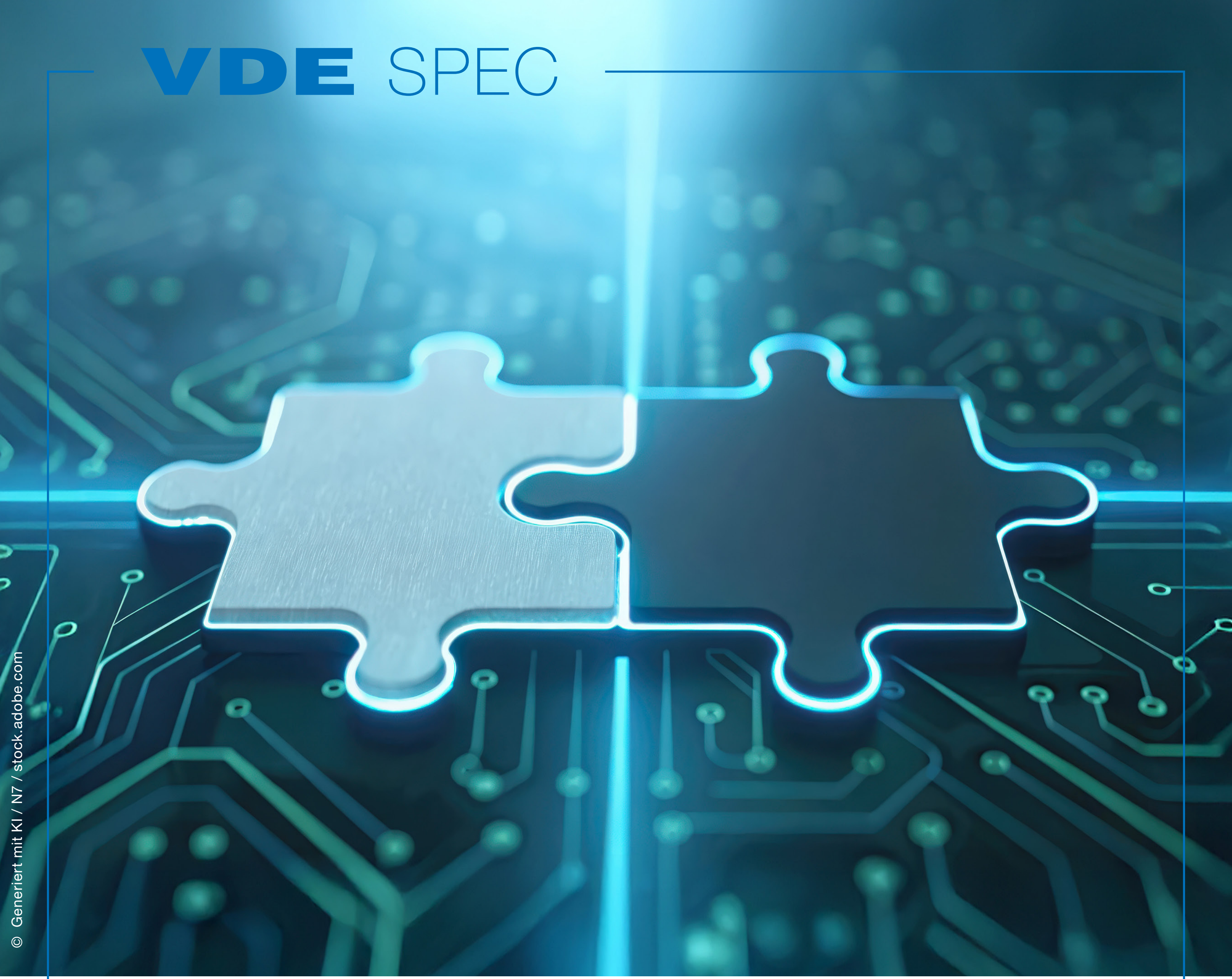
VDE SPEC



int:net Interoperability Maturity Model ‘EMINENT’

VDE SPEC 90020 V1.0 (en)

VDE

Foreword

Publication date of this VDE SPEC: 22.05.2026

No draft has been published for the present VDE SPEC.

This VDE SPEC is a result of the "int:net" project which has received funding from the European Union’s Horizon Europe research and innovation programme under grant agreement no. 101070086.

This document has been developed and adopted by the initiators and authors named below:

- García Montero, Carmen, ENTSO-E
- Guitart, Laia, E.DSO
- Hurley, Jemima, EPRI
- Kosslers, Sebastian, VDE DKE
- Kuchenbuch, René, OFFIS (initiator)
- Lipari, Gianluca, EPRI
- McGranaghan, Mark, EPRI
- Schmitt, Beate, VDE DKE
- Schütz, Johann, OFFIS
- Uslar, Mathias, OFFIS
- van Genuchten, Joep, EPRI Contractor (initiator)

Despite every effort to ensure the correctness, reliability, and precision of technical and non-technical descriptions, the VDE SPEC project group cannot provide any explicit or implicit guarantee for the correctness of this document. The use of this document is made with the understanding that the VDE SPEC project group cannot be held liable for damages or losses of any kind. The use of the present VDE SPEC does not release the user from responsibility for their own actions and is therefore at their own risk.

When manufacturing and/or introducing products into the European single market, the manufacturer must carry out a risk analysis to first determine what risks the product may entail. After conducting the risk analysis, the manufacturer evaluates these risks and takes appropriate measures to effectively eliminate or minimize the risks (risk assessment). This VDE SPEC does not release the user from this responsibility.

Attention is drawn to the possibility that some elements of this document may involve patent rights. VDE is not responsible for identifying any or all of the patent rights related to this.

Executive Summary

This document, which was created as part of the EU-funded project int:net, presents a comprehensive maturity model designed to assess and enhance interoperability efforts in the energy sector. Interoperability is crucial for integrating heterogeneous systems within the energy domain seamlessly and efficiently. Our maturity model provides a structured framework for evaluating the maturity level of interoperability communities in terms of their interoperability capabilities. It encompasses various dimensions and capabilities, addressing interoperability challenges such as layers, testing, and security. By assessing their maturity level across these dimensions, interoperability communities can identify areas for improvement, establish priorities, and align their interoperability strategies accordingly. The model is designed to be user-friendly and practical, enabling its application in different contexts. By using this maturity model, interoperability communities can strengthen their interoperability capabilities, foster collaboration, and drive innovation in the energy sector.

Following extensive literature research, the int:net Interoperability Maturity Model "EMINENT" was developed in several steps. It provides a structured framework for evaluating the maturity level of interoperability communities in terms of their interoperability capabilities. It was then tested in three interoperabiltiy communities and finally analysed.

The document primarily focuses on utilizing the EMINENT questionnaire as a tool for conducting such interoperability maturity assessments. The EMINENT questionnaire can be administered in two different ways: researchers can directly utilise the existing infrastructure through the int:net community or set up a separate instance of the survey. Each option has its advantages and considerations regarding data management and confidentiality.

Apart from the researchers, who define the maturity assessment process and facilitate its execution, the other key actors involved are the interviewees, representing organizations members of a specific interoperability community undergoing assessment; the interoperability community itself, which comprises professionals and experts from different organizations.

The maturity assessment process involves several stages: The selection process, the interview process, data management, reporting the results and the maturity tracking assessment.

The EMINENT tool aims to foster interoperable solutions and encourage communities to share responses for mutual learning and growth. After testing and validating the model with three different interoperability communities, the main takeaways from the research work are summarized below:

- The relevant object of study for an interoperability maturity assessment has proven to be the interoperability community, understood as a community of individuals and organizations that collaborate for the purpose of developing and implementing an interoperable solution.
- Creating a maturity assessment by combining a capability model with a maturity model has proven to be a successful methodology that can be implemented within and beyond the energy domain.
- The maturity assessment methodology has been implemented as a questionnaire and a public database where interoperable communities can share their results.
- Doing a maturity assessment on a group setting where participants can discuss their observations with a facilitator is the most effective method for executing the maturity assessment.
- The communities that have performed a maturity assessment have indicated that they recognize the results and find the insights that the tool provides valuable specifically for setting a roadmap for the further development of the interoperability community.

Contents

List of figures

List of tables

Introduction

The int:net project (Interoperability Network for the Energy Transition) [1] aims to enhance interoperability in the energy domain across Europe and establish an interdisciplinary network of stakeholders. This network will facilitate continuous knowledge exchange on interoperability throughout the project and beyond.

Project partners are Fraunhofer, AIT, B.A.U.M., E.DSO, ENTSO-E, EPRI, EUI, OFFIS, RWTH Aachen, Tecnalia, Trialog and VDE DKE.

This VDE SPEC focuses on the work of int:net Work Package 2 "Develop Interoperability Maturity Model (IMM) and Reference" and combines the deliverables D2.1 "Interoperability Maturity Model Framework and Background" and D2.2 "IMM Assessment Tool, Users Guide and example applications".

The Interoperability Maturity Model (IMM) and its framework represent the central artifact in this document. The goal of the developed int:net Maturity Model called *Evaluating the Maturity of Interoperability for the Energy Transition (EMINENT)* is to measure interoperability efforts in terms of processes in the electric energy sector. Here, the aim is to establish collaborative community-driven processes (e.g. usage of established standards and documentation) for different challenges that contribute to increase the overall interoperability between heterogeneous, multi-vendor and cross-organizational systems of independent actors of different domains in the energy sector.

Although there are existing interoperability models in the electric energy sector, such as the Smart Grid Maturity Model (SG MM) and the Smart Grid Interoperability Maturity Model (SG IMM), the developed maturity model takes a unique approach by focusing on interoperability efforts for community processes. It goes beyond existing models by identifying and considering additional capabilities and dimensions arising from recent technological innovations and/or regulatory requirements, as (e.g.) dataspaces or GDPR.

1 Scope

This VDE SPEC discusses the development of maturity assessment for interoperability in the energy sector.

It includes the

- research process,
- tool design,
- maturity assessments,
- evaluation of the results.

The presented int:net Interoperability Maturity Model "EMINENT" focuses on interoperability communities. These are defined in chapter 5.10.1 as a group of experts and developers from different industries that come together to promote interoperability within the energy sector. This group can be involved in the development of interoperability solutions or has comprehensive knowledge of interoperability challenges.

2 Normative references

The following documents are referred to in the text in such a way that some or all of their content constitutes requirements of this document. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments) applies.

IEC 62559 (all parts), Use Case Methodology [2]

CEN-CENELEC-ETSI Smart Grid Coordination Group (SG-CG): SGAM User Manual - Applying, testing & refining the Smart Grid Architecture Model (SGAM) [3]

3 Terms and definitions

No terms and definitions are listed in this document.

ISO and IEC maintain terminological databases for use in standardization at the following addresses:

- ISO Online browsing platform: available at https://www.iso.org/obp
- IEC Electropedia: available at https://www.electropedia.org/

DIN and DKE maintain terminology databases for use in standardization at the following addresses:

- DIN-TERMinologieportal: available at https://www.din.de/go/din-term
- DKE-IEV: available at https://www.dke.de/DKE-IEV

4 Abbreviations

API	Application Programming Interface
CEN	Comité Européen de Normalisation (European Committee for Standardization)
CENELEC	Comité Européen de Normalisation Electrotechnique (European Committee for Electrotechnical Standardization)
CGMES	Common Grid Model Exchange Specification
CIM	Common Information Model
CMM	Capability Maturity Model
CMMI	Capability Maturity Model Integration
DER	Distributed Energy Resources
DSO	Distributed System Operator
EMINENT	**E**valuating the **M**aturity of **IN**teroperability for the **EN**ergy **T**ransition
ETSI	European Telecommunications Standards Institute
FAIR	**F**indability, **A**ccessibility, **I**nteroperability, **R**euse (of digital assets)
GDPR	General Data Protection Regulation
Git	Free open-source software for distributed version control of files
GWAC	GridWise Architecture Council
ICSF	Interoperability Context-Setting Framework
ICT	Information and Communications Technologies
IEC	International Electrotechnical Commission
IMM	Interoperability Maturity Model
int:net	Interoperability Network for the Energy Transition
IOP	Interoperability
MM	Maturity Model
MVP	Minimum Viable Product
NB	nota bene (note well)
PII	Personal Identifiable Information
RCC	Regional Coordination Center
RDF	Resource Description Framework
RSC	Regional Security Coordinator

SAREF	Smart Appliances REFerence
SG IMM	Smart Grid Interoperability Maturity Model
SG MM	Smart Grid Maturity Model
SGAM	Smart Grid Architecture Model
SG-CG	Smart Grid Coordination Group
SHACL	Shapes Constraint Language
SIF	Semantic Interoperability Framework
TRL	Technology Readiness Level
TSO	Transmission System Operator
UI	User Interface
W3C	World Wide Web Consortium
WG	Working Group
WP	Work Package

5 int:net Interoperability Maturity Model “EMINENT”

5.1 Overall Methodology

This chapter presents the methodology used to derive the int:net Interoperability Maturity Model. The first section provides the core statements of the relevant literature that have been reviewed in order to gain an understanding of the current state-of-the-art approaches for developing maturity models. In the second part of the chapter, the approach of our maturity model development is presented and explained.

5.2 Background: State-of-the-Art

The development of maturity models is not a recent undertaking. Over the last few decades, considerable research has focused on the creation of processes for developing such models. Furthermore, design principles have been established that can be employed in the development of maturity models. The following section presents an overview of the literature used in this research project, focusing on the key aspects relevant to the development of the maturity model.

5.3 Procedure model for developing maturity models

The procedure model according to Becker et al. [4] represents a guideline for the creation of maturity models in order to minimize widespread deficiencies in new maturity models as far as possible. Requirements for such a model were worked out, which are reflected in the phases of the process model. From a comparison study of several process model, Becker et. al. [4] derived the following requirements (R) for being integrated in the procedure models:

- R1: Comparison with existing maturity models
- R2: Iterative Procedure
- R3: Evaluation
- R4: Multimethodological Procedure
- R5: Identification of Problem Relevance
- R6: Problem Definition
- R7: Targeted publication of result
- R8: Scientific Documentation

The maturity development was divided into eight phases, which provide iterative working. The relationships between the phases, the associated documents and requirements are visualized in Figure 1.

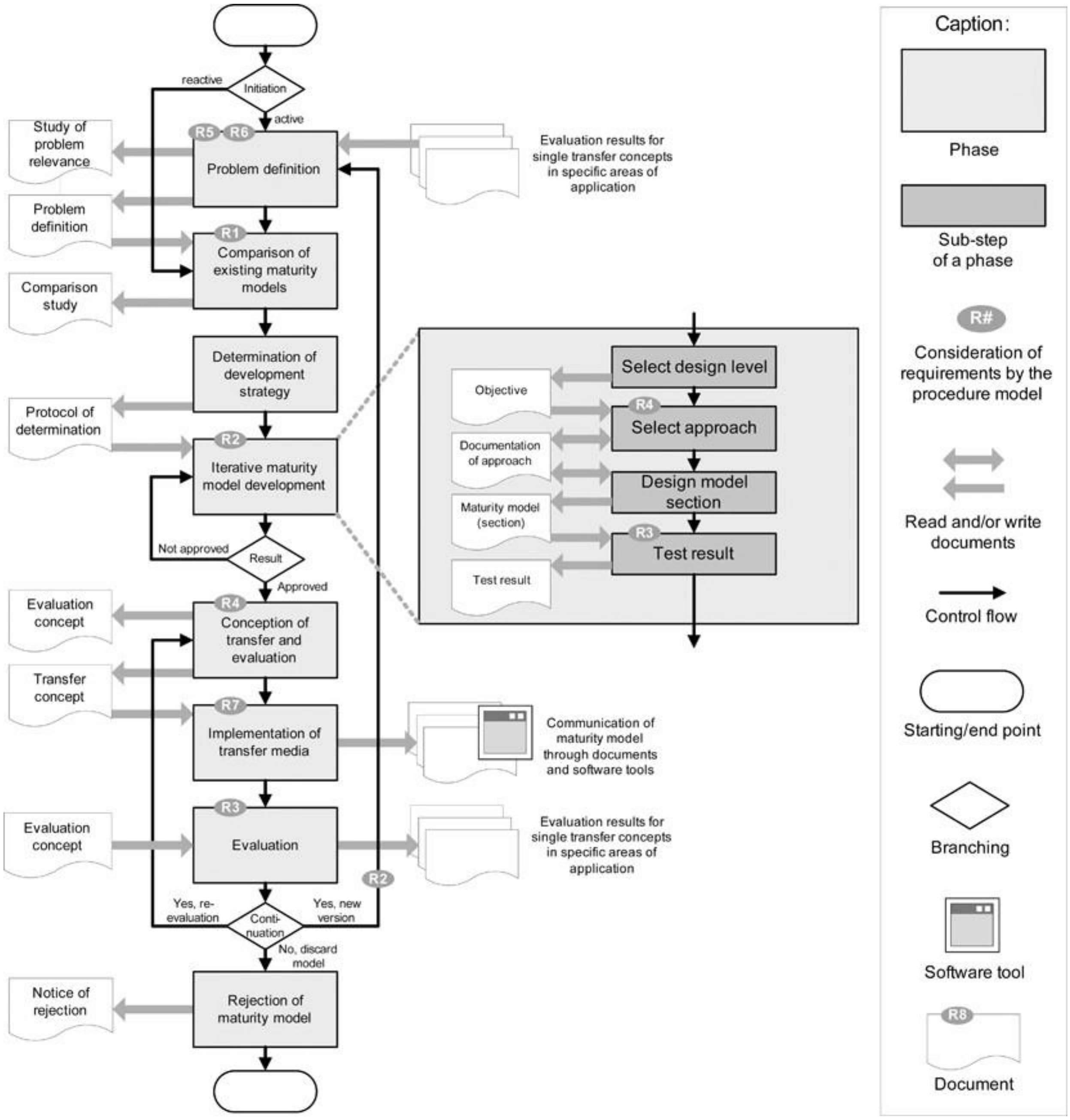


Figure 1 – Procedure Model for developing maturity models [4]

- **Problem definition:** The problem definition envisions which problem the maturity model shall observe. In regard to requirement *R5*, the relevance of the maturity model needs to be shown either by practice or in research. The requirement *R6* demands the maturity model to be placed in an area of application and the knowledge about the determined conditions of its applications.
- **Comparison of existing maturity models:** A comparison of existing maturity models shows the shortcoming or the lack of transferability of existing maturity models that operates as motivation for the development of a new maturity model. The justified need for the development for a new maturity model by a comparison of existing maturity models represent requirement *R1*.
- **Determination of development strategy:** The determination of a development strategy can be handled if a comparison of maturity has been executed beforehand. The focus of the development strategy is mainly in the (scientific) documentation, which represent requirement *R8*. From previous maturity models, the following basic strategies could be sought:

– Completely new design

- Enhancement of an existing model design
- The combination of several models into a new model
- Transferring structures as well as content from several models into a new model

- **Iterative maturity model development:** The iterative maturity model development represents the main point of the procedure model. It consists of four sub phases, which requires being iterative according to the requirement *R2*. The first sub phase is the selection of the design level, which represents the highest-level of abstraction fundamental structure of the maturity model. The second sub phase is bound to requirement *R4* (multi-methodological procedure) and select the methods for concerned design level. The third sub phase concerns with the designing of the maturity model. The fourth and last sub phase is the testing phase of the maturity model. The testing phase requires in according with requirement *R3* a fully-fledged evaluation.
- **Conception of transfer and evaluation:** The transfer and the evaluation for the usage of the developed Maturity Model has to be designed in the scope of the academic- and practical user bases. Therefore, document-based checklists, manuals, software-tool supported accessibility of maturity models and literature in general are proved practices. The resulting phase artefact in form of an evaluation concept must be implemented using multi-methodological procedure, which corresponds requirement *R4*.
- **Implementation of transfer media:** The accessibility of the phase for all the target users via target point corresponds the intention of the phase. At this stage, the maturity models considered in the definition of the process model often used reports and/or self-assessment questionnaires. Requirements *R7* envisions a targeted publication of the results.
- **Evaluation:** The fulfillment of the purpose to solve the defined problem has to be determined critically in the evaluation phase. This was realized in the analyzed maturity models via scientific methods (e.g. via case studies, expert groups). A public, free deployment can also be enlisted to reach a quantitative larger number of users. Furthermore, this can be linked via web-based self-assessment questionnaires to generate a high amount of data. The evaluation is accompanied by requirement *R3* having the same name. Based on the result of the evaluation, a rework is necessary, which allows jumping into phase Conception of transfer and evaluation if a revaluation is necessary or in phase Problem definition if a new version of the maturity model is planned. In worst-case, results could be negative which may lead to discarding the model.
- **Rejection of maturity model:** In case the model is being discarded (because of the evaluation phase), the model should be revoked purposefully, explicitly and actively from the market.

The widely used proposed process model has influenced the development of various maturity models. Exemplary maturity models are OSCM4.0 [5], DREAMY [6], M2DDM [7] or ITPM [8]. These either use the process model directly in their methodology or indirectly used it by adapting.

5.3.1 General design principles for maturity models

For the development of maturity models, a framework for the general creation of maturity models was established by Pöppelbuß and Röglinger [9]. These included design principles, which can be used as a guideline for the creation of maturity models. Pöppelbuß and Röglinger [9] contrast three purposes in the application of maturity models:

- **Descriptive:** The maturity model is used to analyze the current state in order to show the object under examination in relation to predefined criteria. The maturity model is used as a diagnostic tool.
- **Prescriptive:** The maturity model provides the user with a guideline for reaching the desired maturity level.
- **Comparative:** The maturity model is used as an internal benchmarking tool to compare based on historical data.

Based on these types of application, Pöppelbuß and Röglinger [9] build design principles that can be divided into three categories. While the basic design principles are independent for maturity models, on one hand design principles for descriptive purposes of use refer to the basic design principles, on the other hand design principles for prescriptive purposes of use refer to those of the descriptive ones.

Basic design principles

The basic design principles address the categories "Basic Information", "Definition of Key Constructs Related to Maturity", "Definition of Key Constructs Related to Scope" and "Target Group-Oriented Documentation":

- *Basic Information* envisions a sound definition of the domain, prerequisites for the application, the purpose of use, the target audience and the entities to concern, the distinction to similar maturity models and the concrete design process for the empirical validation.
- *Definition of central constructs related to maturity and maturation* envisions the definition of maturity and its dimensions, the maturity levels and the maturation paths, available levels of granularity of maturation and an underpinning theoretical framework with respect to evolution and change.
- Definition of central constructs related to the application domain foresees the use of terms in the given domain
- *Target Group-Oriented Documentation* foresees transparent documentation to the target group-oriented manner.

Design principles for descriptive purposes of use

The design principles for descriptive purposes of use build on the basic design principles and additionally address the categories "Intersubjectively verifiable criteria for each maturity level and level of granularity" and "Target group-oriented assessment methodology".

- *Intersubjectively verifiable criteria for each maturity level and level of granularity* envisions proposing assessment criteria for every maturity level and available granularity level.
- *Target group-oriented assessment methodology* looks for intersubjective verifiable assessment methodology. Explanation to the maturity level assessment to the user needs to be done in a transparent, precise and repeatable manner.

Design principles for prescriptive purposes of use

The design principles for prescriptive purposes of use builds on descriptive design principles and additionally address the categories "Improvement measures for each maturity level and level of granularity", “Decision calculus for selecting improvement measures” and "Target group-oriented decision methodology".

- *Improvement measures for each maturity level and level of granularity* ensures that the maturity model informs the user for opportunities how to improve maturity.
- *Decision calculus for selecting improvement measures* ensures the usage of decision calculus for evaluating different alternatives and to identify which option satisfies the objectives as best as possible. Second aspect is the usage of a decision calculus for identifying which factors have an (high/low) influence. The third aspect related to the principle is that the maturity model perspective must distinguish between external reporting and internal improvement.

5.3.2 Activities and phases embedded in the context of int:net

Based on the scientific practice of maturity model development and the derived requirements, the section derives the maturity model procedure. Based on the procedure model of Becker et al. [4] visualized in Figure 1, the procedure model of our work is determined.

First, the essential phases from the reference procedure model have to be selected. This deliverable is part of int:net Task 2.1, which in turn is part of Work Package 2. Based on the descriptions of the tasks from the int:net project proposition and the phase descriptions, a task/phase mapping can be realized in form of a matrix in Table 1.

int:net task descriptions:

- Task 2.1: Develop categories and characteristics for Interoperability Reference Framework
- Task 2.2: Develop Interoperability Maturity Model (IMM) Assessment tool
- Task 2.3: Database and user interface for tracking interoperability maturity
- Task 2.4: Workshop to promote application of the IMM

Table 1 – Mapping of the int:net Work Package 2 tasks to the phases acc. Becker et al. [4]

	Task 2.1	Task 2.2	Task 2.3	Task 2.4
Problem definition	R5, R6			
Comparison of existing maturity models	R1			
Determination of development strategy	R8			
Iterative maturity model development	R2, R3, R4			
Conception of transfer and evaluation		R4		
Implementation of transfer media		R7		
Evaluation				R3

Consequently, from the mapping, the phases and requirements necessary for int:net Task 2.1 can be extracted and derived. Based on these phases, a concrete procedure model for deriving EMINENT (**E**valuating the **M**aturity of **IN**teroperability for the **EN**ergy **T**ransition) can be identified for the specific int:net context visualized in Figure 2.

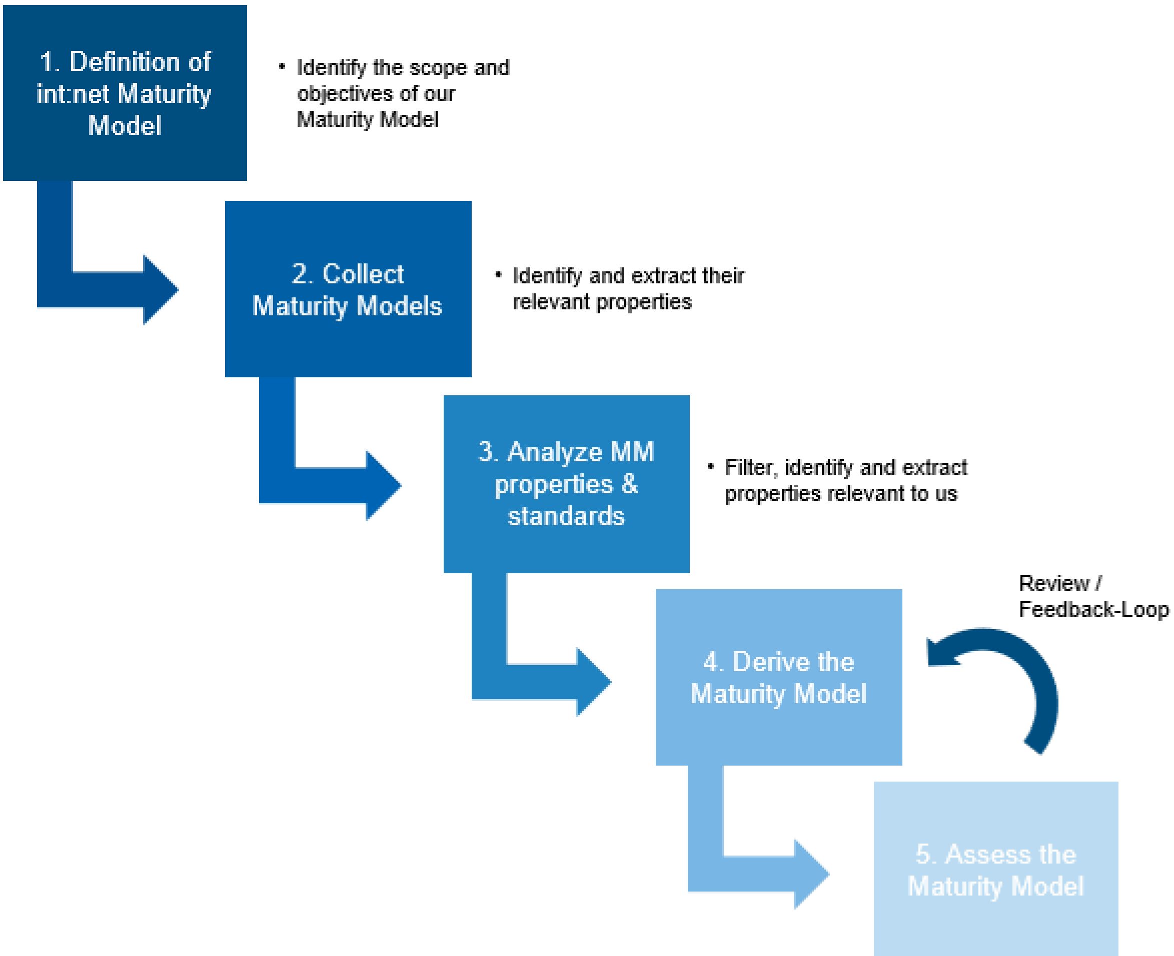


Figure 2 – Procedure model for the development of EMINENT

The procedure model consists of five phases, whereby phase 4 and 5 can be run through multiple times due to the iterative structure. The requirements defined by Becker et al. [4] (see section 5.3) are assigned to our phases. The phases are defined as follows:

1. **Definition of the Maturity Model:** The scope, objectives and requirements for EMINENT are to be defined and specified. In particular, the basic design principles, especially "Basic Information" from [9] are considered in the implementation of the phase. This phase is linked to requirements R5 and R6 of the Becker procedure model.

2. **Collect Maturity Models:** Collecting maturity models represents the preliminary step for analyzing them. First, related maturity models and frameworks need to get identified and collected. This step represents preliminary work for the R1 requirement.
3. **Analyze Maturity Model properties and standards:** To derive EMINENT, it is important to analyze the models and frameworks identified from the previous step to identify the relevant properties for our own maturity model. In addition, the phase serves as a differentiation to other maturity models via the creation of a Comparison Study. In the phase the requirement R1 is assigned.
4. **Derive the Maturity Model:** The maturity model needs to be derived in this phase. Through previous results applies and the feedback from the evaluation of the model is to derive the maturity model. In this phase, categories, dimensions as well as characteristics and their goals are defined, but also a questionnaire, which can be used for the evaluation. The phase is connected by the requirements R2 and R4.
5. **Assess the Maturity Model:** The phase builds on the developed version of the maturity model. Through the int:net consortium and its experts on research and energy-related business associations (such as E.DSO and ENTSO-E), the maturity model is evaluated. This involves running through a feedback loop until a final version of the maturity model is produced. This phase is covered by the R3 requirement.

5.4 Related Research

This chapter provides an overview of the existing research and literature relevant to interoperability and maturity models in the energy sector. It serves as a foundation for understanding the current state of knowledge and the gaps that the proposed maturity model aims to address. The research presented here covers a wide range of topics, including the maturity models in different domains, and specific studies related to interoperability in the energy sector and the choice of categories and dimension. The topic of (interoperability) maturity models do not represent a novelty, also in the energy sector.

One of the widely known maturity models in the smart grid sector is the Smart Grid Maturity Model (SG MM) [10]. This measures essential characteristics that are required for participation in the smart grid. It considers a wide range of topics, such as organization, structure, strategy, management, regulation, network management, society, technologies, etc. The SG MM does not primarily consider interoperability but foresees energy domain-specific categories and issues.

As second reference, the Smart Grid Interoperability Maturity Model (SG IMM) developed by GridWise Architecture Council (GWAC) is a maturity model especially focuses interoperability primary, in the context of the smart grid sector. It builds on the GWAC interoperability categories and is used to improve the interoperability of communities via a self-evaluation questionnaire. The Smart Grid Interoperability Maturity Model can be represented as a 3D cube visualization, with the issues (Configuration and Evaluation, Operation and Performance, and Security and Protection), categories (Organizational, Informational, and Technical Interoperability), and the maturity levels (based on those of CMMI) as dimensions.

The maturity model to be developed takes the SG IMM as a baseline model and focuses on wide-ranging categories and interoperability issues across the smart grid domain. In addition, the model focuses more on the processes of interoperability efforts that lead to an increscent of interoperability awareness. The assessment of the existence of such processes is to be evaluated via the maturity model for organizations and provide them with support for the improvement of such processes (e.g. via current examples). In addition, the complexity of the maturity model should be simplified so that the user can understand it more easily.

5.5 Background

The topic of interoperability has become increasingly important in recent years as the adoption of advanced technologies and the integration of different systems and devices have become more widespread. Although a lot of effort within various national as well as international initiatives and projects has already been invested to improve the interoperability within the electric energy system, various challenges remain [11]. This is where maturity models can provide support. Interoperability maturity models provide a framework for assessing the level of interoperability achieved in a given system or network and can help organizations develop interoperable systems. This background chapter provides an overview of the most important concepts and approaches to interoperability, (interoperability) maturity models and their background, and the topic of (energy) data spaces, which is also becoming increasingly important.

5.5.1 Interoperability

Interoperability is a key issue for smart grids. Smart grids are complex socio-technical systems-of-systems consisting of a variety of technologies, devices and infrastructures. For these systems to function effectively and efficiently, it is essential that they can communicate and cooperate with each other seamlessly. Interoperability refers to the ability of different components of the smart grid to communicate and work together. This means that systems and devices of different vendors must be able to exchange data (technical interoperability), interpret the data in the right way (semantical interoperability) and embed it within the business processes in a meaningful way (pragmatical interoperability), regardless of the specific characteristics and functionalities of the individual systems. [12]

To ensure interoperability in the smart grid, standards and specifications are essential. These standards define common protocols and interfaces that facilitate the exchange of data and information. For example, there are standards for communication between smart meters and the network, interoperability between different electricity suppliers, and the integration of renewable energy and electric vehicles into the smart grid. [12]

Ensuring interoperability is also important to encourage smart grid innovation and investment. An open and interoperable smart grid system enables companies and vendors to develop and offer new products and services that can be seamlessly integrated into the overall system [12]. To provide an easy-to-understand indicator for non-technical stakeholders, the GridWise Architecture Council describes the so-called “distance to integrate” (visualized in Figure 3), whereby the costs for an integration increases with the size of the gap of standardization between systems. The concept delivers a first (and simplified) assessment for the maturity of interoperability between two parties and consists of four levels that represent progress toward full interoperability in the energy grid. The higher the level, the smaller is the gap between the parties and consequently less effort is required for integration. [13]

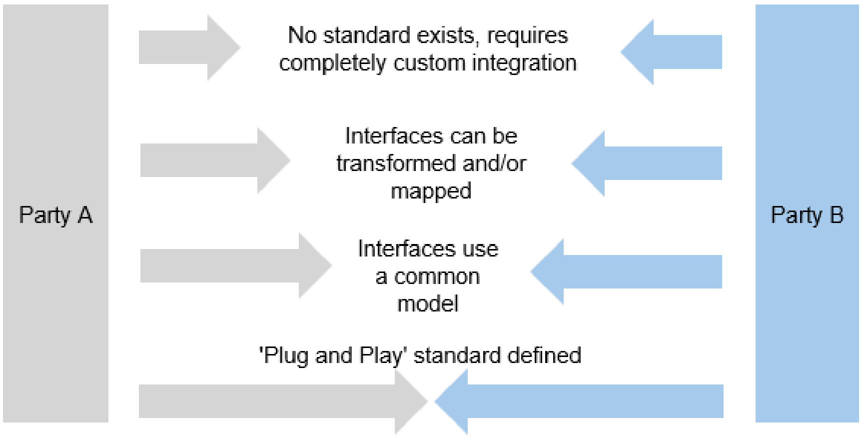


Figure 3 – Distance to Integrate from GWAC ICSF [13]

For the integration of different parties, the following stages are defined as follows:

- **No standards:** There are no standards for the interfaces between the various components of the smart grid. This makes the integration of systems and technologies difficult and time-consuming.
- **Mapping of interfaces:** Interfaces are defined and documented to improve interoperability between systems. However, no common semantics are used for the interfaces, which can still lead to integration challenges.
- **Use of common models through interfaces:** Common models are used for the interfaces that provide common semantics for the data and processes within the smart grid. This makes the integration of systems and technologies easier and more efficient.
- **Plug-and-play:** The interfaces are highly standardized so that they are plug-and-play capable. This means that systems and technologies can be integrated easily and automatically without the need for manual configuration. Plug-and-play significantly improves interoperability in the smart grid.

Interoperability is an essential aspect of integrating systems and components to enable smooth communication and data exchange. Different types of interoperability can be identified which are also accepted in other sectors e.g., healthcare (see Figure 4). The three primary categories of interoperability represent the following:

- **Organizational Interoperability (Pragmatics)**: Ability of organizations to work together in a coordinated manner to achieve their common goals. It involves establishing common policies, procedures, and business rules that enable effective communication, decision-making, and coordination between organizations.
- **Informational Interoperability (Semantics)**: Ability of different systems to understand and interpret data and information exchanged between them. It involves establishing common data models, ontologies, and taxonomies that enable meaningful communication and interpretation of data and information.
- **Technical Interoperability (Syntax)**: Ability of different systems to exchange data and information in a technically correct manner. It involves establishing common communication protocols, message formats, and data exchange standards that enable seamless data exchange between systems.

The GridWise Interoperability Context-Setting Framework is an essential tool that aims to ensure the effective implementation of interoperability in the smart grid. It defines a total of eight interoperability categories and ten cross-cutting issues for the smart grid based in which interoperability must be ensured on the three primary categories of interoperability. Figure 5 shows a visualization of the GWAC interoperability categories including the relations to the three primary categories, which also shows the cross-cutting issues in the smart grid.

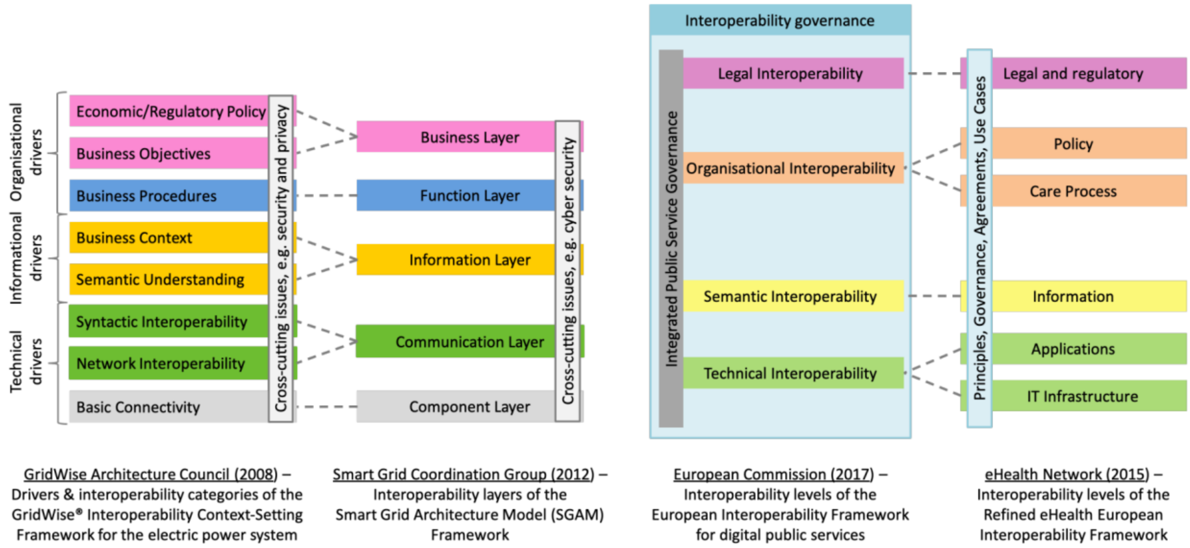


Figure 4 – Interoperability frameworks access sectors [14]

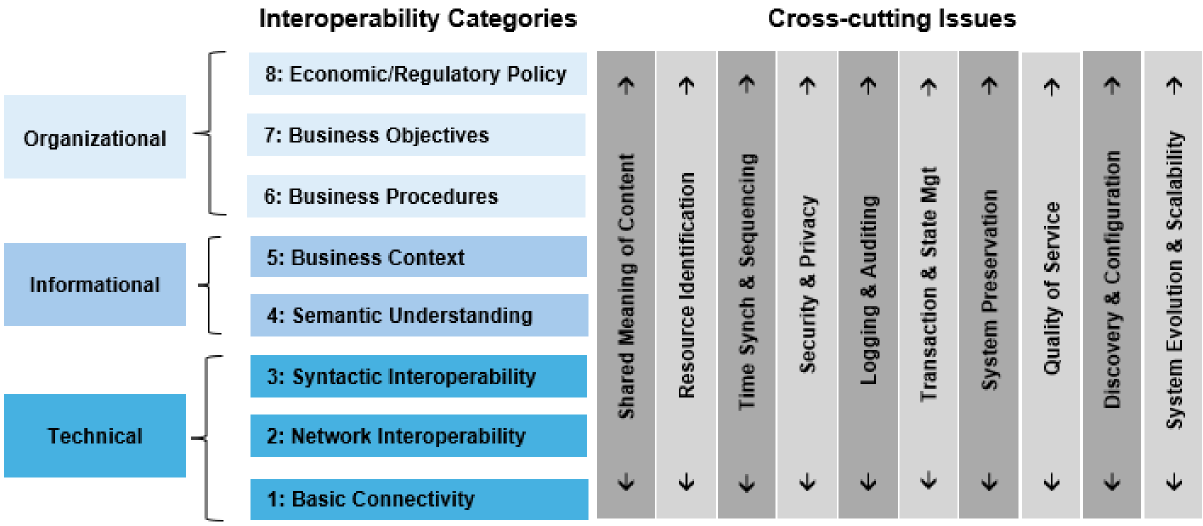


Figure 5 – GWAC Interoperability Context-Setting Framework Diagram [13]

The following subsections give an overview of the key methodologies and elements in the smart grid interoperability context. Among these is the IEC 62559 Use Case Methodology, which as an essential standard for the creation of standardized use cases according to the IEC 62559-2 Use Case Template. The SGAM Framework is a well-accepted framework firstly for identifying standardization gaps and lately for the documenting a System-of-Interest inside the System-of-Systems. The interoperability layers provided in the SGAM are derived from the GWAC stack.

5.5.1.1 IEC 62559 Use Case Methodology

With the increasing complexity of smart grids compared to conventional energy networks, adequate documentation of the participation of participants and stakeholders is essential. A commonly used methodology in energy projects to describe energy systems is the standardized use case methodology according to IEC 62559. This methodology describes the properties and functionalities of a system of interest both statically (as a description of the actors) and dynamically (relationships between actors and the system of interest). Through standardized documentation, stakeholder requirements and goals in the system of interest can be described, and interactions between actors in scenarios can be specified. Additionally, use cases serve as a basis for a common understanding for discussions, conception, and implementation. [15]

IEC 62559-2 specifies the standardized use case template [16], which consists of the following entries:

1. **Description of the use case:** Meta information and textual description of the use case
2. **Diagrams of the use case:** Illustrative diagrams that visualize the interactions of the provided actors
3. **Technical details:** Actors and references of the use case are listed and described
4. **Step-by-step analysis of the use case:** The interactions of the actors are described in detail via scenarios and individual substeps in the part of the template
5. **Information exchanged:** The information that is exchanged between the actors in the use case.
6. **Requirements (optional):** Any requirements that must be met to implement the use case.
7. **Common terms and definitions:** Common terms and definitions used in the use case.
8. **Custom information (optional):** Any additional custom information that may be relevant to the use case.

The use case methodology and template provide a standardized approach to documenting and communicating the interactions and requirements between stakeholders in energy systems, helping to ensure a common understanding of the system of interest [12].

5.5.1.2 Smart Grid Architecture Model (SGAM)

The Smart Grid Architecture Model (SGAM) is a framework developed by the Smart Grid Coordination/Reference Architecture Working Group (SG-CG/RA) via the EU Commission

Standardization Mandate M/490 and serves as a holistic overview in the context of an architecture within the energy domain [15]. The official SGAM User Manual by CEN-CENELEC-ETSI [3] is defining the SGAM framework as following:

> *"The Smart Grid Architecture Model (SGAM) [SG-CG/C] is a reference model to analyse and visualise smart grid use cases in a technology-neutral manner. Furthermore, it supports comparison of different approaches to Smart Grid solutions so that differences and commonalities between various paradigms, roadmaps, and viewpoints can be identified. By supporting the principles of universality, localization, consistency, flexibility and interoperability, it also provides a systematic approach to cope with the complexity of smart grids, allowing a representation of the current state of implementations in the electrical grid as well as the evolution to future smart grid scenarios."* ***– SGAM User Manual by CEN-CENELEC-ETSI*** [15]

The components or systems (depending on the granularity required in the use case by the degree of abstraction) of smart grid solutions are represented in SGAM models in the shape of the-dimensional cuboids. The three SGAM dimensions are the following according to [3]:

- **Domains:** The SGAM domains are based on the energy-electrical energy conversion chain. These are: (Bulk) Generation, Transmission, Distribution, Distributed electrical resources (DER) and Customer Premises
- **Zones:** The SGAM zones represent the hierarchical levels of power system management. These are: Process, Field, Station, Operation, Enterprise, Market
- **Interoperability Layers:** Interoperability Layers provide a framework for ensuring seamless communication and interaction between the various components and systems of the smart grid. These will be illuminated in more detail in this section.

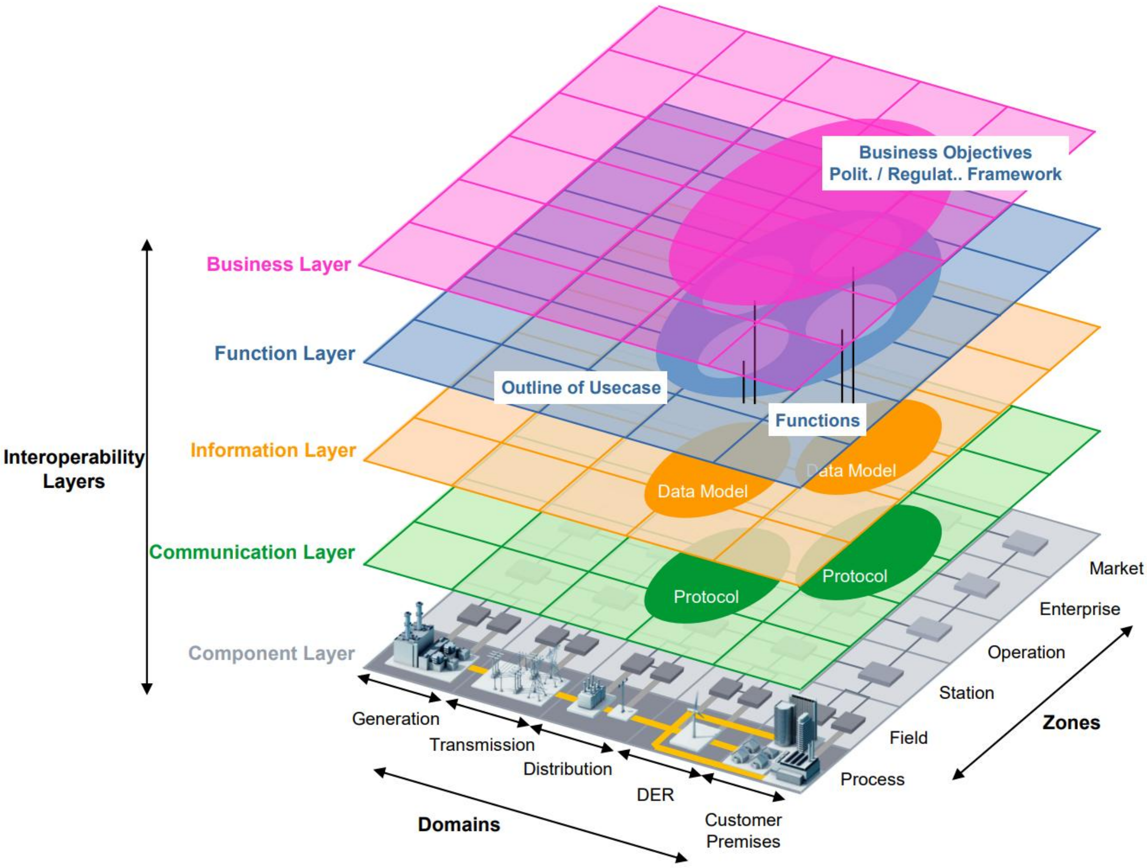


Figure 6 – SGAM Framework [17]

Each interoperability layer represents a plane of domains and zones containing components, protocols, information exchanges, functions, etc. for the corresponding interoperability category. Figure 6 shows the visualization of the SGAM framework. The five SGAM interoperability layers are based on the GWAC interoperability categories and represent a simplification of these. These are mapped to each other in Figure 4. The five provided interoperability layers represent the following [3]:

- **Component Layer:** Representation in form of components, systems, etc. participating in the smart grid
- **Communication Layer:** Description of the interoperable communication way e.g. via protocols, mechanisms
- **Information Layer:** Description of the interoperable information that is used e.g. canonical data model, information objects
- **Function Layer:** Description of the system use cases, functions and relations from the architecture viewpoint
- **Business Layer:** Representation of the business view for mapping regulatory and economic market structures, business models, etc.

In practice, the creation of an SGAM model is based on the use of use cases, in the best case via the use cases according to the IEC 62559-2 Use Case-Template. A standard compliant use case allows a partially direct assignment of the interoperability levels in the SGAM. The SGAM framework as well as the IEC 62559 Use Case Methodology show mutual dependencies in their current reference documents and represent essential techniques in the smart grid area, especially in the requirement engineering area for improving interoperability.

5.5.2 Maturity Models

Maturity models are widely used in a variety of industries and disciplines to assess the current state of an organization's practices and processes, and to guide the development of a roadmap for improvement. In essence, a maturity model provides a structured framework for organizations to identify their strengths and weaknesses as well as to develop a plan to improve their processes and capabilities in a specific domain. [4]

The structure of a maturity model is typically built around a set of dimensions or areas of focus that contribute to overall organizational maturity. Best practices, industry standards, or other relevant frameworks are often part of these dimensions. Within each dimension, the maturity model defines a set of maturity levels that describe how organizations can progress from an initial state to a more mature state over time. Criteria are then established for assessing an organization's current level of maturity within each dimension, typically using a set of standardized assessment questions or a self-assessment tool. Finally, the maturity model provides a roadmap or process for organizations to improve their maturity over time, often through a series of incremental improvements and a continuous cycle of assessment, feedback, and improvement. [4]

The concept of maturity models originated in the field of software engineering in the 1980s, with the Capability Maturity Model (CMM) developed by the Software Engineering Institute (SEI) at Carnegie Mellon University [18]. The CMM was designed to help software organizations improve their software development processes, with five levels of maturity ranging from initial ad-hoc processes to optimized, data-driven processes [18]. In addition to the CMM, the SEI also developed the Capability Maturity Model Integration (CMMI), which includes not only software engineering but also other domains such as systems engineering, hardware, and services [19]. The CMMI provides a framework for organizations to improve their processes across multiple disciplines using the levels from the CMM [19].

5.6 Development of our Maturity Model

In this chapter, the procedure model for the development of the maturity model is derived and shown. In a requirements analysis, requirements are collected for the maturity model and its development. Furthermore, a procedure model for the development of the maturity model is derived based on scientific practice. The procedure model provides the basis for the design chapter of this document.

5.6.1 Preliminary work

The used procedure model as well as the task description of the project envisions the definition of the scope for the maturity model. Preliminary and verification work was necessary to define this scope and the objectives for the EMINENT. From these, requirements were derived, which are collected in 5.6.2. The relevant events and steps that were necessary in the context of the maturity model development are listed below.

5.6.1.1 int:net Internal Interoperability Workshops

Under the broad term interoperability, it is possible to adopt different perspectives. This became particularly apparent at the time of the task beginning, which is why it was necessary to define a project-wide int:net perspective. It was also urgent to how the interoperability perspective affects int:net Task 2.1. These workshops were organized as part of the int:net project and served as a joint brainstorming and platform for goal definition. In addition, the workshops served to provide thinking stimulus for the individual work packages at the project level and thus to identify a consensus in terms of a least common divisor. Participants of the workshop were representatives of the entire int:net consortium. This workshop was divided into two parts: The first part was about collecting the issues raised in the work packages and tasks for creating a common picture. The second part consisted of addressing the collected issues to offer possible solutions within the work packages and steps. In addition to expert presentations and votings, Mural (an online collaborative whiteboard tool) was used as a collaborative workspace for collecting entries and their discussions.

By conducting the workshop, an initial opinion of the project consortium members was able to get raised. This led to the fact that we were able to agree on established frameworks, such as the SGAM framework. Also, the relevance of the topics, such as governance, the consideration of the regulatory level or the enabling of a certain flexibility in the model were aspects that emerged from the workshop. These are reflected in the model requirements from section 5.6.2.

5.6.1.2 Expert group brainstorming

The results of the first part of the int:net internal interoperability workshop was analyzed separately within two expert groups sessions in order to jointly define the scope. For this purpose, relevant aspects of the workshop were transferred to a Conceptboard instance (a similar tool to Mural, which also provides a collaborative workspace) and aspects were put up for discussion. Within the brainstorming, the following topics were considered:

- Collection of topics: Especially the topics from the workshop were collected, discussed and listed in an orderly fashion. In addition, further keywords were collected that the maturity model should consider.
- Definition of the system view: In this area, it was necessary to define the system-of-interest viewpoint in more detail. Here, decisions were made that are in accordance with the project proposal and project call and are adequate according to the problem at hand and the scientific state of the art.
- Definition of the own model: Within the topic, the scopes and objectives of the maturity model were discussed and defined. In addition, focus points were identified in terms of the categories to be covered by the maturity model.

Via the expert brainstorming, the first results of EMINENT have been conducted serving as a guidance for further development. Additional requirements could be specified, which are listed in section 5.6.2.

5.6.1.3 Collection and Analysis of Maturity Models

The collection of maturity models and frameworks and their analysis were part of the procedure model; they served, on the one hand, to refine the scope and goals of the maturity model and, on the other hand, to identify relevant categories and dimensions as well as to differentiate EMINENT from other maturity models and frameworks. For this purpose, the int:net participants contributed to the collection of maturity models and compiled them in an Excel spreadsheet. The relevant entries are included in a profile view in the Annex. The following (meta) information have been collected for every maturity models as well as frameworks:

- Title
- Source (e.g. link or any other kind of reference)
- Considered dimensions and categories
- Measured characteristics
- Domain of application
- References to other maturity models or frameworks
- Focus area
- Perspective

The collected entries were then analyzed within the framework of int:net. In this regard, the following questions were answered for each collected entry:

- Which general aspects can be used in the development of the int:net Interoperability Framework / EMINENT?
- How can the entry affect the development of the int:net Interoperability Framework / EMINENT?
- Which categories are relevant for the int:net Interoperability Framework / EMINENT?
- Which characteristics are relevant for the int:net Interoperability Framework / EMINENT?
- Which relevant goals can be analysed for the int:net Interoperability Framework / EMINENT?
- Which further descriptions in relevance to the analysis (e.g. limitations, relevance, ideas, ...) exist?

5.6.1.4 Review and Feedback

The maturity model development is iterative in accordance with the procedure model. For this purpose, regular internal expert rounds have been introduced in order to integrate adjustments and designate feedback. The expert panels consist of the int:net project partners AIT, E.DSO, ENTSO-E, EPRI, Fraunhofer, OFFIS, TECNALIA and TRIALOG, who contribute feedback and expertise from their main areas of research and practice. The iterations (in the sense of versions) are detailed in section 5.7.

A milestone for establishing the third version was the organization of an int:net Maturity Model Workshop. Purpose of the workshop was to finalize the third draft of the maturity model by presenting it; aligning the categories, dimensions and the questionnaire; getting the feedback for adjustments and further work and for finding a proper name of the developed maturity model. For this purpose, the tool Conceptboard has been used, which was also part of the expert brainstorming (see section 5.6.1.2).

5.6.2 Requirements analysis

Requirements are collected both for the development of our maturity model and for the procedure. These serve to a) determine the development of the maturity model in a targeted manner b) establish a clear expectation towards the maturity model and c) analyze the practical conditions. The requirements are classified and divided into the following three categories:

Requirements based on the objectives

Requirements can be identified from the objectives in regard of int:net. These come from the project proposal, from the project call and from the two parts of the internal int:net interoperability workshop. The requirements are captured in the following table:

Table 2 – Requirements based on the objectives

ID	Requirement	Description
RQ_OBJ_1	The maturity model must be applicable for enterprises	*Based on the project proposal:* A key objective of the maturity model is to measure maturity among companies. The maturity model is intended to support companies in identifying their maturity in terms of interoperability.
RQ_OBJ_2a	The maturity model must assess interoperability maturity and its readiness to be integrated seamlessly	*Based on the project call and proposal:* The maturity model is intended to measure the maturity or readiness of interoperability in the energy sector
RQ_OBJ_2b	The maturity model must provide guidance for reaching higher maturity levels	*Based on the project call:* In addition to highlighting the maturity level, the use of the maturity model should also provide information on how to reach higher maturity levels.
RQ_OBJ_3	The maturity model must be generically applicable to all zones of the automation chain	*Based on the internal int:net IOP workshop*: The maturity model should not limit the zones e.g., to TSO or DSO.
RQ_OBJ_4	The maturity model must consider the systems-of-systems perspective	*Based on the internal int:net IOP workshop:* The goal is for the enterprise to be

		interoperable within the smart grid because it is a system-of-systems.

Requirements based on the energy-related context

In addition to considering the objectives, the energy domain presents challenges that must be considered in the development of the maturity model. The following requirements are listed, which result from the objectives and represent special requirements in the context of the domain:

Table 3 – Requirements based on the domain

ID	Requirement	Description
RQ_DOM_1a	The maturity model must address the SGAM-related interoperability layers	*Based on the project proposal and internal IOP workshop:* The types of interoperability relevant in the domain are defined in the widely recognized Smart Grid Architecture Model (SGAM) framework. These must be covered in the maturity model.
RQ_DOM_1b	The maturity model must also address the regulation layer	*Based on the project call and internal IOP workshop:* In addition, interoperability on the regulatory level through different laws is another essential role.

Requirements for the maturity model

In addition to the objectives and domains, there are also general requirements for the maturity model itself that are necessary. In particular, technical requirements are essential in the development of the maturity model.

Table 4 – Requirements for the maturity model

ID	Requirement	Description
RQ_MM_1	The maturity model must be hybrid maturity model in terms of progression and capability.	*Based on an internal WP2 decision:* While looking at maturity in terms of progression reveals a scaling of a characteristic, Capability deals with looking at a broader maturity to complete a simple or more complex task within an organization [20]. Both aspects should be reflected as within the model.
RQ_MM_2	The categories and dimensions of maturity model must address problem definitions technology neutral	*Based on the internal int:net IOP workshop:* The maturity model should be technology- and solution-neutral within the framework of the categories and dimensions.

5.7 Deriving the Maturity Model

The procedure model for the development of the maturity model presented in section 5.3.2 defines the phases to be run through. This section is based on these defined phases and justifies decisions made in deriving the model. Here, phase 4 "Derive the Maturity Model" provides an iterative approach via phase 5 "Assess the Maturity Model". This means, according to the feedback, several iterations may be necessary to establish the maturity model. In the further course, the development and decisions of the maturity model development are shown based on the iterations.

For the derivation of the maturity model and its procedure model, events and preliminary work, for example the int:net internal interoperability workshops, the asynchronous collection of maturity models or the use of Conceptboards as a common basis for discussion, were used to collect data and information in the context of our approach. These have already been highlighted in section 5.6.1.

The following subsections describe the derivation of the maturity model in the previous stages. In this regard, the major design decisions are pointed out, justified and the challenges presented. The (minimal) versions of the maturity models created in the individual iterations are not described in detail.

5.7.1 First Iteration

In the first iteration, the phases 1 "Definition of the Maturity Model", 2 "Collection of Maturity Models" and 3 "Analysis of Maturity Models and their properties", which have a non-iterative characteristic, were first run through. In addition, Phase 4 “Derive the Maturity Model” and 5 “Assess the Maturity Model” were run in the first iteration which have the “iterative” characteristic. In the following, processes and decisions of the respective phases are described:

In **phase 1 "Definition of the Maturity Model"** necessary decisions about the procedure model, but also about the context and goals within int:net was made especially in the working group of int:net Task 2.1. The deriving of the procedure model was done in this phase and has already been described in section 5.3.2. For the procedure model, established literature in science and practice was used as base. It was necessary to define the context of interoperability in int:net. The definition of interoperability is essential for the development of the maturity model to ensure the demand of what needs to be covered. This was not yet defined at the beginning of the work step, which is why two internal interoperability workshops were necessary to narrow down the scope. The relevance and the execution of the workshops has already been highlighted in section 5.6.1.1. It emerged from these workshops that int:net aims to cover all dimensions of interoperability as possible. In addition, relevant properties were identified that the maturity model needs to integrate. These in turn resulted from the expert rounds based on the project call and the project proposal in the workshops. Based on these rounds of experts, the following requirements could be defined and reinforced: *RQ_OBJ_1*, RQ_OBJ_4, *RQ_DOM_1a, RQ_DOM_1b and RQ_MM_2*.

Building on the first internal IOP workshop, a brainstorming session was also held in the int:net Task 2.1 internal expert group, manifesting the results. Decisions were made about how to use the maturity model, but also about regarding the definition of the scope of the maturity model. Based on the brainstorming sessions, the requirements were derived or reinforced: *RQ_OBJ_2a, RQ_OBJ_2b, RQ_OBJ_3, RQ_OBJ_4, RQ_MM_1 and RQ_MM_2*.

In **phase 2 "Collection of Maturity Models"** existing related maturity models and frameworks relevant for our scope were identified and collected. This step is relevant to have the existing frameworks and maturity models available for further analysis. In addition, it is necessary to develop a maturity model based on the current state of research and to clarify a differentiation to existing ones. Within an Excel spreadsheet the partners of the int:net consortium could collect maturity models, KPIs as well as architecture frameworks related to the maturity model. The Annex corresponds to the compilation of the Excel spreadsheet containing the profiles of the relevant maturity models and frameworks.

Phase 3 "Analysis of Maturity Models and their properties" deals with the analysis of the maturity models and frameworks collected from the second phase and deals with their classification within the int:net context. The scope of the existing maturity models and frameworks had to be critically examined in comparison with the scope defined in the first phase. The aim of the phase was to identify which characteristics, but also categories and dimensions are relevant for own maturity model development. In addition, it was necessary to determine how EMINENT has to be placed in relation to the existing ones.

The Smart Grid Maturity Model (SGMM) [10] and Smart Grid Interoperability Maturity Model (SG IMM) [21] represented the two most relevant maturity models of the energy sector in relevance of the defined scope. The SGMM is concerned with general maturity of energy systems at the ICT level, while the SG IMM measures maturity in terms of interoperability. Both define relevant categories or dimensions and are based on common frameworks. In particular, the SG IMM is based on the GWAC interoperability stack which has been mentioned in section 5.5.1. EMINENT is intended to appeal to a broad acceptance of energy companies, which is the reason for selecting categories that represent common challenges for the broad base. Both models provide categories and dimensions for this purpose, but also further aspects. The SG IMM represents a hybrid model (in the sense of the terminology of progression and capability) and refers in parts to the Capability Maturity Model Integration (CMMI) with the maturity levels. For the implementation of the maturity model requirements, the CMMI maturity levels can also be applied, which the SG IMM has already successfully implemented. The CMMI maturity levels therefore serve as an orientation value for EMINENT.

In the **phase 4 “Deriving the Maturity Model”**, the first draft was made in the sense of a framework. This initial design was built from the structure at SG IMM, which was intended to be the reference maturity model. Here the focus was on the consideration of further categories and the use of the

SGAM layers as interoperability categories. A visualization of the framework based on the SG IMM [21] is shown in Figure 7.

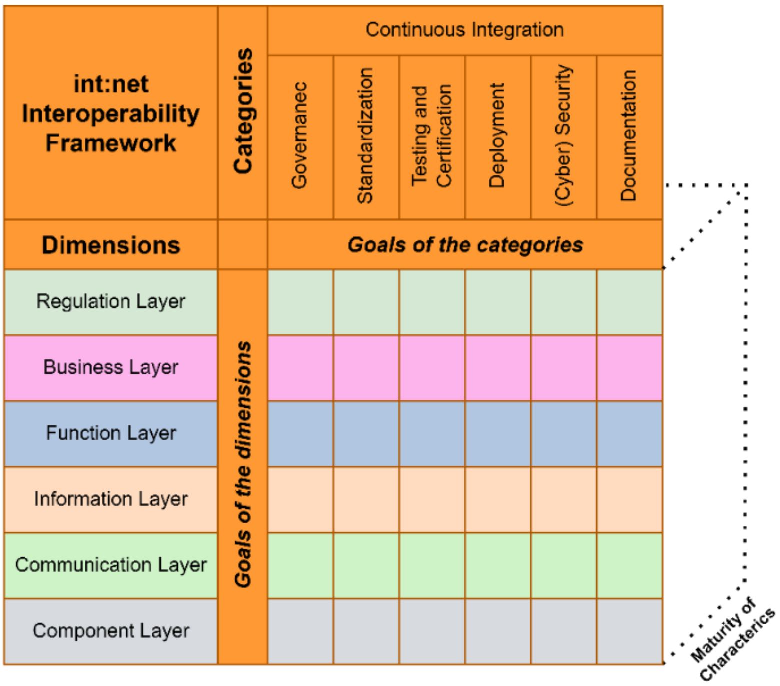


Figure 7 – First draft of the int:net Interoperability Framework

The focus on the first draft was on Continuous Integration in the energy section. The **categories** Governance, Standardization, Testing and Certification, (Cyber) Security and Documentation represent the issues that should be covered by the maturity model. The SGAM layers plus an additional “Regulation Layer” instead of the GWAC interoperability stack (used in the SG IMM) are representing the **dimensions** to fulfill the requirement RQ_DOM_1. For every category and dimension, (multiple) interoperability **goals** needed to be defined. The **maturity levels** and **characteristics** from Table 5 have been setup for the first draft. Here, every category and maturity level envisioned a **characteristic** which should originally been covered by the **questionnaire** of the goals.

Table 5 – Levels and characteristics of the first draft

	Level 1: Initial	Level 2: Managed	Level 3: Defined	Level 4: Quantitatively Managed	Level 5: Optimizing
Governance	Lack of processes (reactive); Ad hoc Management	Simple processes; managed by project agreement	Processes exist in a community; managed by a community agreement	Processes ensure interoperability	Processes managed by a community quality improvement process
Standardization	No standards are used; Ad hoc implementation	Essential standards are taken into account in the project	The standards established in the community are used	Additional standards are taken into account, which go beyond the essentials	Standardization will be actively pursued
Testing and Certification	Ad hoc testing	Tests planned with results captured	Tests exist for community with certification; Members claim compliance with standard	Community test processes demonstrate interoperability; Members claim interoperable conformance	Test processes are regularly reviewed and improved
Deployment	Ad hoc deployment	Simple processes for deployment	Deployment processes exist in a community	Deployment ensures seamless integration	Deployment is based on open community standards
(Cyber) Security	Security is implemented reactively; Ad hoc security	Some security processes are implemented	Essential (cyber) security processes approved from the community are integrated	Follow-up (cyber) security processes are envisaged	(Cyber) security processes are being driven forward
Documentation	Ad hoc documentation	Documented in a project specification	References community standard with some customization	References a community standard without customization	Adopts an open community standard

The **phase 5 "Assess the Maturity Model"** was realized in the expert round of the int:net Task 2.1. In this context, it could be observed that the individual categories have further subcategories, which needed to be covered in the framework. This would mean identifying subcategories. In addition, separate characteristics must be established for the subcategories. This might also lead to a high number of questions being necessary in order to be able to determine the maturity levels for each characteristic. Furthermore, there is the issue that every interoperability dimension cannot cover every category. These aspects complicate both the understanding of the maturity model and the interpretation of the results. Consequently, a simplification of the maturity model is necessary.

5.7.2 Second Iteration

Based on phase 5 of the previous iteration, the next version has to be derived in the **phase 4 "Derive of the Maturity Model"**. Based on the previous evaluation, the following properties shall be now considered:

- The maturity model is intended to put more emphasis on the subcategories of the categories.
- The maturity model should have a manageable questionnaire.
- The maturity model should decrease in complexity.

The framework has been significantly adapted. The categories designated in the first iteration were transformed as topic areas. These are no longer used for direct measurement but serve as a grouping mechanism for subcategories (which are now referred as dimensions). The dimensions used in this version represent the interoperability disciplines and are considered for measurement.

This change in perspective on the framework also resulted in further adjustments to the categories and dimensions. The dimensions used in the first iterations (the SGAM layers) are representing dimensions of the Interoperability Layer category. In this version, the maturity level of each dimension should be now assessed separately. These changes have thus reduced the complexity from 3D to 2D. The maturity levels have to be determined separately across each dimension, which is why each dimension defines characteristics for each maturity level in a 1-to-1-relationship.

These changes lead that a spider-web diagram can be used for the representation. Figure 8 visualizes the maturity model as such diagram. The sections (labelled at the outer corners) represent the categories; the labels next to the center are representing the dimensions, which are positioned to their corresponding categories. Furthermore, from the inside to the outside, the areas dare divided over the maturity levels. Consequently, the diagram can also be used to plot the executed assessment of a system.

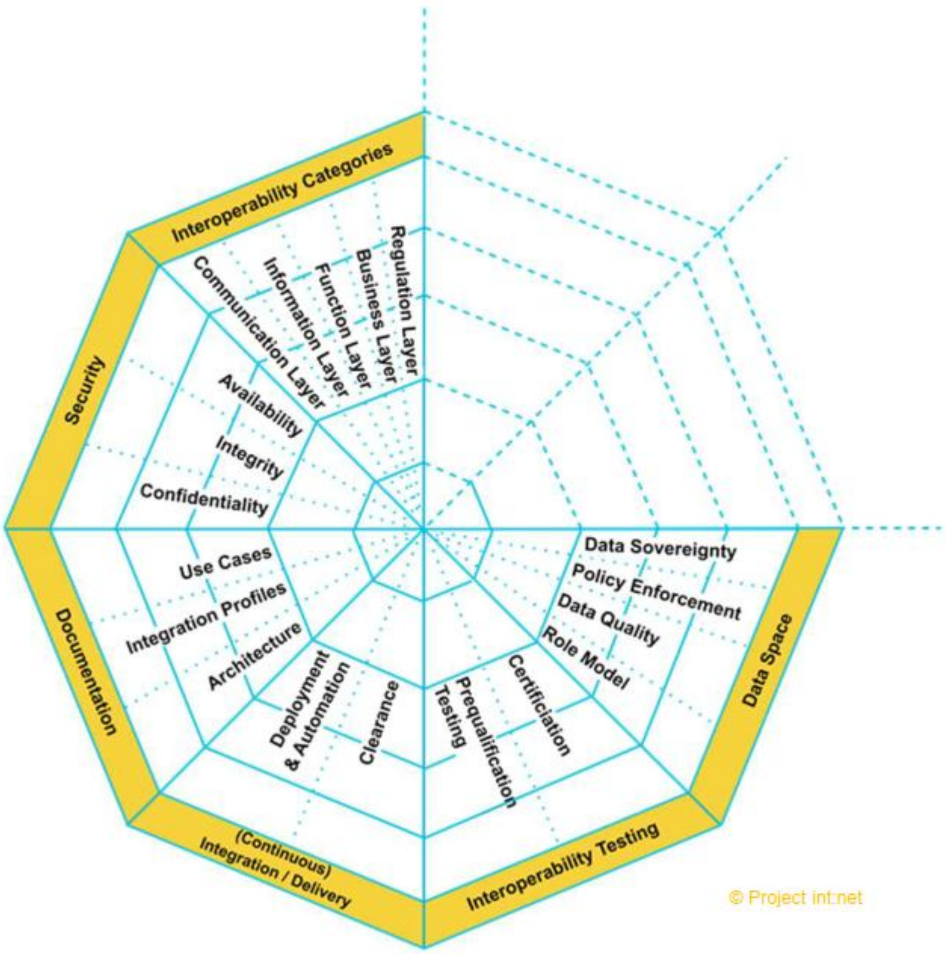


Figure 8 – Second draft of the int:net Maturity Model

Like in the first iteration already done, **phase 5 "Assess the Maturity Model"** was conducted in the expert round of the int:net Task 2.1. This revealed that the maturity model has been simplified in terms of complexity, the subcategories (now called dimensions) gained more relevance and that the catalogue of questions is thus more manageable. This also results in maturity model being more easily adaptable and changes can be integrated more flexibly. This iteration still provides for adjustments to the categories and dimensions for increasing the acceptance as well as the creation of the characteristics and the initial draft of the questionnaire.

5.7.3 Third Iteration

In the third iteration **phase 4 "Derive of the Maturity Model"** was run through again. The general framework remained the same compared to the previous iteration, but shows changes in the categories, dimensions and characteristics and detail work (e.g. an advanced visualization).

The dimensions of the *Interoperability Testing categor*y have been adjusted in order to cover a higher set of interoperability issues via the characteristics. Therefore, *Compliance* is introduced as single dimension, which covers (the previous) topics of prequalification testing, conformance and certification. This also leads to the change, that Clearance dimension of the (Continuous) Integration / Delivery (CI/CD) category (which envisions Recertification processes after changes) can be integrated in the Interoperability Testing category. These changes resulted from the proposal of a testing workshop lead by int:net partner AIT. The dimension Confidentiality was also removed from the

Cybersecurity category, as the Integrity dimension in terms of interoperability challenges already covers the issues addressing.

Furthermore, the Reference Data category was added, which focuses on the subject of data. For the category, the *Data Quality* dimension was moved from the Data Space category to Reference Data. Additionally, the topic of Data Management topic has become more in focus in the framework. In this dimension, the focus is on the use of processes that lead to adequate data management.

In addition to the changes within the categories, the visualization was also adapted to int:net's Cooperate Design (see Figure 9). Furthermore, the questionnaire was finalized in the first version, which will be evaluated by the users in the further course of the project. **Phase 5 "Assess the Maturity Model"** was realized in the sense of the int:net Maturity Model workshop which was organized as an int:net-wide workshop.

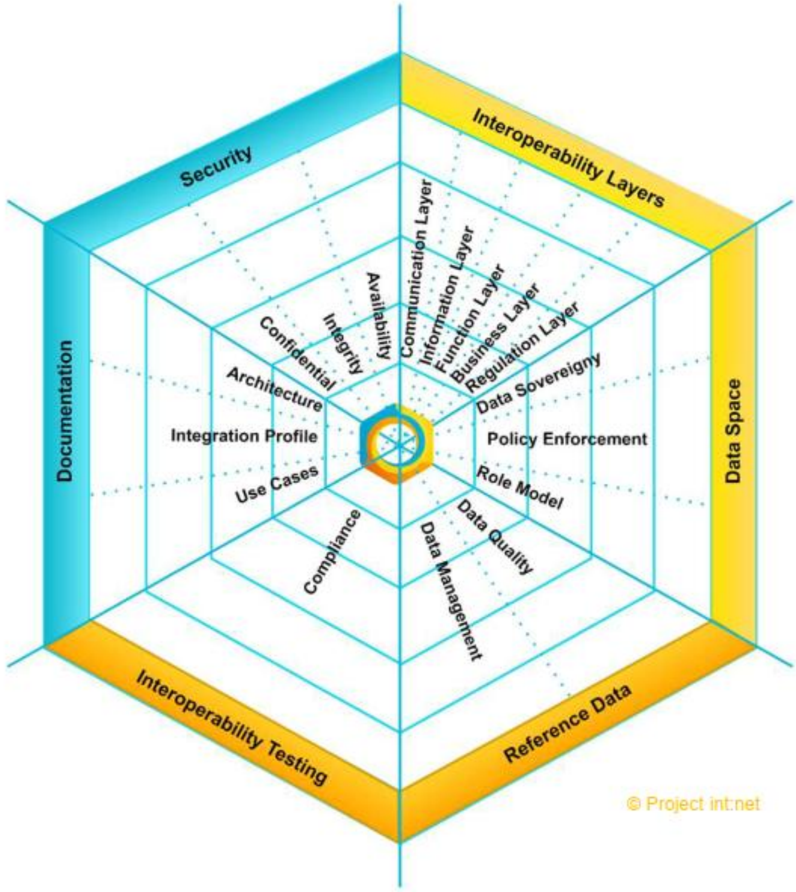


Figure 9 – Third draft of the int:net Maturity Model

5.7.4 Final Iteration

During the transition between int:net task T2.1 "Develop categories and characteristics for Interoperability Reference Framework" and task T2.2 "Develop Interoperability Maturity Model (IMM) Assessment tool", discussions about the appropriate object of study of the maturity assessment changed how the research participants looked at what the maturity model should capture. It was decided that the object of study would most appropriately be the community of individuals and organizations that collaborate to create the standards and implementations that result in an interoperable solution. We started to refer to this community as an 'Interoperability Community'. This leads to a different approach to modelling interoperability maturity.

Rationale for the final iteration:

The further development of EMINENT compared to the maturity model discussed in the third iteration was necessary to provide a more comprehensive perspective on organizational maturity. While the previous model mainly took a technical standpoint, the current version aims to assess not only the technological aspects but also the overarching processes within a community or organization.

The motivation for this shift in focus (i.e., from the ‘organization’ basis to the ‘interoperability community’ basis) was the following thought experiment:

“Imagine two organizations that should be interoperable with each other, for instance a DSO that shares a grid connection with a TSO. After performing an interoperability maturity assessment on both these organizations, they each receive a high score as they both adopt standards, they both test their systems for compliance etcetera. But what if these organizations decided to adopt different standards for the components that form their interface? What if the choices that each of these organizations made independently from each other, based in good interoperability practices, lead to mismatching (technology/business) decisions? In this case, would they together be interoperable?”

The answer to the latter is clearly “no, they would not be interoperable”. So, then we wondered: how is it even possible to measure interoperability maturity, if any assessment we perform on the ability of organizations to be interoperable does not (even remotely) guarantee that the outcomes of that organization's efforts would be interoperable? We concluded that it isn’t possible, because interoperability exists on a level of collaboration beyond the individual organization.

The paradigm shift through these adjustments is based on various reasons. One significant reason is the uniform definition of the interoperability community concept in the int:net project. The definition derived during the project necessitates not only considering the maturity of interoperability efforts in processes for creating ICT solutions in the energy sector but also adapting dimensions and categories to include broader processes within the community/organizations.

Another crucial aspect is the consideration of additional insights and results from the project, particularly the development of the 6th SGAM (Smart Grid Architecture Model) "Framework” layer [22], and the introduction of the "Tube in the cube" principles [22]. These new insights have expanded the perspective on the maturity model and highlighted the need for a stronger incorporation of business- and governance-related interoperability aspects to adequately reflect the entirety of the int:net project's goals. Therefore, it was necessary to integrate these results into the maturity model.

The third iteration of the maturity model primarily focused on the interoperability of (ICT) systems at the levels of components, communication, and information. This was particularly relevant for technical engineers. However, over the course of the project, the focus shifted, placing greater emphasis on business and the 6th "Framework" layer [22] relating Governance. This necessitated a comprehensive adjustment of the maturity model to ensure that it adequately considers both the technical and organizational aspects of interoperability and aligns with the current project results.

Although the third iteration of the maturity model remains useful for providing a basic understanding of the interoperability of (ICT) systems, further development was necessary to align with the new insights and focus areas in the int:net project and ensure consistent integration with the current project results.

It is important to note that the methodology being developed may still be applied within individual organizations. There are lots of interoperability challenges within organizations, or challenges that are adjacent to interoperability, such as data management, internal technology standardization etcetera. These challenges are similar to interoperability in that they require collaboration between teams or departments within an organization. So, while the application to organizations is still met, it is important to note that the primary focus of the methodology has shifted away from the individual organization, and towards the community of organizations that collaborate to achieve interoperability.

5.8 Structure of EMINENT

The previous chapters dealt with the explanation of the derivation process for the maturity model. In this chapter, the maturity model is presented in descriptive form in order to enable its use. In the first section, the objectives and the general structure and functioning of the model are presented. The remainder of the chapter presents the components of the maturity model from a top-down perspective. At the top are the capabilities, which are used as a grouping tool respectively as topic complexes in the model. In the maturity model, the dimensions represent the topics to be evaluated thematically within the capabilities. The maturity levels are representing a scale used from the characteristics as a high-level scale for interoperability maturity assessment. In the maturity model, the characteristics represent the aspects to be evaluated, which differ for each dimension and maturity level.

5.8.1 EMINENT overview

The energy sector is undergoing a significant transformation, with the integration of renewable energy sources, advances in energy storage technologies, and the deployment of smart grid infrastructure. The characteristics of a smart grid, such as increased end-users’ participation, the integration of customers that can both consume and produce energy, as well as the integration of many (smaller) renewable energies than few (large) non-renewable energies, create higher challenges in terms of interoperability awareness, as the number of actors, technologies, business models and stakeholders increases.

The use of a maturity model can help organizations in the energy sector assess and improve their interoperability capabilities over time, ensuring that they can keep pace with the rapidly changing energy landscape. The maturity model is subject to the following objectives:

- Improve interoperability efforts and the own interoperability awareness within the ICT energy sector across a range of identified capabilities and dimensions
- Improve capability of participants in a digital energy sector over the world
- Providing tools to assess interoperability efforts in the digital energy sector on syntactic, semantic, business and governance level
- Development of a User Interface (UI) for tracking interoperability efforts maturity in the digital energy sector
- Guidance is provided to increase the maturity of interoperability

In order to achieve the above-mentioned objectives, it is necessary to take a define of the perspective of the system-of-interest. In the context of the maturity model, the system-of-systems perspective is adopted, meaning that the system corresponds to a part of the larger system and consequently a top-to-bottom view is taken. Furthermore, the model should be able to be used independently from the subdomains of the energy domain, i.e. the model is not specified to TSO's / DSO's or energy generation. However, the model should be able to be used across them.

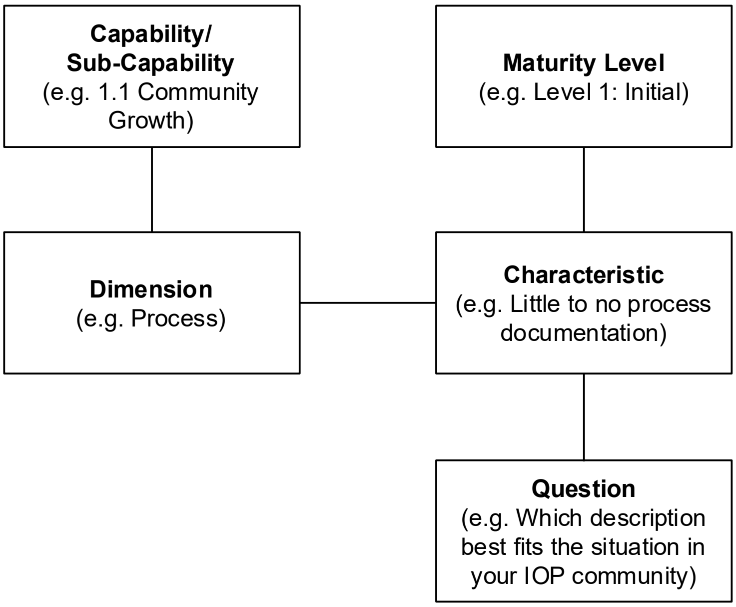


Figure 10 – Components of EMINENT and their relationships

The maturity model aims to assess different disciplines of interoperability challenges within interoperability communities. The core of the maturity model consists of the components listed in the Figure 10. These are inter-related and are defined as follows:

- **Capabilities:** Capabilities are defined as groupings or set of related dimensions, which are necessary for achieving a specific level of maturity. Capabilities provide a structured way to organize the different aspects of a community that need to be evaluated in order to assess its maturity. The selected Capabilities are in the context of the interoperability challenges. The capabilities of the maturity model are defined in section 5.8.2. *Relationships:* A capability can have different amounts of associated dimensions.
- **Dimensions:** The dimensions represent a specific area within the capabilities where interoperability challenges are apparent. For the dimensions, the maturity of interoperability needs to be measured. For this purpose, characteristics represent the prerequisites for

reaching a level. The dimensions of the maturity model are defined in section 5.8.3. *Relationships:* A dimension has the same number of characteristics as there are maturity levels, since they are mapped 1-to-1.

- **Maturity Level:** A maturity level represents a point along a progression of maturity that an interoperability community can achieve with respect to a particular capability or area of focus. Maturity levels are structured in a hierarchical fashion, with each level building upon the previous one. The goal of the interoperability communities is to increase the level of maturity for a given dimension, which are represented by the characteristics. The maturity levels of the maturity model are defined in section 5.8.3. *Relationships:* The maturity levels are the same for all characteristics and consequently for all dimensions.
- **Characteristic:** The characteristics are assigned to the dimensions and represent the requirements for reaching a certain maturity level based on the provided definition. The characteristics are the interoperability property of a dimension to be considered. The degree of fulfillment of the characteristics is determined by a questionnaire, which contains questions that can be assigned to the characteristics. The characteristics of the maturity model are defined in the section 5.8.3. *Relationships:* Every characteristic is assigned to one maturity level, dimensions and is assigned to at least one question in the questionnaire.
- **Questionnaire:** The questionnaire provides the basis for the practical application of the maturity model. Questions are defined to assess the fulfillment of the characteristics. While the characteristics are generic and implementation and technology neutral, the questions in the catalog are specific but still implementation and technology neutral however giving examples. The questionnaire and the assessment way are defined in section 5.8.3. *Relationships:* Every question is assigned to at least one characteristic.

Figure 11 provides an overview of the EMINENT structure.

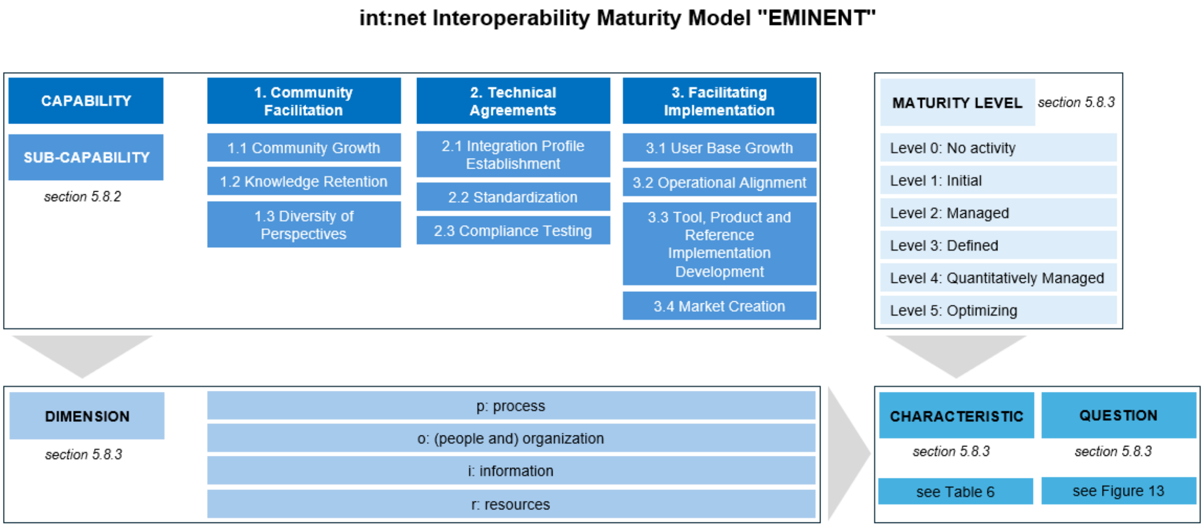


Figure 11 – Structure of EMINENT

5.8.2 Motivation for the capabilities

Just as individuals have skills that allow them to perform certain tasks, organizations have capabilities that allow them to achieve certain goals. In this research, the definition for capability as proposed by Archimate has been adopted [23]. The basic idea is that these interoperability communities have the wish to produce an interoperable outcome. This begs the question: what capabilities should an interoperability community possess in order to be able to deliver these interoperable outcomes? In order to find meaningful capabilities for interoperability, inspiration was drawn from best practices of open-source software. In the case of developing open-source software, different organizations come together -very much like interoperability- to solve a shared problem. *[While many open-source communities could be considered interoperability communities (and all interoperability communities could learn a lot from open-source communities), not all open-source software necessarily results in interoperability. Database management systems like MySQL and PostgreSQL come to mind, that both ‘rely’ on the SQL standards, but a query written for one would not be useable for the other.]* The open-source movement has also developed methods and tools to support this kind of collaboration (like Git).

While we could not find a lot of literature to rely on, conversations with experts from Open-Source Project Offices, as well as experts from the utility domain that are active in standardization efforts lead us to a model with 3 high-level capabilities and 10 sub-capabilities. This section will discuss these capabilities in detail.

Capabilities can be comprised of sub-capabilities that describe in more detail the different aspects of the capability. In other words, capabilities may have a part-whole relationship between each other. The (sub) capabilities investigated within the maturity model are grouped by the following three (higher-level) capabilities:

1. **Community Facilitation:**

   Community facilitation in the context of interoperability typically refers to the process of fostering collaboration and communication among different communities or groups to achieve seamless interaction and compatibility. It involves creating a supportive environment where stakeholders from various backgrounds can come together, share their perspectives, and work towards common goals, especially in the context of technology, standards, or data exchange.

   Facilitators play a key role in guiding discussions, resolving conflicts, and ensuring that all voices are heard. In the realm of interoperability, community facilitation may include activities such as organizing forums, workshops, or working groups where representatives from different communities can discuss and align their approaches to enhance compatibility and integration.

   Ultimately, the goal of community facilitation in interoperability is to build bridges between diverse groups, fostering understanding, and facilitating the development of solutions that enable seamless interaction and data exchange across various systems or platforms.

2. **Technical Agreements:**

   Technical agreements in the context of interoperability refer to formalized agreements or specifications that define how different technologies, systems, or components will interact and work together. These agreements are crucial for ensuring that diverse systems can seamlessly exchange information, communicate, and function cohesively.

   These agreements may include detailed specifications, standards, or protocols that outline the rules, formats, and procedures for data exchange or integration. They serve as a common language or set of guidelines that various parties can adhere to, promoting consistency and compatibility.

   In the world of technology, especially in fields like software development, networking, and data exchange, technical agreements play a vital role in enabling interoperability. Examples of technical agreements could include standardized communication protocols, data formats, or application programming interfaces (APIs) that allow different systems to understand and interact with each other effectively.

   Overall, technical agreements provide a foundation for interoperability by establishing a shared framework that facilitates collaboration and connectivity among diverse technological components or systems.

3. **Facilitating Implementation:**

   Facilitating implementation in the context of interoperability involves putting into action the strategies and processes designed to facilitate collaboration and interaction among different entities or systems. It's about turning the plans and agreements into practical steps that ensure seamless integration and compatibility.

   This can include:

   - Organizing Workshops and Meetings: Actively coordinating and hosting workshops, meetings, or conferences where stakeholders can come together to discuss and implement interoperability solutions.
   - Guiding Discussions: Facilitators play a crucial role in guiding discussions among diverse groups, ensuring that all parties understand the technical agreements and are on the same page regarding the implementation process.
   - Resolving Issues: Addressing and resolving any challenges or conflicts that may arise during the implementation phase. This could involve technical issues, disagreements on specifications, or other hurdles.

- Monitoring Progress: Keeping track of the progress of the interoperability implementation and making adjustments as needed. This may involve regular check-ins, progress reports, and performance evaluations.
- Training and Support: Providing training and support to stakeholders involved in the interoperability implementation to ensure that they have the necessary skills and resources to carry out their roles effectively.

In essence, facilitating implementation is the practical execution of plans and agreements, with the goal of making interoperability a reality. It involves active engagement, communication, and problem-solving to overcome challenges and ensure that the systems or entities involved can work together seamlessly.

Capability model

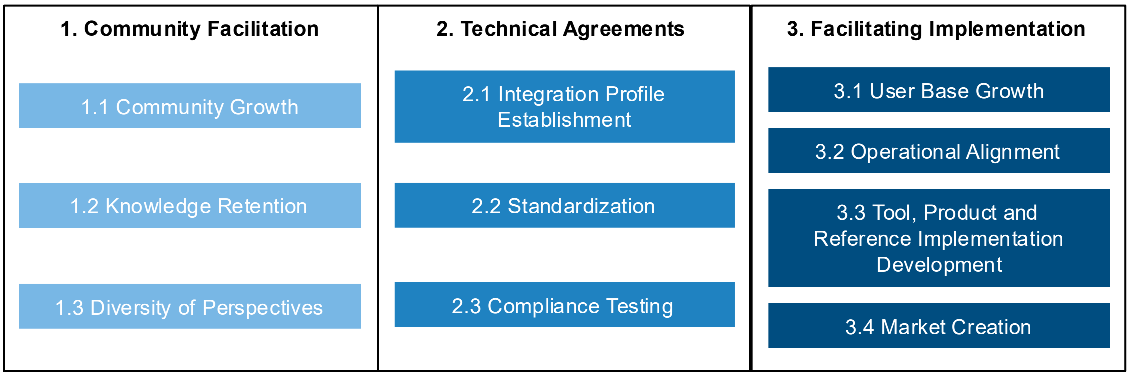


Figure 12 – Overview of the EMINENT Capability model

Within this capability framework, the capabilities are further categorized by the following sub-capabilities:

1.1: Community growth in the context of interoperability refers to the expansion, collaboration, and maturation of a community of entities or stakeholders involved in creating, adopting, and advancing interoperable systems and standards. It involves the collective progress and development of a group of organizations, developers, and individuals who share common interests in achieving seamless connectivity and integration between diverse systems.

1.2: Knowledge retention in the context of interoperability refers to the intentional preservation and accessibility of critical information, expertise, and insights related to the seamless integration and connectivity of diverse systems and technologies. It involves capturing, storing, and making available the knowledge gained from experiences, best practices, challenges, and solutions associated with interoperability efforts.

1.3: Diversity of perspectives in the context of interoperability refers to the inclusion and consideration of a wide range of viewpoints, experiences, and insights from various stakeholders, domains, and disciplines involved in the design, implementation, and governance of interoperable systems. It recognizes that achieving seamless connectivity between diverse systems requires input and understanding from individuals with different backgrounds, expertise, and roles within the ecosystem.

2.1: Integration profile establishment in the context of interoperability refers to the process of defining a set of requirements that outline how different systems or components should interact and exchange information to achieve seamless integration. An integration profile serves as a detailed overview that defines the scope of the problem that is to be solved.

2.2: The sub-capability of Standardization in the context of interoperability refers to the process of establishing a set of agreed-upon norms, specifications, and protocols that solve the problem stated in the Integration Profile. Standardization plays a crucial role in fostering interoperability by providing a common framework that ensures compatibility, consistency, and predictability in the exchange of data and functionality.

2.3: The sub-capability of Compliance Testing in the context of interoperability refers to the systematic evaluation and verification processes designed to ensure that interconnected systems, components, or solutions adhere to established standards, specifications, and protocols. Compliance testing is instrumental in validating that interoperable systems meet the required criteria, fostering consistency, reliability, and adherence to industry or organizational norms.

3.1: The sub-capability of User Base Growth in the context of interoperability refers to the expansion and diversification of the community or user ecosystem that actively engages with and benefits from interoperable systems. This dimension recognizes the importance of not only increasing the number of users but also ensuring that a broad range of stakeholders, including individuals, organizations, and sectors, can effectively participate in and leverage interoperable solutions.

3.2: The sub-capability of the Operational Alignment Process in the context of interoperability places a significant emphasis on the ways in which systematic and strategic procedures are created and then undertaken to intricately synchronize the day-to-day processes, workflows, and activities of interconnected systems, components, or organizations. It underscores the critical importance of ensuring that operational processes are not merely technically integrated but are intricately and purposefully aligned to achieve a seamless and effective interoperability.

3.3: The sub-capability of Tool, Product, and Reference Implementation Development in the context of interoperability refers to the creation and enhancement of software tools, products, and reference implementations that facilitate and exemplify the seamless integration of diverse systems. This dimension acknowledges the significance of developing practical solutions, frameworks, and exemplars that showcase effective interoperability practices, guiding stakeholders in the implementation of interconnected systems.

3.4: The sub-capability of Market Creation in the context of interoperability refers to the strategic efforts and activities aimed at establishing a viable and dynamic market for products, services, and solutions that facilitate seamless connectivity between diverse systems. This dimension recognizes that the successful adoption and growth of interoperability solutions often depend on creating a market ecosystem that fosters innovation, competition, and widespread adoption.

5.8.3 Motivation for the dimensions, maturity levels, characteristics, questions

Dimensions

To turn a capability model into a (capability) maturity model, there needs to be a way to model maturity for these capabilities. To achieve this, it was decided to adopt a maturity framework developed by EPRI [24]. The original maturity model recognizes 5 dimensions:

- **Process:** What are the processes to support this capability?
- **People and organization:** Does the organization consist of people with the right expertise and skillsets? Does the organization have a culture that supports the capability?
- **Information:** What information is available to support the capability and is it managed well?
- **Technology:** Which technology is available to support the capability?
- **Resources:** What resources (financial, tangible, intangible) are available to support the capability?

For this project we decided to adopt all dimensions above except the technology one. The reason for this is that for the work that happens at this level, the relevant technology often comes down to: do you have a file sharing environment? Do you have project management tools (like backlogs, scrum/kanban boards etc.)? Do you have social media accounts? While these are relevant, they were found to be not very insightful for the purpose of modelling Interoperability Maturity.

Maturity levels

The selection for the present maturity model has been oriented to the maturity levels of the CMMI, which has been used as a reference by related maturity models. The following maturity levels are used for this maturity model:

- **Level 0: No Activity**

  There are no activities taking place.

- **Level 1: Initial**

  Interoperability efforts are ad-hoc and inconsistent, with no standardization or coordination across communities.

- **Level 2: Managed**

Interoperability efforts have been established and are repeatable.

- **Level 3: Defined**

Interoperability efforts are well-defined and oriented on standards; integrates in the community interoperability visions.

- **Level 4: Quantitatively Managed**

Interoperability efforts are well-established and integrated into organizational processes and supported by formal standards.

- **Level 5: Optimizing**

Interoperability efforts are strategic enabler that drives innovation, leverages emerging technologies, and optimizes performance through a culture of collaboration and continuous improvement.

Characteristics

The maturity framework captures a sense of maturity by describing 'Characteristics' for each level of maturity for a given dimension.

An overview of the generic characteristic descriptions can be found in the table below:

Note: '### capability ###' can be replaced with any of the capabilities that have been discussed.

Table 6 – Description of the characteristics

Dimension	Maturity level	Characteristic
process	0	There are no processes to support ### capability ####.
process	1	Little to no process documentation, -governance, or -ownership of ### capability ####. Progress on ### capability #### is based on individual's knowledge, manual interventions and with unpredictable results.
process	2	Key processes for ### capability #### are identified and documented locally. Responsibilities and handoff are poorly understood, and results are inconsistent.
process	3	Key processes for ### capability #### are documented community wide, ownership is defined, and handoff points have been established. Adoption, execution, and results are inconsistent.
process	4	Processes for ### capability #### are defined, understood, reliable, standardized, efficient, measured and adopted community wide with consistent results.
process	5	Processes for ### capability #### are continuously reviewed, benchmarked and improved resulting in industry-leading practices and results.
people and organization	0	There is no organization for ### capability ####.
people and organization	1	Community members have a weak understanding of ### capability #### with limited skills, training, and poorly defined roles. The community has not allocated community members/working groups for ### capability ####.
people and organization	2	Community members have some skills for ### capability #### but may be lacking experience or training. Inconsistent roles and responsibilities.
people and organization	3	Community members have good skills, experience and available training is in place to improve skills for ### capability ####. Roles and responsibilities are defined and assigned to members/working groups.
people and organization	4	Community members have clear roles and responsibilities, have suitable training and are adequately staffed for ### capability ####. Members

Dimension	Maturity level	Characteristic
		proactively identify people and organizational improvements and have succession plans in place.
people and organization	5	Community members have an expert and deeply contextualized understanding of ### capability #### and are working in a culture that supports and actively embraces continuous improvement, benchmarking and innovation.
information	0	Data/information to support ### capability #### does not exist.
information	1	Information to support ### capability #### is unavailable, unknown, incomplete, incorrect, inconsistent, and not exploited. Minimal descriptive reporting and analytics are performed and involve manual intervention. These reports not used for decision making.
information	2	Information to support ### capability #### is available in silos, hard to locate for others.
information	3	Information governance defines how information for ### capability #### is collected, stored, understood, accessed, owned, and deleted.
information	4	Information for ### capability #### is available and well understood across the community and externally. Information quality is measured and corrected.
information	5	New information for ### capability #### is continuously identified, benchmarked and included in decision making.
resources	0	There are no resources available to ### capability ####. Individuals who do participate in ### capability #### do so voluntarily in their own time.
resources	1	Few, if any, resources, including budget, are assigned to ### capability ####. Some participating individuals receive resources from the organizations they represent.
resources	2	Some resources are identified for ### capability ####, but additional requirements are not part of investment decisions. Some participating individuals receive resources from the organizations they represent.
resources	3	### capability ####'s relationship to resources is defined and requirements are part of the investment planning process. Most individuals performing work for ### capability #### are compensated for their effort by the organization they represent. Funding is project based and not guaranteed beyond project commitments.
resources	4	New resources are made available to increase the maturity of ### capability ####. Most work done for ### capability #### is compensated.
resources	5	New resources and other innovations that can improve ### capability #### are investigated, benchmarked, and deployed. All work done towards ### capability #### is compensated. Funding is independent of projects and guaranteed for longer periods of time.

Questions

With these characteristics in hand, the tool requires a method to ask the interviewees about the state of their interoperability community across the different capabilities and dimensions. Different versions of the questionnaire were contemplated (both with free text responses and multiple-choice questions). In the end it was decided to just directly ask respondents about which characteristic best described the situation in their interoperability community. This resulted in a framework for questions that could be repeated across the questionnaire. A couple of examples can be found below:

- *"Considering the people and organization dimension of Community Growth, which description best fits the situation in your interoperability community?"*

- *"Considering the resources dimension of Operational Alignment, which description best fits the situation in your interoperability community?"*

In the questionnaire, each of these questions would be accommodated with examples of processes, organization, information and resources that would support the specific capability. So, the question an interviewee will be asked looks like:

"Question 2.2 p: Considering the <u>process dimension</u> of <u>Standardization</u>, which description best fits the situation in your interoperability community?

Examples of processes for standardization include:

- *Backlog and prioritization processes.*
- *Escalation processes to resolve disagreements.*
- *Processes to define deliverables.*
- *Review processes.*
- *External feedback processes."*

['Question 2.2 p' refers to the question that measures the process dimension (p) of sub-capability 2.2 (Standardization)]

The Interviewee can then select the characteristic that best describes the situation in their interoperability community for the given dimension of the given capability.

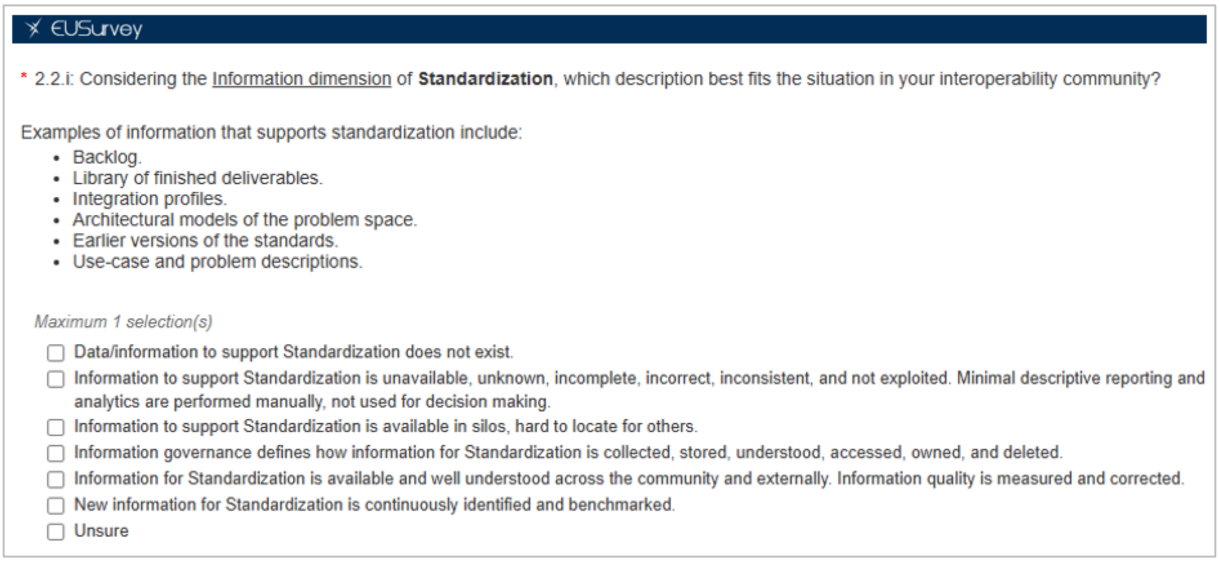


Figure 13 – Extract of the online questionnaire (example question 2.2 i)

The combination of the Capability Model, the Maturity Model and the framework for formulating questions resulted in the **EMINENT questionnaire** [25] [26]**.** This approach was tested in the Minimum Viable Product (MVP) (section 5.9.4) and found to be effective, so it was adopted without change in the production version of the tooling.

- Online survey published at EUSurvey:

  https://ec.europa.eu/eusurvey/runner/Eminent [25]

  (to use this version, join the int:net community focus group at https://community.intnet.eu/Groups/IFG-2-Increasing-Maturity-in-Interoperability [27]
- The questionnaire is also made available for re-use and/or modification:

  https://github.com/int-net/EminentSurvey [26]

The main reason why this method seems to work so well, we suspect, has to do with the consistency of the questions. The recurring of the dimensions and the capabilities in the questionnaire means that interviewees are being repeatedly exposed to these concepts, hence allowing them to become familiar with them in a predictable context.

The approach to combine a capability model with a maturity model and create a maturity assessment in this structured way has been tested on different capabilities (specifically Enterprise Architecture and data management) by EPRI in proprietary research for their members and was found to be an effective method to gain insight in the maturity of the subject organizations.

5.9 Creating the Tool

This section will discuss the development of the tool. It will first discuss the use cases, then the development of the Minimum Viable Product (MVP) version of the maturity assessment and finally the production ready version of the tool.

5.9.1 Use cases for the tool

The int:net grant agreement splits the tooling in 2 tasks:

- T2.2 for the maturity assessment tool (resulting in deliverable D2.2)
- T2.3 for the maturity tracking database (resulting in deliverable D2.3)

It was decided to group these two tasks together for the purpose of execution, as the information requirements for the data base placed a lot of indirect information collection requirements on the performance of every individual study.

For D2.2, the agreement calls for:

[…] a maturity assessment methodology [...]. This will be […] an online tool that will support either self-assessment of interoperability maturity or guided assessment with facilitator/experts. The tool should provide detailed results […] illustrate the maturity across the different categories. The results should also link to databases […] for different organisations that are willing to share their results. (GRANT AGREEMENT Project 101070086 – int:net)

At the moment of writing, these requirements have all been met.

For D2.3, the agreement calls for:

Build a living database and interactive interface for tracking interoperability maturity (D2.3). The database should automatically incorporate results from web-based surveys that are performed. There will also be a need to reevaluate levels as TRLs of technology and associated interoperability requirements evolve over time and technology becomes deprecated. (GRANT AGREEMENT Project 101070086 – int:net)

As of writing, the requirement to automatically incorporate the results to the data base have not been met. They require a handful of manual operations that have been documented as part of the int:net D2.3 deliverable [28]. There are two main motivations for deviating from this requirement:

1. The off-the-shelf questionnaire tools that were available (MS Forms, EUSurvey, SurveyMonkey) all used their own internal data model for collecting survey data that lacked sufficient metadata to be able to meaningfully compare maturity assessments done on the same organization over time, including identifying and correcting for potential changes in interviewing methodology or questionnaire versions. This required the introduction of extra 'questions' to the questionnaire that captured metadata about the interviews and/or assessments. This means that the data has to be interpreted and transformed to a point that could not reasonably fully automated.
2. Both the MVP as well as the final tooling (MS Forms and EUSurvey respectively) keep the data in a private portal that requires a login. They do, however, both offer the ability to create a copy of the questionnaire for third parties to use and collect their own data. We wanted to support this feature but also allow data collected in this fashion to be able to be added to the database, this would require a manual intervention as some kind of quality check would have to be done before such data should be submitted to the database.

Also, the requirement to update the maturity levels based on Technology Readiness Levels was not met. This was primarily due to the fact that we defined the object of study to be the interoperability community, as maturity assessments typically have organizations as objects of study, not technology (for more information see section 5.7.4).

Based on the grant agreement text and the aforementioned motivations, a set of actors and use cases was identified that are shown in the use case diagram in Figure 14.

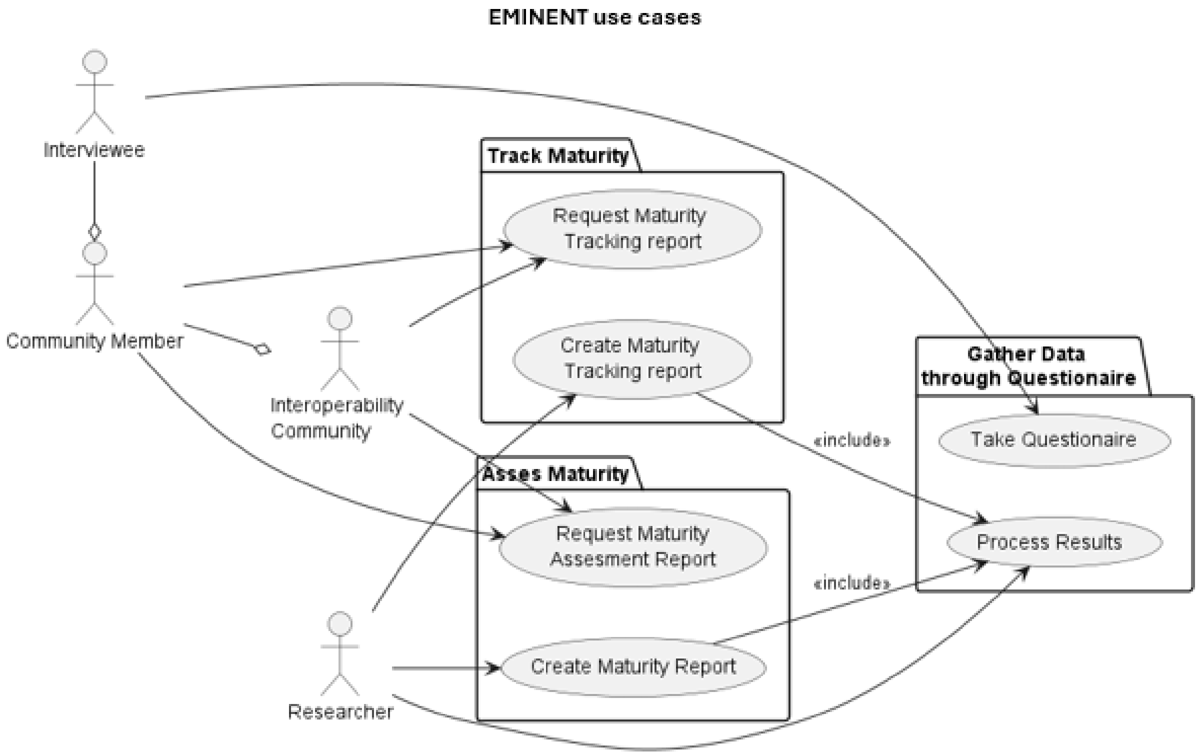


Figure 14 – Overview of actors and use cases related to the Interoperability Maturity Assessment tool

We identified 4 actor types:

1. The researcher is the individual or organization that executes or guides the maturity assessment. The use-cases related to this actor include:
   - Processing results: performing a data analysis based on the questionnaire results (part of "**Gather data through Questionnaire**")
   - Creating a maturity report: writing up a report based on the interpretations of the results (part of "**Assess Maturity**")
   - Creating a maturity tracking report (as part of T2.3): the ability to create report that tracks the changes in maturity over time based on previously performed studies (part of "**Track Maturity**")

   NB: We think that the creation of a tracking report is likely to coincide with (a new iteration of) creating a maturity report. We decided to treat those as separate use cases as it simplifies the model without loss of functionality.
2. The interoperability community is the group of individuals and organizations that collaborate in standardization and implementation efforts in order to develop interoperable solutions. The use cases that are associated to this actor include:
   - Requesting a maturity report: the community can request a maturity assessment to be performed so that they can learn about their interoperability maturity
   - Requesting a maturity tracking report: the community can request a maturity tracking report that may help them analyse the effectiveness of the efforts they have made to become more mature over time (part of "**Track Maturity**")
3. The community member is a person or organization that is active in the interoperability community. The use cases that are associated to this actor include (the same as the interoperability community):
   - Requesting a maturity report: the community can request a maturity assessment to be performed so that they can learn about their interoperability maturity (part of "**Track Maturity**")

- Requesting a maturity tracking report: the community can request a maturity tracking report that may help them analyse (part of "**Gather data through Questionnaire**")

4. The interviewees are the individuals that take part in the questionnaire. They may be community members themselves, or they may work for community members (if the community member is a larger organization that is active in the community). The use cases that are associated to this actor include:
   - Taking the questionnaire: the interviewees are selected by the interoperability community (or community members) to provide their perspective and experience as input to the maturity assessment (report). They do so by filling out the Eminent Maturity Assessment Questionnaire (part of "**Gather data through Questionnaire**").

In addition to these use cases there were 2 main functional requirements:

- The maturity tracking data base shall make data available conform the FAIR Principles [29].
- The maturity tracking data base should conform to the GDPR regulation [30].

While there are multiple ways of complying to the GDPR, any variation that involves personal identifiable information (PII) adds a data management complexity that we cannot guarantee can be continued beyond the scope of the int:net project, for this reason, this requirement was concretized to: there shall be no PII in the result data base.

5.9.2 Business Processes

This section includes the logistical aspects of executing a maturity assessment and managing the results.

If one desires to conduct a maturity assessment of an interoperability community, such as a standardization group, an open-source project community, or any other collective of organizations and individuals collaborating to address a common issue in a standardized manner, the EMINENT questionnaire [25] [26] stands as the preferred tool for such endeavour.

5.9.2.1 Survey management options

The researcher has two options for using the survey. The first is to create a Github issue [31], or join the int:net community focus group [27] to use the survey published at EUSurvey [25] (see also section 5.8.3). This is probably the easiest method as the researcher will be able to use the already implemented infrastructure. Members of the int:net community can also help process the data and add the results to the existing repository.

Alternatively, a researcher may decide to run a separate instance of the survey. This might be desirable if the researcher wants access to the raw EUSurvey data, if the results are confidential, or if the researcher wishes to make modifications to the survey, for instance, if they wish to have more information about the respondents (NB: this may make the data incompatible with the data processing tooling used for the existing repository).

5.9.2.2 Maturity assessment process

Figure 15 provides a high-level overview of the process, which is better described hereafter.

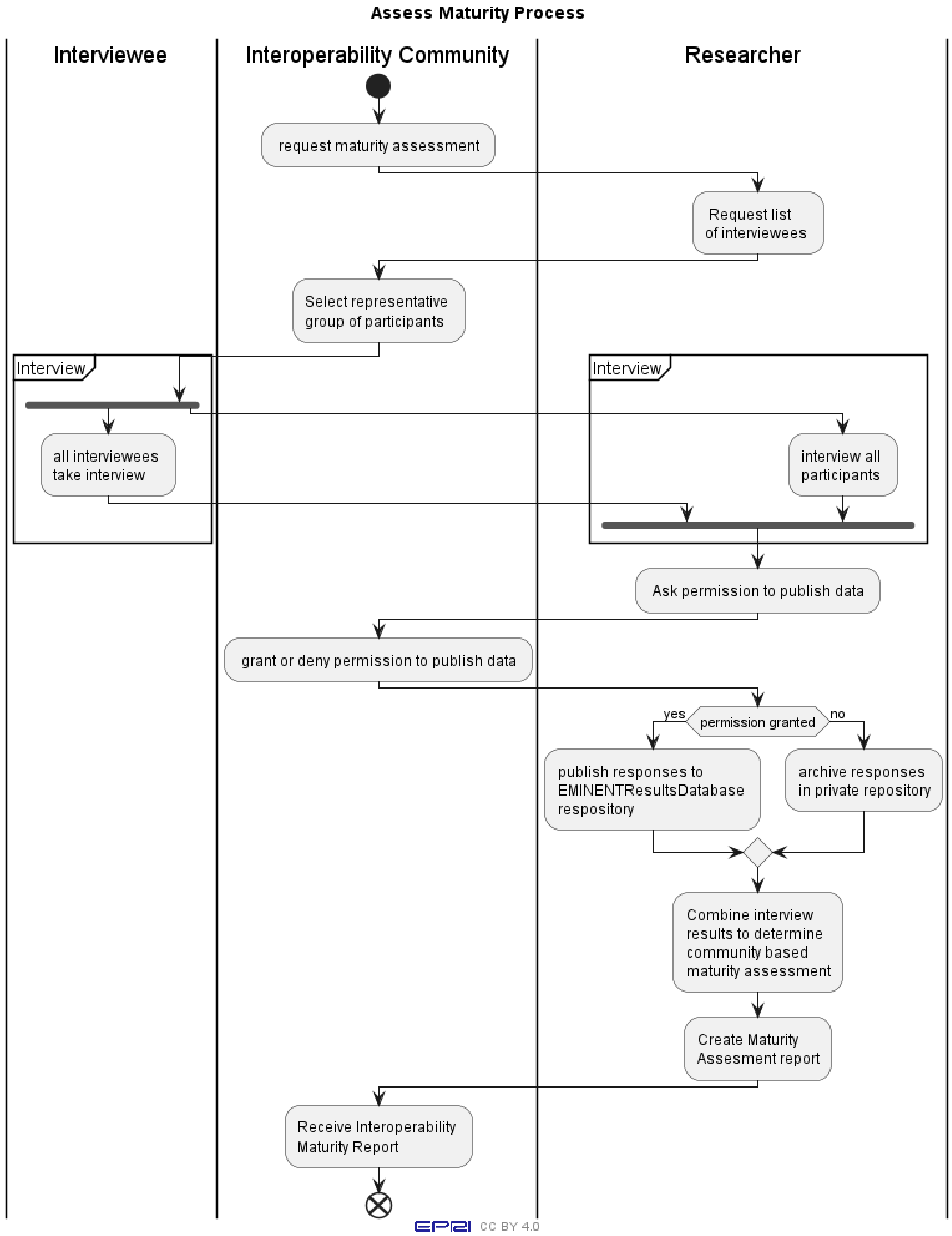


Figure 15 – Overview of the maturity assessment process

Step 1 – Selection process:

The interoperability community reaches out to a researcher to perform a maturity assessment and selects the group of interviewees.

The Researcher will compile a list of potential interviewees from relevant departments, teams, or groups of interest. A diverse and representative group of participants is chosen from the list to ensure comprehensive insights. The researcher will create an identifier for the study and ask all respondents to fill in that code in question 10.

Step 2 – Interview process:

The researcher will conduct interviews with the identified group. There are multiple ways of conducting this maturity assessment:

a) Structured interviews are conducted with all identified interviewees: In-person interviews where the researcher interviews every interviewee one by one.

   Pros:

   - Interviewees get to ask clarification questions
   - High response rate

   Cons:

   - Time consuming: If, for instance, a study involves 10 interviewees, this would require making 10 appointments in an hour.
   - Isolation: The questionnaire involves complex questions/answers at a level some interviewees may not be operating on a day-to-day basis. The researcher can clarify questions but cannot help the interviewee make the translation from the questions and examples in the survey to their real-world situation.

b) Self-assessment: The researcher sends the questionnaire around and interviewees fill it in at their own convenience. Each selected participant undergoes an individual interview to gather detailed perspectives and experiences using the link.

   Pros:

   - Very flexible
   - Relatively low effort for the researcher

   Cons:

   - Low response rate: Expect about 5-10% of the invited people to respond after multiple reminders.
   - Isolation: Similar to the previous method, but the interviewee cannot ask clarifying questions. We have received feedback that people just give up and do not submit the answers.

c) Workshop: Organize one or more sessions (online or in-person) where you fill in the survey simultaneously. It is important that every individual fills in their own survey as supposed to one survey for the group as opinions might vary and this should be reflected in the results and analysis.

   Pros:

   - Manageable effort for the researcher
   - Medium/high response rate (not all of the intended interviewees will be able to attend the workshop)
   - Group discussion: One of the biggest challenges for most of the interviewees has been to translate the language of the questionnaire to their experience. In a group setting, people can discuss their interpretation or think of -and share- concrete examples of why they think a certain characteristic is appropriate for a given dimension.
   - Interviewees get to ask clarification questions
   - Effectiveness: During the interviewing process, community members can think and provide ways the community could improve.

   Cons:

   - Workshops with many attending can be difficult to plan
   - Strong voices may influence quiet dissenters in how they respond

Step 3 – Data management:

Participants are requested permission for the potential publication of their responses. Permission to publish data is either granted or denied based on participant preferences.

During this stage, the researcher processes the data, creates a maturity assessment report and, depending on whether permission was given, adds the response data to the right repository:

a) If granted, responses are uploaded to the *EMINENT Results Database* repository [31] for broader access. All responses that are collected using the EUSurvey version of the maturity assessment are completely anonymous. There is no way of tracing responses to an individual.

b) If denied, responses are securely archived in a private repository to maintain confidentiality.

How to submit the result data to the repository – to add the data to the EMINENT publication, please go through the following steps:

1. Fork the repository
2. Follow the instructions here to transform the raw data from the EUSurvey XML format to RDF and merge that data to the graph pointing the input_rdf as well as the output_rdf variables of the responses_to_ld() function to the './EminentResponses/EminentResponses.ttl' file (effectively replacing it).
3. Create a pull request in the repository.

Step 4 – Create report and share the results and recommendations

Findings and analysis from the assessment are synthesized into a comprehensive report. The report is presented to stakeholders, providing valuable insights and recommendations for organizational improvement. [32]

EMINENT is a tool that aims to increase our ability to create interoperable solutions. Communities learning from each other will absolutely stimulate that growth.

5.9.2.3 How to perform a maturity tracking assessment

Once at least two maturity assessments have been performed on the same community (with sufficient time in between the studies), the community can request a maturity tracking report. This report summarizes the previous results and summarizes the change in maturity across the capabilities and dimensions over time.

Figure 16 depicts the high-level process:

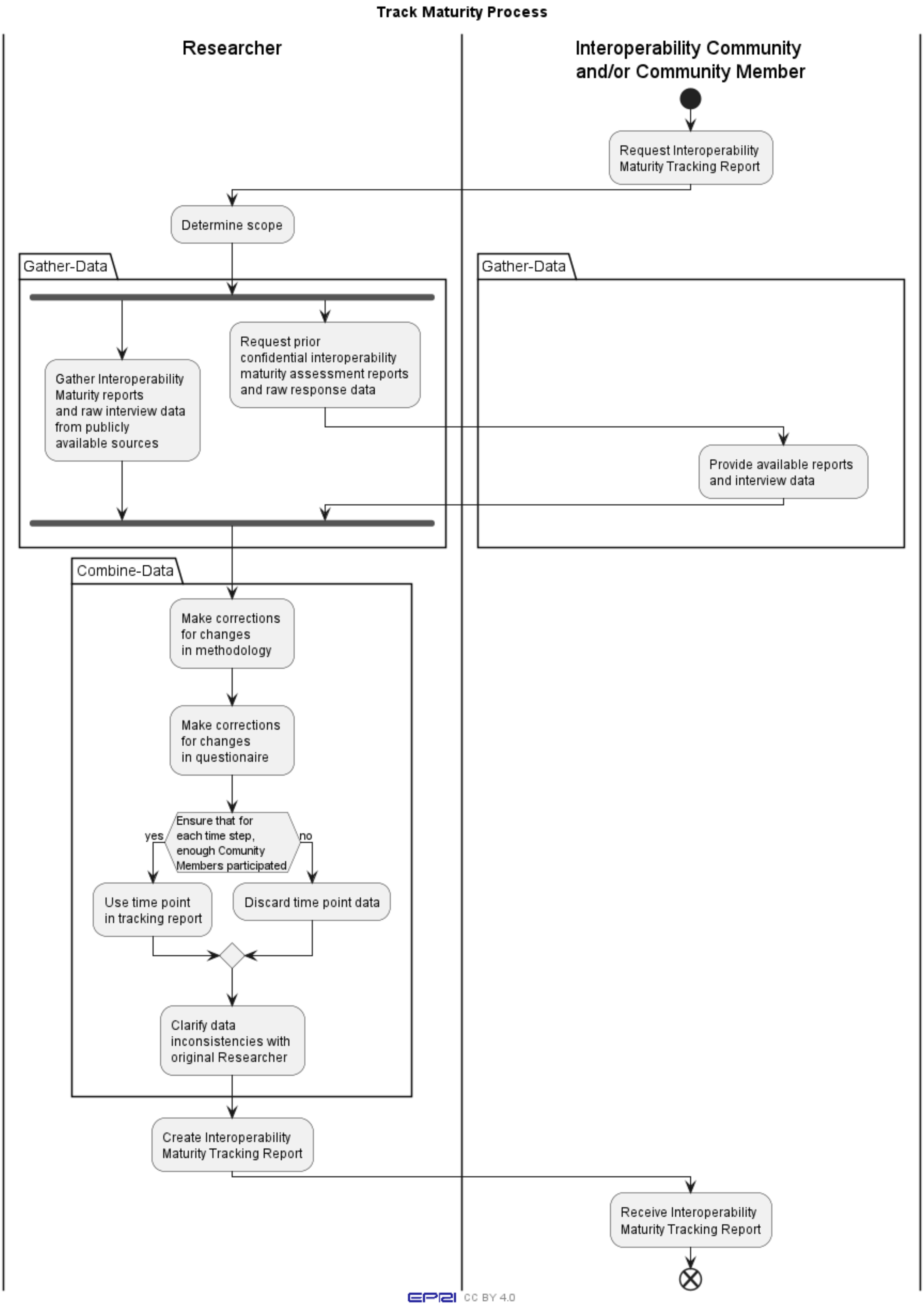


Figure 16 – Overview of the maturity tracking process

Maturity tracking assessment steps:

1. **Process Request Step:**

The Interoperability Community or a Community Member initiates the process by requesting an Interoperability Maturity Tracking assessment. The Researcher collaborates with the requester to determine the scope of the report, ensuring it aligns with the community's objectives.

2. **Gather-Data Step:**

A Researcher gathers all public and/or confidential response data. The Researcher has two options for data collection:

- Option 1: Gathering interoperability maturity reports and raw interview data from publicly available sources, ensuring transparency and accessibility.
- Option 2: Requesting prior confidential interoperability maturity assessment reports and raw response data from stakeholders, maintaining confidentiality where required. The Interoperability Community or Community Member provides available reports and interview data to support the assessment process.

3. **Combine-Data Step:**

The Researcher consolidates the collected data by

- making necessary corrections for any changes in methodology or questionnaire to maintain consistency and accuracy.
- verifying the participation of Community Members at each time step to ensure representative data.
- resolving any data inconsistencies with the original Researcher to ensure the reliability of the final report.

The Researcher may have to reject certain older studies if insufficient people participated (as determined by requirements the community expressed for the study) or if the questionnaire changes sufficiently that the answers given previously cannot be compared any longer to answers given in more recent studies.

4. **Report Creation Step:**

The Researcher performs a data analysis based on the community's needs and creates a report.

The Researcher synthesizes the refined data into an interoperability Maturity Tracking Report, presenting key insights, trends, and recommendations.

The Interoperability Community or Community Member receives the finalized report for review and utilization in decision-making processes, facilitating progress towards enhanced interoperability.

5.9.3 Information models

For the information models we decided to make use of several information standards recommended by the W3C, which are listed hereafter in order of conceptual importance:

- SOSA for the modelling of the questionnaire, the questions and answers as procedures and observations
- Prov-o for the association of the answers to the (non-PII metadata describing) person who supplied the answer
- foaf for the modelling of the respondents
- The Organization Ontology to model the interoperability communities and member(s) (organizations)
- Dublin Core Metadata Initiative Terms for identifiers and part-whole/containment relationships
- Web Ontology Language for the modelling of versions
- Skos for labels and definitions
- RDFS for the information model itself (classes, attributes/associations and subClassOf relationships)

Beyond those several extensions, mostly specializations of SOSA objects were made to make the questionnaire data easier to interpret: calling something a ‘question’ rather than a ‘procedure’ and distinguishing it from a “questionnaire” which is also a ‘procedure’, makes the data easier to consume. Furthermore, we made a model that allowed us to model the area of expertise (of a person) and area of operation (of an organization) in terms of the SGAM framework. An overview of the model can be found in Figure 17.

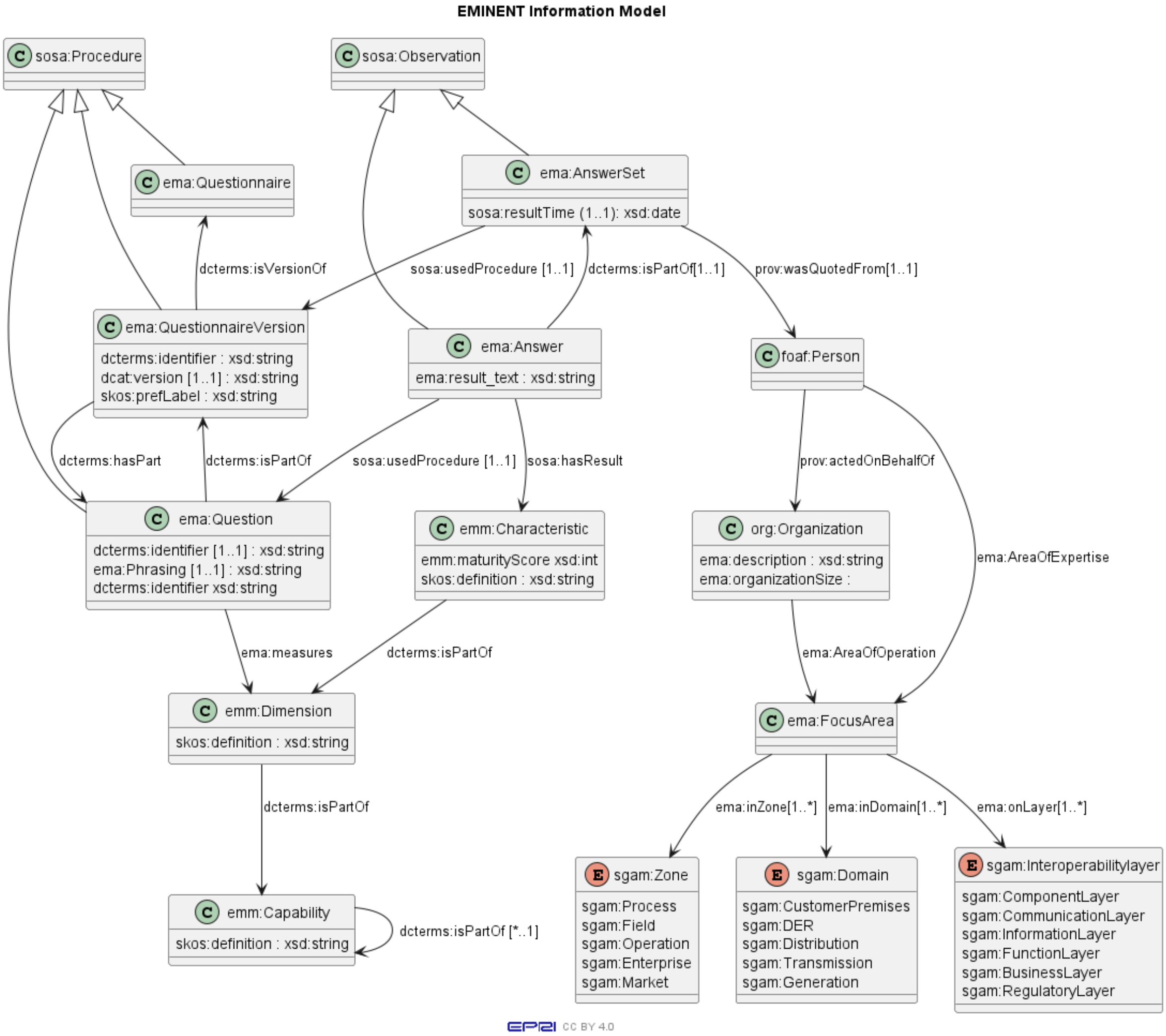


Figure 17 – Overview of the EMINENT Information Model

5.9.4 Minimum Viable Product (MVP)

The Minimum Viable Product (MVP) was created using

- MS Forms for the questionnaire [32]
- Python code for the data analysis
- MS Excel for the database (this data was never published as we were testing the method and are unsure about the quality and consistency of the data)

We chose these technologies because they had the lowest barrier to entry. The MVP allowed us to test the content of the maturity assessment tool with the int:net project community. It suited this function sufficiently. However, we quickly ran into limitations with regards to some of the processes they should support:

- The data model that MS Forms supports for exporting the results is very limited. This has a couple of side effects:

- If the phrasing of a question or a multiple-choice answer changed (because of spelling errors or rephrasing for clarity) the results would become very difficult to combine across changes in the questionnaire.
  - This was a problem while testing the tool and would become an even bigger problem as repeat studies would be done for maturity tracking.
  - The export format required a lot of additional logic for a user to be able to interpret the result data.
- The options that the MS Forms has for sectioning and organizing clarifying information are limited. This means that users would have to scroll up, sometimes multiple screen lengths, to see the definition or clarification of a term used in a specific question.
- MS Forms was ‘eager’ to collect PII. While it is strictly speaking avoidable, the tool makes it very easy to accidentally collect PII as it does it automatically for you, unless you specify that it shouldn’t. If others were to redeploy the survey, or use a private copy, this would collect PII again. We found this unnecessarily risky.
- The excel format did not support the complexity of the information model without adding information structures to compensate for the lack of expressivity that comes with flat tables.
- The excel format for the results (and the database) relies on a proprietary tool, that, while ubiquitous, makes the data less reflective of the FAIR principles.

For these reasons, it was decided to choose a different solution architecture for the EMINENT tooling's production design.

5.9.5 EMINENT Tool

The tests involving the MVP validated our use case and process designs, as well as our reference data models. While python proved a perfectly fine technology to automate the necessary data processing, the questionnaire tooling and the database tooling selected in the MVP required a lot of concessions on either functionality or the simplicity code for automation.

For the production version of EMINENT the following tooling was chosen:

EUSurvey for the **questionnaire**

- The ‘live’ survey can be found here: https://ec.europa.eu/eusurvey/runner/Eminent [25]
- The artifact that allows others to deploy their own implementation can be found here: https://github.com/int-net/EminentSurvey [26]

Python code for the **data analysis**

- Can be found here: https://github.com/int-net/EminentReportingTool [33]

  This package provides two sets of functions:

  - transform the data from the EUSurvey XML format to RDF and add those to the RDF graph
  - generate the spider diagrams based on the RDF data

RDF based **database publication** on Github

- Can be found here: https://github.com/int-net/EminentResultsDatabase [31]

This tooling suite complies fully with the processes and requirements that were stated above.

5.10 Testing the Tool and collecting the Feedback

In this chapter, the process of testing the EMINENT tool with specific groups of interest will be explained. Both challenges and successes have been identified and described.

5.10.1 Identification of the relevant interoperability community

Considering the novelty of the interoperability challenges within the energy transition, it was first crucial to define the notion of interoperability community. In this context, interoperability community refers to a group of experts and developers from different industries that come together to promote interoperability within the energy sector. Once the concept was defined, two relevant communities were selected considering (a) their involvement in the development of interoperability solutions and (b) their knowledge of interoperability challenges, and they were further divided into two segments: utilities and non-utilities.

The Common Information Model Working Group (CIM WG) community is formally established within ENTSO-E with the goal of facilitating the development and the implementation of standardized data exchange formats used by TSOs, Regional Coordination Centers (RCCs), ENTSO-E, and their counterparts. This helps to fulfil requirements from regulations for interoperability and standardization of data exchanges in the electricity sector, while lowering the costs for all parties involved in these activities.

On the other hand, the Semantic Interoperability Framework (SIF) community has been established as "SIF without a centrally hosted facilitator leveraging SAREF ontology in all the project pilots". The goal is to promote interoperability between buildings and the grid to enable the provision of flexibility services. In this context, the SIF provides a structured approach to achieving semantic interoperability by defining common standards, models, and vocabularies that enable effective communication and data exchange across diverse systems and domains where existing models and standards had previously grown in parallel.

5.10.2 Completion of the survey

Once the relevant communities were identified and their interest in evaluating EMINENT was confirmed, the testing was done in two steps. First, the members of the different communities were invited to complete the EMINENT survey.

The SIF community was initially given a presentation of the tool and detailed information on navigating through the questionnaire. Based on the responses received, the second step was the organization of a workshop in which the EMINENT mentors provided a detailed walk-through the tool, with a thorough description of the different elements and capabilities that are assessed in the model. This was followed by a space for the audience to directly question the mentor, gather the participants' feedback and assist in the completion of the survey.

In the context of the CIM community, the initial phase involved a presentation in the monthly working meeting, requesting them to complete the survey by using the tool. During the meeting the importance for energy sector companies to evaluate the level of maturity regarding interoperability in the different capabilities was stressed. Then, it was requested to complete the survey employing the designated tool in the following two weeks. Only three answers trickled in, casting a shadow of doubt on the effectiveness of the approach taken.

After one week, a reminder was sent out. This proactive step provided marginal improvements, but the response rate remained disappointingly low.

Acknowledging the need for a more direct approach, the team decided to organize a specific workshop tailored to the group of interest's needs. This workshop served as an opportunity to go deeper into the survey's intricacies, providing clarity on its purpose and methodology. Armed with a comprehensive understanding, participants filled out the survey during the workshop.

As a final result, the workshop proved to be a turning point. Four additional stakeholders not only participated but also provided valuable insights and feedback. This increased participation reaffirmed the team's confidence in the tool's potential.

5.10.3 Feedback collection

The testing was mainly conducted during the interactive sessions in the online meetings. In this context, it is possible to group the feedback received in 3 different axes:

1. Comprehension and adequacy of the questions to the reality of their communities

This refers to the effectiveness and relevance of questions posed within their community.

- During the pre-testing phase, the int:net consortium highlighted the importance of defining the concept of community and identifying who should be filling the questionnaire on behalf of the community.
- During the testing phase, the SIF community remarked that the length of the questions made it complex to understand the concepts that were being tested. Showcasing the need to define the concepts tested more concisely.
- During the workshop session, the participants indicated that it was not easy to interpret the representation questions without the explanations made during the workshop. Identify if you

are representing the company, an area of the company, the group of interest, or the association was not completely clearly defined in the survey.

2. Privacy concerns

During the pre-testing phase it was highlighted that sharing data from the community members and integrating it to other platforms can raise privacy concerns. These may include data leakage from sensitive data to unintended parties. This is particularly an issue when the data being used in the interoperability test includes personally identifiable information or other sensitive data. As a result, within EMINENT, it is the community that decides the scope of the study and the researcher needs to agree on a code to identify the study. This GDPR compliance has been valued positively by all the communities interviewed in the testing phase.

3. Motivations for them to answer the questionnaire

In this section it is also important to mention the feedback collected about the motivation of the different communities to participate in the EMINENT survey. The SIF community was mainly motivated by the fact that measuring interoperability levels in a community benefits stakeholders in terms of choice, cost and experience in using an interoperable solution such as the SIF.

- During the workshop, the importance of sharing the results with the group of interest and providing next steps was noted. Organizing an additional meeting/workshop to explain the results in detail is also preferable. Additionally, it was proposed to present a summary of the results in the group of interest meeting, but a dedicated meeting could be more fruitful.

5.11 Analysing the Maturity of three different communities

This chapter will look at the results of the survey, as performed on 3 different interoperability communities.

The results from the int:net project community were gathered using the MVP of the tool. While the questionnaire and the answers were phrased identically, the MS Forms tool made use of a different information model, to the point that harmonizing the data between the MVP and the production tooling was considered but rejected as it didn’t add sufficient value.

The ultimate maturity scores are based on the average scores as mapped between the characteristics as selected by the respondents. While medians, modes and standard deviations are also computed by the tool, these have been left out of this discussion. For the full data analysis, these values may be useful to identify outliers and disagreements within the communities. As we wish to focus on the ‘maturity’ discussion and less on the ‘statistical methods for analysis’, we have decided to omit this part of the results from this document.

Finally, the MVP tool did not support the option to analyse the respondent population, whereas this is a supported function in the current version of the tool. Therefore, these diagrams are only included in the analysis of the CIM expert group and SIF community.

5.11.1 int:net project community

For this study, 80 people were invited to participate in the study representing 13 organizations. Of the 80 people, 12 responded. The overall results can be found in the spider diagram of Figure 18.

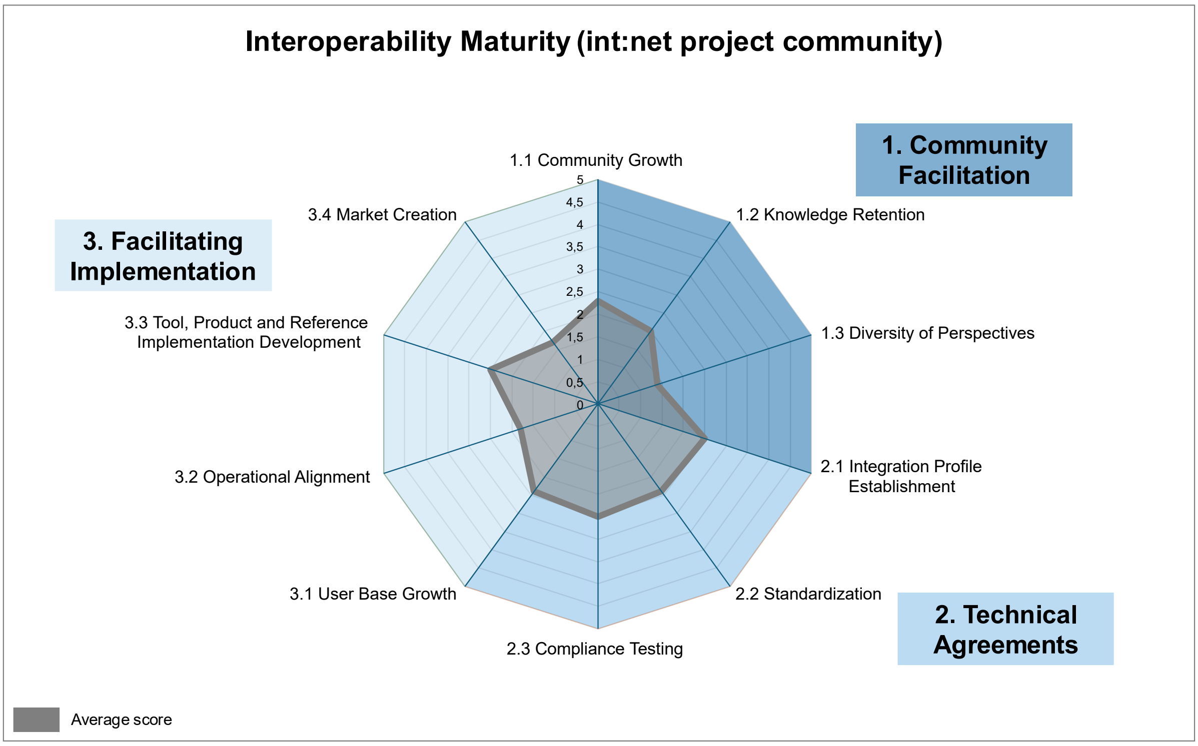


Figure 18 – Overview of IOP maturity of int:net project community across all capabilities

From the diagram, it can be inferred that the *Technical Agreements* capability is the strongest with all three sub capability scores around 2.5. The *Community Facilitation* capability scores lower, specifically showing a dip around *Diversity of Perspectives*. Finally, *Facilitating Implementation* shows scores between 1.7 and 2.5 for *User Base Growth* (2.4)*, Tool, Product and Reference Implementation Development* (2.5), but lower on *Operational Alignment* (1.8) and *Market Creation* (1.7).

Diving deeper into the *Community Facilitation* capability, we can see the scores for the individual dimensions in the diagram of Figure 19.

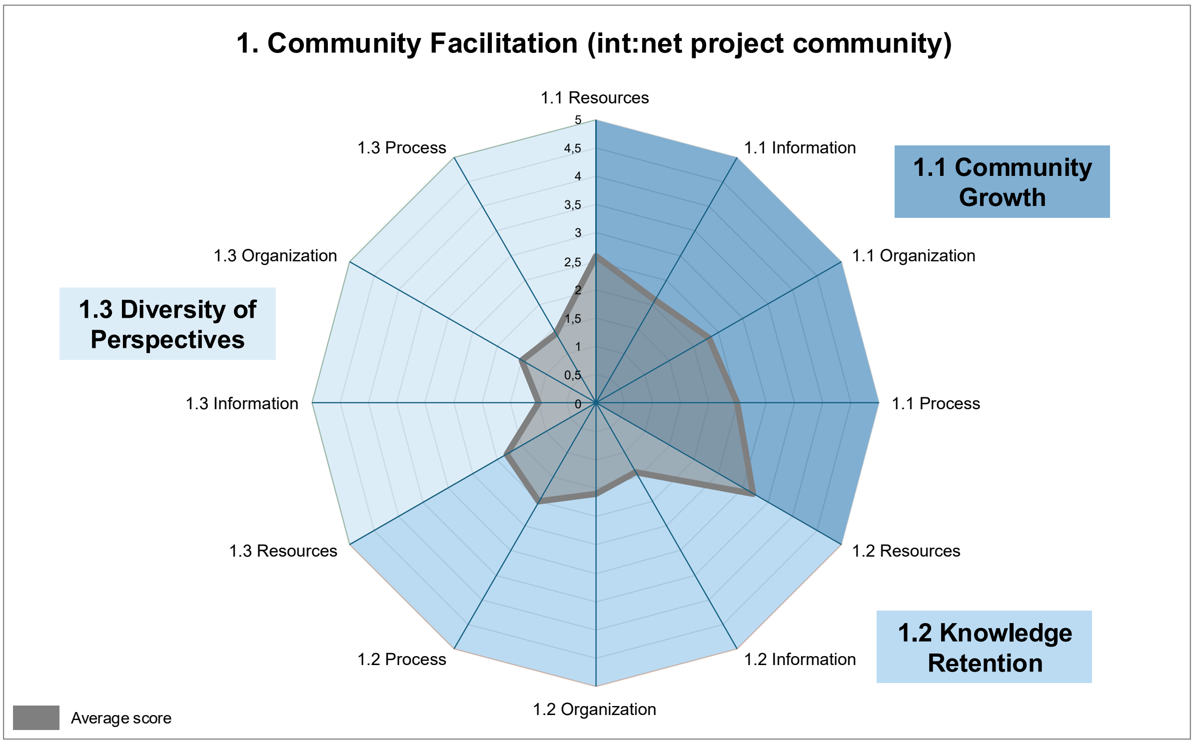


Figure 19 – Detailed view of IOP maturity of int:net project community for 'Community Facilitation' capability

Looking in depth at the sub-capabilities and their respective dimensions, we get more insight into the communities' evaluation of its own maturity in this area. As expected from the overview diagram, *Community Growth* scores well across all dimensions. Looking at *Knowledge Retention*, we see a shift. While the *process* dimension scores reasonably well with a score of 2, the *people and organization* and *information* dimensions score relatively low with a score of 1.6 and 1.4 respectively. The average of this capability is pulled up significantly with the score of 3.2 for the *resources* dimension. Discussing this with the respondents we found that while there are processes for knowledge retention - collecting information on use cases, testing and interoperability is part of the core deliverables of the project after all - the information that results from those processes was considered to be hard to find. As a consequence, the community is paying extra attention to the findability of this information to address this concern.

When looking at *Diversity of Perspectives* the scores are overall low. This is not strange considering the int:net project is executed by a consortium of primarily research organizations. This means that the group, at this point, is relatively static (there are basically no options for introducing new perspectives by bringing on new consortium members) and most of the industry itself - utilities, energy companies, consumers, manufacturers - are at best indirectly represented through the participating umbrella organizations (ENTSO-E and E.DSO). The int:net community itself has limited options to change this aspect of maturity.

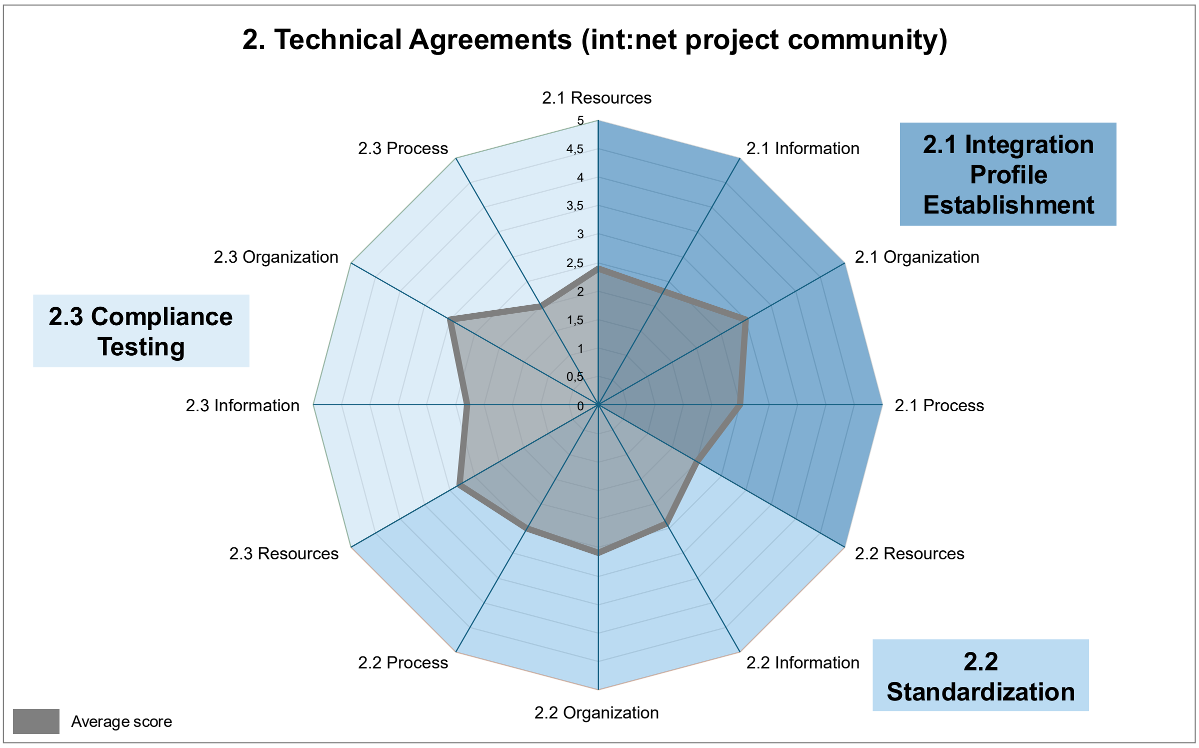


Figure 20 – Detailed view of IOP maturity of int:net project community for 'Technical Agreements' capability

Looking at the detailed overview for the *Technical Agreements* capability, we see overall consistent high scores. The one point that is worth observing is that for the *Compliance Testing* capability, the *people and organization* dimension and the *resources* dimension score high, the *process* dimension (2.3) and *information* dimension (2.3) score a bit lower. But with all scores above 2, that is still a rather strong performance. Discussing this with the community, we received feedback that, because the project does not do any compliance testing itself, it was felt that the *process* dimension for it was weaker as it is out of scope.

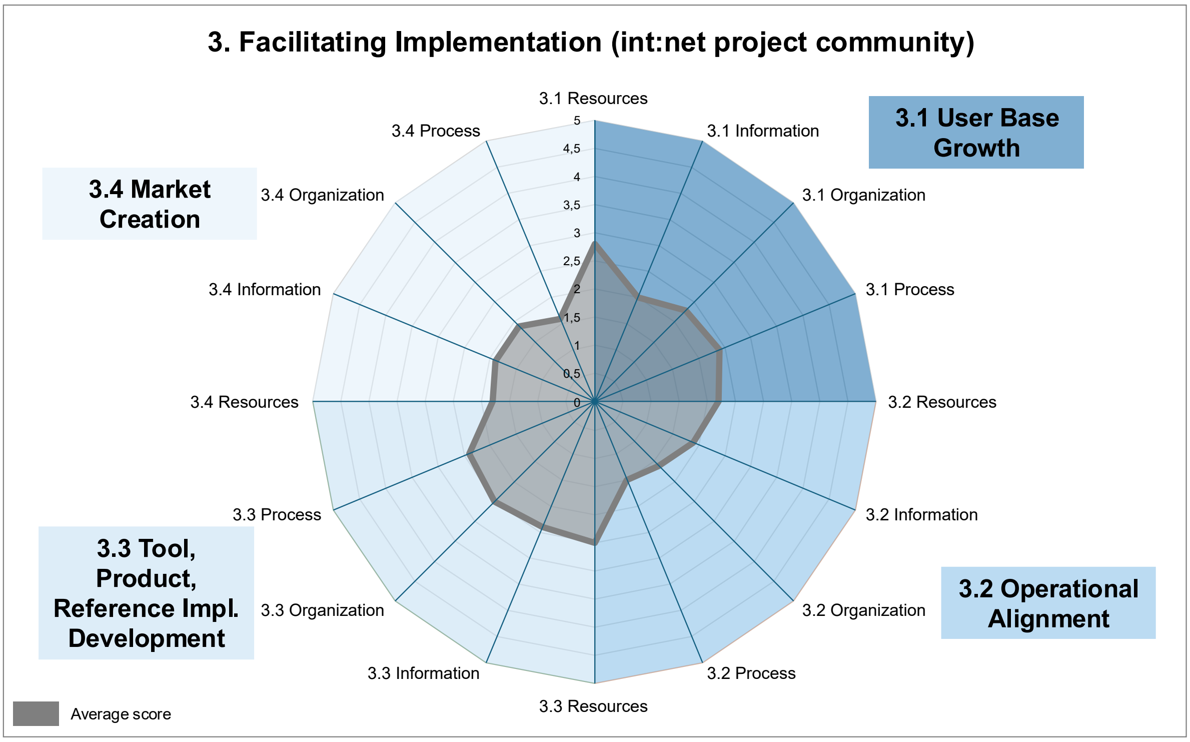


Figure 21 – Detailed view of IOP maturity of int:net project community for 'Facilitating Implementation' capability

Looking at the *Facilitating Implementation* capability in detail, we see strong performances in *User Base Growth* and *Tool, Product and Reference Implementation Development*. In discussions this was explained by the project's efforts on creating the int:net community platform (*User Base Growth*) and the development of the EMINENT maturity model as well as the development of the platform (*Tool, Product and Reference Implementation Development*). *Operational Alignment* scored lower as it is outside the scope of this project and the same can be said for *Market Creation*. It is worth noting on that last one that this study was performed before the start of organizing the workshops for the use of EMINENT. It would be interesting to see if market evaluation scores better as those efforts get started.

Overall, this study gave the sense that the int:net community is quite strong. This study also helped the creators of EMINENT to understand that not all low scores are immediately points of attention. While the *Knowledge Retention* capability, with its low score on the *information* dimension, triggered immediate action in the community to inform each other where information could be found, other capabilities were simply out of scope of the project, or outside of the project's influence to change. The low scores, whether in the power of the community to change or not, do hint at potential risks for the outcome: When funding ends (project based funding consistently limited the score of the *resources* dimension), it remains to be seen if the outcomes of the projects, that have almost exclusively been developed by research organizations, prove relevant enough for the industry to be adopted (this is where the *Diversity of Perspectives* comes into play).

5.11.2 CIM expert group

The CIM expert group, organized by the ENTSO-E, has 34 members representing 40 TSOs. 7 out of 34 addressed replied. Because we have to consider the GDPR for the public data base, no information on the respondents has been collected and we do not know which organizations they represent. However, respondents are asked to indicate their area of expertise in terms of the SGAM framework. The aggregated result is shown in the diagram below.

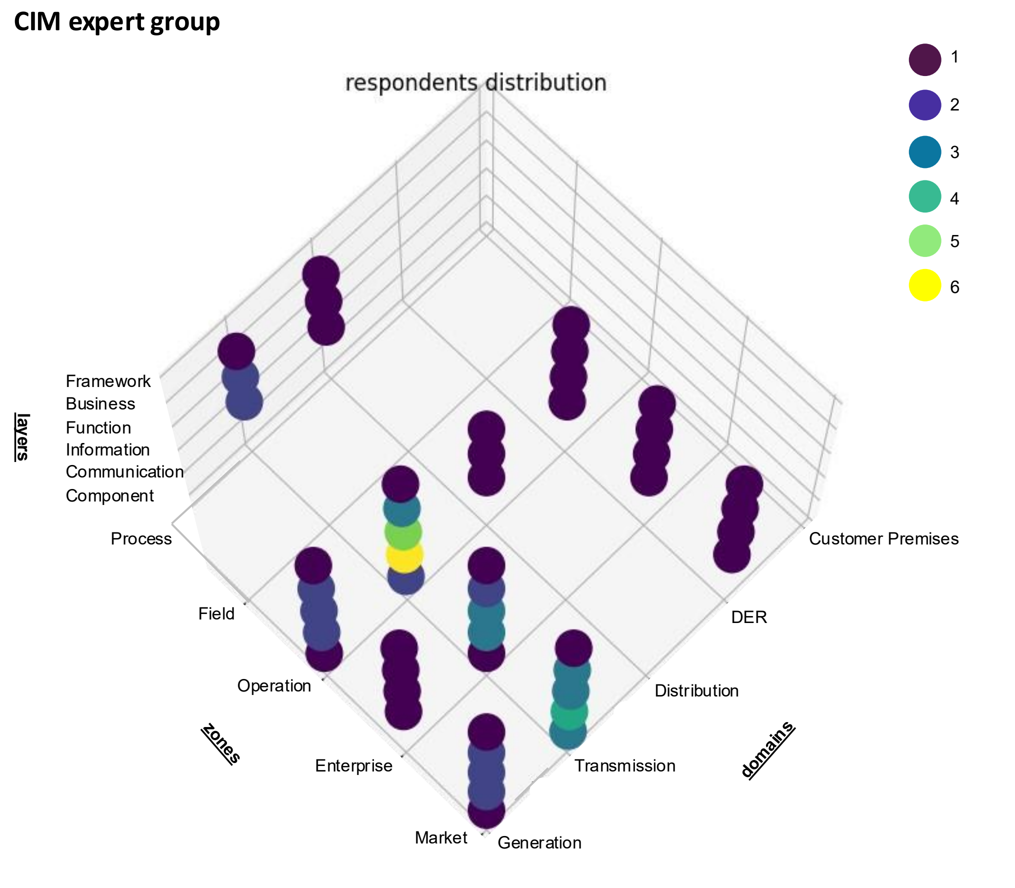


Figure 22 – Overview of area of expertise of respondents of CIM expert group

This diagram shows that while the respondents combined have a wide area of expertise, it also clearly shows that most respondents indicate their area of expertise includes the Transmission-Operation-Information Layer, given that the CGMES as a use case sits at this area in the SGAM Framework.

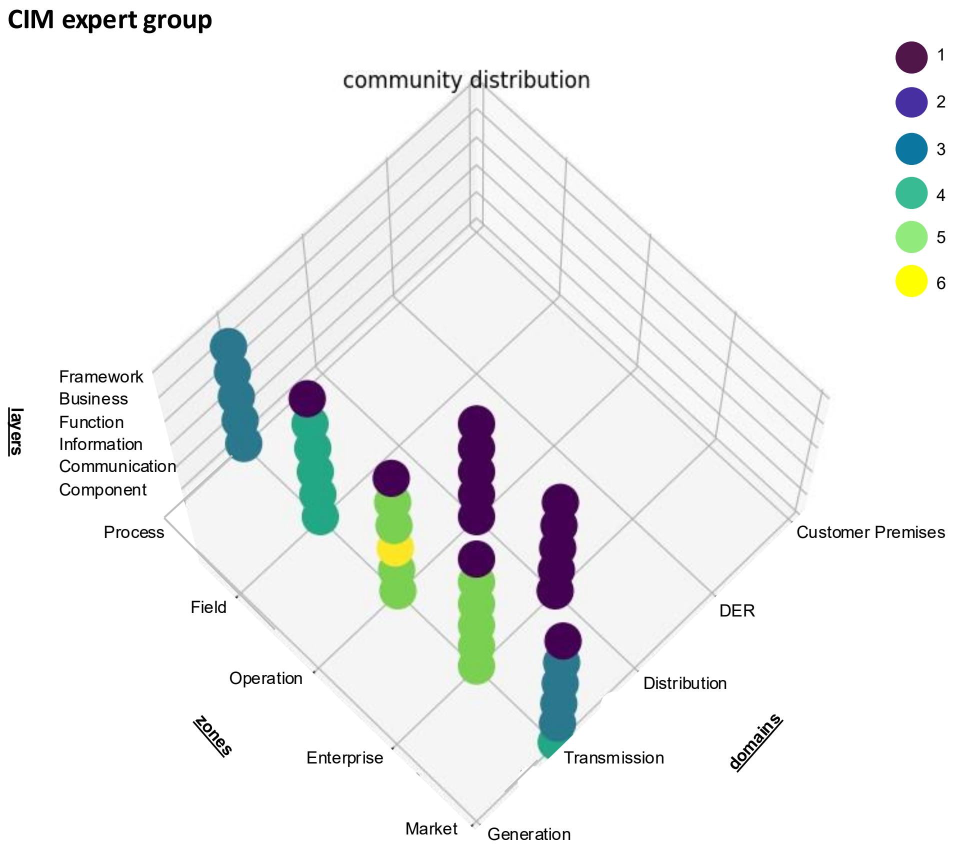


Figure 23 – Overview of area of operation of organizations represented by respondents

The area of operation of the organizations that are represented by the respondents also comes as no surprise with the majority of the respondents indicating their organization is active in the Transmission domain, across all zones and all interoperability layers. Given that these organizations are all TSOs, this is what we would expect.

The overall results from the maturity assessment can be found in Figure 24.

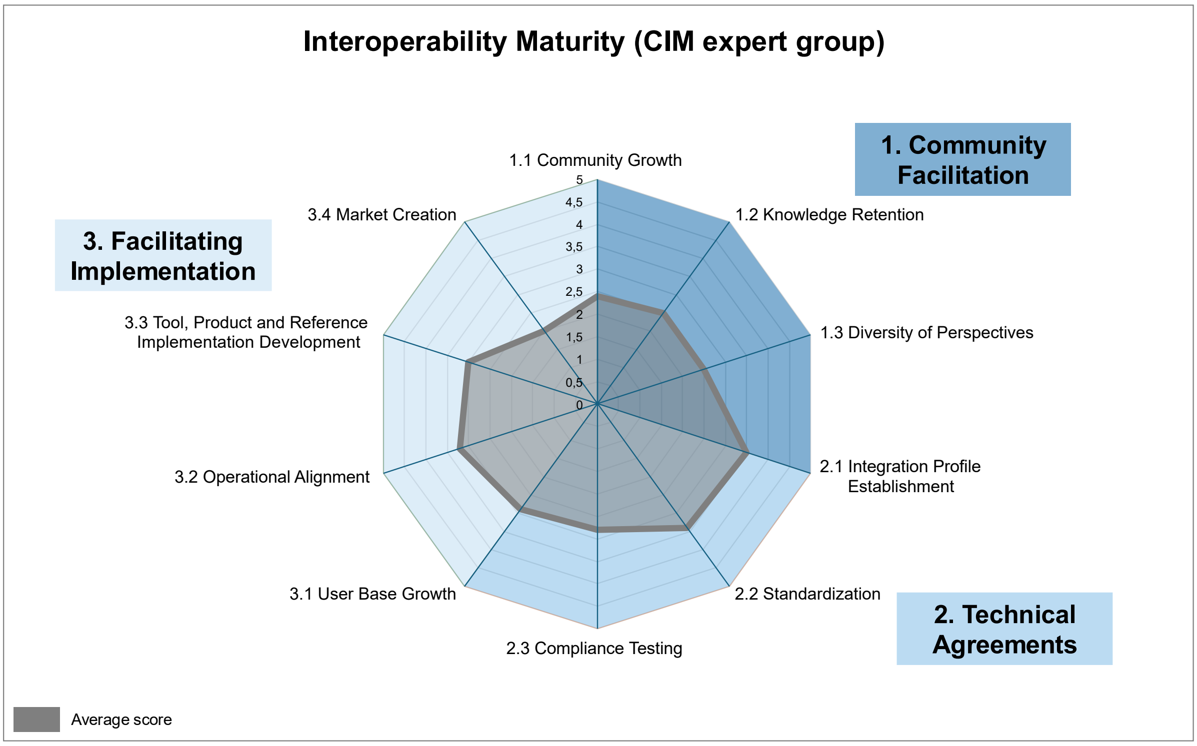


Figure 24 – Overview of IOP maturity of CIM expert group across all capabilities

With a lowest maturity score of 2 across all dimensions, and the capabilities of *Integration Profile Establishment* and *Standardization* receiving scores as high as 3.5 and 3.4 respectively, it can be said that this is a well-rounded, stable interoperability community. This should come as no surprise as this group represents one of the prime examples of interoperability: the continent-wide coordinated security analyses and the standardization of an extremely complex dataset across 40 TSOs. This interoperability effort is the textbook standard of successful interoperability. And yet, according to its own members, there is room for improvement.

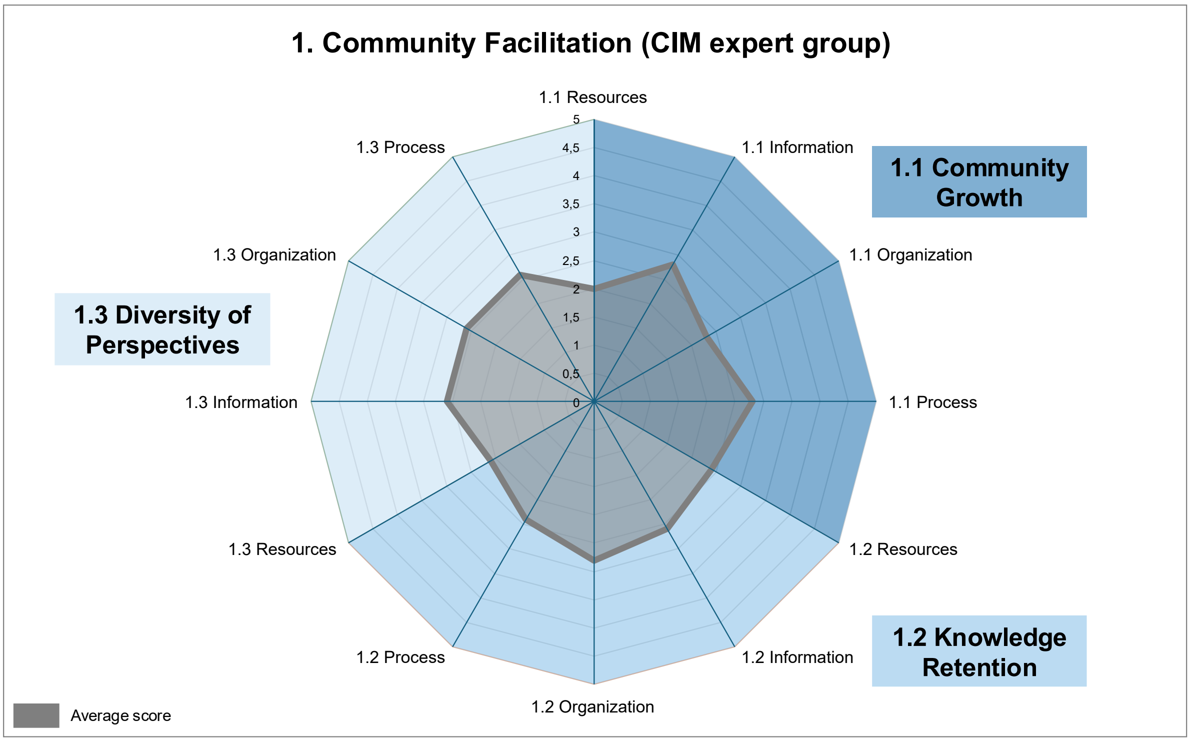


Figure 25 – Detailed view of IOP maturity of CIM expert group for 'Community Facilitation' capability

With average maturity scores between 2 and 3, the *Community Facilitation* is the capability that, for the CIM expert group, has the most room for growth. Between the strictly mandated target audience of the 40 ENTSO-E member organizations, room for *Community Growth* is limited, although replacing people who leave is an important task. This community faces some unique if not ‘extreme’ challenges. The pool of potential CIM experts sits at the (very small) intersection of two small sets. Between scarcity of power grid engineers, and the scarcity of semantic (data/information) modellers, the group of people who understand both is extremely small.

This problem affects the relatively low score (again, compared to the other capabilities and dimensions) of *Knowledge Retention*. The set of standards that this group develops and maintains is, by its very nature, very complex. This community has developed a strong culture of knowledge sharing, training and information/experience sharing. What we see here is that the existing efforts are felt to be ‘not enough’ by the community to meet the needs of the standard.

The *Diversity of Perspectives* capability led to some interesting feedback by the community. On one hand, compared to the mandate that the ENTSO-E has, this group could be considered almost ‘complete’. On the other hand, there are two axes that more diversity may be desired. One concerns the increasing importance of TSO-DSO information exchange. On the other hand, one person expressed that this was a group primarily consisting of enterprise/data architects, while leadership, who is mandated to validate the standards which this group produces, is organized in a separate committee. This seems to suggest a question about whether the current format still fits the needs of the interoperability effort optimally.

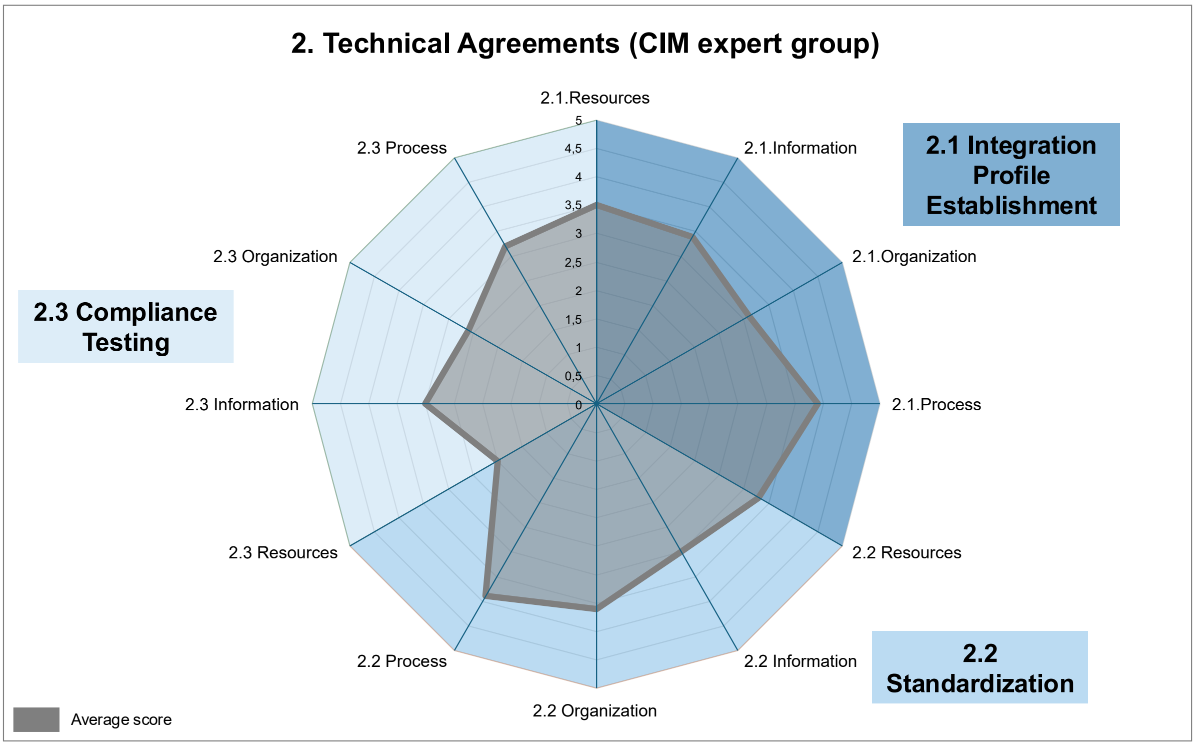


Figure 26 – Detailed view of IOP maturity of CIM expert group for 'Technical Agreements' capability

In the *Technical Agreements* capability, we see more variation with strong scores (>3) for both *Integration Profile Establishment* as well as *Standardization* across all dimensions. The *Compliance Testing* capability lags, comparatively, behind with relatively low scores in the *people and organization* and *resources* dimensions. This could be due to the difficulty of finding a suitable and sufficiently extensive testing framework for the complex data exchange specified by the CGMES. It would be interesting to see if the adoption of the SHACL standard for data validation will change this.

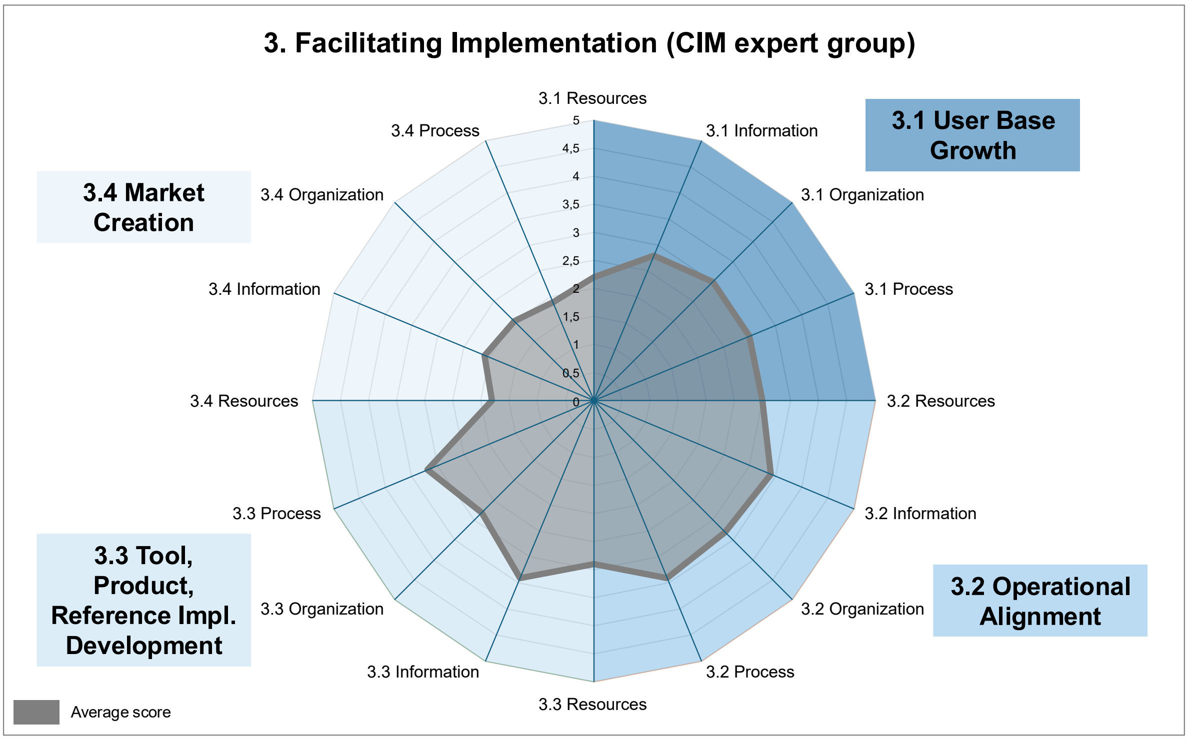


Figure 27 – Detailed view of IOP maturity of CIM expert group for 'Facilitating Implementation' capability

Looking at the detailed maturity scores for *Facilitating Implementation* we see relatively high scores for *Operational Alignment* and *Tool, Product and Reference Implementation*. The high scores for *Operational Alignment* can be explained by the fact that this incredibly complex system is in fact operational. The TSOs and Regional Security Coordinators (RSC) have been required to design and implement the processes that implement these standards and have had to make agreements about how to treat each other's data. The high scores for *Tool, Product and Reference Implementation Development* can probably be ascribed to the fact that this community has had to innovate to be able to develop these standards and several tools to support that effort, as well as applications that comply to the CGMES which have been developed in the process. It has to be noted, that for both these high scoring capabilities, the *resources* dimension is trailing behind the other dimensions with scores around 2.5.

The capabilities *User Base Growth* and *Market Creation* have comparatively low scores in this group. The most obvious explanation for *User Base Growth* is that the scope of this community are the TSO members of the ENTSO-E, which are a relatively static community. It seems plausible that there is a strong correlation between the static group of users and the limited score in *Market Creation* as vendors may have limited incentive to invest in the development of such complex systems while the market, that is required to comply to this standard, is limited to 40 TSOs. Efforts to expand the adoption beyond the ENTSO-E members might make it a more attractive market to engage in. This might include expanding to the DSO domain, which within Europe is moving towards the use of CIM or expanding outside of Europe. While either of these options seems plausible, one should keep in mind that this particular group has a specific mandate derived from the European Network Codes for the TSOs (alignment on the SGAM Framework layer [28]). Introducing new members to this community will therefore also require a revaluation of the Framework layer of this interoperability community and it is, at this point, not self-evident that this is even feasible.

5.11.3 Semantic Interoperability Framework (SIF) community

This study involved the SIF community from the interConnect Horizon Europe project. A total of 7 responded out of 20 people who were invited to fill out the survey.

The area of expertise of the respondents in terms of the SGAM framework can be found in Figure 28.

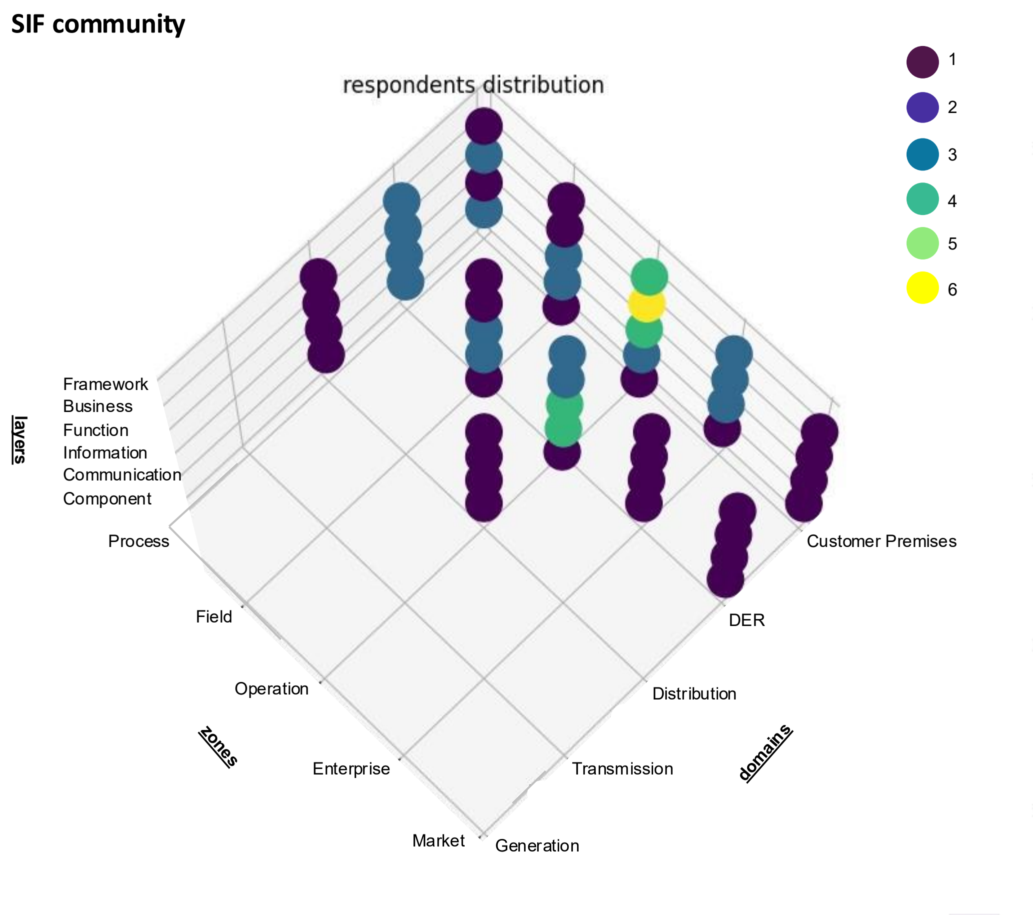


Figure 28 – Overview of area of expertise of respondents of SIF community

Given the fact that the SIF community focusses on home energy management products, it makes sense to see most respondents have expertise in the DER and Customer Premises domains. It is interesting to see that most of the respondents indicate expertise in the Function layer (in the intersection of the Operation zone and the Customer Premises domain). Yet there is still plenty of expertise in the Information layer of the Operation zone for both Customer Premises and DER domains, in line with one would expect for a community focussing on semantic interoperability.

SIF community

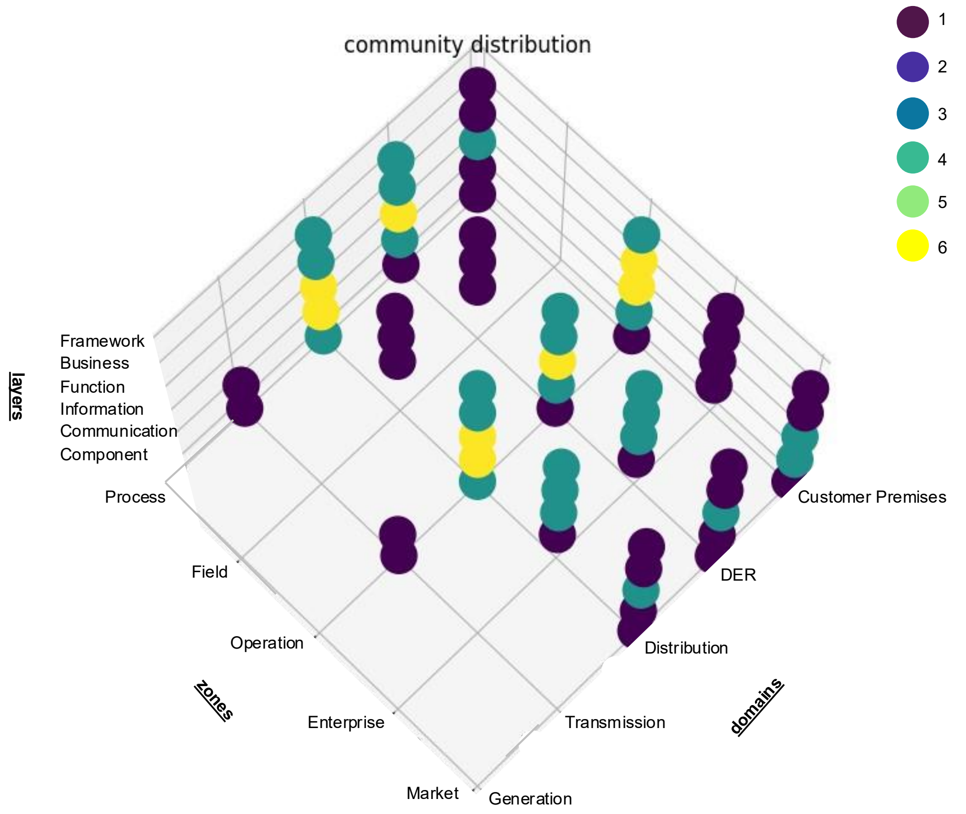


Figure 29 – Overview of area of operation of organizations represented by respondents

The area of operation of the organizations represented by the community is quite diverse, with a clear emphasis on Distribution, DER and Customer Premises domains.

The overall interoperability maturity scores for the SIF community can be found in Figure 30.

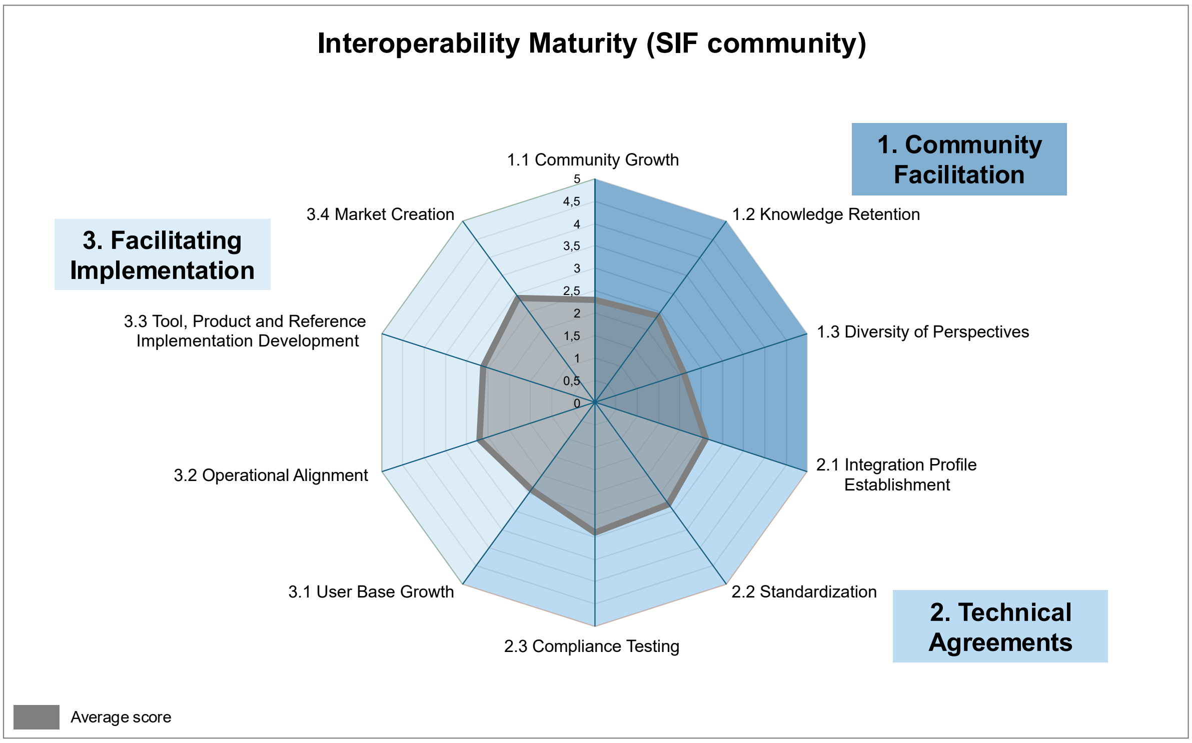


Figure 30 – Overview of IOP maturity of SIF community across all capabilities

With overall consistent scores between 2 and 3, this community is quite well rounded, especially considering how young it is (compared to the >10 years that the ENTSO-E and its members have been working on the CGMES). The high scores (of around 3) in *Standardization*, *Compliance Testing* and *Market Creation* suggest that this effort is very implementation and adoption driven. The lowest score (of a little over 2) for *Diversity of Perspectives* is a trend we see in all the communities while the second lowest score for *User base Growth* (with 2.3 still relatively strong) may be attributed to the relative short period that this community is active.

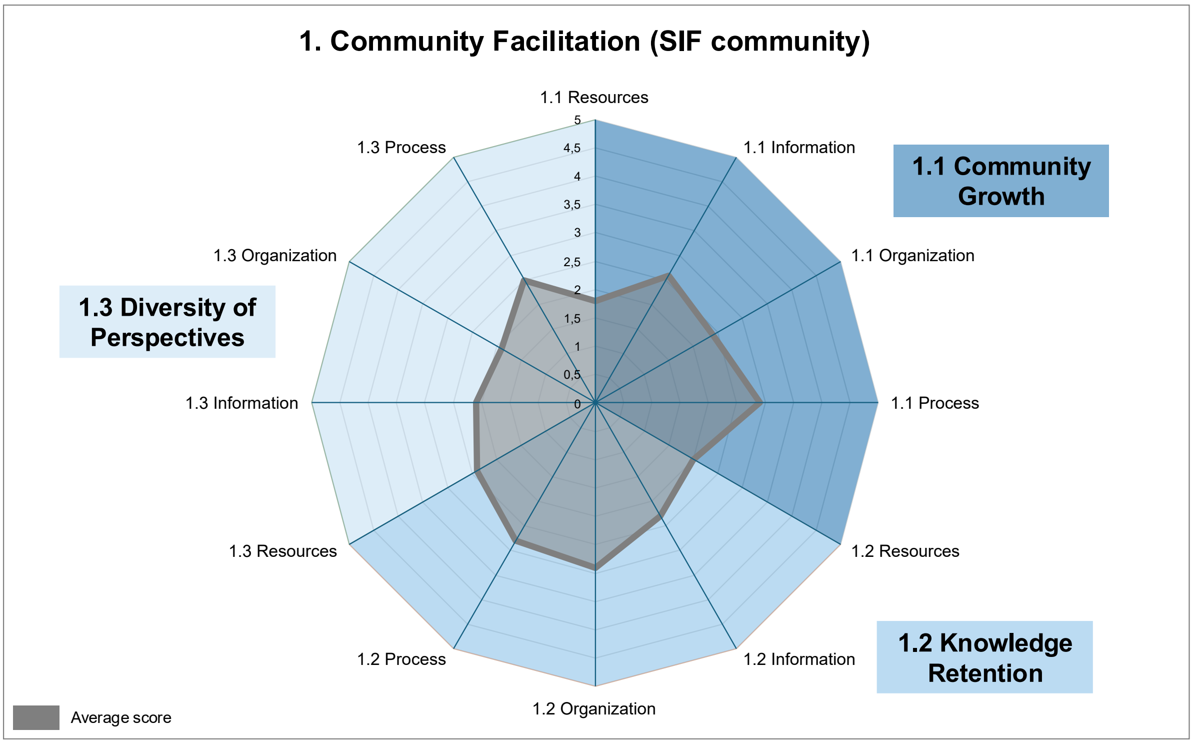


Figure 31 – Detailed view of IOP maturity of SIF community for 'Community Facilitation' capability

Looking at the *Community Facilitation* capability we see some patterns which we recognise from the study on the int:net community. Because this community is formed in the context of a Horizon Europe research fund, the community is restricted to the consortium members that are on board. This limits the opportunities for *Community Growth* and decreases the *Diversity of Perspectives*, as indicated by the relatively low scores the respondents gave. On the other hand, the community has organized *Knowledge Retention* quite well with high scores for both the *process* and *people and organization* dimensions. We will follow up with the community to explore how the *information* and *resources* dimensions may be improved.

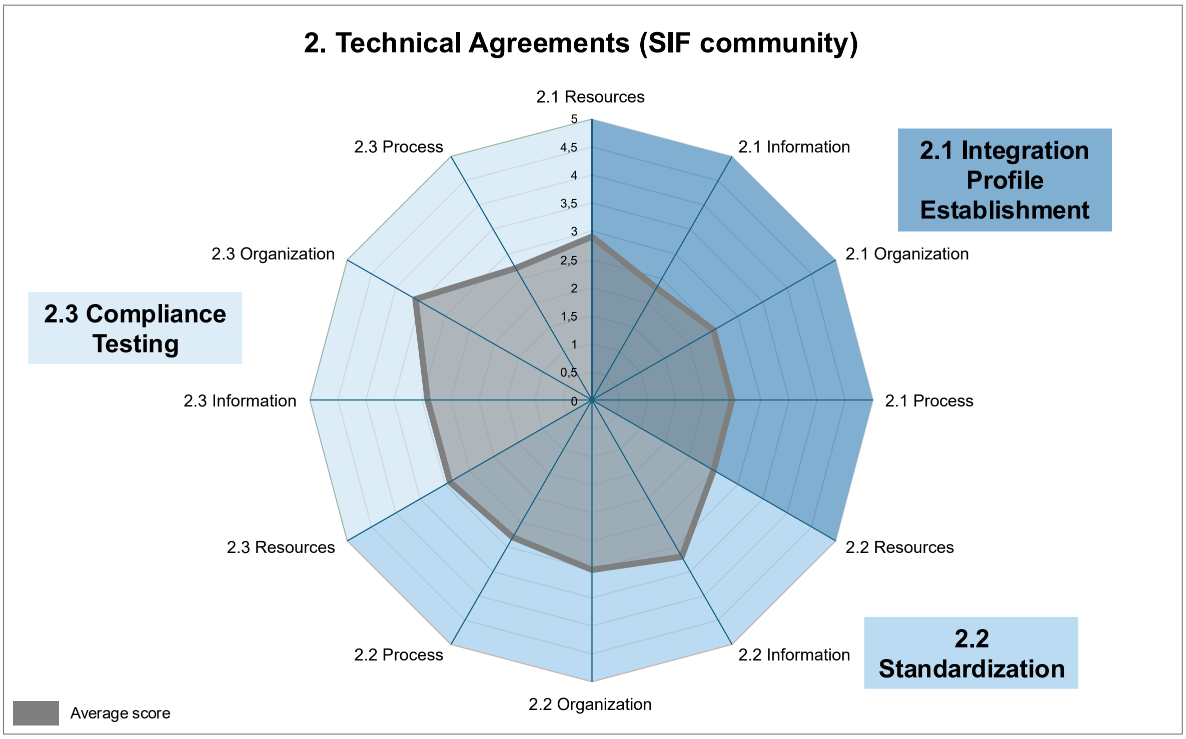


Figure 32 – Detailed view of IOP maturity of SIF community for 'Technical Agreements' capability

Looking at the *Technical Agreements* capability we see strong performance across all three sub-capabilities, but in particular the *people and organization* (3.0) and *information* (3.2) dimensions of *Standardization* and the *people and organization* (3.6) dimension of *Compliance Testing*. The ability to rely on the SAREF standard gives this community a strong reference to work from.

The *process* (2.5), *people and organization* (2.5) and *information* (2.3) dimensions of *Integration Profile Establishment* lag comparatively. While these are still impressive scores, it seems that there is room for improvement on how the community achieves agreement on the problem statement(s) for the use cases that seek an interoperable solution. Another notable (relatively) low score is the *resources* (2.5) dimension of *Standardization*.

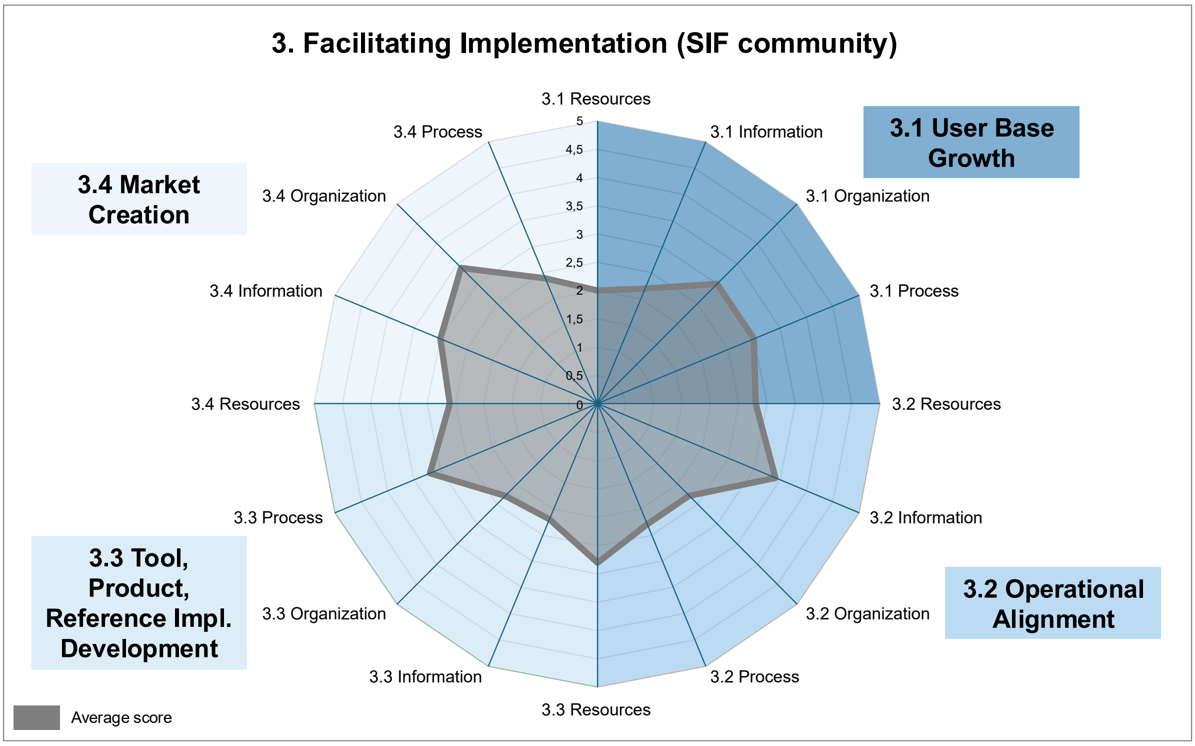


Figure 33 – Detailed view of IOP maturity of SIF community for 'Facilitating Implementation' capability

In the *Facilitating Implementation* capability, we see larger swings in maturity than we see in the other level 1 capabilities. In *User Base Growth* we see high scores for the *process* (3.0) and *people and organization* (3.0) dimensions, but then comparatively low scores for the *information* (2.2) and *resources* (2.0) dimensions.

For *Operational Alignment* we see the opposite pattern, with relatively low scores for the *process* (2.3) and *people and organization* (2.3) dimensions and relatively high scores for the *information* (3.4) and *resources* (2.8) dimensions.

For *Tool, Product and Reference Implementation* we see high scores for the *process* (3.2) and *resource* (2.8) dimensions while we see relatively low scores for the *people and organization* (2.3) and *information* (2.2) dimensions.

Finally, for the *Market Creation* capability, we see relatively high scores for the *people and organization* (3.4) and *information* (3.0) dimensions, but lower scores for the *process* (2.4) and *resources* (2.6) dimensions.

The explanation for this rather high variation in the scores will require a more in-depth exploration with this community. None of these scores should be thought of as ‘bad’. But they do suggest some points for attention.

5.12 Barriers, challenges and lessons learned

The challenges identified during the creation, testing and processing of the results collected by the tool have led to an exhaustive list of lessons learned. These will be clustered considering the phase where they originated and will be the basis upon which int:net task 2.4 will further develop the EMINENT tool.

5.12.1 Barriers, challenges and lessons learned during the creation of the tool

During the development of the EMINENT tool and data analysis software some challenges were encountered that persist in the current.

While the EUSurvey XML format is much more descriptive than the MS Forms and MS Excel formats, EUSurvey still leaves some peculiarities that users should be aware of. The most important points are:

- While questions, multiple choice options and answer sets are assigned a (globally) unique and persistent identifier, an individual response to a question does not. To overcome this, the data transformation tooling in python creates a unique identifier based on a hash of the combination of the question id and the answerset id.

- The XML dump of the data draws no explicit relationship between a question and its permitted multiple-choice answers and instead relies on the order in which the elements occur in the document. Since order may not persist across different (re)serializations of an XML document (the XML standard does not require this), this is a very weak way of linking questions to answers, that can furthermore not easily be parsed by receiving applications.
- The tool allows for the creation of persistent questions and multiple-choice answers, meaning that if you change the phrasing of a question or a multiple-choice answer, the application and the database will remember it as the same question/multiple-choice answer (which was a major deciding factor in selecting this tool: with MS Forms the tool treats a question of which the phrasing has changed as a new question, same with multiple-choice answers).
  - **However, this means that changes must be made by modifying an existing object in the questionnaire, not by deleting one and replacing it by another.** We were reminded of this the hard way.

Concerning long term data management and GDPR, we decided not to collect any person identifiable information. While this has the benefit of simplifying the GDPR process, it creates some challenges for:

- **Following up on particular responses:** If the researcher has some questions about how to interpret specific responses, they do not know who provided those responses so they cannot ask the original submitter for clarifications.
- **Sending out reminders to fill out the survey:** We encountered the challenge of having to send all the invitees reminders to fill out the survey even if some of them already did since we had no way of telling who did and who didn’t. This is a minor inconvenience, but when you are relying on people’s goodwill, it causes some frustration.

5.12.2 Barriers, challenges and lessons learned during the testing of the tool

In this chapter we delve into the obstacles, challenges and lessons learned throughout the testing phase of the tool. Through analysis and reflection, the following key insights have been gained from navigating testing complexities:

- **Shorten and lowering the complexity of the questions:** The issue here lies in the fact that the excessive length of the EMINENT questions may discourage the members of the specific communities to answer the questions as it might be an excessively time-consuming activity. Moreover, the degree of complexity of the terms or lack of knowledge from the respondents may lead to wrong answers due to misunderstood concepts. In this regard, it is important to highlight that the best results and engagement were achieved during the online sessions in which the researcher and the community members had a space to clarify each of the questions and concepts assessed with the EMINENT tool.
- **Enhance communication strategies:** Among the challenges encountered, several key lessons emerged. Firstly, the importance of clear communication. The initial low response highlighted the need for transparent communication regarding the survey's significance and the value it brings to the group of interest. Clearly articulate the significance of any initiative to all stakeholders involved is key for success. This could involve creating communication plans that outline the purpose, benefits, and expected outcomes of the project or survey.
- **Embrace flexibility and agile practices:** Secondly, flexibility is paramount in navigating innovation activities. The team's readiness to adapt its approach, shifting from passive reminders to active engagement through workshops, underscored the significance of agility in achieving desired outcomes.
- Lastly, building and promoting a collaborative environment is crucial for getting a meaningful participation. The workshop served not only as a platform for knowledge exchange but also to strengthen ties with the groups of interest, paving the way for future collaborations.

In hindsight, while the journey to test the tool has been full of challenges, it also yielded invaluable insights and successes. With a deeper understanding of stakeholder dynamics and the experience gained, the team is ready to report the results and drive significant advances in the field of energy sector interoperability.

5.12.3 Barriers, challenges and lessons learned during the collection of results and interpretation

During the collection of the results, we gained a few insights into good/best practices of how to collect responses as well as the questionnaire itself. The main learning points are summarized below:

- **The texts (both questions and multiple-choice answers) have a high concept density**. Respondents indicated that it took them a long time to read and comprehend the questions and the multiple-choice answers.
- **The response rate tends to be low.** We used two different methods for collecting responses, but when we just sent out the survey for respondents to fill out in their own time, the response rates were between 10-15% across the 3 communities. This is on the low side and a higher response rate would give a better sense of the actual interoperability community.
- **Workshop-style response collection is preferable.** While the previous point discussed the challenges faced when respondents fill out the questionnaire by themselves, this point discusses the benefits of organizing (online/in-person) workshops. It was found that this method had multiple benefits:
  - Respondents could ask for clarification if they didn’t understand a particular question or multiple-choice option.
  - EMINENT is meant as a tool for learning. During the workshops, participants started discussing strengths and challenges amongst themselves. When people were unsure about examples of activities or information that indicate a certain maturity level, they discussed amongst themselves what the community is already doing and how it could improve.
- **Data management:** Unfortunately, most of the questionnaire tooling in the market does not handle changes very well. Effectively, this means that when there are changes to the questionnaire, it is likely to break the data analysis pipeline. Several pre- and post-processing steps have been introduced to compensate for this. Still data was lost when a mistake in the questionnaire needed to be fixed. The EUSurvey tool just does not provide responses anymore that were given before the change. It is therefore important to make regular exports of the responses and upload them to the public database.

5.13 Conclusion

Following extensive literature research, a maturity model framework has been developed that can be applied domain-agonistically within the electric energy sector to assess interoperability efforts.

It has been used to derive the final int:net Interoperability Maturity Model EMINENT. This assessment tool is based on an interoperability capability model for interoperability communities and uses a maturity model framework that defines characteristics across 4 dimensions. This maturity model has been transformed into an online questionnaire that can be used by both interoperability communities as well as individual organizations to evaluate their interoperability maturity.

The assessments that have been performed within the int:net project itself, the CIM expert group and the SIF community have confirmed that the capability model and the maturity model are appropriate. Comments like “this model describes the abstract challenges of interoperability quite well” (a respondent from the CIM expert group) and “the EMINENT capability model is quite clever” (an interested party from one of int:net's sister projects) give the researchers confidence that we have found a model for interoperability communities that addresses challenges that people working on interoperable solutions face.

Having said that, the model and the tool rely on concepts that have proven to be complex and hard to understand to people who are new to the subject. Within the scope of the project this has changed the recommended practice from "self-evaluation" in the form of community members filling out the online survey by themselves, to a method involving maturity assessment workshops, where individuals discuss the questions, their observations about how their community operates, and then fill out their own answers in the survey.

Future developments of the tool can look at how to simplify the questionnaire to make it easier for users to complete. The developed information model based on W3C information standards should be robust enough to allow results from the current version of the questionnaire to be compared to results coming from any future version of the questionnaire, meaning that tracking the maturity over time remains possible. int:net plans to promote the IMM, and actions towards standardisation could be considered.

Annex A
Collection of Maturity Models and Framework

A.1 Smart Grid Interoperability Maturity Model

Name & Abbreviation:	Smart Grid Interoperability Maturity Model [SG IMM]
Author or Publisher:	GridWise Architecture Council (GWAC) [21]
Created at / Last Update:	2012
Location:	USA
Type: *e.g. Maturity Model, Architecture Framework …*	Maturity Model
Description: *What is the purpose of the entry? Which dimensions and/or categories does the entry cover?*	The Smart Grid Interoperability Maturity Model (SG IMM), which is based on the principles of the CMMI and the National E-Health Transition Authority (NEHTA), was developed to evaluate, assess and compare the inter-organizational interoperability within a system-of-systems and the maturity of this system. It considers various factors and uses more than 70 detailed metrics (based on the Interoperability Context-Setting Framework) to evaluate the quality of interoperability. The SG IMM covers: • Interoperability: Technical, Informational and Organizational • Cross-Cutting issues: Configuration & Evolution, Operation and Security & Safety • Governance issues: Management, Documentation, Testing and Integration
Possible effects for int:net: *How could the entry effect the development of the int:net Maturity Model?*	As the SG IMM already assess the interoperability within a System-of-Systems of a given Use Case, some of the basic assumptions can be adapted flawlessly, e.g. the: • The Smart Grid Interoperability Context Setting-Framework as a foundation • The questionnaire and quality requirements to assess the technical, semantic and pragmatical interoperability
Categories / characteristics relevant for int:net: *Which dimensions and/or categories are relevant for int:net?*	• Interoperability: Technical, Informational and Organizational • Cross-Cutting issues (in general) • Governance issues: Management, Documentation, Testing and Integration
Further description from the analysis: *e.g. delimitations to int:net, limitations, particularly relevant aspects*	With its development in 2012 the SG IMM and its cross-cutting issues are outdated (to some extent). The basic assumptions still apply and should be adopted or at least considered, but the new (technological and regulatory) developments as well as their accompanying requirements (like Data Spaces or Data Sovereignty (especially in regard to GDPR)) must be supplemented with more up-to-date cross-cutting issues.

A.2 Electricity Subsector Cybersecurity Capability Maturity Model

Name & Abbreviation:	Electricity Subsector Cybersecurity Capability Maturity Model (ES-C2M2)
Author or Publisher:	The US Department of Energy (DOE) [34]
Created at / Last Update:	Version 1.1 2014
Location:	USA
Type: *e.g. Maturity Model, Architecture Framework …*	Maturity Model
Description: *What is the purpose of the entry? Which dimensions and/or categories does the entry cover?*	The ES-C2M2 was created as part of the DOE Cybersecurity Capability Maturity Model (C2M2) Program to address the specific characteristics of the energy subsector. The initiative contributes to the continual development and measurement of cybersecurity capabilities in the electrical industry. The model was created in support of the Electricity Subsector Cybersecurity Risk Management Maturity Initiative, which is headed by the DOE in partnership with experts from the business and governmental sectors, as well as representatives from asset owners and operators in the electricity subsector. The model can be used to: • Strengthen cybersecurity capabilities in the electricity subsector. • Enable utilities to effectively and consistently evaluate and benchmark cybersecurity capabilities. • Share knowledge, best practices, and relevant references within the subsector to improve cybersecurity capabilities. • Enable utilities to prioritize actions and investments to improve cybersecurity. The ES-C2M2 is designed for use with a self-evaluation methodology and toolkit for an organization to measure and improve its cybersecurity program.
Possible effects for int:net: *How could the entry effect the development of the int:net Maturity Model?*	ES-C2M2 is focused on cybersecurity in the electricity subsector and do not directly affect the int:net maturity model other than the security aspects. It would be possible to harmonize, adopt or to get inspiration.
Categories / characteristics relevant for int:net: *Which dimensions and/or categories are relevant for int:net?*	Since ES-C2M2 is also a maturity model that is focused on cybersecurity in electrical power systems and utilities, the following aspects can be interesting for int:net • Maturity domains • Maturity levels Additionally, the application toolkit can also be valuable while designing a similar concept for the implementation of the int:net maturity model.
Further description from the analysis: *e.g. delimitations to int:net, limitations, particularly relevant aspects*	• Evaluation methodology • Gap analysis • Roadmap development

A.3 Smart Grid Maturity Model

Name & Abbreviation:	Smart Grid Maturity Model [SGMM]
Author or Publisher:	Software Engineering Institute (SEI) [21]
Created at / Last Update:	2011
Location:	USA
Type: *e.g. Maturity Model, Architecture Framework …*	Maturity Model
Description: *What is the purpose of the entry? Which dimensions and/or categories does the entry cover?*	The Smart Grid Maturity Model (SGMM) is a management tool originally developed by electric utilities for electric utilities and is now being stewarded by the Software Engineering Institute1 at Carnegie Mellon University. The model provides a framework for understanding the current state of smart grid deployment and capability within an electric utility, and it provides a context for establishing future strategies and work plans to meet the challenges of grid modernization. It can also help organizations bridge gaps between strategy and execution. The SGMM helps create and communicate a common vision of the smart grid for internal and external stakeholders. An electric utility can use the SGMM to identify its smart grid target, assess where it is on the journey to implementing the smart grid, prioritize options, and measure success. The model describes a common framework with defined smart grid stages and options, as well as a common language for defining key elements of a smart grid transformation. It is composed of eight model domains that correspond with six defined levels of maturity.
Possible effects for int:net: *How could the entry effect the development of the int:net Maturity Model?*	• Wide-ranging smart grid-related topics, which are determined within the framework of different aspects of its maturity. In particular, policy and regulatory characteristics and objectives can be extracted from the maturity model • Extracting essential characteristics that are required in the smart grid context • Identification of further relevant (agnostic) categories required for smart grid context
Categories / characteristics relevant for int:net: *Which dimensions and/or categories are relevant for int:net?*	• Strategy, Management and Regulatory • Organization and Structure • Grid Operations • Work and Asset Management • Technology • Customer • Value Chain Integration • Societal and Environmental
Further description from the analysis: *e.g. delimitations to int:net, limitations, particularly relevant aspects*	• Besides SG IMM, the most prominent representative in the smart grid context

A.4 Distributed Energy Resources Integration Maturity Model

Name & Abbreviation:	Distributed Energy Resources Integration Maturity Model [iDER]
Author or Publisher:	Navigant Inc. [35]
Created at / Last Update:	2016
Location:	USA / International
Type: *e.g. Maturity Model, Architecture Framework …*	Maturity Model
Description: *What is the purpose of the entry? Which dimensions and/or categories does the entry cover?*	The Distributed Energy Resources Integration Maturity Model is a framework designed to assess and guide the integration of distributed energy resources (DERs) into existing energy systems. It provides a structured approach to evaluate the maturity level of DER integration across various dimensions, including technical capabilities, regulatory frameworks, market structures, and grid operations. The model aims to support stakeholders, such as utilities, regulators, and technology providers, in understanding the current state of DER integration and identifying areas for improvement.
Possible effects for int:net: *How could the entry effect the development of the int:net Maturity Model?*	• It can help us establish who the 'users' of the model should be • While it takes the perspective of the utility, it considers the utility as the facilitator of a DER intense energy system. the "facilitator of a community/ecosystem" could be an interesting perspective on ' who our maturity model is for'
Categories / characteristics relevant for int:net: *Which dimensions and/or categories are relevant for int:net?*	• Categories can be plotted onto the SGAM
Further description from the analysis: *e.g. delimitations to int:net, limitations, particularly relevant aspects*	• Model considers only DER integration as part of the energy sector

A.5 Technology Readiness Level

Name & Abbreviation:	Technology Readiness Level [TRL]
Author or Publisher:	NASA [36]
Created at / Last Update:	1988
Location:	USA / EU
Type: *e.g. Maturity Model, Architecture Framework …*	Maturity Model
Description: *What is the purpose of the entry? Which dimensions and/or categories does the entry cover?*	Technology Readiness Levels (TRL) are a type of measurement system used to assess the maturity level of a particular technology. Each technology project is evaluated against the parameters for each technology level and is then assigned a TRL rating based on the project's progress. There are nine technology readiness levels. TRL 1 is the lowest and TRL 9 is the highest.
Possible effects for int:net: *How could the entry effect the development of the int:net Maturity Model?*	• Using for evaluating the characteristics under consideration. • The characteristics to be considered in our model should have in particular in the higher level of TRL, if this can be determined. A classification of the technology under consideration in the characteristics can also help to classify the maturity level.
Categories / characteristics relevant for int:net: *Which dimensions and/or categories are relevant for int:net?*	N/A
Further description from the analysis: *e.g. delimitations to int:net, limitations, particularly relevant aspects*	• Use of the TRL for possible technology-related characteristics within our model

A.6 Integrated DER Maturity Assessment

Name & Abbreviation:	Integrated DER Maturity Assessment [iDER]
Author or Publisher:	Guidehouse [37]
Created at / Last Update:	2016
Location:	International
Type: *e.g. Maturity Model, Architecture Framework …*	Maturity Model
Description: *What is the purpose of the entry? Which dimensions and/or categories does the entry cover?*	The Integrated DER Maturity Assessment is a comprehensive tool that evaluates the level of maturity in integrating Distributed Energy Resources (DERs) within energy systems. It assesses technical infrastructure, regulations, markets, and operations to identify areas for improvement and enhance DER integration. This assessment aids strategic planning and decision-making to maximize system efficiency and leverage renewable energy resources effectively.
Possible effects for int:net: *How could the entry effect the development of the int:net Maturity Model?*	• Since this model covers all domains, the approach could be relevant as an example also for other characteristics relevant for the int:net IMM
Categories / characteristics relevant for int:net: *Which dimensions and/or categories are relevant for int:net?*	• Customer • Operations • Technology
Further description from the analysis: *e.g. delimitations to int:net, limitations, particularly relevant aspects*	• Model considers only DER integration as part of the energy sector

A.7 Smart Readiness Indicator

Name & Abbreviation:	Smart Readiness Indicator (SRI)
Author or Publisher:	European Commission [38]
Created at / Last Update:	2020
Location:	EU
Type: *e.g. Maturity Model, Architecture Framework …*	KPI
Description: *What is the purpose of the entry? Which dimensions and/or categories does the entry cover?*	The SRI is a common EU framework that rates the smart readiness of buildings or building units in n their capability to perform 3 key functionalities: optimise energy efficiency and overall in-use performance. Adapt their operation to the needs of the occupant and adapt to grid signals (for example energy flexibility) with the ultimate goal to raise awareness of the value of smart building technologies. The categories covered include: (a) heating, (b) cooling, (c) domestic hot water, (d) ventilation, (e) lighting, (f) dynamic building envelope, (g) electricity, (h) electric vehicle charging, (i) monitoring and control.
Possible effects for int:net: *How could the entry effect the development of the int:net Maturity Model?*	The governance of the indicator might be interesting, as it enables voluntary adoption by member states and allows flexibility in what parts will be adopted. Moreover, it also sets up a mechanism for monitoring of the indicator implementation and effectiveness. The SRI could be used for reference in our model considering the pursuit of replicability and scalability as well as the energy context in which it is developed.
Categories / characteristics relevant for int:net: *Which dimensions and/or categories are relevant for int:net?*	• Energy efficiency • Maintenance and fault prediction • Information to occupants • Energy flexibility and storage
Further description from the analysis: *e.g. delimitations to int:net, limitations, particularly relevant aspects*	The methodology for this indicator is defined in EU law. Its application on the national level is optional (for now). EU institutions will probably require this to be a basis for measuring smart readiness of buildings. However, there are no specific requirements regarding interoperability.

A.8 Industry 4.0 Readiness Indicator

Name & Abbreviation:	Industry 4.0 Readiness Index
Author or Publisher:	IMPULS [39]
Created at / Last Update:	2015
Location:	Germany
Type: *e.g. Maturity Model, Architecture Framework …*	KPI
Description: *What is the purpose of the entry? Which dimensions and/or categories does the entry coer?*	The Industry 4.0 Readiness indicator is a tool used to assess the readiness and preparedness of organizations for the adoption and implementation of Industry 4.0 technologies. It measures various dimensions such as technology infrastructure, digital capabilities, workforce skills, and organizational culture to determine the organization's level of readiness. The indicator provides valuable insights and benchmarks for organizations to identify areas of improvement and develop strategies for successful Industry 4.0 integration, enabling them to stay competitive and thrive in the digital era.
Possible effects for int:net: *How could the entry effect the development of the int:net Maturity Model?*	• Online-Tool for the evaluation of the readiness • For the evaluation of a given use case, an online tool can be developed that assesses the capability for integration within the energy sector at a system-of-systems level. The focus lays on Energy Data Spaces
Categories / characteristics relevant for int:net: *Which dimensions and/or categories are relevant for int:net?*	N/A
Further description from the analysis: *e.g. delimitations to int:net, limitations, particularly relevant aspects*	• Further relevance more in the evaluation

A.9 Smart Industry Readiness Index

Name & Abbreviation:	Smart Industry Readiness Index [SIRI]
Author or Publisher:	Singapore Economic Development Board [40]
Created at / Last Update:	2020
Location:	Singapore
Type: *e.g. Maturity Model, Architecture Framework …*	Maturity Model: Framework
Description: *What is the purpose of the entry? Which dimensions and/or categories does the entry cover?*	Optimize energy efficiency and overall, in-use performance
Possible effects for int:net: *How could the entry effect the development of the int:net Maturity Model?*	Dimensions 7–9 about Connectivity — Shop Floor, Enterprise, and Facility
Categories / characteristics relevant for int:net: *Which dimensions and/or categories are relevant for int:net?*	• Connectivity • Interoperability • Security • Scalable • Real-time
Further description from the analysis: *e.g. delimitations to int:net, limitations, particularly relevant aspects*	Its proposed connectivity criteria & scale can be used for int:net. Specifically on Interoperability: • To have the ability to access data across assets and systems with ease • To mitigate cyber-attacks • To have secure and resilient cyber-physical security architecture

A.10 Interoperability Score

Name & Abbreviation:	Interoperability Score [iScore]
Author or Publisher:	Air Force Institute of Technology [41]
Created at / Last Update:	2007
Location:	USA
Type: *e.g. Maturity Model, Architecture Framework …*	KPI
Description: *What is the purpose of the entry? Which dimensions and/or categories does the entry cover?*	The interoperability score (iScore) is a metric used to evaluate the interoperability of software systems in a standardized manner. It assesses the ability of systems to exchange and use information seamlessly, promoting effective communication and collaboration between different platforms. The iScore measures various aspects of interoperability, including data format compatibility, system integration capabilities, and adherence to industry standards. By using the iScore, organizations can gauge the level of interoperability of their software systems and identify areas for improvement to enhance overall system integration and efficiency.
Possible effects for int:net: *How could the entry effect the development of the int:net Maturity Model?*	• Numerical calculation of interoperability • For the evaluation of a given use case, the iScore can be used to numerically determine interoperability. This can be particularly relevant in evaluation if numerical assessment is wished.
Categories / characteristics relevant for int:net: *Which dimensions and/or categories are relevant for int:net?*	• Interoperability of non-homogeneous systems (generic applicable)
Further description from the analysis: *e.g. delimitations to int:net, limitations, particularly relevant aspects*	• Could gain further relevance in the evaluation than the development

A.11 Capability Maturity Model

Name & Abbreviation:	Capability Maturity Model [CMM]
Author or Publisher:	U.S. Department of defense [18]
Created at / Last Update:	1986
Location:	USA
Type: *e.g. Maturity Model, Architecture Framework …*	Maturity Model
Description: *What is the purpose of the entry? Which dimensions and/or categories does the entry cover?*	The Capability Maturity Model (CMM) is a framework that assesses and improves the maturity level of an organization's processes. It provides a structured approach to measure and enhance capabilities across different areas, such as software development, project management, and system engineering. The CMM helps organizations identify strengths, weaknesses, and areas for improvement, enabling them to optimize processes, increase efficiency, and achieve higher levels of performance and quality.
Possible effects for int:net: *How could the entry effect the development of the int:net Maturity Model?*	• The CMM considers an important reference for maturity model theory in general. use of the maturity levels • The definition of the maturity levels (1-5)
Categories / characteristics relevant for int:net: *Which dimensions and/or categories are relevant for int:net?*	N/A
Further description from the analysis: *e.g. delimitations to int:net, limitations, particularly relevant aspects*	• This is more a metamodel for maturity models

A.12 Capability Maturity Model Integration

Name & Abbreviation:	Capability Maturity Model Integration [CMMI]
Author or Publisher:	CMMI Institute (ISACA) [19]
Created at / Last Update:	2002
Location:	USA
Type: *e.g. Maturity Model, Architecture Framework …*	Maturity Model
Description: *What is the purpose of the entry? Which dimensions and/or categories does the entry cover?*	The Capability Maturity Model Integration (CMMI) is a process improvement framework that helps organizations enhance their capability to deliver high-quality products and services. It provides a set of best practices and guidelines for managing and improving processes across various disciplines, including software engineering, systems engineering, and project management. By implementing the CMMI, organizations can assess their current process maturity, identify areas for improvement, and systematically evolve their practices to achieve higher levels of performance, efficiency, and customer satisfaction.
Possible effects for int:net: *How could the entry effect the development of the int:net Maturity Model?*	• Good examples for how to be explicit about characteristics • The CMMI considered an important reference for maturity model theory in general
Categories / characteristics relevant for int:net: *Which dimensions and/or categories are relevant for int:net?*	N/A
Further description from the analysis: *e.g. delimitations to int:net, limitations, particularly relevant aspects*	• Quite elaborate on software development

A.13 Control Objectives for Information and Related Technologies

Name & Abbreviation:	Control Objectives for Information and Related Technologies [COBIT]
Author or Publisher:	ISACA & ITGI [42]
Created at / Last Update:	Mid-1990s
Location:	USA
Type: *e.g. Maturity Model, Architecture Framework …*	Maturity Model: Framework
Description: *What is the purpose of the entry? Which dimensions and/or categories does the entry cover?*	Framework that aims to help organizations that are looking to develop, implement, monitor, and improve IT governance and information management.
Possible effects for int:net: *How could the entry effect the development of the int:net Maturity Model?*	It can use concepts and methods such as capability levels (processes) and maturity levels (Focus areas)
Categories / characteristics relevant for int:net: *Which dimensions and/or categories are relevant for int:net?*	• Performance management for maturity • Continuous Improvement
Further description from the analysis: *e.g. delimitations to int:net, limitations, particularly relevant aspects*	It could consider the following principles: • Principle 1: Meeting Stakeholder Needs • Principle 2: Covering the Enterprise End-to-End • Principle 3: Applying a Single Integrated Framework • Principle 4: Enabling a Holistic Approach • Principle 5: Separating Governance from Management

A.14 Use Cases from int:net T1.2

Name & Abbreviation:	Use Cases from the Interoperability Network for the Energy Transition project [int:net]
Author or Publisher:	int:net
Created at / Last Update:	2023
Location:	Europe
Type: *e.g. Maturity Model, Architecture Framework …*	Use Cases
Description: *What is the purpose of the entry? Which dimensions and/or categories does the entry cover?*	The collection of use cases is used to derive interoperability aspects and best practices in the int:net project. 50 use cases from existing projects were defined and analyzed.
Possible effects for int:net: *How could the entry effect the development of the int:net Maturity Model?*	The use case analysis could support intMM validation
Categories / characteristics relevant for int:net: *Which dimensions and/or categories are relevant for int:net?*	The analysis considers the following dimensions: • Common framework • Regulation, policy and law • Standardisation activities • R&D project • Implementation project, real-life demonstration • Laboratory testing facility • Best practices • Working group • Report
Further description from the analysis: *e.g. delimitations to int:net, limitations, particularly relevant aspects*	The results of the analysis offers intMM validation based on UCs

Bibliography

[1] int:net project group, "Project int:net," 2022-2025. [Online]. Available: https://intnet.eu/. [Accessed 23 08 2025].

[2] IEC SyC Smart Energy, "IEC 62559 Use Case Methodology," 2025. [Online]. Available: https://syc-se.iec.ch/deliveries/iec-62559-use-cases/. [Accessed 23 08 2025].

[3] CEN-CENELEC-ETSI, "SGAM User Manual - Applying, testing & refining the Smart Grid Architecture Model (SGAM)," Nov. 2014. [Online]. Available: https://syc-se.iec.ch/wp-content/uploads/2019/10/SGCG_Methodology_SGAMUserManual.pdf. [Accessed 28 Oct. 2022].

[4] J. Becker, R. Knackstedt and J. Pöppelbuß, "Developing Maturity Models for IT Management: A Procedure Model and its Application," *Bus. Inf. Syst. Eng.,* vol. 1, no. 3, pp. 213-222, Jun. 2009, doi: 10.1007/s12599-009-0044-5.

[5] R. G. G. Caiado, L. F. Scavarda, L. O. Gavião, P. Ivson, D. L. de M. Nascimento and J. A. Garza-Reyes, "A fuzzy rule-based industry 4.0 maturity model for operations and supply chain management," *International Journal of Production Economics,* vol. 231, p. 107883, Jan. 2021, doi: 10.1016/j.ijpe.2020.107883.

[6] A. De Carolis, M. Macchi, E. Negri and S. Terzi, "A Maturity Model for Assessing the Digital Readiness of Manufacturing Companies," in *Advances in Production Management Systems. The Path to Intelligent, Collaborative and Sustainable Manufacturing*, H. Lödding, R. Riedel, K.-D. Thoben, G. von Cieminski, and D. Kiritsis, Eds., in IFIP Advances in Information and Communication Technology, Cham, Springer International Publishing, 2017, pp. 13-20, doi: 10.1007/978-3-319-66923-6_2.

[7] C. Weber, J. Königsberger, L. Kassner and B. Mitschang, "M2DDM -- A Maturity Model for Data-Driven Manufacturing," *Procedia CIRP,* vol. 63, pp. 173-178, 2017, doi: 10.1016/j.procir.2017.03.309.

[8] J. Becker, R. Knackstedt, J. Pöppelbuß and L. Schwarze, "Das IT Performance Measurement Maturity Model -- Ein Reifegradmodell für die Business Intelligence-Unterstützung des IT-Managements," Gesellschaft für Informatik e.V., 2008. [Online]. Available: http://dl.gi.de/handle/20.500.12116/30935. [Accessed 02 Feb. 2023].

[9] J. Pöppelbuß and M. Röglinger, "WHAT MAKES A USEFUL MATURITY MODEL? A FRAMEWORK OF GENERAL DESIGN PRINCIPLES FOR MATURITY MODELS AND ITS DEMONSTRATION IN BUSINESS PROCESS MANAGEMENT," ECIS 2011 Proceedings, Oct. 2011. [Online]. Available: https://aisel.aisnet.org/ecis2011/28.

[10] The SGMM Team, "Smart Grid Maturity Model, Version 1.2: Model Definition," p. 3108321 Bytes, doi: 10.1184/R1/6583835.V1, 2011.

[11] J. Schütz, M. Uslar and J. Meister, "A case study research on interoperability improvement in Smart Grids: state-of-the-art and further opportunities," *Open Res Europe,* vol. 1, p. 33, Apr. 2021, doi: 10.12688/openreseurope.13313.1.

[12] M. Uslar et al., Standardization in smart grids: introduction to IT-related methodologies, architectures and standards, in Power systems, Berlin, New York: Springer, 2013.

[13] S. Widergren et al., "GridWise Interoperability Context-Setting Framework," Jan. 2008.

[14] European University Institute, "Getting our act together on the EU interoperability acts," LU: Publications Office, 2020. [Online]. Available: https://data.europa.eu/doi/10.2870/645347. [Accessed 18 Apr. 2023].

[15] M. Gottschalk, M. Uslar and C. Delfs, The Use Case and Smart Grid Architecture Model Approach, in SpringerBriefs in Energy, Cham: Springer International Publishing, 2017, doi: 10.1007/978-3-319-49229-2.

[16] IEC TC 8, *Use case methodology - Part 2: Definition of the templates for use cases, actor list and requirements list,* International Organization for Standardization, Standard IEC 62559-2:2015, 2015.

[17] CEN-CENELEC-ETSI, "Smart Grid Reference Architecture," Nov. 2012. [Online]. Available: https://www.cencenelec.eu/media/CEN-CENELEC/AreasOfWork/CEN-CENELEC_Topics/Smart%20Grids%20and%20Meters/Smart%20Grids/reference_architecture_smartgrids.pdf. [Accessed 14 Mar. 2023].

[18] M. C. Paulk, B. Curtis, M. B. Chrissis and C. V. Weber, "Capability maturity model, version 1.1," *IEEE software,* vol. 10, no. 4, pp. 18-27, 1993.

[19] CMMI Product Team, "CMMI for Development, Version 1.2," Software Engineering Institute, Carnegie Mellon University, Pittsburgh, PA, CMU/SEI-2006-TR-008, 2006. [Online]. Available: http://resources.sei.cmu.edu/library/asset-view.cfm?AssetID=8091.

[20] M. Knight, S. Widergren, J. Mater and A. Montgomery, "Maturity model for advancing smart grid interoperability," in *2013 IEEE PES Innovative Smart Grid Technologies Conference (ISGT)*, Washington, DC, IEEE, Feb. 2013, pp. 1-6, doi: 10.1109/ISGT.2013.6497915.

[21] S. Widergren, A. Levinson, J. Mater and R. Drummond, "Smart grid interoperability maturity model," in *IEEE PES General Meeting*, Minneapolis, MN, IEEE, Jul. 2010, pp. 1-6, doi: 10.1109/PES.2010.5589785.

[22] L. Karg, M. Santos Mugica, J. Jimeno Huarte, "int:net Deliverable 4.3," 10 11 2023. [Online]. Available: https://intnet.eu/resources/technical-resources.

[23] "Pubs opengroup," 1995-2025. [Online]. Available: https://pubs.opengroup.org/architecture/archimate3-doc/ch-Strategy-Layer.html#sec-Capability.

[24] EPRI, "EPRI," 2001-2025. [Online]. Available: https://www.epri.com/research/products/000000003002028128.

[25] int:net project group, "EMINENT online questionnaire (EUSurvey)," 2023. [Online]. Available: https://ec.europa.eu/eusurvey/runner/Eminent.

[26] int:net project group, "EMINENT questionnaire (Github)," 2023. [Online]. Available: https://github.com/int-net/EminentSurvey.

[27] int:net project group, "int:net Community," [Online]. Available: https://community.intnet.eu/Groups/IFG-2-Increasing-Maturity-in-Interoperability. [Accessed 23 08 2025].

[28] J. v. Genuchten, "int:net Deliverable 2.3," 02 05 2024. [Online]. Available: https://intnet.eu/resources/technical-resources.

[29] GO FAIR, "FAIR Principles," 2016. [Online]. Available: https://www.go-fair.org/fair-principles/.

[30] European Parliament and Council, "GDPR - General Data Protection Regulation," 2016. [Online]. Available: https://gdpr-info.eu/.

[31] int:net project group, "EMINENT Results Database (Github)," 2023. [Online]. Available: https://github.com/int-net/EminentResultsDatabase.

[32] int:net project group, "EMINENT questionnaire (MS Forms)," 2023. [Online]. Available: https://forms.office.com/Pages/ResponsePage.aspx?id=AGTMMj0V90K8VXflpQ8bz6Frp-VsYDVBjhf0zMRmJBZUQlRMMTNUN0lXUUVNVTZEUzY2M1ZWVENFNi4u.

[33] int:net project group, "EMINENT Reporting Tool (Github)," 2023. [Online]. Available: https://github.com/int-net/EminentReportingTool.

[34] "Electricity Subsector Cybersecurity Capability Maturity Model," [Online]. Available: https://esc2m2.pnnl.gov/. [Accessed 02 Jun. 2023].

[35] "Integrated DER Maturity Assessment, Part II of III," [Online]. Available: https://guidehouseinsights.com/news-and-views/integrated-der-maturity-assessment-part-ii-of-iii. [Accessed 02 Jun. 2023].

[36] J. C. Mankins and others, "Technology readiness levels," White Paper, April, vol. 6, no. 1995, p. 1995, 1995.

[37] "Integrated DER Maturity Assessment, Part I of III," [Online]. Available: https://guidehouseinsights.com/news-and-views/integrated-der-maturity-assessment-part-i-of-iii. [Accessed 02 Jun. 2023].

[38] European Commission, "Smart readiness indicator," [Online]. Available: https://energy.ec.europa.eu/topics/energy-efficiency/energy-efficient-buildings/smart-readiness-indicator_en. [Accessed 02 Jun. 2023].

[39] IMPULS, "Industrie 4.0-Readiness-Check," [Online]. Available: https://www.industrie40-readiness.de/?lang=en. [Accessed 02 Jun. 2023].

[40] Singapore Economic Development Board, "Smart Industry Readiness Index," SIRI, [Online]. Available: https://siri.incit.org. [Accessed 02 Jun. 2023].

[41] T. Ford, J. Colombi, S. Graham and D. Jacques, "The interoperability score," AIR FORCE INST OF TECH WRIGHT-PATTERSON AFB OH, 2007.

[42] ISACA & ITGI, "Control Objectives for Information Technologies," ISACA, [Online]. Available: https://www.isaca.org/resources/cobit. [Accessed 02 Jun. 2023].

VDE Verband der Elektrotechnik
Elektronik Informationstechnik e. V.

Merianstraße 28
63069 Offenbach am Main
Tel. +49 69 6308-0
service@vde.com
www.vde.com

VDE