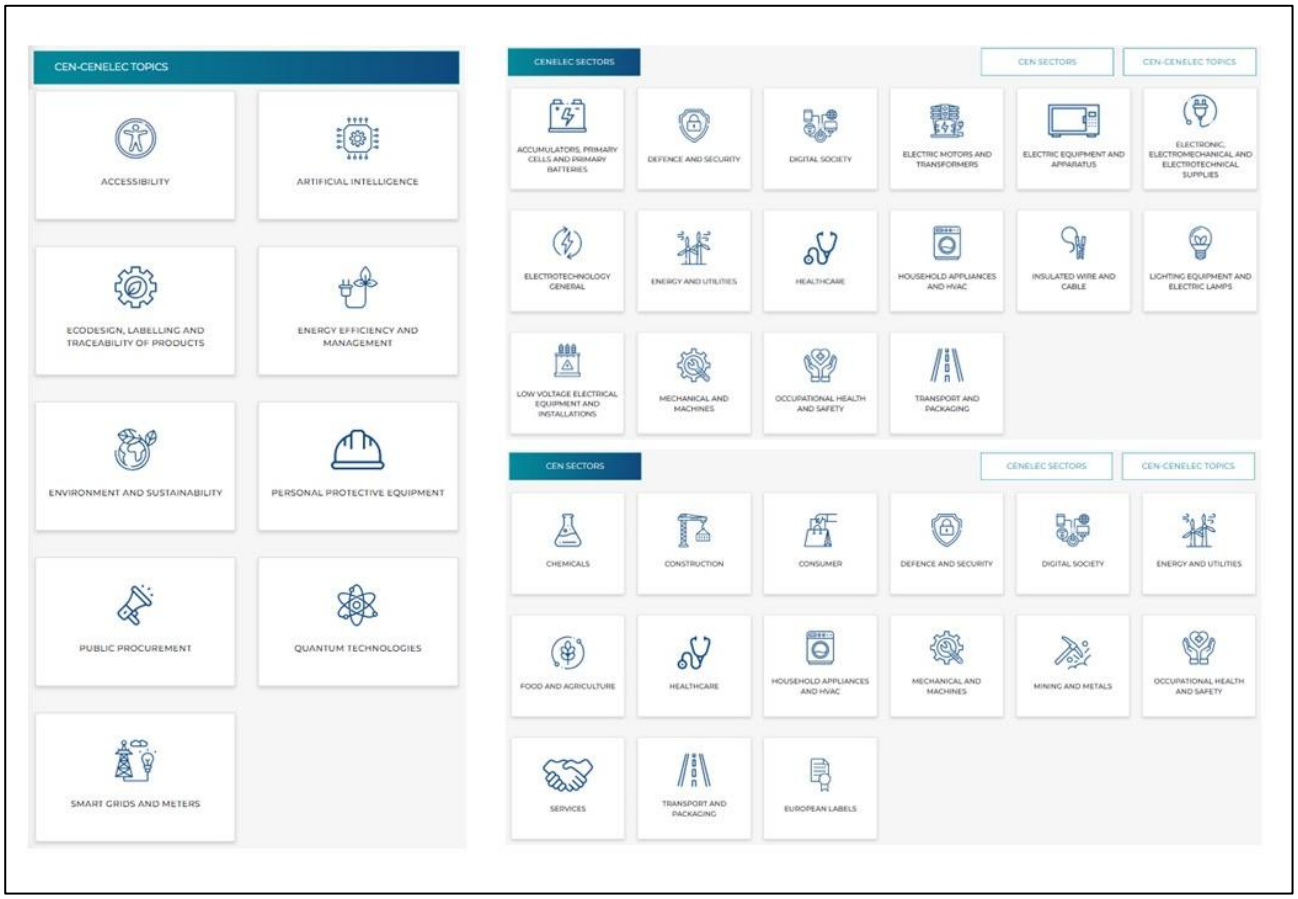
The two organisations represent a network of 90,000 experts, 366 European partners, and 482 Technical Bodies.[3] The total number of living documents from these organisations is 24,721 at the end of September 2025[4].

2 Based on Regulation EU 1025/2012 amended by EU 2022/2084, see https://eur-lex.europa.eu/eli/reg/2022/2480/oj/eng

3 https://www.cencenelec.eu/

4 CEN CENELEC in figures - Quarterly

CEN CENELEC TOPICS AND SECTORS



Source: CEN and CENELEC https://www.cencenelec.eu/areas-of-work/cenelec-sectors/
Figure 3: CEN and CENELEC's fields of activities

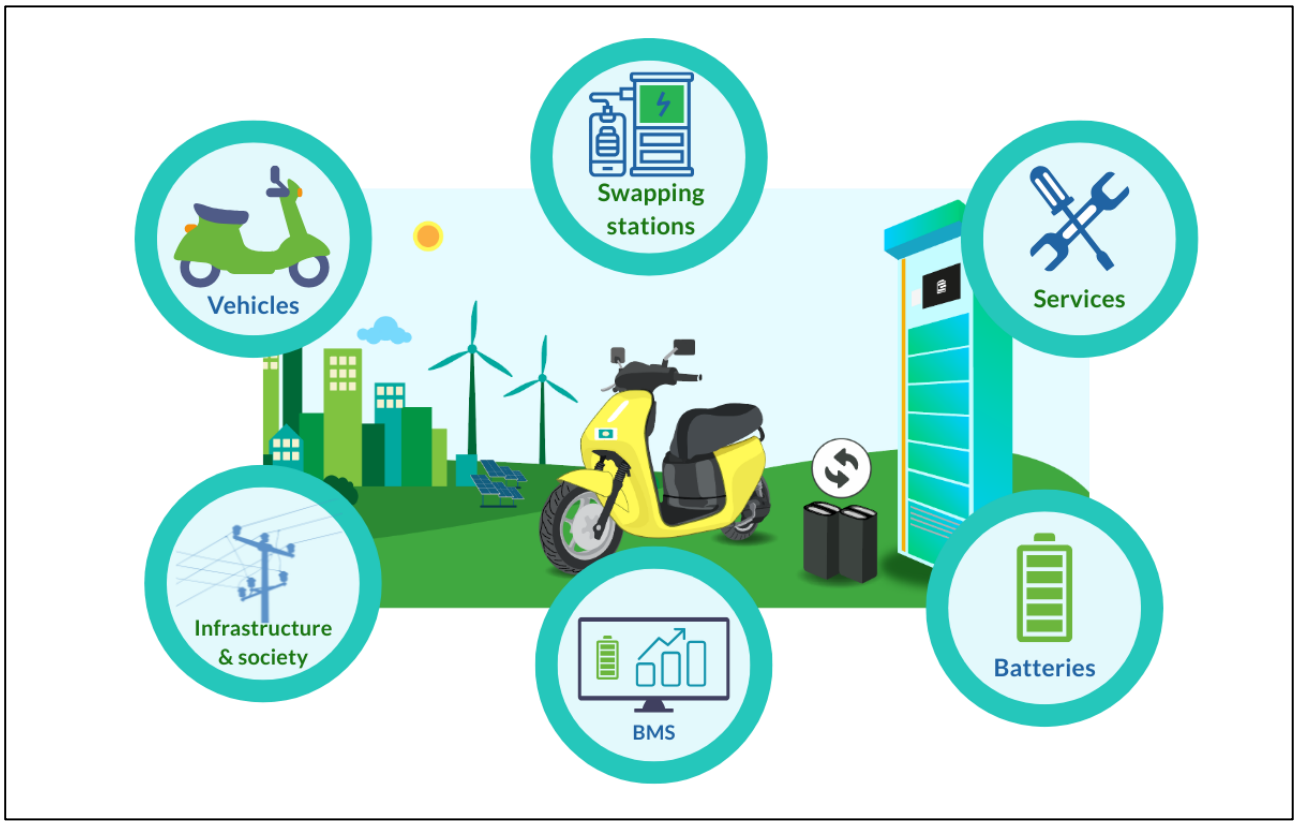
More information on CEN and CENELEC can be found on their website at https://www.cencenelec.eu/.

4. The Ecosystem of Swappable Batteries

Before coming to specific standardisation aspects for swappable batteries for L-cat EVs, this chapter explains the principles of their ecosystem. This system comprises six key elements, each essential to the smooth operation and wide adoption of battery swapping systems for these vehicles:

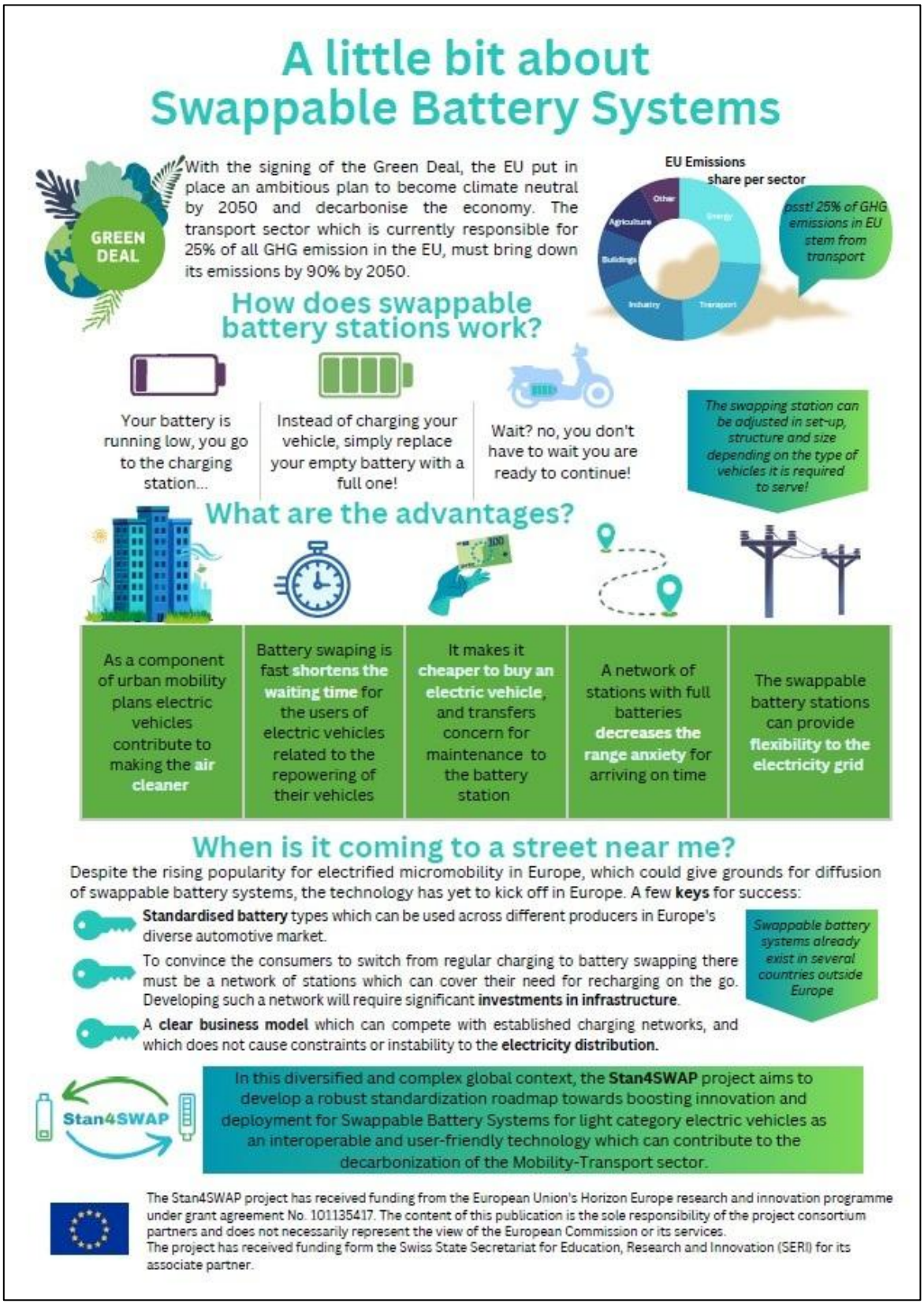
- Swappable batteries
- Vehicles
- Swapping stations
- Battery Management Systems
- Services
- Broader infrastructure and society

These components are shown in Figure 4 and explained afterwards. More details on the principles of the ecosystem are shown in Figure 5.



Source: Stan4SWAP
Figure 4: The ecosystem of swappable batteries

Swappable batteries are components of **electric vehicles**, while Stan4SWAP has a specific focus on "L-cat EVs". Standardised, safe, and readily available swappable batteries must be stored at all stations.



Source: Stan4SWAP

Figure 5: Detailed information on the ecosystem of swappable batteries

These batteries should be easy to handle and designed with user safety in mind. To encourage adoption, the system should have a low barrier to entry, meaning minimal technical knowledge should be needed to perform a battery swap. Uniform compatibility across different vehicle models and manufacturers can further support the practicality and scalability of the system.

As the center of a swappable battery system, a **dense and reliable network of battery swapping stations** is required. These stations must be strategically located to allow EV users to exchange their depleted batteries for fully charged ones with minimal disruption to their travel plans. The process should be seamless and intuitive, ensuring that drivers do not need to carefully plan routes around limited station availability. Convenience and accessibility are critical to building user trust and promoting widespread use.

Another pillar of the ecosystem is the presence of **advanced Battery Management Systems (BMS)**. These systems are vital for ensuring the efficient and safe operation of the batteries within the swapping infrastructure. A sophisticated BMS monitors battery health in real time, manages charging and discharging cycles, and helps prevent malfunctions or degradation. Additionally, it ensures that both the battery and the vehicle remain safe throughout the swapping process, extending battery life and preserving performance.

In addition, the success of this ecosystem depends on a robust **network of partners and service providers**. This includes material suppliers, infrastructure developers, and companies that offer maintenance and repair services for both the batteries and the stations. A well-coordinated supply and service chain ensures that operations remain sustainable, scalable, and responsive to evolving technological and market demands.

Together, these components form the foundation of a functional and future-ready swappable battery ecosystem—one that supports the transition to cleaner mobility and enhances the user experience for EV owners.

The sixth element - **broader infrastructure and society** - embodies society in a more comprehensive sense, e.g., the relevant cities, the citizens, environmental organisations, policy makers and public procurement.

The symbol in the centre of the illustration for battery swapping already highlights important standardisation issues in the swappable battery ecosystem: compatibility and interchangeability. These and many other topics are explored in greater depth in this handbook.

5. Benefits of Standards and Standardisation for Stakeholders in the Ecosystem of Swappable Batteries

This chapter explains why standardisation is beneficial for the ecosystem of swappable batteries. Before outlining the specific benefits of this application area, Chapter 5.1 will first look at the general benefits of standardisation. Chapter 5.2 will present specific aspects.

5.1 Fundamental benefits of standards

Standards are paramount for a market like the European Single Market, which combines several national markets. They ensure alignment across borders and facilitate a harmonised implementation of the law, which in turn creates trust and fosters international trade. They support international trade not only across borders in Europe, but also internally thanks to the international standards developed in ISO and IEC where also national European standardisation bodies participate.

The following list outlines specific additional aspects of how standards positively impact economic efficiency, innovation, and market dynamics (see e.g., Blind, 2009 and CEN-CENELEC STAIR, 2011).

1. Cutting costs by reducing variants to the necessary minimum

One of the most direct benefits of standards is the reduction of unnecessary variations in products and services. By defining the required specifications, standards limit the need for costly customization and reduce production complexities. This streamlining of design and manufacturing processes ensures that resources are utilized efficiently, leading to cost reductions across the supply chain.

2. Guaranteeing a consistent level of quality

Standards are instrumental in setting benchmarks for product and service quality and safety. By defining criteria for acceptable quality levels, standards ensure that all products and services meet a consistent standard. This consistency builds consumer trust, reduces defects, and lowers the need for costly rework or warranty claims, thus enhancing overall economic efficiency.

3. Reduction of time to market

The automotive industry, in particular, benefits greatly from standards, as they reduce the time to market for new models. With a standardised set of components and technologies, manufacturers can speed up the design, testing, and production processes. This efficiency allows them to bring new vehicles to the market more quickly, responding faster to consumer demands and market trends.

4. Ensuring interoperability

Standards ensure that different systems, products, and services can work together seamlessly. In industries such as high-tech industries, energy, and vehicle manufacturing, interoperability is crucial for smooth functioning and the integration of new technologies. By adhering to common standards, businesses ensure that their products can interact with others in the market, enhancing customer satisfaction and reducing compatibility issues that would otherwise incur additional costs.

5. Easier and more cost-effective infrastructure setup

The implementation of standards simplifies the establishment of infrastructure. For instance, charging infrastructure is easier to set up if interoperability is ensured. This reduces initial capital expenditures and operational complexities, creating a more favorable economic environment for businesses.

6. Scaling effects for components

Standardisation enables economies of scale, particularly for components and materials. When businesses adhere to common standards, suppliers can mass-produce standardised parts, leading to lower unit costs. This scaling effect is particularly beneficial in industries, where components are used across multiple vehicle models, thus reducing production costs.

7. Comparability for different products and services

Standards allow for easy comparison between different products and services, enabling consumers to make informed decisions based on objective criteria. In sectors such as automotive and electronics, where choices are abundant, having common standards helps users evaluate and select products according to their needs, without the confusion of inconsistent specifications.

8. Easier diffusion of new products and services

New technologies and products often face resistance in terms of adoption, especially when they require specialized infrastructure or skills. However, when these new products are aligned with established standards, their adoption becomes easier, both for producers and users. Standardisation promotes faster acceptance, reduces adoption costs, and accelerates the diffusion of innovations across different markets.

9. Harmonisation to access bigger markets

By standardising product specifications and service processes, businesses can access broader, global markets. Harmonised standards ensure that products are accepted and meet the requirements of multiple regions, making it easier for companies to expand their reach. This global alignment is particularly crucial in industries such as electronics and automotive, where diverse regulations can otherwise create barriers to market entry.

10. Speeding up transitional processes

Standardisation also facilitates smoother transitions in industries undergoing technological shifts. For example, in the transition from internal combustion engine vehicles to electric vehicles, the use of common standards helps manufacturers adapt more quickly, ensuring compatibility with existing infrastructure and minimising disruption during the transition.

11. Reducing overall costs

By using standardised components and processes, the overall costs of manufacturing vehicles and components, for example, are significantly reduced. Standardisation of parts, materials, and production methods allows for bulk purchasing, reduced waste, and streamlined assembly, all contributing to lower production costs. Comparability standards enable a reduction in search costs, and in the case of standards supporting infrastructures, the cost reductions by users by lowering the price of vehicles and improving affordability.

12. Providing the foundation for further developments and innovations

Standards provide a stable foundation for future innovations by establishing a common framework upon which new technologies can be built. Rather than starting from scratch, developers can innovate within a defined set of parameters, accelerating the pace of technological advancements. By maintaining a balance between standardisation and flexibility, industries can continuously evolve while maintaining compatibility and stability.

As explained in detail in Chapter 7, using the example of the *New Legislative Framework*, standards also offer advantages for regulatory authorities. They reduce the need for these authorities to develop technical specifications, thereby saving on both time and resources. In this context, regulation can refer to safety and relevant standards, to indicate how products and services can ensure a minimum level of safety and quality (see Chapter 7 for further details).

5.2 Importance of standards for stakeholders in the ecosystem of swappable batteries

According to Figure 6, all kinds of standards are relevant for the ecosystem of swappable batteries. Their support ranges from interoperability and compatibility, safety and handling, to infrastructure development, innovation and various additional advantages related to these benefits. The following overview describes seven benefits in this context.

- **Interoperability and compatibility**: In the context of swappable batteries, specific definitions of these terms were formulated:[5]

[5] Source: Swappable Batteries Motorcycle Consortium (SBMC) representatives in Stan4SWAP, based on discussions with the ISO/TC22/SC38/WG2

Source: Stan4SWAP partner CENELEC
Figure 6: Selected benefits of e-mobility standards in the context of swappable batteries

Interoperability (of swappable battery systems) is defined as the capability to transfer power and / or data among various swappable battery systems, vehicles and battery swap stations, without requiring modifications, special interfaces or conversion hardware.

Compatibility (of swappable battery systems) is defined as the capability of swappable battery systems to meet the requirements of battery swap stations and vehicles to transfer energy and exchange data without appreciable modifications and any undesirable consequences of unpredictable shortage of performance.

Interoperability and compatibility are fundamental to the success of the swappable battery ecosystem. Achieving these goals would be challenging without the relevant standards in place. These standards offer all stakeholders a framework for technical and operational aspects, allowing them to concentrate on their core roles and business functions within the ecosystem while ensuring that their products or services can be seamlessly integrated.

- **Safety and quality**: Other benefits pertain to quality and safety aspects. A comprehensive set of standards enables all stakeholders within the ecosystem to have confidence in the safety and security levels - specifically regarding data exchanges within the ecosystem and interfaces with external parties - of the standardised components. Furthermore, these standards ensure a consistent level of safety and security performance across individual elements, thereby addressing risks associated with their combination through the established guidelines.

- **Trust**: Another benefit refers to users' trust. Following the principle of "verifiability", as specified in the CEN-CENELEC internal regulation, part 3 (CEN-CENELEC, 2022), the standards are supporting the assessment of compliance. This is an important aspect for the users of such standardised products, as they may trust in the quality and performance of the products when verified according to a standard.

- **Freedom of choice**: For the consumers and users of products and services of that ecosystem the standardised components provide them with the necessary freedom of choice, which is essential for a viable and sustainable free market.

- **Global trade and appropriate consideration of the international stakeholder landscape:** Besides the European perspective, considering the international dimension of standards and standardisation is essential in the ecosystem of swappable batteries because of the international nature of its stakeholder landscape.

- **Innovation and keeping the ecosystem updated with technical progress**: The framework of technical and operational aspects, outlined in the relevant standards, must adhere to the "performance principle" and the "aim-oriented approach", as specified in the CEN and CENELEC internal regulations. This ensures that the elements within the ecosystem remain aligned with technical advancements and state-of-the-art

developments while facilitating the management of both forward and backward compatibility among components from different generations. Additionally, the standards clarify responsibilities and liabilities, further reinforced by a precise definition of what constitutes state-of-the-art technology.

- **Innovation and facilitating ecosystem extension:** In line with the specific contributions of interoperability and comparability standards, another significant benefit is the facilitation of the expansion of the swappable batteries ecosystem. Standards enable a straightforward assessment of ecosystem extensions by providing a set of specifications and functional requirements that can be utilized for modelling a virtual ecosystem or integrating individual elements into existing business models. Consequently, these standards support the application of standardised swappable batteries in use cases beyond light vehicles. Furthermore, the relevant standards allow for the establishment and operation of entirely isolated ecosystems while still offering the flexibility to choose from multiple suppliers and service providers for the various elements of that isolated (public or non-public) ecosystem, thereby benefiting from economies of scale.

Regarding the international dimension of the ecosystem, the case studies in Chapter 10 show the importance of international standardisation in the swappable battery system and presents experts' contributions from various European and non-European countries, e.g. from Asia and North America.

6. How European and International Standards Are Made

This chapter provides you with information on standardisation from the SDOs (e.g. CEN, CENELEC, ISO and IEC), which are the key European and international standardisation organisations for swappable batteries and their different properties. This chapter describes the creation of European and international standards and related deliverables, such as Technical Reports and Technical Specifications.

6.1 Characteristics of European standards

This section is focused on three types of documents of the European standardisation organisations, namely CEN and CENELEC: European standards, technical specifications and CEN and CENELEC Workshop Agreements. The characteristics of these three are shown in Table 2 and described further below. In addition to these documents, CEN and CENELEC publish guides on European standardisation and technical reports.[6]

The development of **European Standards (EN)** represents the main activity of CEN, CENELEC, and ETSI. An EN is a standard adopted by one of these three organisations. It is created by all parties through a transparent and open process based on consensus.

European standards are an integral part of the European internal market. The three standardisation organisations cooperate with the European Commission and support the European legislation through their committees in the implementation of European directives.

To support its policy and legislation, the European Commission calls upon the European standardisation committees, sometimes through standardisation mandates, to develop and adopt standards. European standards, which are developed in response to a mandate, are referred to as "harmonised standards."

European standards are developed with a global perspective. CEN signed the Vienna Agreement[7] with ISO, which allows the parallel development of European and international standards. A substantial number of the ENs from CEN are identical to ISO standards. These EN ISO standards have the dual benefit of automatic and uniform implementation in all CEN member countries and global applicability.

[6] More information on their products is provided by CEN-CENELEC (2025b).

[7] See https://www.cencenelec.eu/about-cen/cen-and-iso-cooperation/ for details

Standard/ Characteristic	European Standard (EN)	Technical Specification (TS)	CEN and CENELEC Workshop Agreement (CWA)
Possible foundation	• New need for a standard • National standards • International standards • Joint development with an international standard	• No immediate need or not enough consensus for a European standard • Relevant technology not yet mature enough, still in development	• Need for a consensus-based result and validation in an open process • Possible basis: research results of an R&D project
Initiation	• Usually, members of national European standards organisa-tions	• Usually technical body from CEN/CENELEC	• Any interested party
Development decision	• Technical committee from CEN/ CENELEC • Technical Boards for new standardisation areas	• Technical body or board from CEN/CENELEC	• Freedom of decision for all interested parties
Development process	• Predefined process	• Predefined process	• Process with minimum re-quirements
Publication decision	• Formal vote of CEN and CENELEC members	• Vote of CEN/CENELEC members	• Interested parties
Duration of development	• Benchmark 36 months with options for reduction	• 24 months	• 10-12 months
National Introduction	• Introduction as unaltered as possible, withdrawal of conflicting national standards	• No obligation to adopt as a national standard • No obligation to withdraw conflicting na-tional standards	• No obligation to adopt as a national standard • No obligation to withdraw conflicting national standards

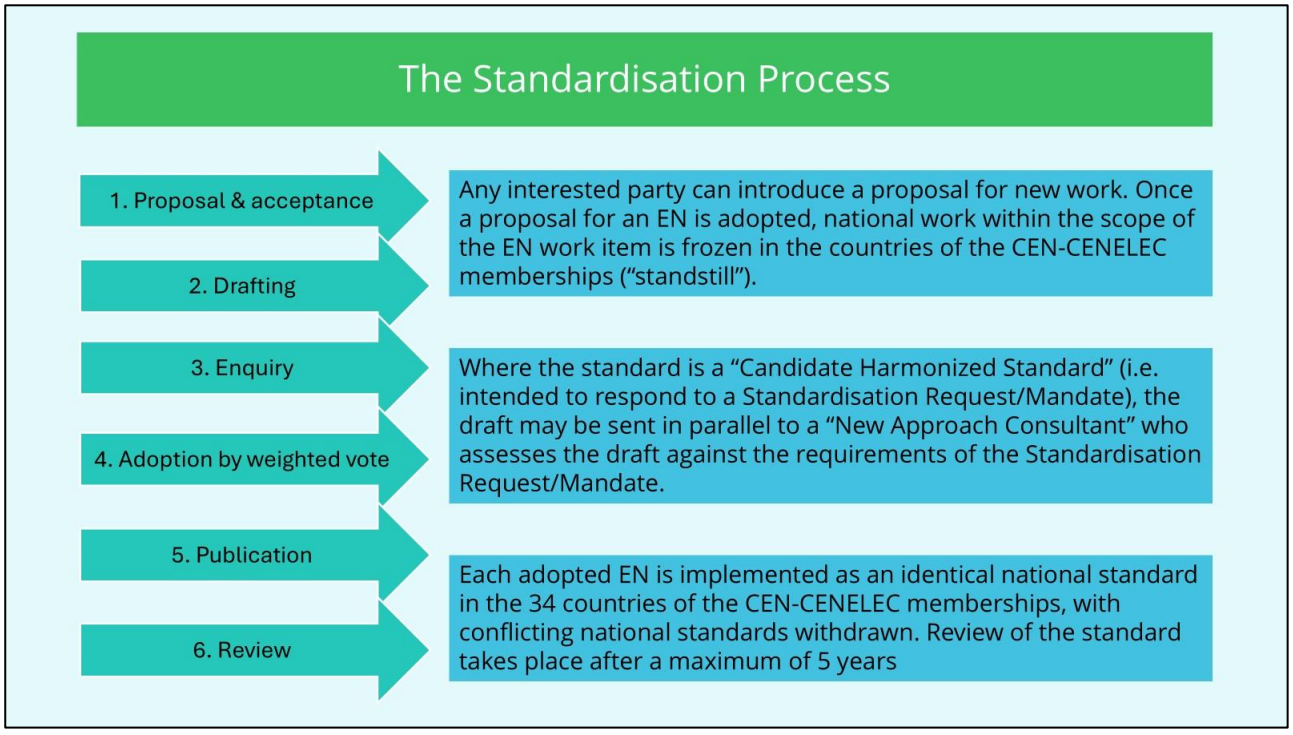
Source: based on CEN-CENELEC (2021, 2025c), CEN (2025b)

Table 2: Characteristics of European standards, specifications and Workshop Agreements

6.2 Development of European Standards

The European standardisation work begins, according to Figure 7, with a **standardisation proposal**. Nominations may be made by members of the European standardisation organisations CEN and CENELEC, such as the DIN, the European Commission, and a number of

European and international organisations. Excluded as standardisation principles are work results, which are in an experimental stage. For this, there are other normative instruments from CEN and CENELEC available, in particular Technical Specifications and CEN and/or CENELEC Workshop Agreements.



Source: based on ANEC (2017)
Figure 7: Development of a European standard

The **work** is assigned to an existing technical committee or, if necessary, a new committee is set up with the agreement of the respective European standards organisation, a sufficient willingness to participate from the national standards organisations/national committees and a guarantee of the necessary financial resources. One of the participating national standardisation organisations will be entrusted with the secretariat.

If there is no international standard that can be adopted, unchanged, as a European standard, a working committee in charge develops a first manuscript for a **draft European standard**. If, for the standardisation subject, international or national standards, are already published, they must be considered.

Further proposals can follow, until it is decided based on consensus, to provide national standards organisations/national committees with a **proposal for public discussion**. For this purpose, a public poll with the publication of the draft standard (prEN) will be initiated. The data will be published in German, English and French. The national standardisation organisations/national committees then have the opportunity to give a national opinion within five months. A version in the national language version will be made public to comment on,

after which anyone can submit a contribution within two months. According to the advice given, the responsible national committee (mirror committee) establishes a national opinion.

Based on the opinions of the European national committee a **final draft** will be prepared to be published again in the three languages. Subsequently, the national standards organisations/national committees decide in a two-month final vote on the acceptance as a European standard. In this phase the design can only be accepted or rejected, justifying their reasons for the rejection. A European Standard shall be considered adopted, if at least 71% of the weighted votes[8] of the CEN and/ or CENELEC members are cast (see DIN, 2025a, section "Entstehung einer europäischen Norm").

The development of a European Standard usually takes a maximum of three years from the beginning of the technical work. Upon acceptance of European standards at national level, they are implemented as identical **national standards** and conflicting national standards are withdrawn (see cencenelec.eu).

The standardisation work at CEN and CENELEC shall rely on nine principles, which are summarised in the following table.

[8] See https://boss.cen.eu/reference-material/guidancedoc/pages/dow/. Each national participant in the Member States of CEN and CENELEC has a fixed number of votes available. The population served as a basis for determining the assessment, considering a correction for less populous countries.

Principle	Description
Planning and Preparation	Establish the intended structure, interrelationships, and organisation of subject matter before drafting to avoid delays.
Aim-oriented Approach	Standardisation should focus on characteristics relevant to the document's objectives, rather than attempting to standardise everything.
Fitness for Implementation as National Standard	Content should be suitable for adoption as a national standard without changes, focusing on internationally accepted characteristics.
Performance Principle	Requirements should emphasize performance over design specifications, allowing for greater flexibility and innovation.
Verifiability:	All requirements must be objectively verifiable, avoiding subjective language and ensuring tests can confirm claims.
Consistency	Maintain consistency within each document and across related documents in terms of structure, terminology, and expression.
Avoidance of Duplication and Unnecessary Deviations	Avoid duplicating content across documents, especially in test methods, and refer to existing standards rather than repeating them.
Accommodation of More Than One Product Size	If standardising a product size, consider including alternative sizes that are widely accepted in international trade, while minimizing options.
Characteristics Not Specified in a Document	For characteristics that suppliers can choose freely, clear communication on how these should be stated is necessary, especially for complex items.

Source: based on CEN-CENELEC (2022)
Table 3: Principles for standardisation at CEN and CENELEC

The specific relevance of these principles for the development of standards for the ecosystem of swappable batteries will be explained in Chapter 7.

6.3 Characteristics and development of European specifications

As seen in Table 2, specifications of CEN and CENELEC, which include, in particular, Technical Specifications (TS) and CEN and CENELEC Workshop Agreements (CWAs) differ from standards in a number of ways.

A **Technical Specification (TS)** is a "normative document, the development of which can be envisaged when various alternatives that would not gather enough as to allow agreement on a European Standard (EN), need to coexist in anticipation of future harmonization, or for providing specifications in experimental circumstances and/or evolving technologies" (CEN-CENELEC, 2025b). For the national standardisation committees, these specifications do not imply any obligation to adopt them as a national standard (see CEN-CENELEC, 2025b).

A **CEN and/or CENELEC Workshop Agreement (CWA)** is "a deliverable, which may take various forms such as a text file or computer code, developed and agreed by the participants in a temporary working group (CEN and/or CENELEC Workshop). It is designed to meet an immediate need, can be quickly developed and can be used as a fast track to future standardisation activities." (CEN-CENELEC, 2024). It is developed in a CEN and/or CENELEC Workshop, which is a temporary group open to the participation of any interested parties for elaboration of CEN and/or CENELEC Workshop Agreements (see CEN-CENELEC, 2024).

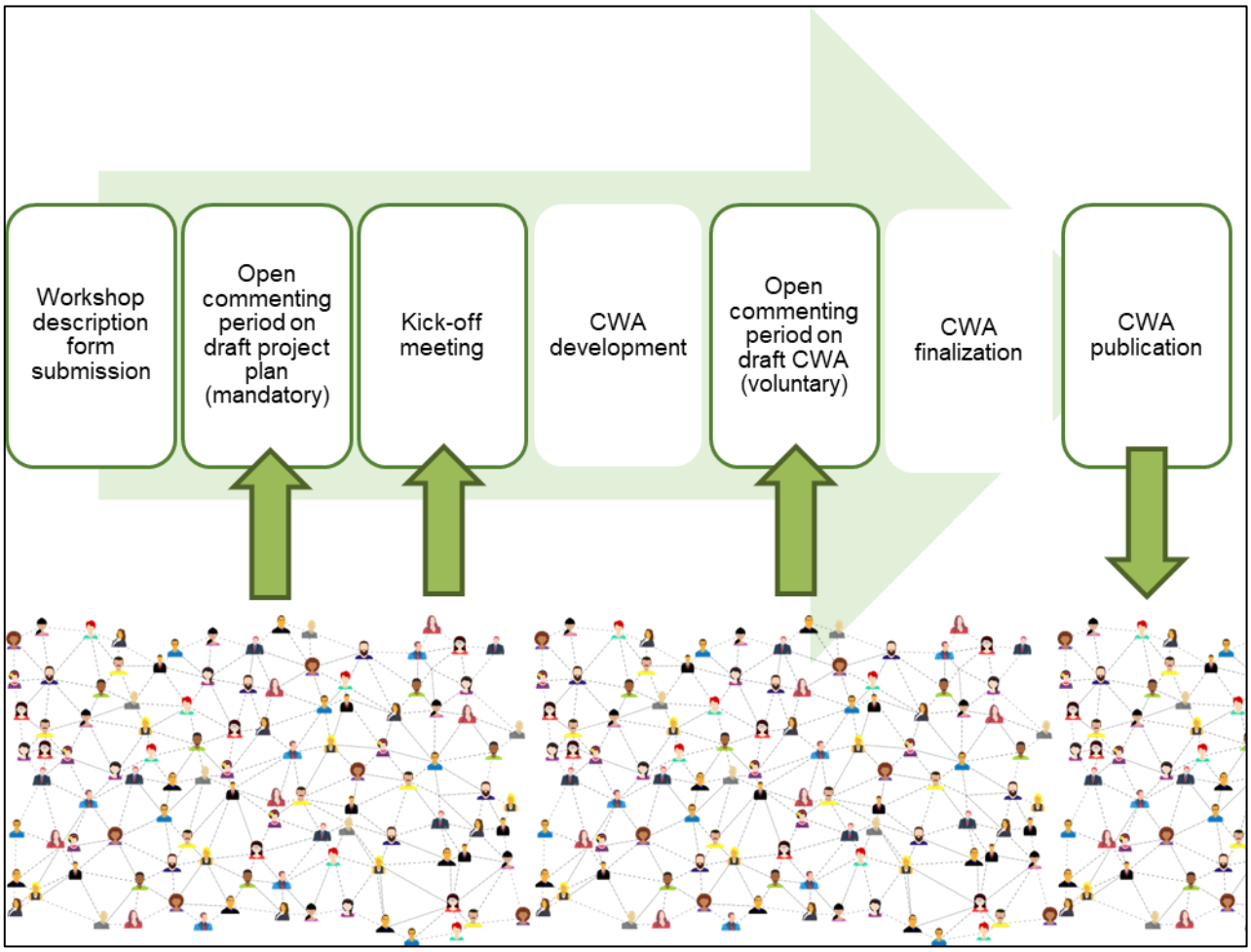
The workshop concept provides stakeholders with solutions to problems that can be addressed through standardisation, the possibility to contact market participants in a similar situation, and to develop a validated, consensus-based result in an open manner. CEN/CENELEC Workshops are used in a special way for the transfer of R&D project results.

The procedures for establishing and implementing the workshops are deliberately reduced to a minimum, see Figure 8 and CEN-CNELEC (2024), for detailed descriptions.

CWAs are a more flexible and faster alternative to the traditional EN standards. The organisation of the workshops is completely separated from the conventional work of Technical Committees responsible for the development of the CEN and CENELEC standards. Therefore, they avoid both the lack of openness of de facto standards as well as the high formalisation for an EN creation.

Industry consortia can achieve a wider market acceptance of their documents through a CEN Workshop. It is possible to develop CWAs further to ENs or use them as a base for the development of ENs. CWAs can compete both with European Standards and with each other.

Safety matters are excluded from being the subject of a CWA (see CEN-CENELEC 2024).



Source: CEN-CENELEC (2024)
Figure 8: Development of a CWA

A CWA is reviewed after three years to determine if it shall be confirmed for another 3 years, revised, withdrawn, or converted into another deliverable by a CEN and/or CENELEC Technical Body. If an extension for another three years is wanted, the maximum validity as a CWA is 6 years (see CEN-CENELEC, 2024).

6.4 Characteristics and Development of International Standards and Specifications

According to Chapter 2, ISO and IEC are key international organisations for standardisation measures to support the ecosystem of swappable batteries. They are presented in the following sections. The allocation of one of these SDOs to a specific standardisation topic in the context of swappable batteries depends on the relevant topic and the current work at both organisations. Chapter 10 provides additional praxis information in this context.

6.4.1 Charcteristics and development of ISO deliverables

In this section standards of the International Organisation for Standardisation (ISO) are presented. It is dedicated to five groups of documents: ISO Standards, ISO/PAS (Publicly Available Specifications), ISO/TS (Technical Specifications), and IWA (International Workshop Agreement) and ISO Guides (not discussed in this book), see ISO (n.d.-a). Their characteristics are shown in Table 4 in an overview and then described.

An **ISO Standard** is a normative document, developed according to the consensus process and recognized by the ISO membership of the committee responsible, in accordance with Part 1 of the ISO and IEC Directives. It was approved as a Draft of International Standard (Draft International Standard) and/or as the final draft version (Final Draft International Standard), and published by the central secretariat of the ISO.

As shown in Figure 9, the beginning of an international standardisation project is a **standardisation proposal** from an ISO member, (e.g., from a national standards body, the secretariat of a technical committee or subcommittee of the ISO, an international organisation with liaison status, ISO's technical steering committee or its secretary general).

If those in the relevant field of active national standards organisations/national committees (P-members[9]) **agree to** the proposal by simple majority, and if there is a sufficient number of members willing to cooperate actively, the proposal will be included in the work program of a relevant committee or, if necessary, a new committee will be established.

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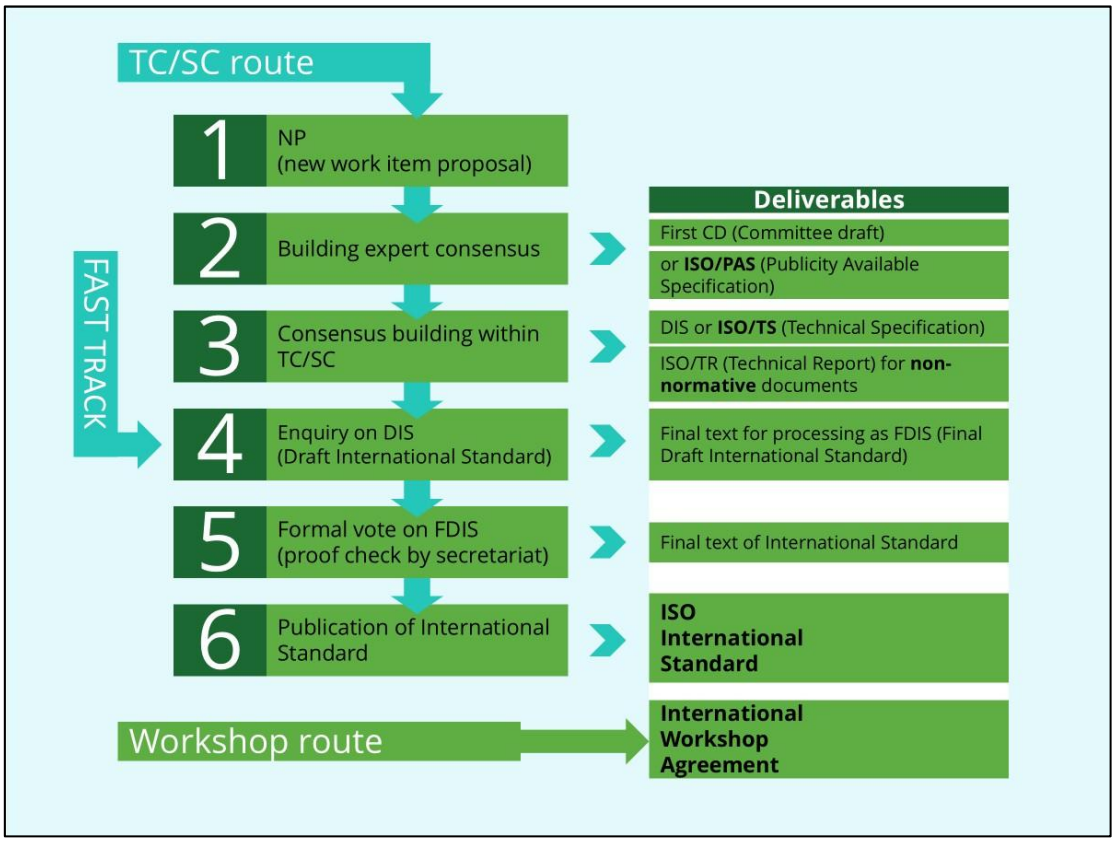
[9] Participant members (P-members) are actively involved in standardisation work. They have an obligation to attend meetings and vote on all the formal questions, requests, drafts, and Final Draft International Standards. Observing Members (O-members) agree to follow the work of the Committee as observers, and therefore receive the documents of the committee. O-members have the right to express opinions and participate in the meetings. A national standards organisation may decide to take either a P- or an O-member status in a committee. In this case, they neither have the rights nor obligations of the relevant technical committees (TCs), but they retain the right to vote on Draft International Standard and International Final Drafts. International organisations can participate in TCs as "liaison organisations," but they are not permitted to vote in the balloting in connection with development of draft standards (see Morikawa / Morrison, 2004).

Standard/ Characteristic	ISO Standard	ISO/PAS (Publicly Available Specification)	ISO/TS Technical Specification	ISO/TR Technical Report	International Workshop Agreement (IWA)
Content	• Consensus of the ISO members on a normative document	• Consensus of an ISO working group on a normative document	• Consensus of an ISO committee on a normative document	• Additional information on a normative document	• Normative ISO document, created in one or more workshop sessions
Initiation	• ISO Member[1]	• ISO Working group	• ISO TC or SC • P-Member or organisation with liaison status of category A or D	• ISO work committee	• Interested parties
Development decision (minimum requirements)	• Simple majority of P-members	• ISO TC or SC	• ISO TC or SC	• ISO working group	• No special requirements • Decision by interested parties
Process	• 3 – 6 steps	• 2 steps	• 3 steps	• 2 steps: collection of information, making it public	• No technical committee procedure or predetermined stages
Decision to publish (minimum requirements)	• 2/3 majority of P-members, ≤ 1/4 of the total number of votes cast are negative	• Simple majority of P-members	• Consensus within an ISO committee	• Simple majority of P-members	• Determined specifically at a workshop
Development time	• 18 - 36 months, usually 36 months	• Usually < 3 years	• Usually < 3 years	• Usually a few months	• Usually a few months
National introduction	• No obligation	• No obligation	• No obligation	• No obligation	• No obligation
[1] e.g. national standards organisations, ISO Technical (sub-) Committees, organisations with a liaison status, the ISO Technical Steering Committee, ISO general secretary					

Source: based on ISO (n.d.1), ISO (n.d.-b) with related links, ISO (n.d.-c)

Table 4: Overview of ISO documents



Source: based on ISO (n.d.1), figure "ISO deliverables"

Figure 9: Creation of ISO documents

Following the previous step, the relevant group of the committee creates a **Committee Draft** (CD) for transmission to the relevant committees of the participating national standards organisations/national committees. The national technical committees submit their comments in writing within three months. If consensus is achieved to provide a proposal for public discussion, a **Draft International Standard** (DIS) is provided by the ISO in English and French for public inquiry. To formulate a national opinion, the ISO members then have a period of five months.

A final document text is drawn after the **comments** of the member institutions in the DIS are considered. This text is then made public for a formal vote as a **Final Draft International Standard** (FDIS). If the content from two-thirds of the P-members is accepted and not more than a quarter of all votes cast are negative, the text is approved and issued by the central secretariat as an international standard (see, e.g., DIN, 2025a, section "Erstellung einer internationalen Norm).

The ISO members are not required to include the international standard in the national standards (see e.g., DIN, 2025a). They are free to accept the standard completely, modify it or not accept it at all nationally. An exception exists, however, if the standard originated under the

Vienna Agreement[10] and, by parallel voting procedures, gained simultaneous recognition as an international and European standard.

If this happens, conflicting national standards must be withdrawn.

When using the Fast Track process, the steps for creating an ISO standard are reduced. Such a reduction is possible if a document already has a high level of maturity at the start of a standardisation project, e.g., due to development in another organisation.

An **ISO/PAS (Publicly Available Specification)** is a normative document representing the **consensus** within **a working group of the ISO**. Its creation is decided by a technical or subcommittee (TC/SC). This decision should be made simultaneously with the approval of the appropriate "New Work Item Proposals" (NP).

The text of ISO/PAS is developed by a working group in a preparatory phase. At the end of this phase the document is to be given to the technical or subcommittee, under which the working group acts, to be published for recognition as a PAS. Acceptance requires the approval of a simple majority of P-members. Competing PASs with different technical solutions are possible, if they are not inconsistent with existing international standards. The specifications should be reviewed at least every three years to:

- confirm ISO/PAS for another three years,
- make changes,
- do further work on the PAS,
- to obtain a technical specification or an international standard or withdraw the PAS.

After six years a PAS should either be converted into an International Standard or withdrawn.

The **ISO/TS Technical Specification** is a normative document that represents the technical consensus within an **ISO committee**. The development includes, in contrast to PAS, the committee stage. In the committee stage, the text will be sent for a three-month vote to all P-members of the committee to approve publication as a technical specification. There are two other variants of development, which are explained on the ISO website.

Technical specifications, which compete with different technical solutions are possible, provided they do not conflict with existing international standards. The specifications should be checked by the technical committee or subcommittee no later than three years after their publication. The aim is, where possible, the publication of an International Standard.

The term **ISO/TR Technical Report** is an informative document, which, in addition to the possible content of a deliverable from the ISO, provides supplemental information. If a committee has collected information for the benefit of an approved work item or more work, it may decide to publish it as a technical report by a simple majority vote of P-members. The

[10] See https://www.cencenelec.eu/about-cen/cen-and-iso-cooperation/ for details

implementation requires the consent of the Secretary General of the ISO, and, if necessary, in consultation with the Technical Management Board.

An **IWA (International Workshop Agreement)** is an ISO document, which is not produced in one or more session(s) of a workshop by the technical committee procedure. It is used to address a rapidly evolving market demand or other requirement of public interest. All interested parties can propose and participate in the development of an IWA. An ISO member body is instructed to organize and execute the workshop session(s). Participants then work directly with the preparation of this document and do not undergo national delegation.

An IWA can be made on any subject. It can be developed in less than twelve months and be used to address a rapidly evolving market demand or other requirement of public interest. IWAs can be used as precursors to international standards (see ISO, 2011).

6.4.2 Charcteristics and development of IEC deliverables

The **International Electrotechnical Commission (IEC)**, which is comparable in function to ISO (see ISO/IEC, 2024), is responsible for developing international standards in the field of electrical and electronic technologies. Its publications can broadly be classified into two categories (see IEC, n.d.-a,):

- **Normative publications**, which establish technical specifications and performance criteria.
- **Informative publications**, which provide guidance on implementation procedures and best practices

The overarching objective of the IEC is to foster technological innovation, support the development of cost-effective infrastructure, and promote efficient as well as sustainable access to energy. In addition, its work contributes to smart urbanization and transportation systems, supports climate change mitigation, and enhances the safety of both individuals and the environment. Operating on a global scale, the IEC currently unites approximately 170 member countries and coordinates the expertise of more than 30,000 specialists.

IEC's main deliverables are international IEC Standards, Technical Reports, Technical Specifications and Guides. More information on the development of these deliverables, which is comparable to the standardisation processes at ISO, is provided at IEC (n.d.-a).

All IEC standards are developed through a consensus-based process. Consensus requires that the views of all stakeholders be duly considered, major issues resolved, and significant opposition addressed. Formally, adoption of a standard requires a two-thirds majority among participating experts and national committees, with fewer than 25% of negative votes from the total IEC membership.

The IEC is of particular relevance for swappable batteries, as its standardisation activities intersect directly with the domains of electric mobility and sustainability. The IEC's mandate to establish globally recognized norms for electrical and electronic technologies aligns closely with the need for standardised battery systems and communication protocols. Standardised approaches in these areas are essential not only for ensuring technical interoperability and safety but also for facilitating large-scale deployment, reducing market fragmentation, and supporting the broader transition towards sustainable mobility solutions (see IEC, n.d.-b and n.d.-c).

7. Regulatory and Standardisation Landscape in the Ecosystem of Swappable Batteries

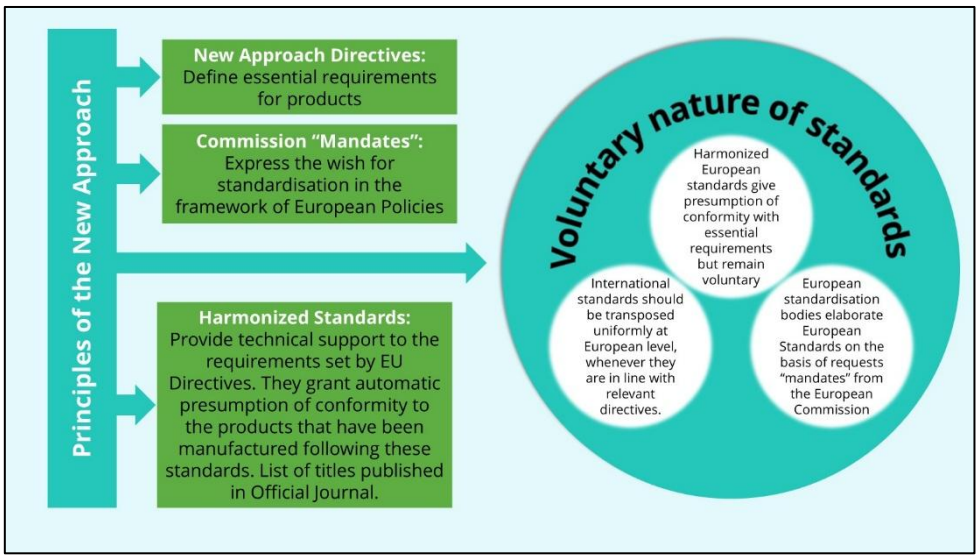
This chapter provides you with information on regulatory framework conditions and the standardisation landscape of swappable batteries. It presents three key regulations, eight specific standardisation activities in this area, and an important standards series developed by IEC.

7.1 Regulatory framework conditions

Various interrelations between regulations and standards exist although they are fundamentally different. Regulations emanate from governments (local or national) or from the EU and are enforceable for everyone while standards, defined in Chapter 2, are in principle voluntary documents of good practice. Interactions between the two realms include, in particular, standards being referred to in legislation, and the EU's promotion of standards development through standardisation mandates addressed to CEN and CENELEC.

Key concepts in this context are the Better Regulation initiative of the European Commission and the "New Approach", which are described in detail by European Commission (n.d.), CEN and CENELEC (2015), and Kamara (2022).

Under Europe's "New Approach" system, the legislative documents, such as the EU regulations and directives, state only essential requirements while for the technical details of these requirements reference is made to the relevant harmonized European standards. The latter remain voluntary as they are standards, but by following these standards, conformity with the essential requirements is presumed, see Figure 10.



Source: own figure based on CENELEC (2007)

Figure 10: The relationship between standards and regulation

The "**New Approach**" is applied to most domains of the European market.

Regulatory EU documents with direct relevance for swappable battery systems include the following regulations which are also considered in Chapter 7.2 below:

- Regulation (EU) 168/2013 on two- or three-wheel vehicles and quadricycles (European Parliament and the Council, 2013)
- Battery Regulation (EU) 2023/1542 (European Parliament and the Council, 2023a)
- Alternative Fuel Infrastructure Regulation (EU) 2023/1804 (European Parliament and the Council, 2023b)

Regulation (EU) 168/2013 on two- or three-wheel vehicles and quadricycles

This regulation applies to all two-, and three-wheeled vehicles, as well as quadricycles (L-cat vehicles) intended for road use. Its main objectives are to:

- Establish uniform rules for type-approval across the EU
- Facilitate the free movement of L-cat vehicles within the EU
- Reduce emissions from these vehicles
- Enhance safety standards and monitor areas for necessary improvement
- Remain flexible and responsive to future technological developments
- Ensure unrestricted access to vehicle repair information

Alternative Fuel Infrastructure Regulation (EU) 2023/1804

This regulation mandates the deployment of accessible alternative fuels infrastructure across all sectors within the EU. Its main objectives are to:

- Achieve net-zero emissions through the use of alternative fuels
- Phase out the use of fossil fuels
- Establish mandatory minimum targets for publicly accessible recharging and refuelling stations
- Assess the infrastructure needs for L-cat vehicles
- Ensure accessibility, safety, and transparent pricing for users

Battery Regulation (EU) 2023/1542

This regulation provides a framework for the entire battery lifecycle. Its main objectives are to:

- Reduce the environmental impact of batteries
- Increase recycling targets and promote circular economy practices
- Introduce a battery passport containing digital information on battery characteristics
- Establish mandatory safety requirements
- Ensure batteries are easily replaceable by the end user
- Extend end-of-life responsibility for producers

7.2 State of the art in standardisation of swappable batteries

When it comes to standardisation of swappable batteries in particular seven technical committees are active:

- IEC TC 69 Electrical power/energy transfer systems for electrically propelled road vehicles and industrial trucks
- IEC TC 21 Repurposing batteries a valuable solution to clean energy storage, specifically SC21A Secondary cells and batteries containing alkaline or other non-acid electrolytes
- IEC TC 23 Electrical accessories, specifically SC23H Plugs, Socket-outlets and Couplers for industrial and similar applications, and for Electric Vehicles
- ISO TC 22 Road vehicles, specifically SC 38 Motorcycles and mopeds
- CEN TC 391 Electrically propelled road vehicles, specifically WG19 Swappable battery system for L-cat vehicles
- CENELEC TC 21X Secondary Cells and Batteries
- CENELEC TC 69X Electrical Systems for Electric Road Vehicles

In addition, another important organisation is the Open Traffic Systems City Association e.V. (OCA).

The following figure summariese these eight organisations and committees.

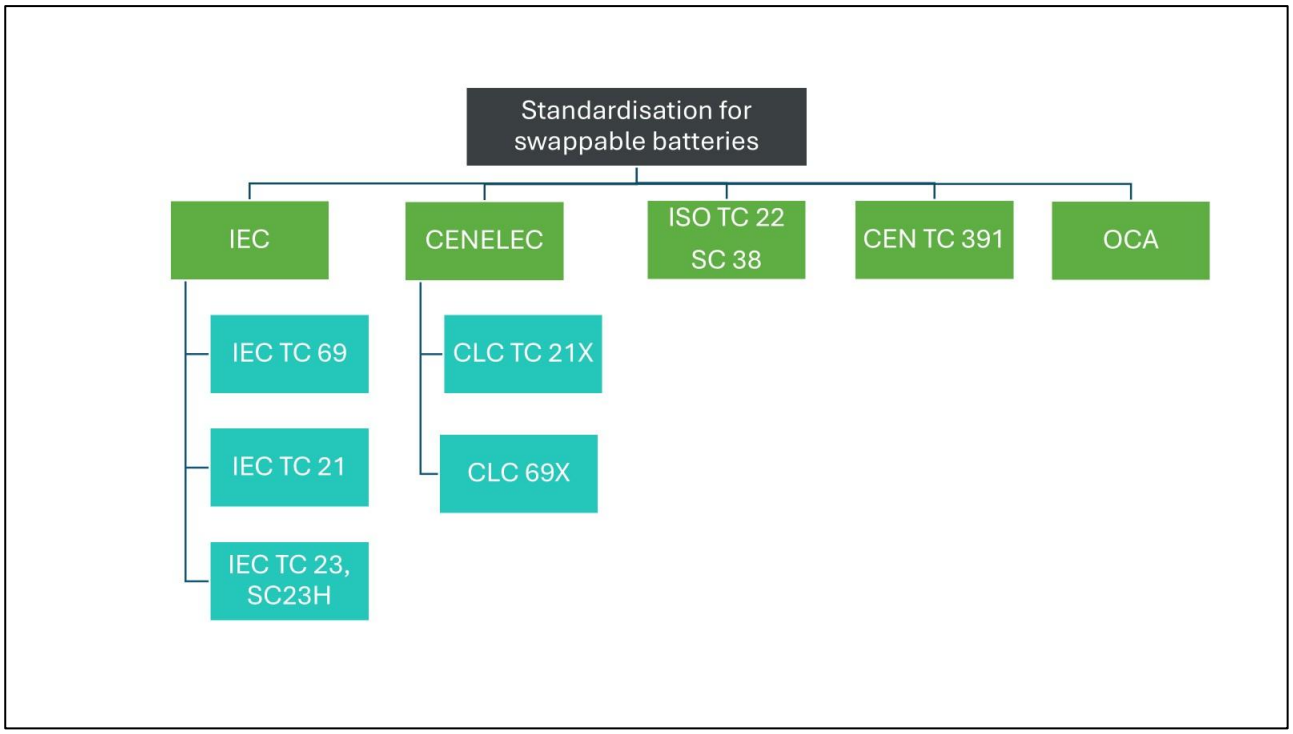


Figure 11: Key standardisation activities in the context of swappable batteries

Standardisation efforts strictly related to electric vehicle battery swap systems are firstly treated in the IEC62840 family of standards "Electric vehicle battery swap system", developed by IEC TC69.

Part 1, "General and guidance" (2025), gives a general overview of battery exchange systems for electrical road vehicle batteries, introducing system concepts and use cases.

This also marks the difference between "swappable" and "removable" battery systems, describing typical system components for both. The swappable battery system, where the batteries are moved by the charging station handling system, is foremostly aimed at larger vehicles (cars and heavy-duty vehicles), while as the removable system aims at lighter vehicles, such as covered by the project.

The second part, on "Safety requirements" (2016, second edition expected end 2025), contains the general safety requirements for swappable or removable battery systems. The battery swap system shall be so designed and constructed that, in normal use, its performance is reliable and minimizes the risk of danger to individuals, equipment and surroundings.

The third part of IEC 62840 provides specific requirements and test methods for battery swap systems operating with handheld swappable battery systems (HBS) of totally or partly electrically propelled vehicles. It extends parts 1 and 2 with specific requirements for the given application. Originally, it was created in the IEC 61851 series and then assigned to the IEC 62840 series. Both standards series are also considered in Chapter 10's case studies on standards development, specifically in Chapters 10.1 and 10.5.

Other standards which may be relevant for battery swapping systems are treated by IEC TC21 and SC21A (Battery safety), and IEC SC23H (Accessories, such as connectors), and the consortium standards of the Open Traffic Systems City Association e.V. (OCA) dealing with the Open Charge Point Protocol (OCPP) protocol. These documents are now being adopted as international IEC standards.

Looking at the vehicle level, work is being performed in vehicle committees, such as ISO TC22 SC38 or CEN TC301. New initiatives are being started on European level, with the inception in CEN TC301 of a new working group, WG19, on Swappable battery system for L-cat vehicles. Standardisation on the vehicle side is essential to allow true interoperability of a swappable battery system transcending vehicle makes or models. The provision of standard batteries for different vehicles may be a special challenge, since it implies direct involvement in the design and appearance of the vehicle which are key elements of the individuality of a brand; particularly for smaller-size vehicles like L-cat vehicles.

8. Standardistion Strategies for the Ecosystem of Swappable Batteries

This chapter presents standardization strategies for the ecosystem of swappable batteries, starting with basic technical recommendations and negotiation principles for effective collaboration among stakeholders, and continuing by addressing transnational activities by considering cultural differences and other challenges. Finally, specific strategies and recommendations are provided to maximize individual benefits within this framework. The strategies are also applicable to many other technical standardisation activities, particularly when it comes to interoperability.[11]

8.1 Basic Technical Recommendations

For the successful development of standards and technical specifications Piersall (2003) has defined a set of general requirements, see Figure 12, which should be considered by the standard drafters.

Market-based nature	**Timing**	**Comprehensive acceptance**
Developed concurrently with new technologies	**System-based management, focus on performance and interchangeability**	**Installability**
Ensuring the manufacturability	**Usability**	**Efficient usability at competitive cost**
Secure supportability	**Appropriate possibilities for maintenance**	

Source: based on Piersall (2003)

Figure 12: Technical recommendations for successful standardisation

Market aspects play a central role in standardisation. First, it must be defined which stakeholders represent the market. Possible target groups are, e.g. manufacturers, system operators and end users. In standardisation all target groups, with their partially heterogeneous expectations, are to be considered. For the identification of market and user requirements, there are a number of options available. ETSI (2012) mentions, for example, observations, focus groups and surveys. The demand is, among other things, influenced by **temporal aspects (timing)**.

11 Parts of Chapters 8 and 9 are based on material originally developed by Stan4SWAP experts for TU Berlin and EURAS, which has been updated and used with permission for Stan4SWAP.

Technical quality cannot be separated from standardisation success and is also an important **acceptance condition**.

Consideration of **technical progress** is a fundamental prerequisite for standardisation work in many standardisation organisations. Dohlmans (2002) pointed out the importance of fair and open selection processes for technologies. Objective and verifiable criteria have high importance in this context. The total cost of technology use, for example, represents a suitable selection criterion. It is to ensure that the selection is not affected by the origin of a technical approach. Persons or organisations that have no direct interest in the selection result, are especially suitable for the implementation of these procedures.

Interchangeability is defined by ISO as "module property allowing it to be capable of being used to replace another module", with the note that such "interchangeability can relate to modules produced by one manufacturer or from different manufacturers" (see ISO, 2021b).

Standards and specifications must allow for the use of alternative technologies (see e.g., Dohlmans, 2002). Special aspects of interchangeability will be mentioned in more detail later in this chapter.

A **suitable technical specification** aims to ensure maximum competition based on quality and product differentiation. Therefore, the standard must be limited to essential elements. This is particularly true in relation to requirements for product or system design, or technology implementations (see Dohlmans, 2002).

Efficient implementability can, for example, be favoured by an appropriate technology choice and technical approach, while measures to ensure **manufacturability** and **usability** are considered among the models for document management. To ensure **installability**, recommendations for document management can include the provision of user manuals. Specificities to enable appropriate **maintenance** must be defined according to the context.

8.2 Negotiation Principles in Standardisation

According to Fomin et al. (2003), standardisation can be understood as processes, which are characterized by three mutually interacting strands of action: design, sense-making and negotiation. Pfetsch (2008) specified five rules for successful (standardisation) negotiations:

- Separate personal and objective aspects
- Focus negotiations on interests and not on positions
- Ensure that all parties benefit from the options and acquire common benefits
- Use objective decision criteria, scientific or professional assessments, and fair procedures
- If negotiation objectives cannot be achieved implement the best alternative.

Consensus-building in the development of interoperability and compatibility standards is characterized by specific conditions. The following negotiation strategies by Schmidt/Werle (1998) were developed specifically for standards developers with products and services whose value may be influenced by the potential standard or specification. The development of such standards can take place in two contexts: the existence of compatible complements and the existence of compatible substitutes.

Existence of compatible complements means that two technical components, "y" and "z", are compatible and can be shared. They only gain clear benefits by cooperating with compatible technologies. Their producers and users have, therefore, a great interest in obtaining compatibility between the two.

Existence of compatible substitutes means that not only "y" but also a functionally equivalent component "x" is compatible with "z". It is insignificant from the user's and manufacturer's point of view whether "x" or "y" is applied. Regarding interoperability with "z", both components are compatible substitutes. These situations imply competition between "y" and "x".

To provide recommendations for both cases, game-theory principles are applied. Game theory relies on the assumption that individual results depend not only on individual decisions, but also on other players, though the players' possible steps need to be considered with their own steps. There is no possible independent solution that an individual can decide by himself. Schmidt/Werle (1998) distinguish among four cases in the consideration of compatibility constellations: Pure Coordination Game, Battle of the Sexes, Zero-sum game and the Prisoner's Dilemma. The different constellations are presented in Table 5.

Game Type	Description	Conflict Potential	Outcome
Pure Coordination Game	Common goal of standardisation, little difference between individual and common solutions.	Low, as no particular strategy is expected.	High coordination required; common solution possible.
Battle of the Sexes	Different preferences between parties for solutions "A" and "B".	High, as individual advantages take precedence.	Risk of project failure; suboptimal solutions are possible.
Zero-sum Game	Substitutability of incompatible technical alternatives; conflicts over standard configurations.	High, as the decision for one solution means success or loss.	No agreement reached; potential conflicts between providers.
Prisoner's Dilemma	Possibility of a compromise that is unattractive due to cost concerns; hesitation due to trust issues.	Moderate, as uncertainty about cooperation exists.	No standard realized, despite better alternatives being available.

Table 5: Constellations in the development of compatibility standards from a game theoratical perspective

The following figure summarizes the financial effects of the different constellations.

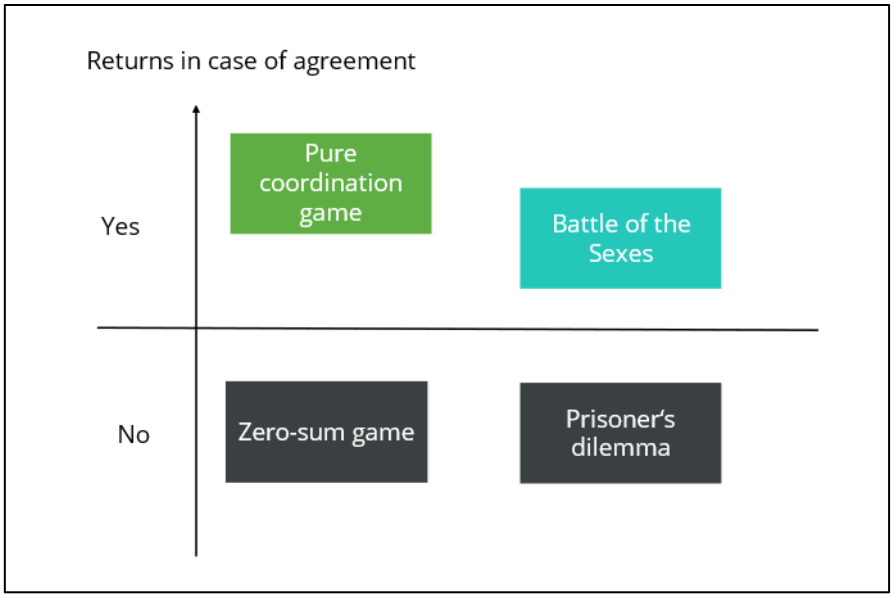


Figure 13: Specific constellations in the development of compatibility standards from a game theoretical perspective

To avoid negotiations without positive outcomes, solution-oriented project management is of great significance, as well as a common understanding of possible solutions with benefits for all parties involved. Due to the conflict potential in the above-mentioned constellations, specific resolution mechanisms are needed.

Conflict resolution in the standardisation process

Pfetsch (2008) defined seven basic rules for the handling of conflicts in standardisation processes.

- Try to find out how willing the other side is to negotiate and where the limits of their willingness to negotiate lie!
- Identify the key parties who are directly or indirectly involved in the conflict. Try to understand the power structure or power relationships, and focus on the most important!
- Identify aspects included and their meaning, evaluate own priorities and those of the other side!
- Develop sensitivity for compatible and non-compatible aspects!
- Evaluate the credibility and trustworthiness of your opponents and rate their limitations; ensure that they can meet their obligations and wants!
- Consider the circumstances regarding time and space, which can influence decisions, and evaluate their significance!
- Develop strategies in case these rules cannot be adhered to!

If no solution can be achieved, the application of mediation mechanisms is needed. Various SDOs, such as CEN, CENELEC, ISO and IEC provide specific assistance to identify solutions in such contexts.

8.3 Strategies for Transnational Standardisation Activities

8.3.1 Addressing cultural differences

The cultural differences between the experts are a specific challenge for international standardisation bodies, see Wehnert (2006). These differences may lead to misunderstandings or tensions which can hamper the standardisation process. Therefore, an awareness of these differences is important in transnational standardisation meetings. In this context, Hofstede (2001, 2003) distinguishes the characteristics of power distance, individualism, uncertainty avoidance, masculinity, and long-term/short-term orientation. On this basis, five cultural indices have been developed.

The **Individualism Index (IDV)** differentiates between individualism and collectivism. The interest of the individual is compared to the interest of the group.

The **Power Distance Index (PDI)** evaluates the relationship between supervisors and employees in terms of the dependence on power figures.

In the **Uncertainty Avoidance Index (UAI)** the willingness reflects taking unknown risks. He describes the tolerance of a cultural group for uncertain and unknown situations.

"Motivation Toward Achievement and Success" (MAS) is a new label created by The Culture Factor (TCF) for Hofstede's original dimension "Femininity - Masculinity", see Hofstede (2025).

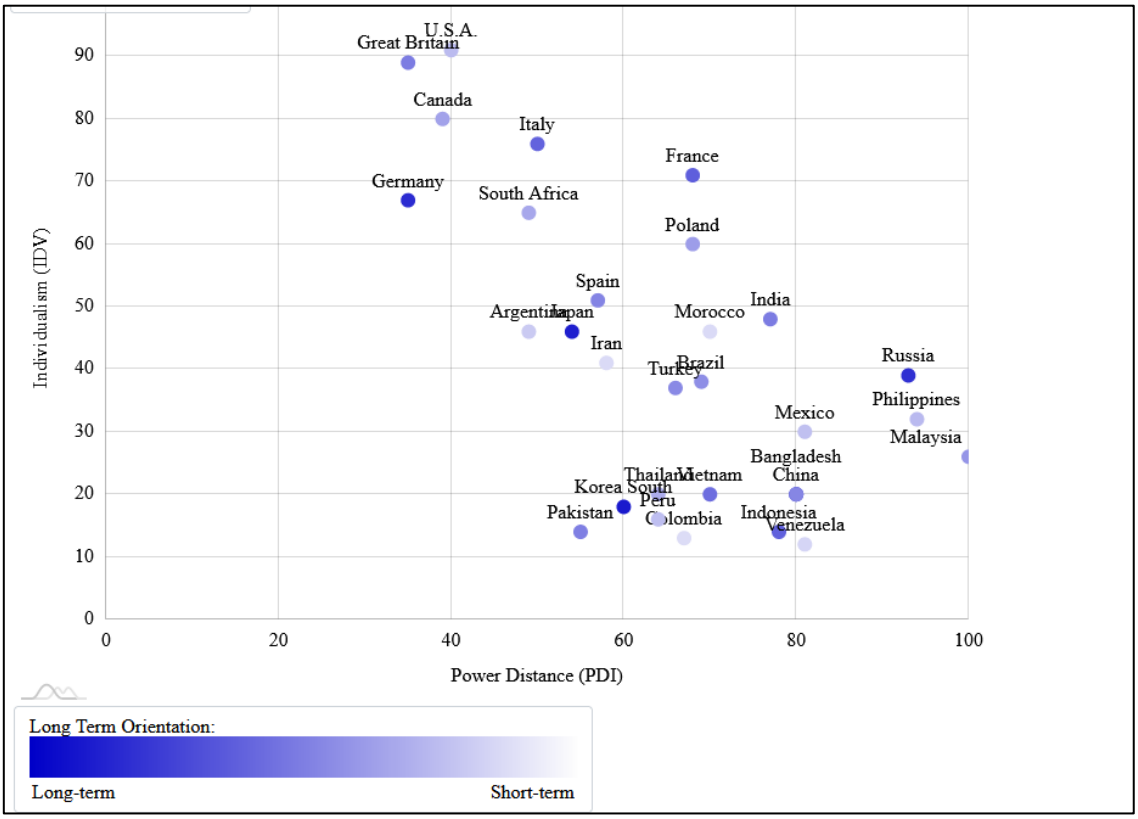
Long-Term Orientation (LTO) refers to differences in the way of thinking in Asian and Western industrial countries. The status of a person has high importance to high long-term orientation with respect to the design of relationships. In such cultures negotiations usually are more time consuming than in cultures with a short-term orientation, such as in Germany.

To determine the expression of the various dimensions, Hofstede surveyed IBM employees in 83 countries, and calculated indices on scales from 0 to 120 for each dimension and every country. The work was further developed in the following years.

The nature of the different indices represents a particular framework condition in standardisation negotiations.

Figure 14 shows the values of 50 countries with respect to power distance, individualism, and Long-Term Orientation.

Germany, for example, is characterized by a high value of individualism (IDV) score and low power distance (PDI). However, in other very active standardisation nations, such as South Korea and China, the power distance plays an important role, while the individualism index is much less pronounced. Instead, close relationships are given great importance. The expression of power distance can, e.g., be reflected in the organisation of relations between chairpersons and body representatives.



Source: https://geerthofstede.com/country-comparison-graphs/
Figure 14: Different indices based on Hofstede

A combined analysis of UAI and MAS values illustrates the relationship between the willingness to take unknown risks and the importance of achieving visible results.

The uncertainty avoidance index for France, for example is relatively high. This reflects a strong common tendency to avoid uncertainties through targeted planning. In China for example, the UAI is significantly less pronounced. Such differences are seen, for example, in a different understanding of planning and behaviour in standardisation projects. Differences in the

masculinity index may be expressed in negotiation behaviour and a possible willingness to compromise.

In addition to the information in Figure 14, a new Hofstede culture comparison tool was launched at https://geerthofstede.com/country-comparison-bar-charts/ in February 2025, see Hofstede (2025).The tool provides the opportunity to create bar charts showing country scores on all six Hofstede dimensions of culture. The bar charts show data from an official Hofstede database, as given also in Cultures & Organisations, 3rd ed. 2010. One can add up to twelve countries.

8.3.2 Addressing additional challenges

Five additional challenges of transnational standardisation activities were identified based on a literature review and previous work with standardisation experts.[12] The barriers include linguistic and additional cultural aspects as well as issues related to the standards landscape, resources, and negotiation power, see Table 6.

Barriers	Selected aspects	Possible solutions
Linguistic barriers	• Misconceptions regarding formulations in the draft standards	• Sensibility, giving enough time for clarification • Use terms from ISO/IEC DIR 2[13]
Culture	• Different culturally influenced perspectives on the use of technologies	• Practice sensitivity to cultural differences • Allow sufficient time for clarification
Standards landscape	• Feared abandoning of established (national) standards (in new standardisation areas a less common problem)	• Sensibility • Allow sufficient time for clarification
Resources	• Required time • Travel expenses	• Delegate tasks to smaller working groups
Negotiation power	• Language barriers resulting in lower impact of non-native speakers compared to English-speaking delegates	• Improve language skills • Consider language skills in the selection of delegates

Source: own table
Table 6: Additional challenges in international standardisation activities and solutions

[12] The topic was particularly considered by Hatto (2013) and Sherif (2007).

[13] See https://www.iso.org/sites/directives/current/part2/index.xhtml

Specific challenges may arise due to language differences and different country-specific conditions. Sherif et al. (2007) emphasized the importance of international working groups dealing appropriately with linguistic aspects in document management. Challenges can exist in English negotiation processes, especially with delegates from the UK and the US, as potential disadvantages for non-native speakers.

Hatto (2013) has compiled some English terms, where the correct application and boundary are especially important in international standardisation:

"Shall" means a requirement, "should", however, represents a recommendation, not an absolute requirement. "May" is based on a permit ("permission"), while "can" describes a possibility.

Furthermore, Hatto has indicated that some terms are not used in international standardisation, in order to, avoid irritations. On that basis:

> instead of the word "must", the term "shall" and
> instead of "may not" the phrase "shall not"

should be used (see Hatto 2013:26). Furthermore, the author refers to linguistic references for international standardisation in the ISO and IEC Directives, Part 2 (ISO/IEC DIR 2 Rules for the structure and drafting of International Standards. Its latest version is provided by ISO (2021).

Another potential problem is defensive attitudes if the international standardisation involves changes in individual countries, in particular, in cases where national standards already exist. In addition, basic defensive reactions are possible if, by inappropriate action, the impression is given that through a European or international standardisation project, benefits for the initiating nation should be achieved.

In summary**,** **language and cultural barriers** require particular sensitivity. Sherif et al. (2007) stress the importance of appropriate formulations for document preparation. Even problems that are associated with the feared limitations of *national standardisation freedoms*, **standard-related barriers** can be addressed through sensitivity. If the introduction of transnational standards creates exchange costs at the national level, it is particularly important to present the benefits of transnational standardisation. In general, this aspect usually plays a minor role in new areas of standardisation.

More fundamental solutions exist, where necessary, to use general formulations in the standards. It is possible to explicitly define degrees of freedom to enable countries to be in the position when adopting transnational standards, to define appropriate framework conditions according to their circumstances. It is possible, however, based on the different types of standards, that the compatibility of the standards and the corresponding products and technologies will be affected.

Barriers related to **negotiation strategies** can be addressed by language and intercultural training, and by an appropriate selection of the delegates.

8.4 Specific standardisation strategies for the ecosystem of swappable batteries

Based on the specific framework conditions in the context of swappable battery standardisation and discussions in the Stan4SWAP project, particularly three strategies appear to be relevant for the ecosystem's stakeholders:

- Focus on compatibility and interoperability
- Focus on collaboration with other standardisation projects
- Focus on harmonized standards and references in regulations

They are described in the following:

Focus on compatibility and interoperability: Based on the ecosystem aspect, described in Chapter 4, it is of particular importance that the standards for swappable batteries respect the principles stated in CEN and CENELEC Internal Regulations Part 3:2022. Especially the "performance principle" and the "aim-oriented approach", which were explained in Chapter 6, are of essence. Based on the experience of Stan4SWAP's project partners, four goals have to be considered specifically, which are shown in Table 7.

.Goal	Description
1. Ensure freedom of choice for technical solutions	Establish standards that primarily set performance targets (firm values or ranges) and prescribe explicit technical solutions only in exceptional cases. This goal promotes diverse technical solutions, fostering competition among suppliers and enhancing market sustainability.
2. Facilitate adaptation to technical progress	Create standards that follow an "aim-oriented" approach, enabling elements within the swappable batteries' ecosystem to adapt to technical advancements. This includes designing components for forward and backward compatibility to ensure ongoing compatibility with existing and new elements.
3. Enable simultaneous participation of different actors	Develop standards that guarantee interoperability among components and services from various suppliers, allowing for concurrent development of vehicles, batteries, and swapping stations. This ensures efficient operation of a standardised ecosystem without delays.
4. Promote extension of the ecosystem	Facilitate the extension of the swappable batteries' ecosystem through standards that support component innovations, enhancing the overall functionality and adaptability of the ecosystem.

Source: Stan4SWAP

Table 7: Specific implications from CEN-CENELEC internal regulations part 3 for the development of standards in the ecosystem of swappable batteries

Compatibility and interoperability play an important role in the context of swappable batteries. Egyedi (2007) provides specific recommendations to ensure compatibility and interoperability. As shown in Table 8, she identified a number of possible causes of interoperability problems, in particular a high degree of complexity, ambiguity of natural language and uncertainty in dealing with options. The problems are explained in the following. Table 9 summarizes possible solutions.

Complexity: An interoperability risk features, e.g., standards with too many details. A suitable level of detail is dependent on the relevant technology life-cycle phase. If a standard contains too many details early on, there is a risk of a failure of standardisation.

Poor structuring of a standard: Possible causes of failure pertain to, e.g., the completeness, clarity, readability and structuring.

Ambiguity of natural language: To cope with the ambiguity of natural language, formal specification languages are available for development of complex protocol specifications. These specifications offer a fundamental added value to the extent that their use may facilitate the

examination of the relevant protocols and offer added value in the development of validated models. Their actual benefit is dependent on the individual standardisation project.

Reasons for incompatibility	Occurance*
Errors, ambiguities, contradictions Uncertainty in dealing with options	SP/S
Ambiguity of natural language	SP/S
Missing details, monopoly on tacit knowledge	S/IP
Poor structuring	S
Uncertainty in dealing with options	S
Unclear compatibility of non-binding recommendations	S
Complexity of comprehensive, ambitious standards	C
Too many options and parameters	SP/S/IP
Parallel options with overlapping functions	SP/S/IP
One company pushes a standard; weak specifications	SP
Overload	C/IP
Deviation from the standard or only partial implementation	IP
*C: Conceptual idea, SP: Standardisation process, S: Standard/Specification, IP: Implementation process	

Source: based on Egyedi (2007) and Egyedi/Dahanayake (2003)
Table 8: Reasons for incompatibility and occurance

Uncertainty in dealing with options; too many options and parameters or parallel options with overlapping functions: Standards with a narrow range and few options tend to be implemented correctly, and lead to relatively few compatibility problems. However, the variety of products made possible is generally low. On the other hand, diversity promoting standards contain interoperability risks. **Compatibility** is also not necessarily given for standard compliant products. In this context, special problems can arise from **ambiguities** due to improper specification of choices and a lack of recommendations with non-use of such options.

Overload: In addition to the problem of complexity, based on comprehensive standards, a lack of interoperability can also result in an overload of standards.

Missing values, monopoly on tacit knowledge: Working groups see the need to build on an implicit, common understanding of the target group. Due to time and resources, only selected information can be incorporated into a normative standard. On the other hand, it cannot be generally assumed that each member of the committee shares his or her knowledge. Errors and incorrect information are to be removed as soon as possible. Another risk regards a

dominating company in the standardisation process is that **one company pushes standard and weak specifications.**

A list of ways to **bypass interoperability problems** is described in Table 9. **Solutions** for dealing with errors, contradictions and unclear formulations include, for example, according to Egyedi/Dahanayake (2003), revisions, reference implementations, interoperability testing, interoperability conformance statements and reference guides. Uncertainties related to general interoperability are also reduced through interoperability testing and interoperability conformance statements. Problems because of too high of a complexity of the standard can, e.g., be avoided by setting priorities.

Measures to reduce interoperability problems
Development of standards and specifications
• Clarification of the types of options (optional/mandatory orthogonal/equivalent) • Determining how to deal with the options (e.g. profiles) • Specification of the consequences of (non-) implementation of the options • Adding of a standard to a reference guide
Before implementation
• Validation of standard implemented in products prior to implementation • Development of reference and pre-implementations • Development of a reference environment • Inclusion of tests (for standard conformance and interoperability) • Organisation of interoperability events with products from different vendors (e.g. plug-tests) • Organisation of events for dialogue between developers and implementers of the rules
After implementation
• Improvement of the uniform standards of use, e.g., by means of compliance, interoperability and conformance statements, certification programs and test suites

Source: based on Egyedi (2007)
Table 9: Measures to reduce interoperability problems

Focus on collaboration with other standardisation projects

As Chapter 7.2 has shown, various organisations and committees have standardisation activities related to swappable batteries. The chapter also mentions the relation between different standardisation activities at the IEC to integrate the updated version of a previous IEC 61851 document in the IEC 62840 series. Likewise, the case study in section 10.4 will refer to

parallel work on international (ISO) and EU (CEN) level. Considering the work of the other initiatives and appropriate interactions are of key relevance in this context.

Focus on harmonized standards and references in regulations

Legislation can promote the development of standards through multiple mechanisms. In some cases, standardization is explicitly mandated by law, requiring compliance with specified technical norms or protocols. For instance, the European Union's Low Voltage Directive (2014/35/EU) obliges manufacturers to adhere to harmonized safety standards for electrical equipment. In other cases, regulations that define minimum requirements—such as those concerning vehicle safety, emissions limits, or energy efficiency—may indirectly drive the creation of new standards. These standards provide a practical and efficient means for manufacturers and service providers to demonstrate compliance with the legal provisions. Examples include the adoption of the Worldwide Harmonized Light Vehicles Test Procedure (WLTP) to meet EU emissions regulations, and the implementation of ISO 50001 standards for energy management to satisfy statutory energy-efficiency obligations (see e.g., European Parliament and the Council, 2014b, European Commission, 2017).

Specific mechanisms to create harmonised standards and implement references to standards in regulations were presented in Chapter 7. To support the implementation of swapable battery systems in the EU, it would be beneficial to have selected standards referenced in relevant EU regulations, ideally implemented as EU harmonized standards. Some of the relevant EU regulations are Regulation (EU) 2023/1542, Regulation (EU) 2023/1804 and Regulation (EU) No 168/2013:

Regulation (EU) 2023/1542 of the European Parliament and of the Council of 12 July 2023 concerning batteries and waste batteries: The specific use case of standardised batteries in different vehicles and eventually other applications, and the existence of comprehensive standardisation for swappable batteries may lead to a reconsideration of the battery types and related requirements. For such batteries the compliance with the standard could be considered as the sole criteria for the definition of the battery type.

Regulation (EU) 2023/1804 of the European Parliament and of the Council of 13 September 2023 on the deployment of alternative fuels infrastructure (AFIR): To avoid unfair competition with other battery powered vehicles, the AFIR regulation should refer as well to standardised battery swapping stations including minimum requirements for the density of the network of such charging infrastructure.

Regulation (EU) 168/2013 of the European Parliament and of the Council of 15 January 2013 on the approval and market surveillance of two- or three-wheel vehicles and quadricycles: Standards may facilitate an amendment of the vehicle type approval requirements in order to allow for the vehicle type approval without including a specific propulsion battery. This is important to maintain the validity of the whole vehicle type approval when using any of the available standardised batteries.

If standards shall be developed to be used for the implementation of legislation, three steps are relevant: 1) The European Commission drafts a standardization request and consults with the European Standardization Organisations and other stakeholders. 2) CEN or CENELEC standards are developed in response to the request. 3) The Commission proceeds to recognize the standards through publication in the Official Journal of the European Union (OJEU), following a compliance check.

Specific information and guidance in this context is given by CEN and CENELEC (2015), in particular by its Chapter 4, "The standards-making process and additional elements when supporting regulation", together with its flowcharts.

8.5 Recommendations for maximising individual benefits

This subsection provides additional recommendations, not only relevant in the context of swappable batteries, but for standardisation success in general. According to Updegrove (n.d.-b), organisations involved in standardisation often fail to derive maximum benefit from their committee work. The author describes three challenges and solutions in particular:

1. Lack of defined objectives for committee work. A participating organisation must have a clear idea of the benefits it expects to gain from participation. Taking on the chairmanship is particularly helpful in achieving these objectives.

2. Misunderstandings regarding the expected added value of committee work. Usually, information about the work of specific committees is easily available. A proper analysis of the material can help prevent misunderstandings.

3. Misunderstandings arising from a lack of continuity. This issue can occur when committee members disengage from their committee's communication processes or intentionally exclude themselves. As a result, fostering continuous collaboration should be prioritized. The problem can also result from another aspect. When employees change employers, organisations often struggle to maintain the continuity of standardisation activities (see Updegrove, 2007b). This aspect necessitates careful consideration. This book aims to make a supplementary contribution to equipping employees with appropriate standardisation skills.

A key general recommendation given by Updegrove (n.d.-b) is to **entrust appropriate people** with standardisation tasks. A key recommendation in this context for companies is to either select or equip employees with the relevant skills of ISO IWA 30-1 (ISO, 2019). Although this standard titled "Competence of standards professionals — Part 1: In companies" addresses this target group specifically, it also provides helpful guidance for other organisations *involved* in standardisation. (Part 2 also addresses standards-related organisations.)

Broader challenges related to internal delegates and solutions are described in Table **10**.

Challenge	Solution
Appointment of employees with inadequate social skills as representatives	Select representatives with a high level of social competence, check social skills according to ISO (2019)
Failure of stable participation	Ensure regular attendance. Various bodies accept additional participants per organisation, but without voting rights.
Failed vote	Maximising the benefits of committee work requires the exercise of voting rights.
Committee members with insufficient decision-making authority	Standardisation experts should not only be knowledgeable, but also sufficiently authorized to speak for their organisation and to receive internal support from this organisation

Source: based on Updegrove (n.d.-b)

Table 10: Selected challenges and solutions to maximise individual benefits of standardisation

In summary, a suitable selection of committee members is of high importance.

Additional issues may arise if pertinent information is not effectively communicated to other relevant departments (e.g., R&D or construction) within the delegates' organisation, highlighting the need for appropriate countermeasures. In this context, it is helpful to promote internal cooperation, so that information on agendas, working documents and voting announcements is sent out before meetings. This allows participants to prepare for voting in their organisations and better represent their internal interests.

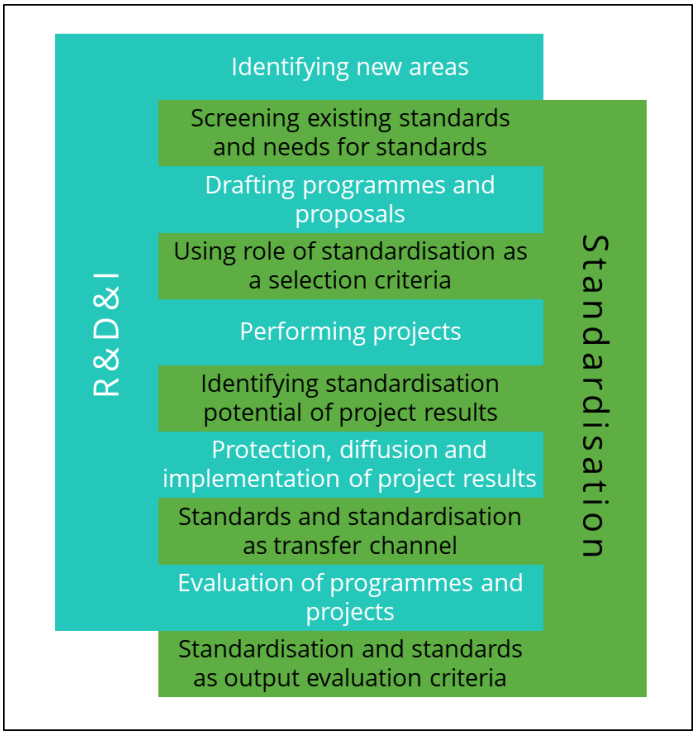
9. Recommendations to Connect Research and Standardisation in the Ecosystem of Swappable Batteries

Prenormative research plays an important role for swappable battery standardisation, particularly in the context of the Stan4SWAP project (see Stan4SWAP, 2024). This chapter provides specific guidance in this regard.

9.1 Recommendations for the integration of standardisation activities in R&D projects

9.1.1 Relevant implementation times

Various studies highlighted the importance of considering standards and standardisation aspects early in the research process, see e.g. Hatto (2010). As shown in Figure 15 below, various links between the stages of R&D and standardiation exist.



Source: based on CEN-CENELEC STAIR (2011, p. 3)
Figure 15: Interrelation between R&D&I and Standardisation

When developing concepts for research projects, the already existing standards should be identified first to avoid a duplication of efforts and to prevent conflicting standards as a result. Furthermore, the standardisation potential may represent an additional selection criterion for

a potential research project. In the implementation of a project, standardisation should explicitly be reflected in work packages and/or deliverables. In later stages, standards can serve as a tool for disseminating the results of R&D and innovation projects, and lead to a marketable product or service. Finally, standards and standardisation are suitable as a criterion for the evaluation of project results from R&D and innovation (see CEN-CENELEC STAIR, 2011, p. 3, chart and Figure 15).

Hatto (2010) defined five milestones and associated them with specific recommendations related to how standardisation can be integrated in an R&D project. In the following table they were specified for swappable battery standards.

Milestone	Recommendation
1. The Planning Phase	Consider potential contributions to standards and specifications. Projects typically allocate a minimum of six person-months for standardisation, while European projects may reserve 12 person months over 18 to 36 months. This refers to the management of standardisation processes, not research. Sufficient resources should be planned in the R&D project bidding phase; fewer resources are needed for developing specifications.
2. Beginning of the Project	Appoint individuals responsible for standardisation at the project's start. Determine the relevant standards committee and ensure at least one partner collaborates early with this committee to understand procedures and influential committee members. Consider creating CWAs within CEN workshops if early participation in existing committees is not feasible. Contact standards organisations early regarding standardisation considerations.
3. Definition of Requirements	Research projects should begin with specifying requirements and designing the technologies to be developed. These requirements help assess the standardisation potential of the research results.
4. Available Results for Submission to Standards Committees	The potential for a standardisation proposal depends on technology maturity. Filing in a standards committee can occur during the R&D phase or after initial validation, such as with demonstrators. Submission of finished concepts is not required.
5. Project Completion	At project closure, determine how standardisation will proceed. Early standardisation planning and actions enhance project resource utilization and increase the likelihood of achieving standardisation goals as planned.

Table 11: R&D milestones and recommendations in the context of swappable batteries – specifications of Hatto's general suggestions

In addition to the introduction of the R&D results into existing standards committees, Section 6.3 discusses the possibility to create CWAs within CEN workshops regardless of existing CEN committees. In these cases, no early participation in existing standards committees is necessary. But it is important to contact the standards organisations at an early stage regarding the potential standardisation plans.

9.1.2 Support for implementation

To connect standardisation and research projects, different tools are available, which are provided below and evaluated:

- Project life cycle-based guide to linking research and standardisation from CENCENELEC,
- Technical checklist from Hatto (2010),
- Extended technical checklist from Hatto (2010),
- Broader innovation economic checklist of CEN/CENELEC
- Decision tree from Hatto (2010).

Project life cycle-based guide to linking research and standardisation

The project life cycle-based guide of CEN and CENELEC proposes interactions between research projects and standardisation activities based on targeted recommendations for each project phase. For this purpose, four project phases were specified: development of a new project proposal (1), project planning and implementation (2 and 3), as well as protection, dissemination and exploitation of project results (4), see Figure 16.

Establishing links between research and standardisation		
RESEARCH and DEVELOPMENT	⟷	**STANDARDISATION**
Development of a new project proposal	⟷	• Screening of current standards and specifications; determining the necessity for new standards and specifications
Planning of the project	⟷	• Identifying when and where standards and standardisation have positive effects on the project • Definition of how standards and specifications shall be elaborated in the project • Determining potential project partners for the development of the standard(s) or specification(s)
Implementation of the project	⟷	• Identifying standardisation potential based on the project results • Development with the partners • Contributing to standards and standardisation
Protection, dissemination and exploitation of project results	⟷	• Using the document for the dissemination of project results

Source: based on CEN-CENELEC (n.d.-b, p. 9)

Figure 16: Project life cycle-based guide to linking research and standardisation

Technical checklist for determining the standardisation potential

The technical checklist is particularly relevant for consideration in the development of compatibility and interface standards. Figure 17 shows technical aspects, in which participants of an R&D project should consider a standardisation project.

Indicator	Reason
Addition of new elements to existing standards and specifications	Need to achieve consensus for new elements
Use of existing standards and specifications beyond the original cases of application	Need to expand original specifications or modify them
Integration of different standards and specifications in a common system, e.g. in architecture or a platform	Need for amendments to standards or specifications for preventing inappropriate improvisations
Delivering technology solutions for value-added systems consisting of several stages, each with several providers who have small market shares	Ensure wide dissemination of the project results with a large number of potential customers and suppliers
Use of research results as a basis of a new generation of products or services	Industry stakeholders call for standards and specifications to reduce investment risks when introducing new products and technologies

Source: own table based on Hatto (2010)

Figure 17: Technical checklist for the identification of the standardisation potential

The checklist can be combined with other tools in this chapter.

Extended technical checklist to identify the potential standardisation

The extended technical checklist from Hatto (2010) (Figure 18) is characterized by a slightly more extensive questionnaire of nine questions with a slightly stronger market orientation. Both the reference to existing standards and specifications (questions 1 and 2 of the technical checklist) and the relationship to other technologies and providers (3 to 5 of the technical checklist) are considered specifically. In order to identify the standardisation potential of a project and use the checklist, the results of all work packages must first be identified. Then the questions according to Figure 17, must be answered for each development outcome.

Technical Checklist for the Identification of the Standardisation Potential	
Reference to existing standards	1. Is the development result built on an existing standard? 2. Will it be used by companies that are already using standards and specifications for their products or services? 3. Would it have to be amended, if a normative rule changes?
Reference to other technologies and suppliers	4. Does it serve companies as a basis for new products or services? 5. Does it have to be consistently used by the industry to develop the expected benefits of the project? 6. Does it aim to stimulate the development of many complementary technologies and products? 7. Will a use of products from multiple suppliers take place? 8. Does it make a significant contribution to the future use of advanced technologies and solutions? 9. Will it fill a gap or address an area that is only partially covered by existing standards and specifications?

Source: own table based on Hatto (2010)

Figure 18: Extended technical checklist to identify the potential standardisation

Broader innovation economic checklist to determine the standardisation potential

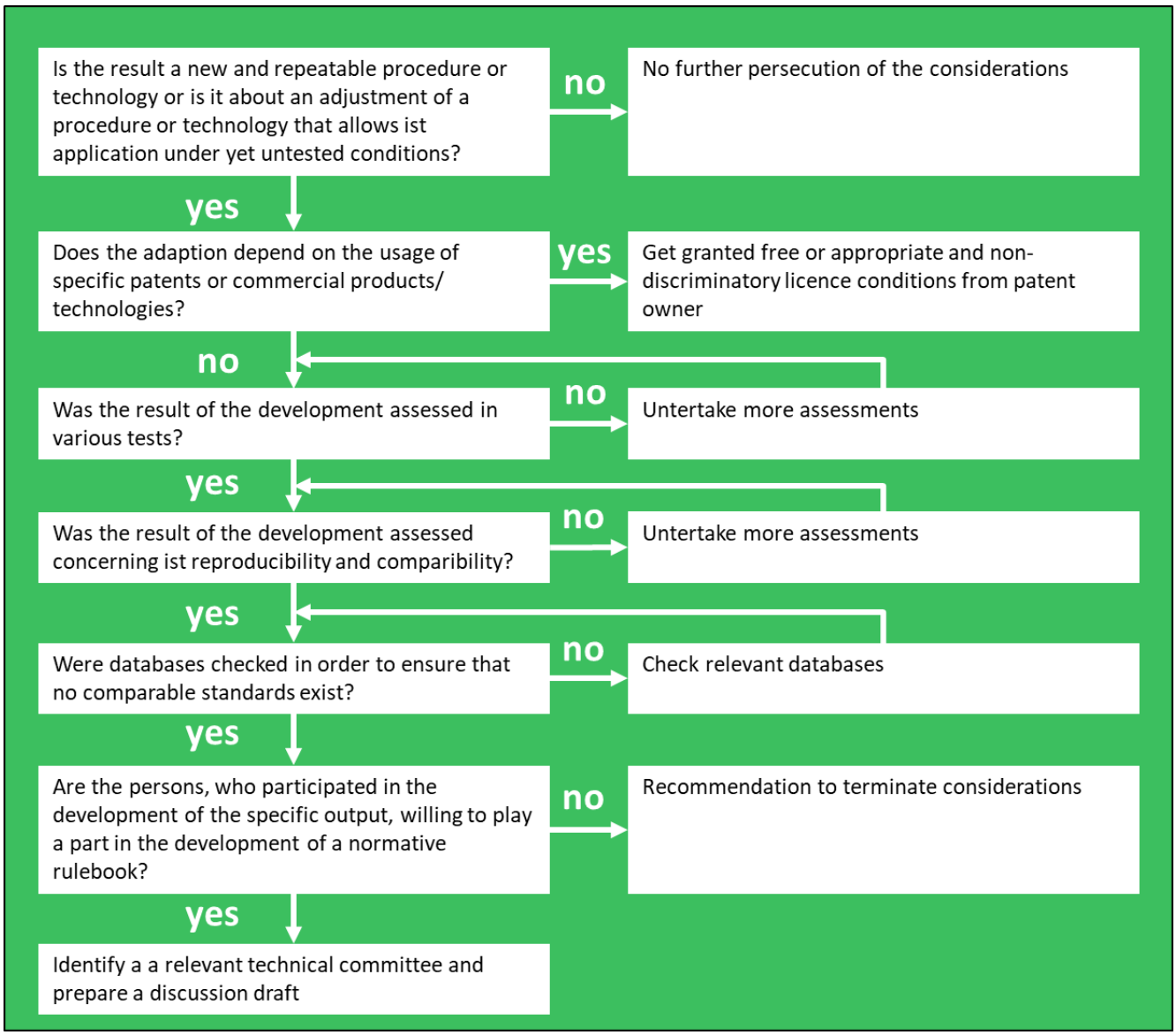
A specific technology and economics checklist was developed by CEN/CENELEC, see Figure 19. If three of the eleven questions presented are answered in the affirmative, then standardisation measures should be considered. Compared to the checklist in Figure 18, the advantage of this tool is that it defines how many affirmative responses are required for the initiation of a standardisation project.

Innovation economic checklist for determining the standardisation potential		
	Yes	No
1. Have you developed innovative products or services, or are you actively aligned to this project?	☐	☐
2. Does your program have a potentially broad market application?	☐	☐
3. Do you intend to export your innovative products and technologies to other countries in Europe or worldwide markets?	☐	☐
4. Are there elements in your project/ innovative development that are covered by regulations?	☐	☐
5. Are there standards or specifications (national, European or international) that are associated with your project, or are such standards in development?	☐	☐
6. Are products resulting from the project/your development of interest to public procurement?	☐	☐
7. Is it likely that in the next three years marketable products will emerge?	☐	☐
8. Will you be able to confirm/ensure the safety of your innovations to consumers and other stakeholders?	☐	☐
9. Do you need to introduce new measures in order to ensure the reliability and comparability of the results?	☐	☐
10. Does your development result have to be compatible with other technologies?	☐	☐
11. Do you have to prove the product quality on the basis of a quality label?	☐	☐

Source: based on CEN-CENELEC (n.d.2, p. 7)
Figure 19: Broader innovation economic checklist

Decision tree by Hatto (2010), taking into account the actual feasibility of a possible standardisation project

Hatto's (2010) decision tree includes important additional elements, originating from the tools previously shown. In addition to the consideration of the technical and market context, the actual feasibility is more specifically taken into account, see Figure 20.



Source: based on Hatto (2010)
Figure 20: Decision tree for determining the potential standardisation

In a defined process sequence, among other things, questions about existing patents and a willingness to standardise from project partners are addressed. Furthermore, reference is made to the implementation of database searches to determine the actual need for the desired standard.

Summary

All tools of this section provide specific benefits. The tools in Figure 19 and Figure 20 are particularly easy to use. The other tools are especially helpful in raising awareness of potential for standardisation in research.

9.2 Barriers for participation in standardisation and how to overcome them

In the previous sections the connection between research and standardisation has been demonstrated. In the implementation, however, obstacles can occur hindering the desired knowledge transfer. In general, these obstacles can be classified into three categories: lack of resources, process-related problems, as well as a lack of awareness and visibility of standards and standardisation processes (see Blind/Gauch, 2007a, p. 14).

Possible **cost-related barriers** refer, for example, to the fees of standardisation participation. In this context, the INTEREST project[14] showed that the standardisation costs are about the same as what would be saved later in costs. In addition, some SDOs use a customized membership fee system. In Germany, for example, DIN does not charge any registration fees for public research institutions and universities. Small and medium-sized enterprises (SMEs) will benefit, in that the membership fees will be charged depending on the size of the company (see DIN 2025b).

Resource-related problems can also be reduced by the selection of appropriate standardisation processes. Implementation opportunities occur particularly when resource-saving development processes appear to be possible. CEN workshops, for example, are a tool for connecting research and standardisation at the European level. For European projects of average length of about two to three years, an opportunity is offered within the project period to develop CEN Workshop Agreements (CWAs) (see INTEREST, 2006, p. 21).

Since standardisation bodies represent scientific fora simultaneously (see Blind/Gauch, 2007b), the participating organisations may financially benefit indirectly through standardisation activities. The contacts from the bodies provide opportunities to participate in R&D projects and collaborations.

Beyond the above barriers, the **lack of awareness of** standards and standardisation in general is the main obstacle to participation. The European Commission is currently funding a number of initiatives, including Edu4Standards.eu to close this knowledge gap. In the case of swappable batteries, it is a specific goal of this handbook, Stan4SWAP's additional education measures and the project as a whole to also raise awareness about the importance of standardisation to achieve key policy goals such as the decarbonisation of transport.

[14] See https://cordis.europa.eu/project/id/503594/en

10. Case studies of Mobility Standardisation in the Ecosystem of Swappable Batteries

This chapter presents six case studies to provide a deeper understanding of the conditions new technical standards are initiated and developed, specifically in the context of e-mobility and swappable batteries. By examining concrete examples, this chapter sheds light on how specific standards came into being, the actors involved, and the dynamics that influence their progression.

The case studies highlight the specific challenges encountered during the development phases, ranging from consensus building among diverse stakeholders to technological uncertainties, and further illustrate the strategies and mechanisms used to overcome these obstacles. Through these insights, the case studies offer a practical perspective on the complexities and success factors of modern standardisation efforts.

The case studies illustrate diverse standardisation efforts across swap-enabled mobility and e-mobility in general. The following subchapter is dedicated to each of the following example of standards:

- IEC 62840, which clarifies battery swap system interfaces, promoting interoperability and safety in heavy-duty and passenger contexts.
- ISO 18243, which targets electrically propelled mopeds and motorcycles, outlining performance, testing, and compatibility criteria.
- ISO 19453-6, which addresses environmental conditions and testing for drive-system electronics, ensuring reliability across climates.
- ISO 23625, which covers lithium-ion batteries for small craft, establishing safety and performance benchmarks for maritime applications.
- IEC 61851-25, which defines conductive charging infrastructure, enabling seamless charging interoperability.
- DIN SPEC 91533, which focuses on battery swap systems for heavy electric commercial vehicles, guiding system integration and operations.

The case studies provide information on the following aspects:

- Background of the development process
- Initiation process
- Problem definition and standardisation goals
- Success factors of the development process
- Challenges and solutions
- Lessons learned

To conclude the chapter, a summary of key findings is presented.

10.1 Case study IEC 62840 Standards Series

Background of the development process

The rapid expansion of the EV market around 2010 gave rise to the concept of battery swapping as an alternative to conventional charging methods, which are time-consuming and therefore limit operational flexibility. Battery swapping offers the potential to significantly reduce the time required for energy replenishment, making it especially advantageous for high-utilization applications, such as taxi fleets and logistics operations. After 2018, the swift proliferation of electric two-wheelers in regions (including China, Japan, Europe, and Southeast Asia) shifted market demand for this technology from four-wheeled vehicles to two-wheeled vehicles.

The widespread deployment of such vehicles by various manufacturers has made it necessary for technical standardisation. The Chinese government has already provided active support and strategic guidance for the adoption of battery-swapping technology in electric heavy-duty vehicles, reflecting a policy-driven approach for its promotion. On an international level, a coordinated effort was initiated through the collaboration between the International Electrotechnical Commission (IEC), the International Organisation for Standardisation (ISO), and national committees, aiming to establish a globally applicable framework. This initiative culminated in the development of the IEC 62840 series of standards.

The initial proposal was jointly initiated in 2012 by several companies that had heavily invested in EV battery-swapping technology at the time, including major industry players, such as the State Grid Corporation of China, Better Place in Israel, and Renault in France.

In summary, the development of the IEC 62840 series of standards was driven by the expanding EV market and the increasing deployment and utilization of such vehicles across various regions.

Success Factors of the Development Process

In particular, three success factors were identified regarding 1) international collaboration and industry engagement, 2) the development process and 3) the coordination with related standards:

International collaboration and industry engagement: The international development of the IEC 62840 series, involving global experts, national committees, and industry representatives from a range of countries—including China, Japan, Germany, France, Israel, South Korea, and Indonesia—ensured broad input and contributed to the global applicability of the standards.

Structured development process: The multi-stage development process enabled iterative feedback, thereby ensuring technical rigour and broad consensus. The standardisation effort was guided by the actual state of industrial development, beginning with considerations of

safety, system architecture, and use cases, and progressively advancing towards the definition of interoperability requirements.

Coordination with related standards: Alignment with standards like IEC 61851-3 ensured consistency across the EV ecosystem. According to a representative of the relevant IEC working group, these factors collectively ensure the gradual advancement of technical depth and global applicability of the IEC 62840 series of standards.

Challenges and Solutions

The creation of IEC 62840 was facing a lot of challenges, in which it had to overcome. These challenges can be roughly divided into four categories, which were summarized in the following table.

Problem	Solution
Technical Complexity*	To address the specific problem described under * below, IEC 62840-1 provided general guidance, while IEC 62840-2 defined safety requirements. Propose corresponding safety requirements based on a clear system architecture and use cases. *Problem in detail: Battery swapping systems involve diverse components (batteries, swap stations, interfaces), requiring robust safety and compatibility standards.
Global Applicability	Standards allowed flexibility for local adaptations, for instance, the first part outlines diverse use cases for different battery-swap solutions, while the second section establishes more uniform basic safety requirements.
Industry Alignment	Open standardisation processes and active participation from industry stakeholders significantly contributed to building consensus throughout the development of the standard. For example, Part 3 incorporates use- cases for two-wheeled vehicles contributed by Japan and China. During the drafting process, technical consultations were held to establish agreement on fundamental terminology as a foundation for further discussion. Distinct use cases and requirements were organized in separate appendices, while ongoing coordination with additional participants, such as Indonesia, was pursued to ensure broad acceptance and applicability of the standardised terms.
Evolving Technology	In response to ongoing technological advancements, the technical orientation of the IEC 62840 series was adapted accordingly. Initially, the standard concentrated primarily on technical considerations for four-wheeled passenger vehicles. However, with the growing adoption of low-voltage platforms for two-wheeled vehicles, the focus shifted to address the emerging requirements of this segment. In subsequent stages, in alignment with evolving market trends, the technical specifications for light two- and three-wheeled vehicles were progressively redefined and codified in the form of a Technical Specification (TS).

Table 12: Challenges and Solutions in the development of the IEC62840 Standards Series

Lessons Learned

The development process of the IEC 62840 series offers three key lessons, referring to 1) the importance of early participation across diverse industries, 2) the need to balance global and local requirements, and 3) sensitivity regarding technological uncertainty and its impact on standardisation:

The importance of early participation across diverse industries: The initial version of the IEC 62840 series was largely shaped by early contributions from the commercial vehicle battery swapping solution developed in China and the passenger vehicle battery swapping concept introduced by Israel's Better Place. Early engagement from stakeholders across various sectors played a critical role in framing the foundational direction of the standard.

Need to balance global and local requirements: Significant divergences emerged among participating countries regarding specific technical provisions, driven by differing regional priorities and regulatory contexts. In some instances, actions taken by individual experts further intensified these disagreements, requiring extensive time and effort during the standardisation process to reconcile conflicting perspectives and clarify regional differences.

Sensitivity regarding technological uncertainty and its impact on standardisation: The uncertain trajectory of battery-swapping technology, particularly for passenger vehicles, presents substantial challenges for standardisation. This is largely due to the complexity and high cost of implementation, along with substantial sunk investments made by early market entrants. As a result, despite progress in meeting basic safety requirements, the standardisation and interoperability of critical components - such as battery systems - remain difficult to achieve in practice.

10.2 Case study ISO 18243 – Electrically propelled mopeds and motorcycles

Background of the Development Process

In general, the standard specifies the test procedures for lithium-ion battery packs and systems used in electrically propelled mopeds and motorcycles.

While the original version of the standard was created in 2017, the case study refers to the upcoming version, of which the publication is scheduled for October 2025.

This standard defines the performance evaluation methods and safety requirements for lithium-ion batteries used in motorcycles and mopeds. Its goal is to enhance the safety and quality of electric motorcycles and mopeds by establishing clear, internationally agreed testing and evaluation procedures.

The revision was initiated due to changes in related international standards and regulations. These updates had caused inconsistencies with the existing version, prompting the need for revision during the systematic review process to restore alignment and ensure relevance.

Initiation Process*:* The revision of Edition 2 began in October 2023 as part of the 24 month update of the project. As of July 2025, the standard is in the final stages of development, with the transition to the Final Draft International Standard (FDIS) already agreed upon.

Problem Definition and Standardisation Goals: See Background and Development Process.

Success Factors of the Development Process: A key success factor was the adaptation of existing standards and regulations, originally developed for electric cars. By modifying the content to reflect the specific characteristics and requirements of motorcycles and mopeds, the team ensured the standard would be both relevant and practical for its intended application.

Challenges and Solutions

The key challenge of the project was the diversity of relevant products. To address the challenge, the testing methods were made more robust, allowing them to accommodate a wide range of applications. At the same time, efforts were made to maintain consistency with related international standards and regulatory frameworks.

Lessons Learned

A significant lesson from this project is the importance of maintaining alignment with international regulations. By restoring consistency, the revised standard is expected to be more user-friendly and widely applicable, ultimately supporting safer and more reliable electric two-wheelers.

10.3 Case study ISO 19453-6 Road vehicles - Environmental conditions and testing for electrical and electronic equipment for drive system of electric propulsion vehicles; Part 6: Traction battery packs and systems

Framework conditions that lead to the initiation of the standardisation project

The development of this standard took place in the ISO committee ISO/TC22/SC32 Electrical and electronic components and general system aspects, working group 02 Environmental Conditions.

Given that the ISO 19453 series addresses the testing of high-voltage components in electrical power trains, a high-voltage traction power source, like the HV-battery, would typically fall within the scope. However, when the ISO project to develop ISO 19453, parts 1 through 5, was started, the environmental testing for traction batteries had already been described in the ISO 12405 series with the title “Electrically propelled road vehicles - Test specification for lithium-ion traction battery packs and systems”, developed by the ISO committee ISO/TC22/SC37 for electrically propelled vehicles. Therefore, in the parts 1 through 5 of ISO 19453 on traction batteries were explicitly excluded to avoid conflicts or contradictions with the existing ISO 12405 series.

When the SC37 working groups learned about the start of the ISO 19453 project they established a contact between the two sub-committees in a series of face-to-face workshops in order to discuss how to transfer the content of the standard ISO 12405 documents to the documents in ISO/TC22/SC32/WG02, as the content needed an urgent technical update anyway and the experts for environmental testing are allocated within SC32/WG02 and the SC37 working groups lacked such expertise.

Once this transfer of content and responsibility was finally decided the progress on the parts 1 through 5 of ISO 19453 was already too significant, which is why it was decided, also due to the unique characteristics of batteries, being active components and containing hazardous materials creating specific boundaries and items to be taken care of, to create a separate standard as ISO 19453-6.

Short description of the standardisation process

As mentioned in chapter 6.4 standardisation process at ISO typically progresses through six main phases, each with specific functions and milestones. The duration, that is the number of iterations within each phase, depends on the standard's complexity and the degree of consensus achieved. Each phase is iterative and consensus-driven, meaning that a lack of consensus or significant comments will necessitate additional rounds of review and reconciliation. The overall duration depends on the standardisation topic’s complexity.

Throughout the following phases, virtual or in-person meetings were held to discuss as and align the content of the standard's drafts and manuscripts and vote on proposed changes. Participants are the delegates from the national standardisation bodies.

Phase	Description
1. New Work Item Proposal (NWIP) Phase	The process begins with a proposal for a new standard submitted by a national standardisation body/national committee or industry association to the relevant technical committee (TC) or subcommittee (SC). The body evaluates the proposal's relevance and feasibility. If accepted, a project leader is appointed, and a working group (WG) is established.
2. Working Draft (WD) Phase	The Working Draft (WD) is developed and revised exclusively within the working group by national delegations. Multiple revisions typically occur before the WD is forwarded to the superordinate committee for review.
3. Committee Draft (CD) Phase	The WD progresses to a Committee Draft (CD), which is distributed to the entire responsible Technical Committee (TC) or Subcommittee (SC) for comments and voting. This phase allows additional national standardisation organisations and nominated experts to submit feedback. After consolidation, the CD becomes a Draft International Standard (DIS).
4. Draft International Standard (DIS) Phase	The DIS is submitted to all national member bodies of ISO for comments and voting. It is publicly available for a wide international audience, including experts and stakeholders, to review and provide feedback. All comments received are collected and reviewed by the responsible committee.
5. Final Draft International Standard (FDIS) Phase	After incorporating agreed-upon comments from the DIS, the Final Draft International Standard (FDIS) is created. Only editorial changes and minor annotations are permitted at this stage.
6. Publication Phase	Following the successful approval of the FDIS (or DIS if the FDIS stage is skipped), the standard is published by ISO as an International Standard.

Table 13: Stages to develop ISO standards relevant for the develpment of ISO 19453-6

In addition to the ISO committee, there typically are mirror organisations in the national standardisation body, such as DIN, that have a parallel working group that develops and agrees on the national point of view that is then taken by the respective national delegation to the ISO committee meetings.

Short description of the standard and the problems it addresses

The purpose and main issue addressed in the ISO 19453-6 is described in the foreword of the standard as follows: "The ISO 19453 series specifies the test conditions on environment and

reliability for electrical and electric equipment for the drive system of electric propulsion vehicles. The battery pack or system is the electric system which charges and discharges electricity through the converter. The test condition for mechanical load in ISO 19453-3 is too severe to apply to the battery pack or system from the standpoint of frequency range and amplitude of vibration in the test input spectrum. The test conditions for climatic load in ISO 19453-4 is also excessive to apply to the battery pack or system, because lithium-ion battery pack is designed to control temperature within adequate operational range. That is the reason why appropriate conditions for the lithium-ion battery were specified in that document."

Success factors of the development process

All participants from the national delegations for ISO 19453-6 were technically experienced in the field of batteries and their testing, ensuring discussions consistently at a high technical level. Furthermore, comments were typically formulated in a solution-oriented manner or could be worked out due to the expertise available in the meetings. Only a few items were adjourned.

Challenges and Solutions

The primary challenge in developing ISO 19453-6 as well as any other standard was to achieve consensus that could reconcile the diverse experiences and, sometimes, opposing expectations of the participants. Equally important was fostering a willingness to explore new approaches and actively contribute to the standard's development.

Previous battery testing standards inherently treat the battery as a genuine item, subjecting it to the same set of test conditions regardless of its characteristics. However, batteries in electric vehicles vary significantly, ranging from smaller, approximately 20 kg units to massive units that form the entire underbody and structural base of a passenger vehicle. These cannot be treated and tested identically. Instead, they require differentiated testing approaches, based on its specific properties, such as size and weight. Developing and implementing this nuanced approach was a significant challenge of the ISO 19453-6.

Another challenge at the start of the project was the fact that in some countries the national mirror committees to ISO/TC22/SC32/WG02 did not have the proper experts yet for this topic, or that the two mainstreams, Internal Combustion Engine (ICE) and battery-electric vehicles, were handled by different national associations and experts, which led to some rather political discussions which experts are delegated to work on this project.

Lessons learned

As a key representative of the relevant technical committee formulate, being courageous and standing up for one's ideas pays off, as exemplarily demonstrated by the differentiation of test object characteristics within ISO 19453-6.

A further lesson was that, in case of doubt, it is helpful to seek contact and discussions with other committees related to the subject at hand to avoid a false interpretation of expertise and responsibilities, as was the case with the existing ISO 12405 series for battery testing.

Lastly, having an as broad as possible participation by Original Equipment Manufacturers (OEMs) and tier-1 suppliers from as many major countries as possible leads to a successful acceptance of a standard.

10.4 Case study ISO 23625 – Small craft - Lithium-ion batteries

Background of the development process

The standardisation project ISO 23625 was initiated to address a regulatory gap. Existing regulations did not adequately cover the installation of lithium-ion batteries on small craft. With the growing use of electric propulsion and onboard electrical systems, there was increasing demand from boat builders and Notified Bodies for an industry standard.

This document was prepared by the technical committee ISO/TC 188 “Small craft”, in collaboration with CEN/TC 464 “Small Craft”, in accordance with the Agreement on technical cooperation between ISO and CEN (Vienna Agreement).[15]

Initiation Process

The standardisation process built on an industry-developed Technical Specification, which served as a foundation for the initial working draft prepared in December 2022. Development was led by ISO TC 188 Working Group 32 (WG 32), which conducted a series of structured meetings to refine the draft and guide it through the ISO standardisation process. The final standard, ISO 23625:2025, was published in March 2025.

Problem Definition and Standardisation Goals

ISO 23625:2025 sets out requirements and recommendations for:

- The selection and installation of lithium-ion batteries on small craft
- The safety information that manufacturers must provide.

[15] See https://www.cencenelec.eu/about-cen/cen-and-iso-cooperation/

It applies to battery systems over 500 Wh, intended to supply power for general onboard loads or electric propulsion. The standard is primarily intended for manufacturers and installers, ensuring that lithium-ion battery systems are integrated safely and effectively.

The standard addresses the growing safety concerns and lack of clarity around battery installations in maritime environments.

Success Factors of the Development Process

Broad stakeholder consensus within WG 32 enabled the development of a well-balanced and practically applicable standard.

Alignment with existing industry practices and related standards ensured smooth adoption.

Challenges and Solutions

The project's key challenge was evolving technology. This was successfully addressed by ensuring continuous dialogue with industry to reflect up-to-date practices. In addition, the committee was focused on setting minimum performance requirements because it did not want to hinder innovation.

Lessons Learned

The development process of the standard offers two lessons regarding stakeholder involvement and cooperation:

Stakeholder involvement: A key takeaway was the importance of involving all relevant stakeholders early in the process, ensuring the final standard effectively meets industry needs.

Cooperation and consensus-building: The excellent cooperation and consensus-building within ISO TC 188 WG 32 proved critical to the successful and timely completion of the standard.

10.5 Case study IEC 61851-25 – Electric vehicle conductive charging system

Background of the Development Process

The organisers of the standardisation project, who were aiming for international standardisation, were aware of the resulting need to initiate a standardisation project at a globally recognized organisation such as the IEC, ISO, or ITU.

In the case of IEC 61851-25, the proposal for standardisation was presented during the IEC/TC 69 plenary meeting in 2016. Following this, a New Work Item Proposal (NWIP) was officially

issued in October of the same year. The proposal received approval in February of the following year, after which the Project Team (PT) 61851-25 was established under Technical Committee 69.

Initiation Process

The project began with a kick-off meeting in June 2017. Over the course of the development process, a total of five face-to-face meetings and ten online meetings were conducted. The COVID-19 pandemic impacted the ability to hold physical meetings during the latter half of the project. Ultimately, the international standard IEC 61851-25 was published in December 2020.

Problem Definition and Standardisation Goals

IEC 61851-25 addresses the need for a standardised approach to direct current (DC) battery charging for light electric vehicles (LEVs), covering voltages up to 120 V and currents up to 100 A, using a conductive connection. The standard sets out essential safety requirements, a communication protocol, and basic technical criteria, based on the safety concept of electrical separation. Requirements related to the physical coupler (connector and inlet) are defined separately in IEC 62196-6.

Success Factors of the Development Process

One of the key distinguishing features of this project compared to existing charging standards, designed mainly for passenger cars, was the adoption of the electrical separation safety method. As this concept was initially unfamiliar to many experts involved, the project team made a conscious effort early on to establish a shared understanding. This collective alignment proved crucial for the standard's successful development.

Challenges and Solutions

The standardisation process was shaped by ongoing disagreement. To address this, the team actively collaborated with other professionals who were more receptive to the project goals. This strategic collaboration helped build consensus and move the project forward in line with ISO/IEC Directives.

Lessons Learned

One major takeaway from this standardisation effort is the necessity of international cooperation. Effective standardisation requires careful listening and open dialogue among experts from various countries. It is crucial to seek common ground and avoid pushing national interests, as consensus and mutual understanding form the foundation of global standards development.

10.6 Case study DIN SPEC 91533 - Battery swap systems for heavy electric commercial vehicles to extend range

Background of the development process

This case study describes the early stages of the development of a DIN specification in Germany. This DIN SPEC related to swappable batteries for heavy electric vehicles is currently in development - an important step toward creating a common understanding and technical foundation for such systems.

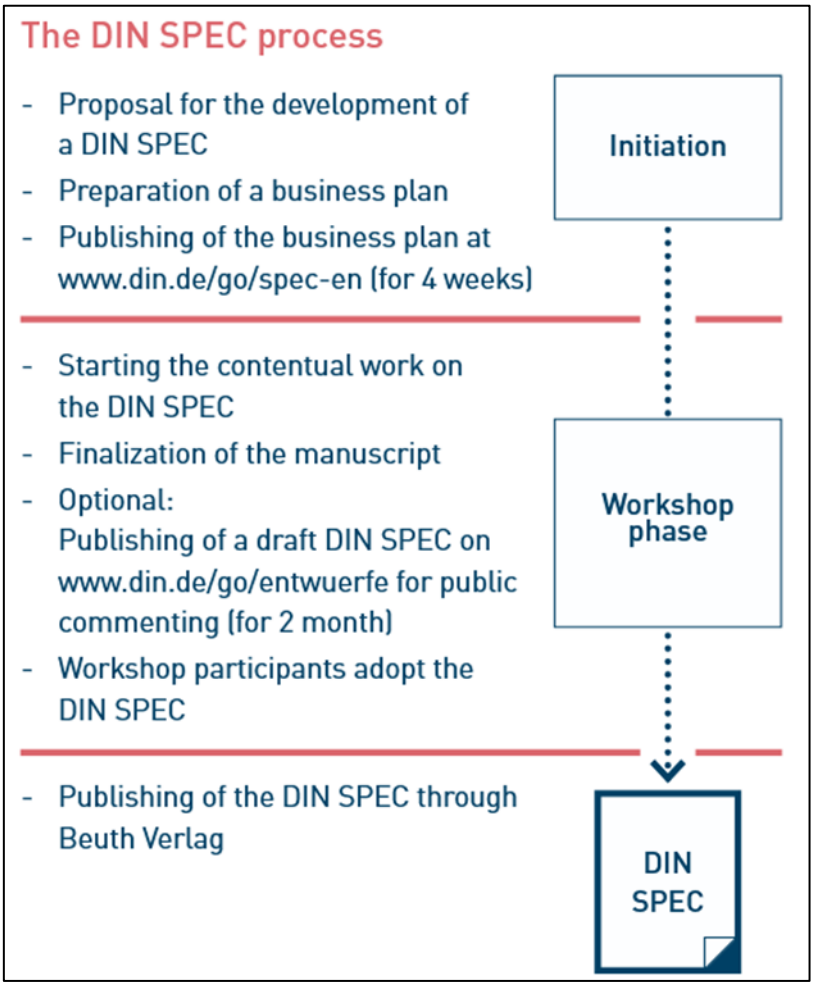
A DIN SPEC (also known as a PAS – Publicly Available Specification) is a type of pre-standard developed under the guidance of DIN, the German Institute for Standardisation. Unlike full DIN standards, which require extensive coordination and broad stakeholder consensus, a DIN SPEC follows a more streamlined and flexible development process.

One of the key features of a DIN SPEC is that any individual or organisation can initiate its creation. Moreover, consensus among all participants is not mandatory, and not every stakeholder needs to be involved. This reduced procedural complexity allows DIN SPECs to be developed much more quickly than traditional standards, making them especially useful in fast-moving or innovation-driven sectors.

Because of this flexibility, DIN SPECs are often used to bring new technologies to market faster. They can serve as a practical tool for early coordination within an industry, helping to establish common terms, interfaces, or safety requirements. Over time, and with broader validation, a DIN SPEC can also form the foundation for a full DIN standard, which would then undergo a more comprehensive and inclusive review process.

Three years after publication, the systematic review of a DIN SPEC (PAS) takes place. The responsible DIN project manager consults the DIN SPEC (PAS) consortium to determine whether the DIN SPEC (PAS) should be confirmed for a further three years, revised, used as the basis for a standardisation application or or withdrawn.

The standardisation project DIN SPEC 91533 emerged from the findings of the UniSwapHD research project, which itself was a continuation of the eHaul initiative. Led by Technische Universität Berlin, UniSwapHD demonstrated the potential of battery-swapping technologies to accelerate the electrification of heavy-duty road freight transport, thereby addressing a critical bottleneck in the logistics sector’s decarbonisation strategy.



Source: DIN.de
Figure 21: Development of a DIN SPEC

Initiation Process

Triggered by the above findings, an initial request was submitted to DIN (German Institute for Standardisation), followed by the preparation of a project proposal. Upon approval, the project transitioned into the planning and content development phase, culminating in the formal kick-off on June 2, 2025. Since then, biweekly online workshops have served as the primary platform for stakeholder engagement and content elaboration.

Problem Definition and Standardisation Goals

The logistics sector is under pressure to drastically reduce emissions within a short timeframe. While battery-electric trucks offer a viable technological path, the rapid and economically viable deployment of charging infrastructure remains a major challenge. Battery-swapping systems offer a complementary solution, enabling flexible and fast energy replenishment.

To unlock their full potential, standardisation is essential. The project has both, short-term and long-term goals: The short-term goal is to ensure interoperability of battery-swapping systems across different European truck manufacturers. The long-term goal is to harmonise all interfaces of e-truck battery systems while allowing internal battery design (e.g., cells, BMS) to remain manufacturer-specific.

Goals for the Development Process

Based on the project team's knowledge successful development process depended on three key factors. First, involving only the most relevant industry actors helps maintain focus and ensures that the expertise brought to the table directly supports the goals of the project. Second, securing reliable funding throughout the entire standardisation period provides the necessary stability to carry the process through to completion. Lastly, a clear and well-documented market need for the proposed technology or standard is essential - it not only justifies the effort but also increases the likelihood of broad industry acceptance and long-term impact.

Challenges and Solutions

The following table summarizes the DIN SPEC's challenges and solutions by the time of the creation of this case study.

Problem	Solution
Technical understanding	Developing an internal understanding and a draft solution before launching the DIN specification process.
Industry Alignment	Continuous engagement of manufacturers and fleet operators through joint workshops and lower hurdle to standadize through two-step approach.
Timeframe	Goal-oriented sessions with clear communication of needed approvals for DIN SPEC creation.

Table 14: Challenges and solutions in the development of DIN SPEC 91533

Lessons Learned

As the standardisation process is ongoing, lessons learned will be finalised at a later stage.

10.7 Summary of case study findings

Table 15 summarizes the success factors, challenges, solutions and lessons learnt from the six cases studes.

Standard	Success Factors of the Development Process	Challenges and Solutions	Lessons Learned
IEC 62840	Broad early international participation; alignment with another relevant IEC standard; iterative, multi-stage process with global use cases.	Technical diversity; solution - flexible use cases and modular safety requirements.	Early, broad stakeholder involvement boosts acceptance.
ISO 18243	Adapting existing EV standards to two-wheel formats; alignment with international regulations.	Product variety; solution- robust, flexible testing methods and early stakeholder in-volvement.	Balance global consistency with local adaptability.
ISO 19453-6	Involvement of battery testing experts from multiple countries; coordination with another ISO standard to ensure continuity.	Different battery sizes/ar-chitectures; solution—clear scope boundaries and cross-committee coordination.	Ongoing alignment with related standards ensures interoperability.
ISO 23625	Broad stakeholder con-sensus within the WG; alignment with existing industry practices.	Environmental/safety needs; solution - tailored, practical requirements.	importance of involving all relevant stakeholders early in the process
IEC 61851-25	Collaboration with another IEC standard; cross-domain coordination.	Aligning with existing charging standards; solution - clear architectures and integrated planning.	Effective standardisation requires careful listening and open dialogue among experts from various countries
DIN SPEC 91533	Fast, flexible process; targeted industry actors; clear funding support.	Harmonizing interfaces across OEMs/fleets; solu-tion - two-step approach and targeted workshops.	As the case study referred to the initiation process only, lessons learned will be finalised at a later stage.

Table 15: Summary of findings based on the case studies

A general observation is that a clear scope, structured coordination, and conflict-minimizing governance was essential for the development of these six standards.

11. Summary and Implications for Future Standardisation Activities in the Ecosystem of Swappable Batteries

This handbook covers standardisation in the ecosystem of swappable batteries for L-cat EVs. It explains why standards are important, how they are created and who creates them – at European and international level.

Target groups include students, standardisation practitioners, the automotive and battery industry, infrastructure providers, researchers, policymakers, municipalities, investors and the general public.

The background was the Stan4SWAP project, which promotes standards for swappable batteries in L-cat EVs to strengthen regulation, competitiveness and excellence in Europe.

The content was based on six subject areas:

- **Fundamentals of standardisation**: definitions, benefits (cost reduction, interoperability, quality, innovation base, market access) and different stages of development of standards (national, European, international) as well as relevant instruments (EN, TS, CWAs, ISO types).
- **Ecosystem of swappable batteries**: Six key factors, including swap stations, safe and interoperable batteries, advanced battery management systems (BMS), networked partner and service networks, and social integration (cities, citizens, environmental organisations, politics).
- **Economic and regulatory framework**: Differences between regulations (legally binding) and standards (voluntary, good practice); New Approach in the EU; important regulations such as battery, infrastructure and vehicle regulations (EU 2023/1542, 2023/1804, 168/2013).
- **State of the art in the standardisation system**: IEC 62840 series (battery swaps) as the leading standard, supplemented by ISO/IEC activities (e.g. ISO 18243, ISO 19453-6, ISO 23625) and vehicle-level work (ISO/IEC TCs, CEN TC301). Challenges such as global applicability, safety and interoperability requirements, and the slow pace of standardisation processes are discussed.
- **Strategies and procedures**: Technical recommendations, negotiation concepts (game theory, conflict resolution), interoperability risks and measures for reduction (options, profiles, reference implementations, tests). Information on barriers (resources, costs, lack of awareness) and ways to overcome them; linking research, standards and standardisation,

- **Case studies:** Specific examples illustrate the practical relevance and global coordination challenges.

Overall, the handbook emphasises that developing a consistent, open, interoperable standards ecosystem is crucial to realising the potential of battery-based exchange systems in a safe, cost-efficient and marketable manner.

In addition, the goal of developing standards that support technical regulations for swappable batteries was described in Chapter 8. This manual is also intended to assist in creating these standards.

This handbook is also intended to serve as a guide for standardisation in various other contexts, particularly for the development of interoperability and compatibility standards, but also beyond. As additional support, the Appendix contains a collection of 20 selected further sources with a broader scope of application.

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Various additional materials (e-mails, links, tables etc.) where provided by standardisation experts of the case studies in Chapter 10.

Annex: Interesting Additional External Links on Standards and Standardisation

Source: own selection from Seeblocks.eu's Standards Visualisation Tool and EDU4Standards.eu repository

Name	Description	Link
1. Introduction to Standardisation	HSbooster.eu Training Academy Session 1: Introduction to Standardisation This training session aims to bring standardisation closer to those without prior knowledge of standardisation. By using interactive approaches, the training will help active participants find answers to the following questions: • Why do researchers need standards and standardisation? • Why do researchers need standards and standardisation? • What is standardisation, and what are standards? • Who develops standards?	https://seeblocks.eu/visualisation-tool/introduction-standardisation
2. What is standardisation and what are standards?	This material of the EU project HSbooser.eu aims to help: 1. understand the basic meaning of standards and standardisation; 2. explain how and why consensus has a different meaning in standardisation; 3. explain why standardisation can be called "the habit-forming process of the industry"; and 4. understand that, based on different points of view, standard can be defined as a document (for standard makers) or solution (for standard takers).	https://seeblocks.eu/visualisation-tool/what-standardisation-and-what-are-standards

Name	Description	Link
3. Standards Users and Use of Standards	HSbooster.eu Training Academy Session 3: Standards Users and Use of Standards A successful standard is a standard that is accepted in the market. Understanding standards users might be a changing point in understanding the needs for one standard. There are plenty of reasons why the voice of direct and indirect standards users is vital in standardisation development. This training session aims to raise awareness of standards users.	https://seeblocks.eu/visualisation-tool/standards-users-and-use-standards
4. Classification of Standards	This material of the EU project HSbooster.eu aims to help: 1. understand the need for the classification of standards; 2. understand subject-matter-related classifications; 3. understand classifications related to standards development; 4. understand classifications related to standards use; 5. explain the differences between de jure and de facto standards; 6. explain the differences between horizontal and vertical standards; and 7. understand that standards developed by professional and industrial associations, business associations, consortia, and fora may eventually become formal standards.	https://seeblocks.eu/visualisation-tool/classification-standards
5. European Standardisation System - text	HSbooster.eu Training Academy Session 2: European Standardisation System This material wants to give a comprehensive overview of European standard bodies like: CEN, CENELEC and ETSI • The Committee for Standardisation (CEN) • The European Committee for Electrical Standardisation (CENELEC) • The European Telecommunications Standards Institute (ETSI)	https://seeblocks.eu/visualisation-tool/european-standardisation-system
6. European Standardisation System – video		https://seeblocks.eu/visualisation-tool/european-standardisation-system

Name	Description	Link
7. How standards are developed within SDOs in Europe?	HSbooster.eu Training Academy: How standards are developed within SDOs in Europe. This material should help to understand how the development process within SDOs is settled, which deliverables are developed by which European SDO and which deliverables might be a good choice in a specific situation.	https://seeblocks.eu/visualisation-tool/how-standards-are-developed-within-sdos-europe
8. How standards are developed within SDOs internation-ally?	HSbooster.eu Training Academy: How standards are developed within SDSs internationally This material should help to understand how standard development processes within SDOs are settled, which deliverables are developed by ISO or IEC and which deliverables might be a good choice in a specific situation.	https://seeblocks.eu/visualisation-tool/how-standards-are-developed-within-sdos-internationally
9. How to participate in TCs or WGs?	HSbooster.eu Training Academy: How to participate in TCs or WGs This material should help you to understand who can participate in a standardisation process, how the process is structured, and what it means to be an O-member or a P-member.	https://seeblocks.eu/visualisation-tool/how-participate-tcs-or-wgs
10. How to write stand-ards	This material, provided by ISO, contains a guideline on how to write a clear, concise and user-friendly standard.	https://seeblocks.eu/visualisation-tool/how-write-standards
11. Mastering Tech Standardization	More than 20 videos from ETSI, e.g. on the following topics: • What are standards and why are they important? • SDOs - What are they?; Who does what and how can I find them? • How are standards written? • Tools and Initiatives to Link Research and Standards • Harmonised Standards and Europe's New Regulatory Frame-work • Testing & Interoperability • Key benefits for small organisations • Committee Technical Working Procedures • The crucial role played by NSOs and NSBs	https://seeblocks.eu/visualisation-tool/mastering-tech-standardization

Name	Description	Link
12. How to find the right standard?	HSbooster.eu Training Academy: How to find the right standard? The objective of this course is to help to find the right standard within the various standard bodies.	https://seeblocks.eu/visualisation-tool/how-find-right-standard
13. ISO Online Browsing Platform	The Online Browsing Platform offers a search tool for ISO standards, collections, publications, graphical symbols, terms and definitions, and country codes.	https://seeblocks.eu/visualisation-tool/iso-online-browsing-platform-obp
14. Legal aspects of standardisation – standards and law in the EU	HSbooster.eu Training Academy: Legal aspect of standardization This course should enable you to understand the key legal issues surrounding standardisation, the differences between law and technical standards, and their effect on legislation.	https://seeblocks.eu/visualisation-tool/legal-aspects-standardisation-relationship-standards-and-law-eu
15. Introduction to Standard Essential Patents (SEP)	HSbooster.eu Training Academy: Introduction to standard essential patents (SEP): This course aims to provide an understanding of the relationship between patents and standards and explain why standard-essential patents (SEPs) are important and how they affect businesses and interoperability.	https://seeblocks.eu/visualisation-tool/introduction-standard-essential-patents-sep
16. Company Standardi-sation	HSbooster.eu Training Academy: Company Standardisation This course aims to provide an understanding of why companies develop standards, the different types of standards and why they are applied differently.	https://seeblocks.eu/visualisation-tool/company-standardisation
17. Consortia-based standardisation	HSbooster.eu Training Academy: Consortia-based standardization This course aims to provide an understanding of the differences and similarities between standards consortia and SDOs and help to decide which would be best suited to a particular task. It should also help to understand their relationship with EU standardisation policies and how they link to SDOs.	https://seeblocks.eu/visualisation-tool/consortia-based-standardisation
18. CEN and CEN-ELEC Workshop Agree-ments – A rapid way to standardization	This material should provide you with an understanding of the mechanisms and characteristics of CEN and/or CENELEC deliverables, known as CEN and/or CENELEC Workshop Agreements, and their development process.	https://seeblocks.eu/visualisation-tool/cen-andor-cenelec-workshop-agreements-rapid-way-standardization

Name	Description	Link
19. CEN-CENELEC GUIDE 39. The role of standards in support of Technology Transfer. Edition 1, March 2022	The main target audience of this Guide are the researchers and providers of new technologies who want to see their research outcome taken up by the market as well as innovators and entrepreneurs who want their innovation to enter the market and are interested to know whether and how standardization can help them to meet their objective. The use of standardization in support of the uptake of an innovation by the market consists of: a) the application of existing standards on which the innovative product/service relies; and b) contributions to and participation in the standardization process, to ensure the standards accommodate the innovative product/service. In addition to addressing these topics, the Guide contains information on how researchers and innovators can make initial contacts with the standardization community, as well as information on the ways that CEN and CENELEC can offer them to take advantage of standardization.	https://seeblocks.eu/visualisation-tool/role-standards-support-technology-transfer
20. Understanding ICT Standardisation. 2nd ed.	Key topics of this handbook include: 1. Introduction to standards, 2. The standards ecosystem, 3. The production of standards, 4. Standardization and innovation, 5. A strategic perspective on standardization, 6. IPR and standardization and 7. Standardization and public procurement	https://www.etsi.org/images/files/Education/Textbook_Understanding_ICT_Standardization.pdf

Annex 2

STANDARDIZATION AND STANDARDS FOR MOBILITY AND TRANSPORT IN THE ECOSYSTEM OF SWAPPABLE BATTERIES

- Basic topics -

Prof. Dr. Knut Blind
Fraunhofer ISI

Learning objectives

- Acquiring fundamental knowledge of standards
- Understanding the effects of standards
- Exploring the connections between research and development and standardization
- Identifying the various roles of different standards
- Understanding the impacts of standards for appropriate use

This project has received funding from the European Union's Horizon Europe research and innovation programme under grant agreement No 101135417. Additionally, this Work has received funding from the Swiss State Secretariat for Education, Research and Innovation (SERI) for its Associate Partner.

1. Basics of standards
What standards are (in a wide sense) and why they're needed

- The most general definition for a «standard» may be

  «a widely agreed way of doing something» ...

  ... where, depending on the specific area of application, **"doing something"** may be replaced by, e.g., **"designing a product", "building a process", "implementing a procedure"** or **"delivering a service"**.

- «Standard» (i.e. agreed and common) ways of doing things bring lot of benefits; our technological world without «standards» **simply would not work (or, at least, it would be much harder to make it work)**

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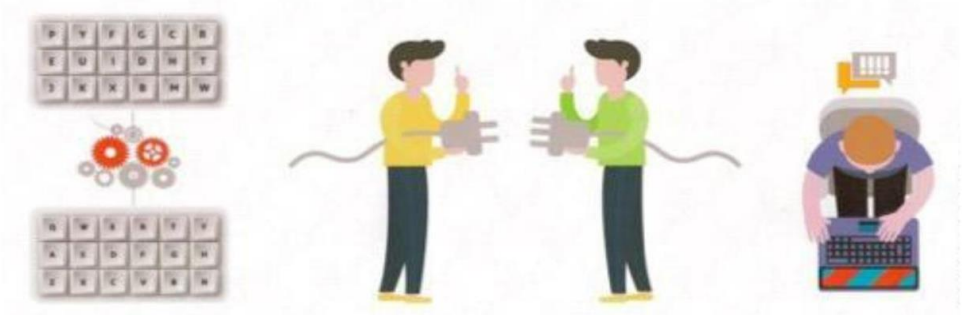
1. Basics of standards
What standards are (in a wide sense) and why they're needed

- For instance, what if



each computer had its own type of keyboard

each smartphone and PC had its own specific set of connectors and charger (though some have by choice… more on this later)

each device had its own protocol for interoperation

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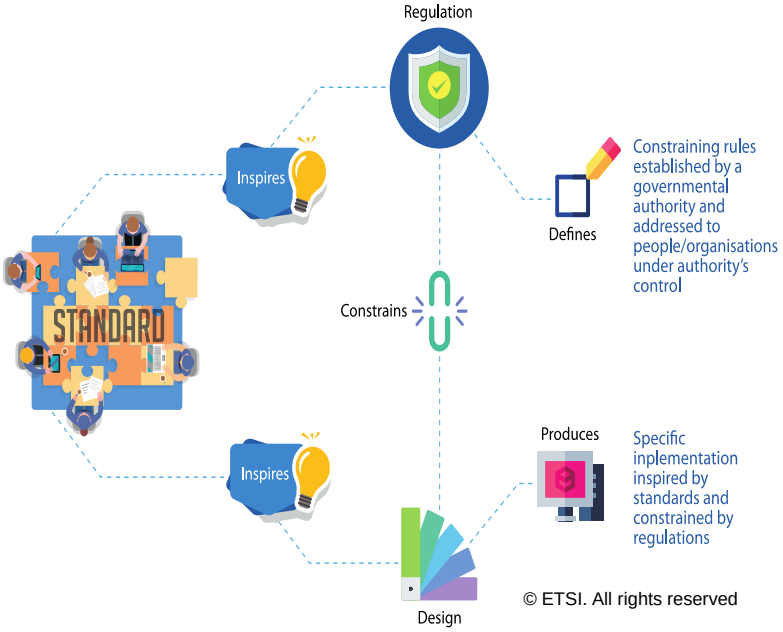
1. Basics of standards
Formal standardisation, SDO standards, and regulation

- **Standards are NOT regulations**
- Compliance with standards is voluntary; regulations are mandatory.
- Non-compliance with regulations restricts market access; non-compliance with standards does not.
- Example: Some smartphones with proprietary connectors.
- Standards can be incorporated into regulations to simplify regulatory processes.
- **Standards are NOT detailed design rules**
- They define a **minimum set of requirements** to achieve specific goals (e.g., interoperability, performance).
- Many 'standard-compliant' implementations are possible



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1. Basics of standards
Two main different types of "standards"

De facto standards, or standards in actuality, are adopted widely by an industry and its customers. These standards arise when a critical mass simply likes them well enough to collectively use them.

SDO standards are produced by devoted organizations, called Standards Development Organizations (SDOs). SDOs are organizations whose main purpose is to develop standards. They have that put in place formal well-defined procedures to guarantee a fair development process.

De facto standards can become formal standards if they are approved by an SDO. Examples: HTML, PDF

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1. Basics of standards
Formal standardisation, SDO standards, and regulation

- A standard **must be clear and unambiguous**.
- It should help readers understand **what is essential for compliance**.
- It must clearly distinguish between:
- **Normative parts**: mandatory requirements for compliance.
- **Informative parts**: for conceptual understanding.
- It should be written in **plain language,** using **simple and short sentences**.
- Requirements must be **consistent, testable,** and **non-redundant**.
- Objectives should be **well-defined** and address **real needs**.
- It should **avoid unnecessary over-prescriptiveness**.

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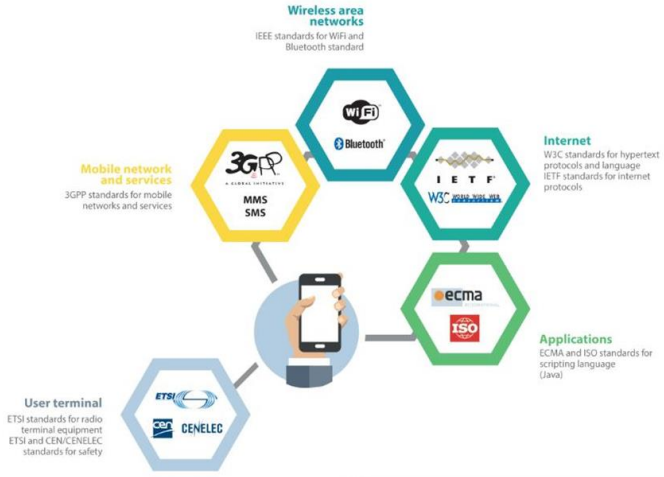
1. Basics of standards
Standards in everyday life

- Using a Smartphone for browsing

  (some probably deployed standards):
  - User equipment, e.g. hardware characteristics and safety/security aspects
  - Connectivity between user devices and wireless network, functionality of this network
  - Internet access and the protocols to support web browsing



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1. Basics of standards
Standards in everyday life

- A typical laptop uses over **500** standards.
- **251** technical interoperability standards were identified in a 2010 study (Biddle et al.).
- **80%** of these were developed by **Standards Development Organizations (SDOs).**
- **20%** came from **individual companies.**

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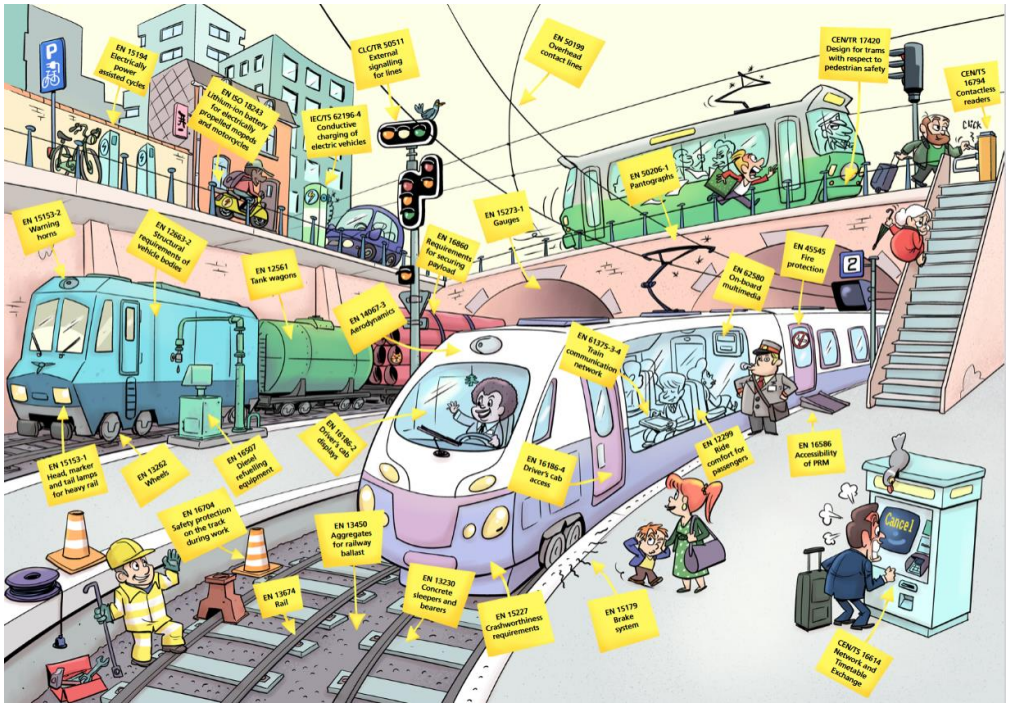
1. Basics of standards
Standards in the mobility ecosystem

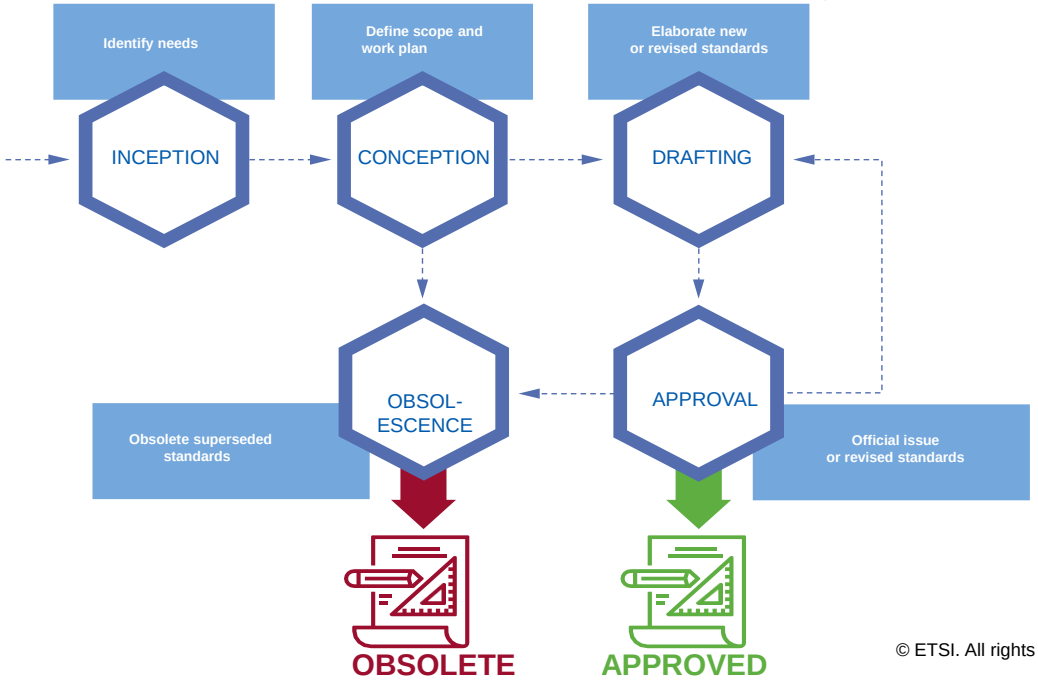
3 emobility standards

Source: CEN CENELEC



1. Basics of standardisation

Formal standardisation, SDO standards, and regulation



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2. Effects of standards

Overview

	Positive Effects	Negative Effects
Compatibility/ Interface Standards	• Network externalities, like enabling seamless global communication • Avoiding lock-in in old technologies • Increased variety of system products • Efficiency in supply chains	• Anti-competition, leading to monopoly • Lock-in in old technologies in case of strong network externalities
Minimum Quality/ Safety Standards	• Avoiding adverse selection, i.e. supply of bad quality drives out good quality • Creating trust • Reducing transaction costs	• Regulatory capture • Increasing barriers to entry
Variety Reduction Standards	• Economies of scale • Building focus and critical mass	• Reduced choice • Leading to monopoly, barriers to market access
Information/ Measurement Standard	• Facilitating trade • Reduced transaction costs • Providing codified knowledge	• Regulatory Capture

Source: Swann (2000), Pham (2006), Blind (2013), modified

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2. Effects of standards
Compatibility and Interface Standards

- **Compatibility** is a core function of standards.
- According to ISO 25010, compatibility includes:
  - **Coexistence**: Systems share resources without conflict.
  - **Interoperability**: Systems work together effectively.
- In the ICT sector, compatibility and interfaces have strong **economic significance**.
- Two key economic influences:
  - **Network effects**: Value increases with more users.
  - **Switching costs**: Costs of changing systems/products.
- When both are present, there is a risk of a **lock-in effect** (users become dependent on a specific system).

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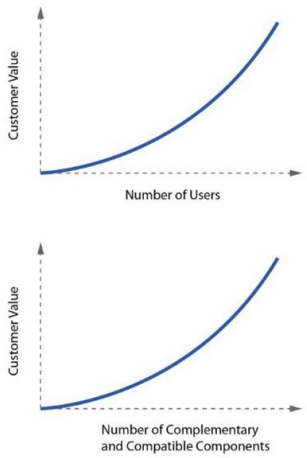
2. Effects of standards
Compatibility and Interface Standards

- Network effects – two forms:
  - **Direct:** The value of a good/ services increases with the number of people using it

  Examples: Telephone, e-mail, Facebook, X, …
  - **Indirect:** The value of a good/service does not depend directly on the number of users but rather on the availability of complementary and compatible components

  Examples: Video game consoles, computer hardware and software, …



Source: Greenstein and Stango (2008)

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2. Effects of standards
Compatibility and Interface Standards

- Switching costs:

Once producers or customers have invested into a particular interface or standard, switching to another one will become increasingly expensive

- Examples:
  - **Acquisition costs:** When new equipment has to be bought or adapted
  - **Training costs:** Associated with learning to use a new product
  - **Testing costs:** If there is uncertainty regarding the suitability of alternative products/services

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Source: Parr et al. (2005)

2. Effects of standards
Compatibility and Interface Standards

- **Lock-in** occurs when markets or users remain tied to inferior technologies.
- Switching only happens if:
  - **Everyone else switches,** and
  - **Switching costs are affordable.**
- If either condition isn't met, **lock-in persists.**
- Lock-in is more likely when:
  - A standard is **not formally standardized,** and
  - It is **controlled by a single organization.**
- Market consequences of lock-in include:
  - **Barriers to entry**
  - **Monopoly formation**

Source: Parr et al. (2005), de Vries et al. (2008)

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2. Effects of standards
Compatibility and Interface Standards

- **Open standards** have **positive market effects.**
- A standard is considered open based on the **openness of the standardization process.**
- In an open process, **anyone (individuals or organizations)** can participate.
- The result is an **open standard.**
- Formal processes should follow **WTO principles:**
  - Transparency, openness, impartiality, consensus, efficiency, relevance, and consistency.
- Open standards **reduce lock-in risks** by:
  - Being accessible and widely implementable
  - Lowering **barriers to entry** and **switching costs** for consumers.

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2. Effects of standards
Compatibility and Interface Standards

- **Compatibility standards reduce transaction costs** by minimizing the need for buyers to verify interoperability (e.g., software with an OS).
- Lower transaction costs enable **greater division of labour.**
- Example:
  - Computers use globally sourced components.
  - **International compatibility standards** have globalized the industry.
  - Producers can specialize in specific value chain segments, gaining **economies of scale** and accessing global markets.

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2. Effects of standards
Minimum Quality and Safety Standards

- **Minimum quality standards** set **baseline requirements**

  for reliability, durability, safety, and other areas (e.g. working conditions).
- They can enhance **welfare,** including **health and environmental** outcomes.
- Help **reduce buyer risk** and build **trust** in trade between traders.
- If set too high, they may become **barriers to market entry**.
- When adopted by regulation (e.g., **CO_2 emission limits** for cars), compliance becomes **legally mandatory**.

Source: based on Swinnen (2015) and Locksley (1990)

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2. Effects of standards
Minimum Quality and Safety Standards

- **Customers struggle** to choose among many product variants.
- If buyers **can't assess quality,**

  high-quality sellers can't justify higher prices.
- This can lead to **Gresham's law**: "*Bad drives out the good.*"
- **Worst case**: Market may **fail completely**

  due to lack of trust in product quality.

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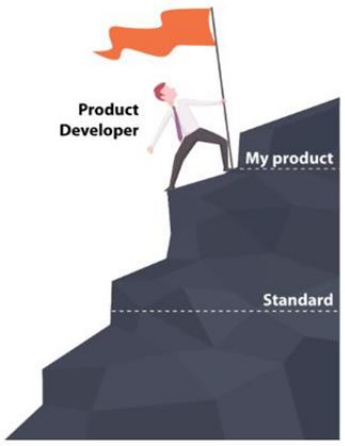
2. Effects of standards
Minimum Quality and Safety Standards

- The issue stems from **information asymmetries,** where sellers know more than buyers.
- This makes it difficult for buyers to make **informed decisions.**
- **Leland (1979)** showed that **minimum quality standards** can reduce these asymmetries by setting clear **baseline requirements.**
- Some firms rely on their **reputation** to justify **higher prices** by offering quality well above the standard.
- **Ex-post restitution** (e.g., guarantees) can also **substitute** for formal quality standards.



This project has received funding from the European Union's Horizon Europe research and innovation programme under grant agreement No 101135417. Additionally, this Work has received funding from the Swiss State Secretariat for Education, Research and Innovation (SERI) for its Associate Partner.

2. Effects of standards
Minimum Quality and Safety Standards

- Minimum quality standards **reduce transaction and search costs** caused by economic exchange
- If a product is defined in a way that reduces buyer uncertainty:
  - The buyer's risk is reduced
  - Less need for the buyer to spend money and time on evaluating different products before a purchase
- Product certification can function as a shortcut for buyers as it proofs the compliance to a standard

Source: Pham (2006); Swann (2000); Swann (2010)

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2. Effects of standards
Minimum Quality and Safety Standards

- **Minimum quality standards** can help **level the playing field** between new entrants and incumbents by clearly defining product requirements.
- Without standards, **incumbents hold an information advantage**.
- However, standards set **too high** can act as **entry barriers**.
- Even if costly for incumbents, such standards may **burden entrants more,** effectively **raising rivals' costs**.
- This strategy can lead to **"regulatory capture"**, where **producers influence regulators** to shape standards in their own interest - rather than in that of consumers.

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2. Effects of standards
Variety Reduction Standards

Two main functions:

- Support of **economies of scale**, by minimizing the proliferation of minimally differentiated models
- Reduction of **transaction costs** for customers, because they do not have to choose between a vast number of slightly different products

Many advantages:

- **Prevention of market fragmentation** and support of a **joint vision**
- For suppliers, less fragmentation also means reduced risk
- Variety reduction standards can also reduce barriers to entry
  - Variety proliferation is sometimes used by incumbents to limit competition from small scale entrants who cannot provide the same degree of variety
  - Some incumbents try to restrict entry by companies with an idiosyncratic product specification

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2. Effects of standards
Information and Measurement Standard

- **Information and measurement standards:** Standards that contain codified knowledge and product descriptions
- These standards an be seen as **important instruments of technology transfer** as they…
  - …contain the work and experience of generations
  - …act as instruments in the dissemination of best practices

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2. Effects of standards
Information and Measurement Standard

Information and measurement standards have a positive effect on the market by **disseminating knowledge.** They support

- …building up competencies
- …spreading essential production knowledge, thus levelling the playing field for incumbents and entrants
- …reducing information asymmetries
- …reducing barriers to market entry

These standards lower transaction costs between companies and contractors, e.g. employees, suppliers and customers, by providing a common language and therefore…

- …ease the writing of job descriptions, contracts etc.
- …achieve a feasible division of labour

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2. Effects of standards
Example: Digital Image compression

- **1990s** saw rapid growth in **image/video processing** and **multimedia technologies.**
- This drove demand for efficient **compression methods.**
- **International SDOs** developed key standards like **JPEG** (Joint Photographic Experts Group).
- These standards enabled **reduced storage needs** and **lower transmission rates.**
- Widely used in applications such as:
  - **Digital image sharing**
  - **Remote sensing**
  - **Archiving**
  - **Image search**

Source picture: Schelkens (2015)

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3. Standard development organisations
De facto standards vs SDO standards (Blind 2008)

SDO STANDARD	DE FACTO STANDARD

• Developed in SDOs
• Open and consensus oriented with the option of opposition, which may sometimes lead to lengthy decision procedures
• Clear and transparent participation and voting rules
	• Dominant design through a standard war or natural selection.
	  • A company achieves a dominant position by public acceptance or market forces, e.g. Windows
	• Standardisation process with restricted access;
	  • homogeneous environment may allow fast decisions
	• Direct participation of company alliances (e.g. consortia) and individual companies

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3. Standard development organisations
Classification of SDOs

- International SDOs
  - These have members worldwide, which sometimes also include national or regional standard bodies, and their deliverables have worldwide coverage.

- Regional SDOs
  - These have members (industries, academia and national SDOs) from well defined geographic regions that usually share, or are interested in promoting common practices and regulations.

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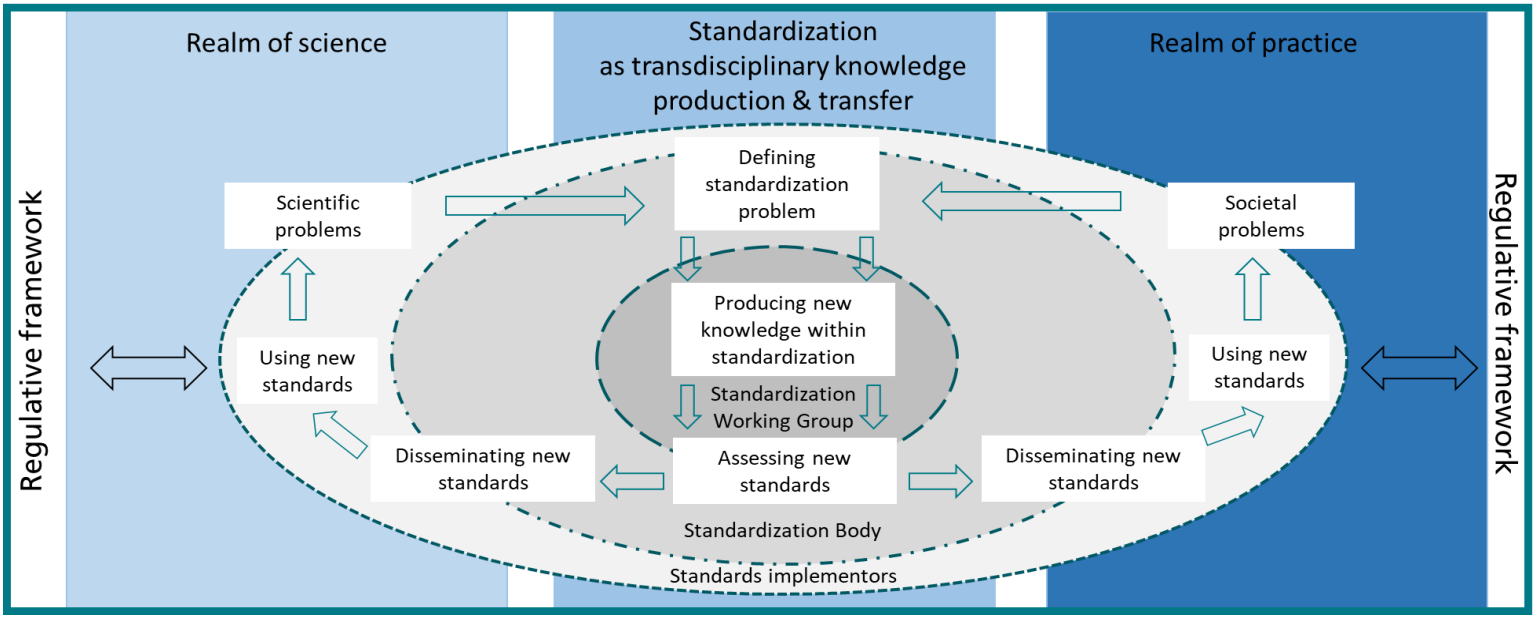
4. Interlinkages between R&D and standardisation:
Standardisation as transdisciplinary knowledge production & transfer



Source: Blind 2004

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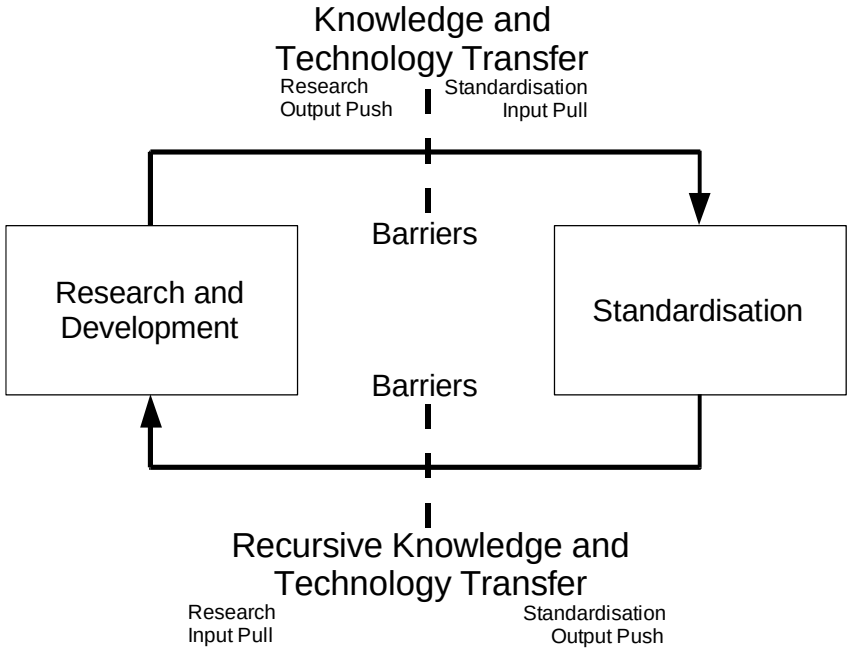
4. Interlinkages between R&D and standardisation:
A Recursive Model of Research and Standardisation



Source: Blind and Gauch 2009

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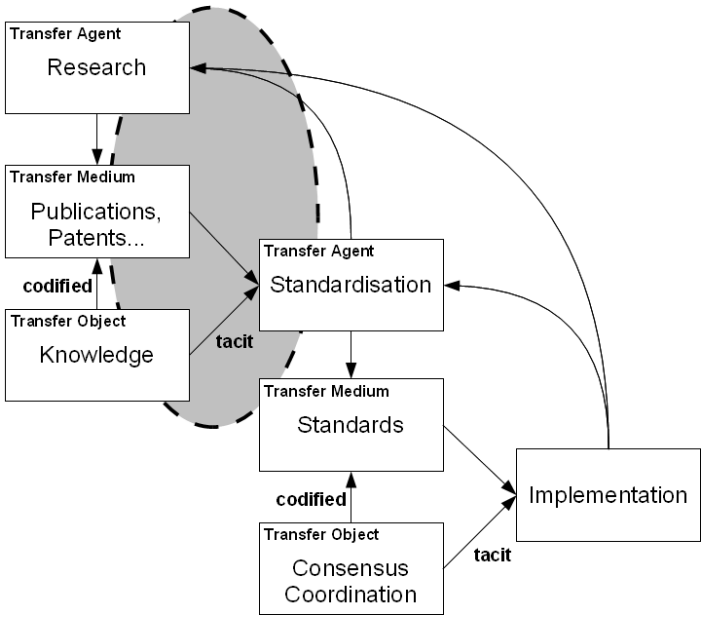
4. Interlinkages between R&D and standardisation:
A Cascading Knowledge Transfer Model



Source: Blind and Gauch 2009

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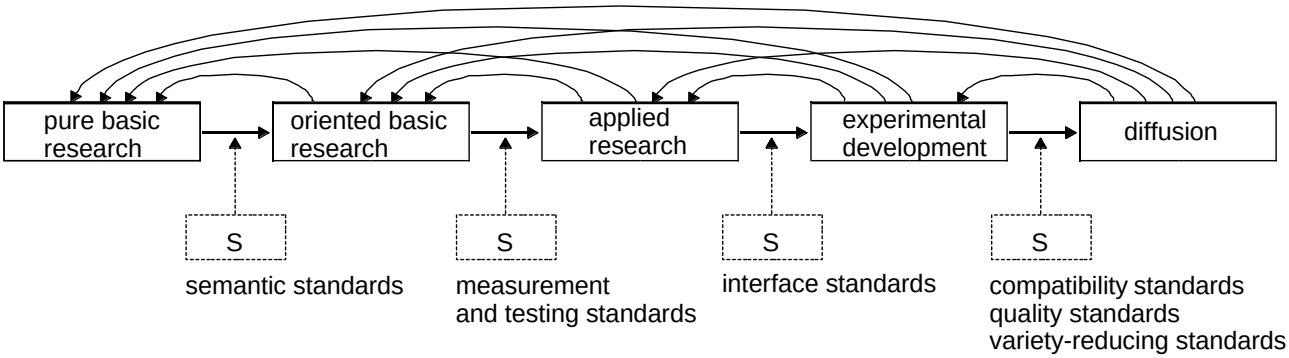
5. Various roles of different types of standards
In the research and innovation process



Function of Standards			
	Reduction of information cost Reduction of transaction cost	Interoperability between components Savings in adaption cost	Increased quality Reduced health, safety, privacy risks Building critical mass Economies of scale Creation of network externalities Interoperability between products

Source: Blind and Gauch 2009

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6. Impacts of standards
On research and innovation

General functions of standards	Positive impacts on research and innovation	Negative impacts on research and innovation
Information	• Provide codified knowledge relevant for innovation • Coordinate collaborative innovation activities	• Generate cost for standards screening • Allow unintended knowledge spillovers to competitors by implementation of standards
Variety reduction	• Allow exploitation of economies of scale via standards • Support critical mass via standards in emerging technologies and industries • Create incentives for incremental innovation based on standards	• Reduce choice • Support market concentration • Push premature selection of technologies • Limit incentives for radical innovation
Minimum quality	• Creating trust in innovative technologies and products at the demand side	• Promote market concentration
Compatibility	• Increase variety of system products • Promote positive network externalities • Avoid lock-in into old technologies	• Push monopoly power • Foster lock-in into old technologies in case of strong network externalities
Insurance	• Serve as insurance against failure of radical innovation	• Create incentives for incremental instead of radical innovation

Source: Blind 2022 edited by ISO
https://www.iso.org/publication/PUB100466.html

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7. Future prospects
Achievements and next steps

You now have a solid overview of:

- **What standards are**
- **Where they appear**
- **Who develops them**
- **Why they matter** for technology, markets, and society

Thank you for your attention!

We look forward to welcoming you at our **next presentation,** where we'll explore **advanced topics** in mobility standardization.

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Annex 3

STANDARDIZATION AND STANDARDS FOR MOBILITY AND TRANSPORT IN THE ECOSYSTEM OF SWAPPABLE BATTERIES

– Advanced topics -

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Vrije Universiteit Brussel
Dr. Simone Wurster
Fraunhofer ISI

This project has received funding from the European Union's Horizon Europe research and innovation programme under grant agreement No 101135417. Additionally, this Work has received funding from the Swiss State Secretariat for Education, Research and Innovation (SERI) for its Associate Partner.

Learning objectives

- Becoming familiar with the regulatory framework
- Getting to know current standards
- Getting to know specific standardization strategies
- Deepening standardization strategies using a case study

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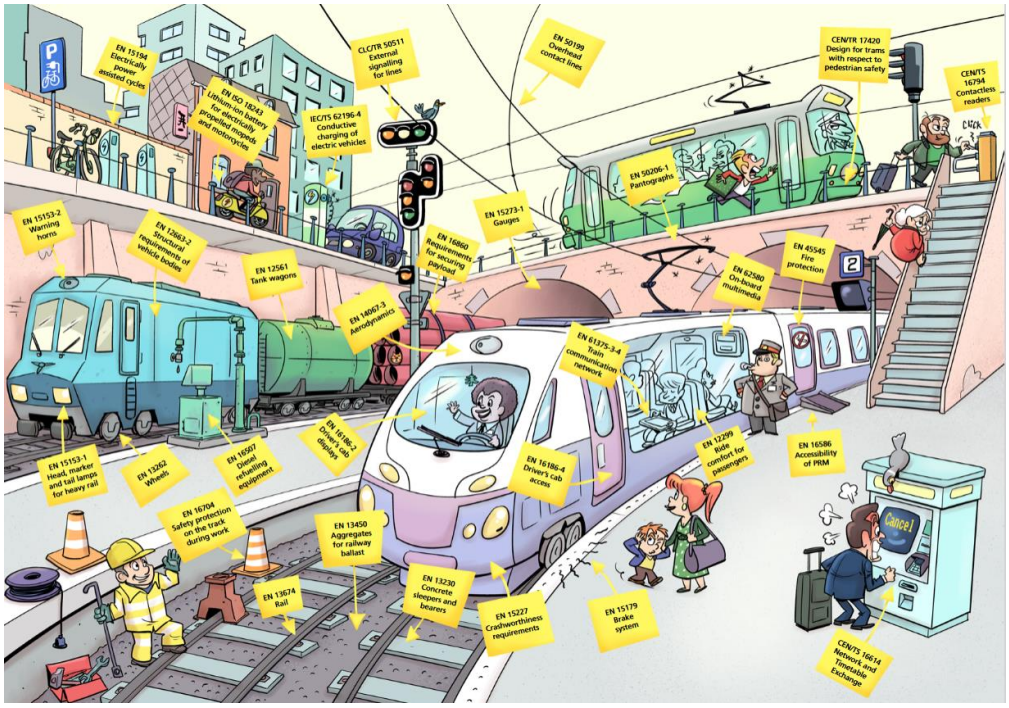
Standards in the mobility ecosystem

emobility standards

Source: CEN-CENELEC



1. Regulatory framework conditions

Regulations and standards in the EU

Regulations and standards differ fundamentally:

- Regulations are issued by governments or the EU and are legally binding.
- Standards are voluntary documents representing best practices.

Despite this, there is frequent interaction between the two:

- Regulations often reference standards.
- The EU promotes standardization by issuing mandates to bodies like CEN and CENELEC.

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1. Regulatory framework conditions
New Approach

The EU's "New Approach"

- Legislation (regulations and directives) defines only essential requirements.
- Technical details are provided by harmonized European standards.
- These standards remain voluntary, but using them creates a presumption of conformity with legal requirements.
- Example: The Low Voltage directive states:
  - *Measures of a technical nature shall be laid down (…), in order to ensure that persons and domestic animals are adequately protected against the danger of physical injury or other harm which might be caused by direct or indirect contact*
- Concordance with directive: annex ZZ of the harmonized EN standard

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1. Regulatory framework conditions
New Approach

"New Approach" is broadly applied

- Low Voltage directive, Machine directive, etc.

NOT for vehicle type approval

- UNECE regulations
- UN level

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1. Regulatory framework conditions
New Approach

Relevant EU regulations for swappable battery systems include:

- Battery Regulation (EU) 2023/1542
- Alternative Fuel Infrastructure Regulation (EU) 2023/1804
- Regulation (EU) 168/2013 on two-/three-wheel vehicles and quadricycles

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2. State of the art
Product safety, security, liability

A comprehensive set of standards ensures trusted safety and security across the entire ecosystem.

- This includes:
  - Data exchange within the system
  - Interfaces with external parties
- Standards ensure a uniform level of safety and security for all components.
- System-level risks arising from combining elements are already addressed through standard requirements.
- Standards help clearly assign responsibilities and liabilities among stakeholders.
- A defined state-of-the-art further supports legal clarity and technical accountability.

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2. State of the art
Product compliance

CEN-CENELEC's principle of standards' "verifiability".

- Ensures that compliance can be assessed objectively.
- Users benefit from increased trust in quality and performance of standardized products.
- Verified compliance provides assurance and supports market confidence
- The standard compliance as "quality label"!

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2. State of the art
Harmonization and reference

Referencing or harmonizing standards in EU regulations supports implementation of swappable battery systems.

Relevant EU regulations:

- Regulation (EU) 2023/1542 – on batteries and waste batteries
  - Standardized swappable batteries could reshape battery type definitions.
  - Compliance with standards might serve as sole classification criteria.
- Regulation (EU) 2023/1804 – on alternative fuels infrastructure
  - Should reference standardized battery swapping stations.
  - Include minimum density requirements for fair infrastructure coverage.
- Regulation (EU) No 168/2013 – on vehicle type approval
  - Standards enable type approval of vehicles without fixed batteries.
  - Helps maintain vehicle approval across different standardized battery options.

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3. State of the art standardization
IEC 62840 standard

IEC 62840 series: Electric vehicle battery swap system

- Drafted by IEC TC69 WG13 (CN lead)

Part 1: "General and guidance" (2025) provides:

- An overview of battery exchange systems for electric road vehicles.
- System concepts and key use cases.
- Differentiates between:
  - **Swappable** battery systems (handled by the charging station; aimed at cars and heavy-duty vehicles).
  - **Removable** battery systems (manually handled; aimed at light vehicles like those in the project).
- Describes typical system components for both types.

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3. State of the art standardization
IEC 62840 standard

Part 2: "Safety requirements" (2016, second edition 2025):

Covers general safety requirements for both swappable and removable battery systems.

- Systems must be reliably designed and constructed to:
  - Ensure safe performance under normal use.
  - Minimize risks to people, equipment, and the environment

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3. State of the art standardization
IEC 62840 standard

Part 3: "Particular safety and interoperability requirements for battery swap systems operating with removable RESS/battery systems"

Initially published as a PAS (Publicly Available Specification) based on IEC 61851-3 draft.

Currently being revised to be fully integrated into the IEC 62840 series. Provides:

- Specific requirements and for handheld swappable battery systems (HBS).
- Extends Parts 1 and 2 with application-specific provisions.
- Applies to partly or fully electric vehicles using removable RESS/battery systems.

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3. State of the art standardization
Additional standards

Other relevant standards for battery swapping systems:

- IEC TC21 and SC21A: Focus on battery safety.
- IEC SC23H: Covers accessories such as connectors.

OCA consortium standards (e.g., OCPP protocol):

- OCPP 2.0.1 → adopted as IEC 63584.
- OCPP 2.1 (includes battery swap) is under development as an IEC standard.

Additional standardization activities

A new CEN TC301 WG19 focuses on swappable battery systems for L-category vehicles (e.g., small/light vehicles).

Vehicle-side standardization is crucial for interoperability across brands and models.

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4. Strategies for mobility-related standardization
Fundamental recommendations

The ideal standardization work

- Interacting with regulatory needs
- Responding to societal needs
- Following technological progress, enabling but not impeding
- No overstandardization

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4. Strategies for mobility-related standardization
The case of swappable batteries

Standardizing swappable batteries:

- Shall be multi-brand, multi-model standard!
- Impact on vehicle design and brand identity, especially for smaller vehicles.
- The standardization process is slow (typically ≥3 years from proposal to publication).

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4. Strategies for mobility-related standardization
The case of swappable batteries

Why is the standardization process so slow?

This is due to its consensus-based, democratic nature, including:

- Democratic, consensus-based process
- Multiple commenting rounds: NP, CD, CDV, FDIS
- Participation from all interested national committees
- Active stakeholder involvement across sectors

This "weakness" is actually a strength!

Despite the pace, this process ensures high-quality, broadly accepted standards.

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4. Strategies for mobility-related standardization
"performance principle" and "aim-oriented approach"

Freedom of Choice in Technical Solutions

- Standards should focus on performance targets rather than prescribing specific technologies.
- Explicit solutions should only be mandated where needed to ensure interoperability (e.g. interfaces and connectors).
- Allows supplier diversity and promotes market competition.

Support for Technological Progress

- Standards should follow an "aim-oriented" approach, allowing flexibility and evolution.
- Ensures components can be designed with forward/backward compatibility in mind.
- Facilitates continuous improvement while maintaining system compatibility.
- No restrictive standards stifling technological progress

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4. Strategies for mobility-related standardization

"performance principle" and "aim-oriented approach"

Simultaneous Participation of Multiple Actors

- Standards enable interoperability among products and services from different suppliers.
- Encourages parallel development:
  - OEMs can develop vehicles without waiting for batteries or stations.
  - Battery manufacturers can proceed independently as well.
  - Helps overcome the "chicken and egg" problem, accelerating market deployment.

Scalability and Ecosystem Extension

- Standards provide a framework for expansion and virtual modeling of ecosystems.
- Support use cases beyond light vehicles.
- Allow creation of additional ecosystems (public or private) with multiple suppliers, benefiting from economies of scale.

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Case study

Development of the IEC 62840 Standards Series
Background and framework conditions

- Initiated in 2012 by China State Grid, Better Place (Israel), and Renault (France)
- Market Driver: Rapid EV market growth since 2010, with battery swapping emerging as a quick charging alternative
- Technical Need: Uniform interfaces, communication protocols, and safety standards to prevent market fragmentation
- Application Focus: Initially for commercial vehicles, later expanded to two-wheelers (post-2018) in China, Japan, Europe, and Southeast Asia
- Policy Support: Government backing for battery-swapping technology, especially in electric heavy-duty vehicles
- Global Collaboration: IEC partnership with ISO and national committees for worldwide applicability

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Case study

Development of the IEC 62840 Standards Series
Development success factors

- International Collaboration: Global experts and companies from China, Japan, Germany, France, Israel, South Korea, and Indonesia participated in standard development
- Structured Process: IEC's multi-stage approach (proposal → draft → voting → release) ensured iterative feedback and technical rigor
- Progressive Development: Started with safety and system architecture, gradually transitioning to interoperability requirements
- Standards Coordination: Alignment with related standards like IEC 61851-3 for consistency across the EV ecosystem
- Broad Industry Engagement: Active participation from various stakeholders fostered consensus and global applicability

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Case study

Development of the IEC 62840 Standards Series
Challenges & Solutions

- Technical Complexity
  - Challenge: Diverse components (batteries, swap stations, interfaces) requiring robust safety standards
  - Solution: IEC 62840-1 for general guidance + IEC 62840-2 for specific safety requirements
- Global Applicability & Industry Alignment
  - Challenge: Regional regulation variations and differing manufacturer interests
  - Solution: Flexible standards allowing local adaptations while maintaining core requirements
- Evolving Technology
  - Challenge: Rapid EV and battery technology advancements
  - Solution: Adaptable standards that adjust technical direction based on market developments

This project has received funding from the European Union's Horizon Europe research and innovation programme under grant agreement No 101135417. Additionally, this Work has received funding from the Swiss State Secretariat for Education, Research and Innovation (SERI) for its Associate Partner.

Case study

Development of the IEC 62840 Standards Series

Key Lessons Learned

- Early Industry Participation Critical: Better Place's bankruptcy in 2013 significantly impacted standardization development, highlighting the importance of diverse industry backing
- Balancing Global vs. Local Needs: Regional differences and expert disagreements consumed significant time in the standard-setting process
- Technology Uncertainty Impact: Complex and high-cost battery-swap technology development, especially for passenger vehicles, made standardization challenging
- Sunk Costs Effect: Companies' early investments created barriers to achieving interoperability requirements, even after meeting safety standards
- Market Evolution: Standards needed to adapt from focus on four-wheel passenger vehicles to include widespread low-voltage two-wheel platforms

The standardization journey demonstrates the complex interplay between technology development, market forces, and regulatory frameworks

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5. Summary

Achievements

You now have a solid overview of:

- **Regulations and standards - The "New Approach"**
- **The IEC 62840 standard series and its development process**
- **Related standards**
- **Why they matter** for technology, markets, and society

Thank you for your attention!

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Annex 4

Interesting Additional External Links on Standards and Standardisation

Name	Description	Link
1. Introduction to Standardisation	HSbooster.eu Training Academy Session 1: Introduction to Standardisation. This training session aims to bring standardisation closer to those without prior knowledge of standardisation. By using interactive approaches, the training will help active participants find answers to the following questions: • Why do researchers need standards and standardisation? • Why do researchers need standards and standardisation? • What is standardisation, and what are standards? • Who develops standards?	https://seeblocks.eu/visualisation-tool/introduction-standardisation
2. What is standardisation and what are standards?	This material of the EU project HSbooser.eu aims to help: 1. understand the basic meaning of standards and standardisation; 2. explain how and why consensus has a different meaning in standardisation; 3. explain why standardisation can be called “the habit-forming process of the industry”; and 4. understand that, based on different points of view, standard can be defined as a document (for standard makers) or solution (for standard takers).	https://seeblocks.eu/visualisation-tool/what-standardisation-and-what-are-standards

Name	Description	Link
3. Standards Users and Use of Standards	HSbooster.eu Training Academy Session 3: Standards Users and Use of Standards A successful standard is a standard that is accepted in the market. Understanding standards users might be a changing point in understanding the needs for one standard. There are plenty of reasons why the voice of direct and indirect standards users is vital in standardisation development. This training session aims to raise awareness of standards users.	https://seeblocks.eu/visualisation-tool/standards-users-and-use-standards
4. Classification of Standards	This material of the EU project HSbooster.eu aims to help: 1. understand the need for the classification of standards; 2. understand subject-matter-related classifications; 3. understand classifications related to standards development; 4. understand classifications related to standards use; 5. explain the differences between de jure and de facto standards; 6. explain the differences between horizontal and vertical standards; and 7. understand that standards developed by professional and industrial associations, business associations, consortia, and fora may eventually become formal standards.	https://seeblocks.eu/visualisation-tool/classification-standards
5. European Standardisation System - text	HSbooster.eu Training Academy Session 2: European Standardisation System This material wants to give a comprehensive overview of European standard bodies like: CEN, CENELEC and ETSI • The Committee for Standardisation (CEN)	https://seeblocks.eu/visualisation-tool/european-standardisation-system
6. European Standardisation System – video		https://seeblocks.eu/visualisation-tool/european-standardisation-system

Name	Description	Link
	• The European Committee for Electrical Standardisation (CENELEC) • The European Telecommunications Standards Institute (ETSI)	
7. How standards are developed within SDOs in Europe?	HSbooster.eu Training Academy: How standards are developed within SDOs in Europe. This material should help to understand how the development process within SDOs is settled, which deliverables are developed by which European SDO and which deliverables might be a good choice in a specific situation.	https://seeblocks.eu/visualisation-tool/how-standards-are-developed-within-sdos-europe
8. How standards are developed within SDOs internationally?	HSbooster.eu Training Academy: How standards are developed within SDSs internationally This material should help to understand how standard development processes within SDOs are settled, which deliverables are developed by ISO or IEC and which deliverables might be a good choice in a specific situation.	https://seeblocks.eu/visualisation-tool/how-standards-are-developed-within-sdos-internationally
9. How to participate in TCs or WGs?	HSbooster.eu Training Academy: How to participate in TCs or WGs This material should help you to understand who can participate in a standardisation process, how the process is structured, and what it means to be an O-member or a P-member.	https://seeblocks.eu/visualisation-tool/how-participate-tcs-or-wgs
10. How to write standards	This material, provided by ISO, contains a guideline on how to write a clear, concise and user-friendly standard.	https://seeblocks.eu/visualisation-tool/how-write-standards
11. Mastering Tech Standardization	More than 20 videos from ETSI, e.g. on the following topics: • What are standards and why are they important? • SDOs - What are they?; Who does what and how can I find them? • How are standards written?	https://seeblocks.eu/visualisation-tool/mastering-tech-standardization

Name	Description	Link
	• Tools and Initiatives to Link Research and Standards • Harmonised Standards and Europe's New Regulatory Framework • Testing & Interoperability • Key benefits for small organisations • Committee Technical Working Procedures • The crucial role played by NSOs and NSBs	
12. How to find the right standard?	HSbooster.eu Training Academy: How to find the right standard? The objective of this course is to help to find the right standard within the various standard bodies.	https://seeblocks.eu/visualisation-tool/how-find-right-standard
13. ISO Online Browsing Platform	The Online Browsing Platform offers a search tool for ISO standards, collections, publications, graphical symbols, terms and definitions, and country codes.	https://seeblocks.eu/visualisation-tool/iso-online-browsing-platform-obp
14. Legal aspects of standardisation – standards and law in the EU	HSbooster.eu Training Academy: Legal aspect of standardization This course should enable you to understand the key legal issues surrounding standardisation, the differences between law and technical standards, and their effect on legislation.	https://seeblocks.eu/visualisation-tool/legal-aspects-standardisation-relationship-standards-and-law-eu
15. Introduction to Standard Essential Patents (SEP)	HSbooster.eu Training Academy: Introduction to standard essential patents (SEP): This course aims to provide an understanding of the relationship between patents and standards and explain why standard-essential patents (SEPs) are important and how they affect businesses and interoperability.	https://seeblocks.eu/visualisation-tool/introduction-standard-essential-patents-sep

Name	Description	Link
16. Company Standardisation	HSbooster.eu Training Academy: Company Standardisation This course aims to provide an understanding of why companies develop standards, the different types of standards and why they are applied differently.	https://seeblocks.eu/visualisation-tool/company-standardisation
17. Consortia-based standardisation	HSbooster.eu Training Academy: Consortia-based standardization This course aims to provide an understanding of the differences and similarities between standards consortia and SDOs and help to decide which would be best suited to a particular task. It should also help to understand their relationship with EU standardisation policies and how they link to SDOs.	https://seeblocks.eu/visualisation-tool/consortia-based-standardisation
18. CEN and CEN-ELEC Workshop Agreements – A rapid way to standardization	This material should provide you with an understanding of the mechanisms and characteristics of CEN and/or CENELEC deliverables, known as CEN and/or CENELEC Workshop Agreements, and their development process.	https://seeblocks.eu/visualisation-tool/cen-andor-cenelec-workshop-agreements-rapid-way-standardization

Name	Description	Link
19. CEN-CENELEC GUIDE 39. The role of standards in support of Technology Transfer. Edition 1, March 2022	The main target audience of this Guide are the researchers and providers of new technologies who want to see their research outcome taken up by the market as well as innovators and entrepreneurs who want their innovation to enter the market and are interested to know whether and how standardization can help them to meet their objective. The use of standardization in support of the uptake of an innovation by the market consists of: a) the application of existing standards on which the innovative product/service relies; and b) contributions to and participation in the standardization process, to ensure the standards accommodate the innovative product/service. In addition to addressing these topics, the Guide contains information on how researchers and innovators can make initial contacts with the standardization community, as well as information on the ways that CEN and CENELEC can offer them to take advantage of standardization.	https://seeblocks.eu/visualisation-tool/role-standards-support-technology-transfer
20. Understanding ICT Standardisation. 2nd ed.	Key topics of this handbook include: 1. Introduction to standards, 2. The standards ecosystem, 3. The production of standards, 4. Standardization and innovation, 5. A strategic perspective on standardization, 6. IPR and standardization and 7. Standardization and public procurement	https://www.etsi.org/images/files/Education/Textbook_Understanding_ICT_Standardization.pdf

Source: own selection from Seeblocks.eu's Standards Visualisation Tool and EDU4Standards.eu repository

This material collection is also integrated in Stan4SWAP's Handbook on standardisation and standards for mobility and transport in the ecosystem of swappable batteries.