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D2.1

Interoperability Maturity Model Framework and Background

int:net

Interoperability Network for the Energy Transition

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AUTHORS AND REVIEWERS

Author(s) / contributor(s)	René Kuchenbuch (OFFIS), rene.kuchenbuch@offis.de Johann Schütz (OFFIS), johann.schuetz@offis.de
Reviewer(s)	Alberto Dognini (Fraunhofer FIT) Beate Schmitt (VDE/DKE) Sebastian Kosslers (VDE/DKE)

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ABSTRACT

This document presents a comprehensive maturity model for assessing and improving interoperability efforts in the energy sector. Interoperability plays the key role in enabling an efficient and seamless integration of heterogeneous systems in the energy domain. Our maturity model aims to provide a structured framework for evaluating the maturity level of organizations and systems in terms of their interoperability capabilities. The model comprises multiple dimensions and categories, which represent different interoperability challenges in the electric energy sector, including (but not limited to) interoperability layers (according to the Smart Grid Architecture Model), testing and security. By assessing the maturity level across these dimensions, organizations can identify their strengths and weaknesses, establish improvement priorities, and align their interoperability strategies accordingly. The model's design emphasizes simplicity and practicality, making it user-friendly and easily applicable in various energy sector contexts. Through the use of this maturity model, organizations can enhance their interoperability capabilities, foster collaboration, and drive innovation in the energy sector.

KEYWORD LIST

Energy domain, Interoperability, Maturity Model

EXECUTIVE SUMMARY

This document 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 organizations and systems in terms of their interoperability capabilities. It encompasses various dimensions and categories, addressing interoperability challenges such as layers, testing, and security. By assessing their maturity level across these dimensions, organizations 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 energy sector contexts. By using this maturity model, organizations can strengthen their interoperability capabilities, foster collaboration, and drive innovation in the energy sector.

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1 Introduction

The int:net project 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. The project has several objectives, starting with the creation of a common knowledge base and best practices repository based on FAIR principles. This will promote interoperability of energy-related services, data, and platforms. A second objective is the development of an interoperability assessment methodology and the Interoperability Maturity Model (IMM), specifically tailored to European energy services. The project also seeks to harmonize testing procedures and establish a distributed network of interoperability testing laboratories. Finally, int:net aims to foster coordination and support among legal and regulatory entities, promote the adoption of interoperable energy services, data spaces, and digital twins, and collaborate with external initiatives such as, for example Gaia-X and DSSC, BRIDGE and ETIP SNET.

The Interoperability Maturity Model (IMM) and its framework, which emerged from Task 2.1 in the project, represents the central artifact in this deliverable. 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 categories and dimensions arising from recent technological innovations and/or regulatory requirements, as (e.g.) dataspaces or GDPR.

1.1 Objectives of the work reported

The goal of the work in Task 2.1 of the int:net project is the development of an Interoperability Maturity Model and its framework, which intends to measure interoperability efforts of a community within the electric energy sector.

The development is oriented towards existing (interoperability) maturity models especially within the context of smart grids. One focus of the maturity model is the *system-of-systems perspective*, which views the individual system from an overall holistic view as interconnected with other systems. Furthermore, the model shall be *domain-agnostic* in regard to the sub-domains of the electric energy system[1] and is oriented according to the sub-domains in a general view according the renown Smart Grid Architecture Model (SGAM). Additionally, *flexibility in the enhancement* of the maturity model as well as adaptiveness should be provided, allowing the model to be extended according to the

[1] Sub-domains refer to the area of generation, TSO, DSO, DER and/or to the end-user on their premises.

stakeholders. An additional goal is to offer a *simplified and user-friendly approach* to assess the interoperability efforts. Unlike existing models in the domain that are often to complex to be applied by non-experts, the proposed model focuses on simplicity while maintaining its validity. An aim is to minimize the training and understanding time required, making it easier for organizations to apply and benefit from the maturity model. *Future-proofing* represents another objective of our maturity model. The categories and dimensions of the proposed maturity model reflect the timeless challenges of interoperability efforts.

Finally, a corresponding questionnaire that serves the assessment of the maturity level refers to the use of current solutions such as established standards (e.g. Common Information Model, IEC 61850), technologies for solving challenges (e. g. Artificial Intelligence, Digital Twins) or principles (e.g. FAIR Principles or the IDS Reference Architecture Model). These are intended to provide guidance to users for process classification, but by no means to limit them to concrete approaches.

Further work in Work Package 2 deals with the creation of both an assessment tool for the maturity model and a database/UI for tracking the actual maturity status. In addition, the maturity model will be made public via a workshop and made accessible to the industry.

1.2 How to read this document

This document shows the development of the maturity model and its based fundamentals. The maturity model as such is described in the descriptive character in chapter 6 and 7, which are particularly relevant for the use and further development.

This document can be read independently from other int:net deliverables. However, this document provides the basis for the subsequent deliverables of Work Package 2, specifically: D2.2, D2.3 and D2.4

1.3 Structure of the document

This section outlines the structure of the deliverable, providing an overview of the main chapters and sections. The document is organized as follows:

1. **Introduction:** In this present chapter, an overview of the purpose, objectives, and scope of the deliverable is provided.
2. **Overall Methodology:** This chapter presents the procedure model and its derivation used to develop the maturity model. The systematic approach taken throughout the development process is described, encompassing data collection, analysis and validation techniques.
3. **Related Research:** This chapter reviews relevant studies, frameworks, and approaches related to (interoperability) maturity models in the smart grid context. Key findings, trends and gaps in the literature are explored.
4. **Background:** The background chapter shows the basics of interoperability and maturity models, which corresponds to the essential part of the maturity model to be developed.
5. **Development of the Maturity Model:** This chapter details the process employed to develop the maturity model. Essential preliminary work is shown and requirements for the model are derived. In addition, decisions from the individual steps and the first preliminary versions are shown based on the procedure model, which has been established for deriving the maturity model in section 2.

6. **Structure of the Model:** This chapter represents the *first descriptive part of the maturity model*. It offers a comprehensive overview of the maturity model's structure. In this chapter, categories, dimensions, maturity levels and its characteristics are shown and placed in relation to each other.
7. **Questionnaire of the Maturity Model:** This chapter represents the *second descriptive part of the maturity model*. The questionnaire is an essential element for the application of the maturity model, which was developed based on the dimensions and its characteristics. In addition, the chapter shows the application in the context of an example as well as the preset principle.
8. **Conclusion:** The final chapter summarizes the key findings and contributions of the maturity model. In summary, the work is concluded, limitations are presented, and the next necessary steps in maturity development are identified in the follow-up tasks.

2 Overall Methodology

This chapter presents the methodology used to derive the int:net 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 development is presented and explained.

2.1 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.

2.1.1 Procedure model for developing maturity models

The procedure model according to Becker et al. [1] 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. [1] derived the following requirements 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.

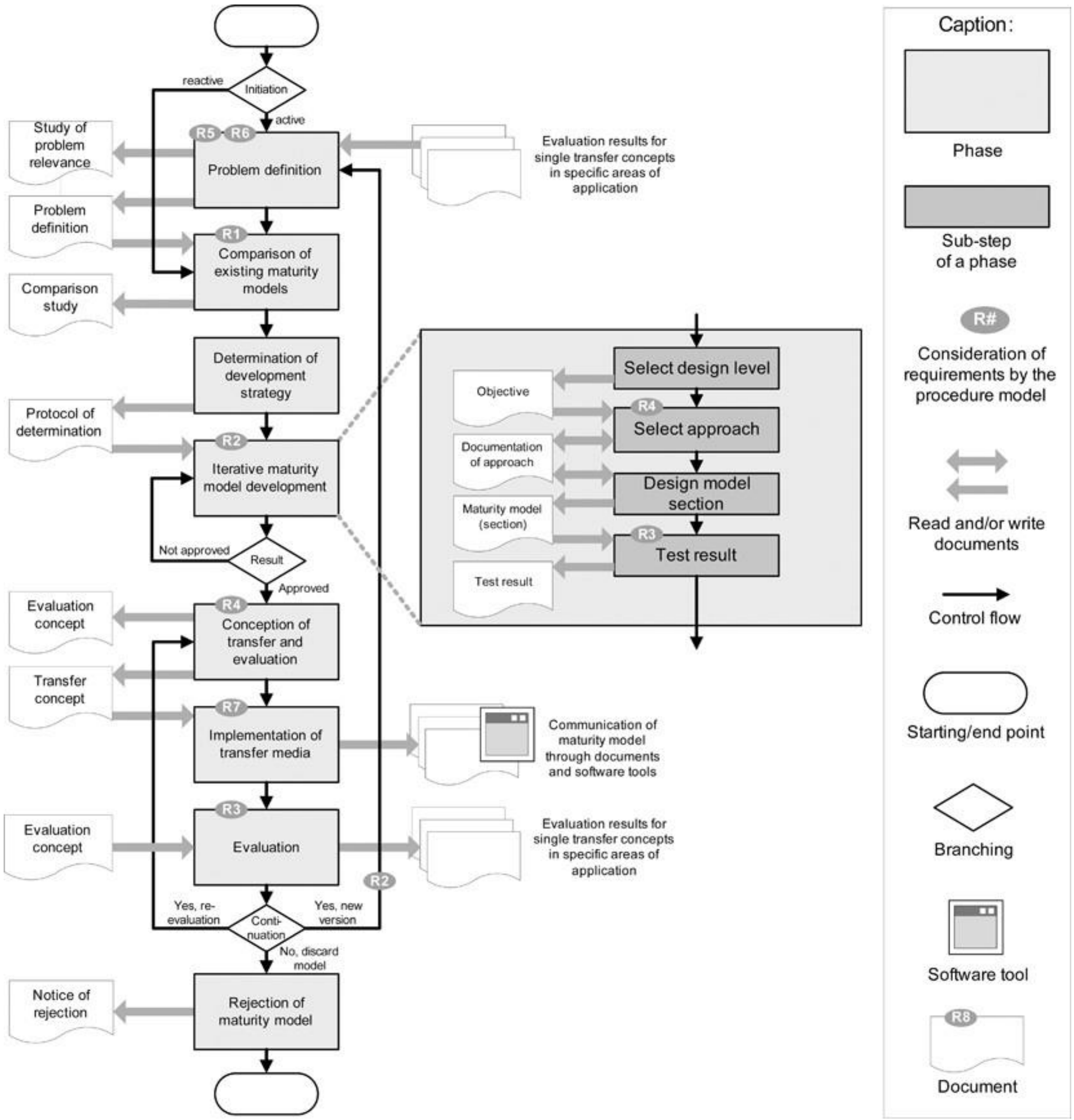

Figure 1: Procedure model for developing maturity models [1]

- **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 seek:
    - Completely new design
    - Enhancement of an existing model design
    - The combination of several models into a new model
    - Tranfering 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 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 reevaluation 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 [2], DREAMY [3], M2DDM [4] or ITPM [5]. These either use the process model directly in their methodology or indirectly used it by adapting.

2.1.2 General design principles for maturity models

For the development of maturity models, a framework for the general creation of maturity models was established by Pöppelbus and Rölinger [6]. These included design principles, which can be used as a guideline for the creation of maturity models. Pöppelbuß and Röglinger [6] 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 [6] 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 a 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.

2.2 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. [1] 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 Task 2.1, which in turn is part of Work Package 2. Based on the descriptions of the tasks from the project proposition and the phase descriptions, a task/phase mapping can be realized in form of a matrix in Table 1: Mapping of the Work Package 2 tasks to the phases acc. Becker et al. [1].

<table>
<tr><th></th><th>Task 2.1</th><th>Task 2.2</th><th>Task 2.3</th><th>Task 2.4</th></tr>
<tr><td>Problem definition</td><td>R5, R6</td><td></td><td></td><td></td></tr>
<tr><td>Comparison of existing maturity models</td><td>R1</td><td></td><td></td><td></td></tr>
<tr><td>Determination of development strategy</td><td>R8</td><td></td><td></td><td></td></tr>
<tr><td>Iterative maturity model development</td><td>R2, R3, R4</td><td></td><td></td><td></td></tr>
<tr><td>Conception of transfer and evaluation</td><td></td><td colspan="2">R4</td><td></td></tr>
<tr><td>Implementation of transfer media</td><td></td><td colspan="2">R7</td><td></td></tr>
<tr><td>Evaluation</td><td></td><td></td><td></td><td>R3</td></tr>
</table>

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

Consequently, from the mapping, the phases and requirements necessary for Task 2.1 can be extracted and derived. Based on these phases, a concrete procedure model for deriving EMINENT can be identified for the specific int:net context visualized in Figure 2.

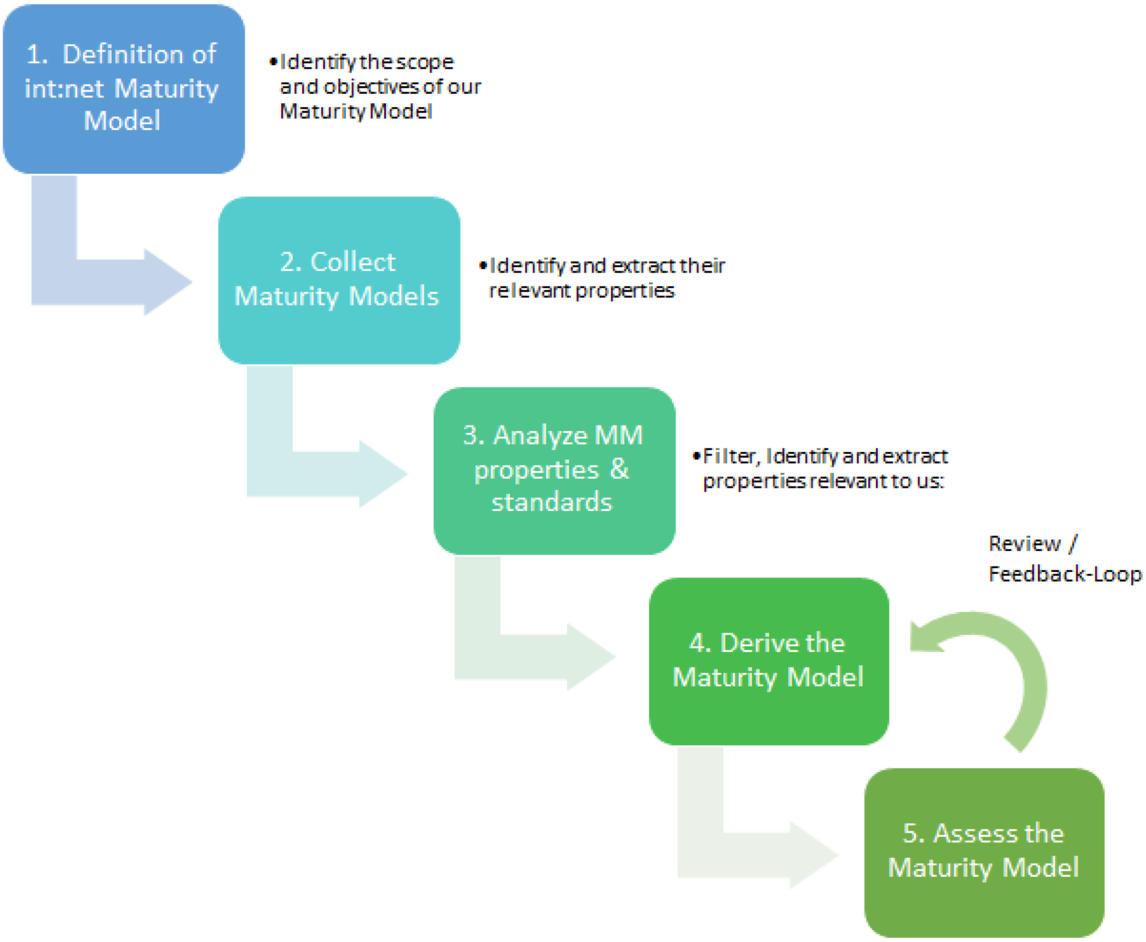

Figure 2: Procedure model for the development of EMINENT

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. [1] (see section 2.1.1) 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 Informations" from [6] 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, dimesions as well as characteristics and its 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 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.

3 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) [7]. 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 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.

4 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 [8]. 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.

4.1 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. [9]

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. [9]

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 [9]. 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. [10]

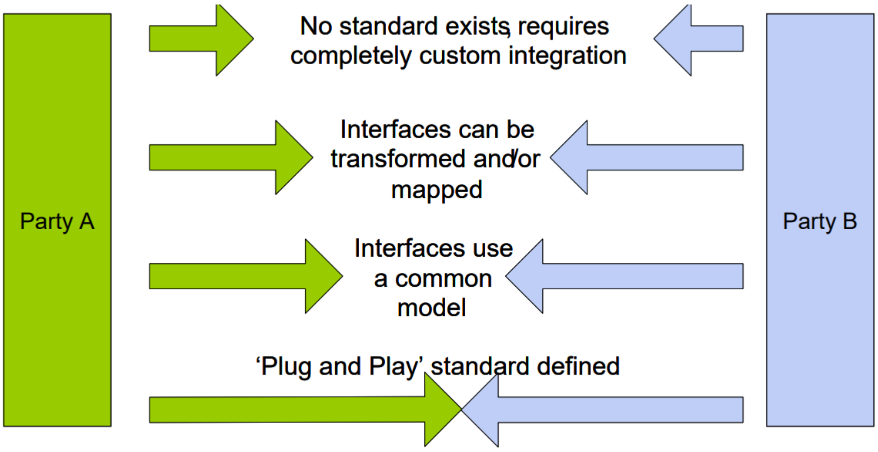

Figure 3: Distance to Integrate from GWAC ICSF [10]

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.

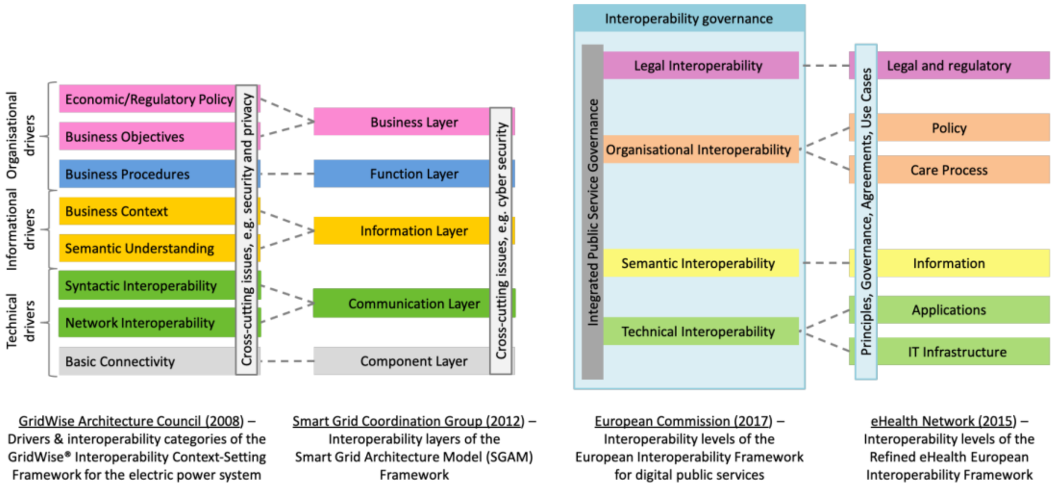

Figure 4: Interoperability frameworks access sectors [11]

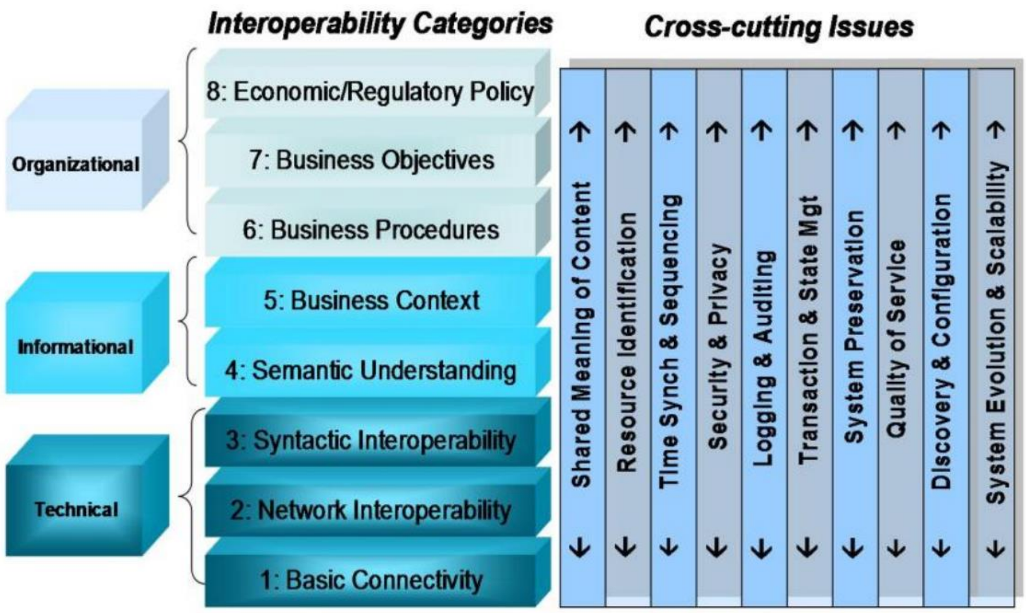

Figure 5: GWAC Interoperabiliy Context-Setting Framework Diagram [10]

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.

4.1.1 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. [12]

IEC 62559-2 specifies the standardized use case template [13], 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 [9].

4.1.2 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 [12]. The official SGAM User Manual by CEN-CENELEC-ETSI [14] 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 [12]**

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 followings according to [14]:

- **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.

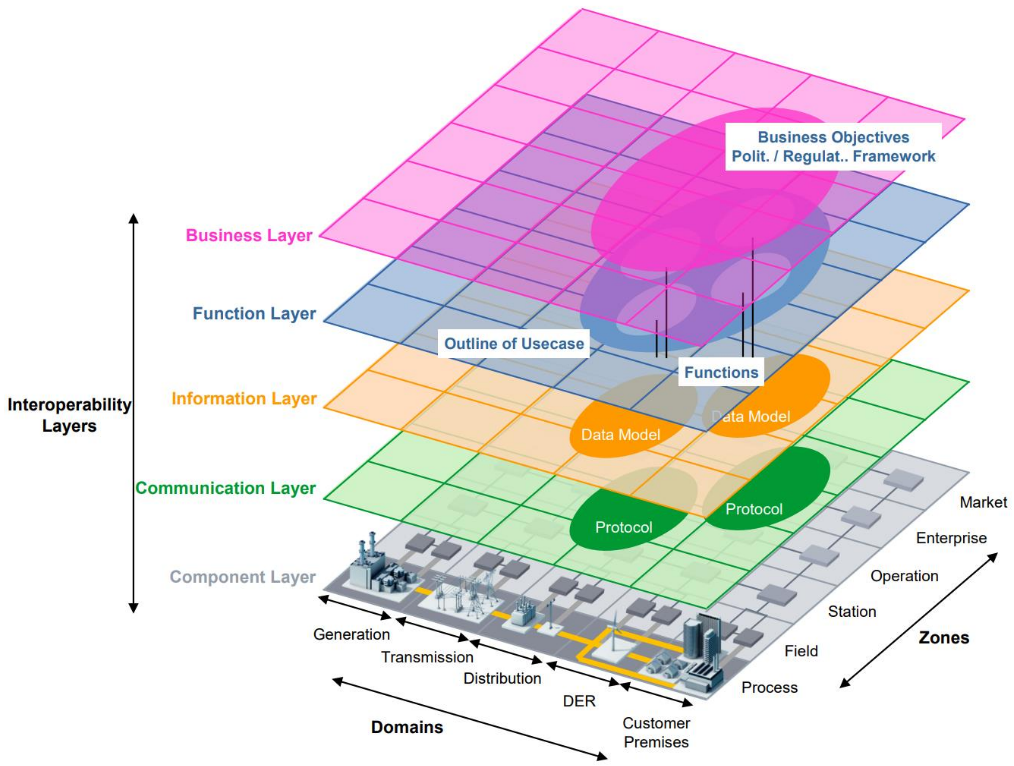

Figure 6: SGAM Framework [15]

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 [14]:

- **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 using 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.

4.2 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. [1]

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. [1]

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 [16]. 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 [16]. 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 [17]. The CMMI provides a framework for organizations to improve their processes across multiple disciplines using the levels from the CMM [17].

5 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.

5.1 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 section 5.2. The relevant events and steps that were necessary in the context of the maturity model development are listed below.

5.1.1 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 begin, which is why it was necessary to define project-wide int:net perspective. It was also urgent to how the interoperability perspective effects Task 2.1. These workshops (held on 25th January 2023 and 8th March 2023) were organized in cooperation with Task 6.2 and served as a joint brainstorming and platform for goal definition. In addition, the workshops served to provide thinking stimuli 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 up 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[2] 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 up. 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 5.2.

5.1.2 Expert group brainstorming

The results of the first part of the int:net internal interoperability workshop was analyzed separately within two expert groups sessions (held on 10th February 2023 and 10th March 2023) 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:

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[2] Mural is an online collaborative whiteboard tool: https://www.mural.co/

- 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, 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, first results of EMINENT have been conducted serving as a guidance for the further development. Additional requirements could be specified, which are listed in section 5.2.

5.1.3 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 Appendix A. 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 for the analysis (e. g. limitations, relevance, ideas, ...) exist?

5.1.4 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 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 5.3.

A milestone for establishing the final version was the organization of an int:net Maturity Model Workshop (held on 22nd May 2023). Purpose of the workshop was to finalize the last 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 5.1.2).

5.2 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) to 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:

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.

Table 2: Requirements based on the objectives

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:

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.

Table 3: Requirements based on the domain

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.

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 [18]. 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.

Table 4: Requirements for the maturity model

5.3 Deriving the Maturity Model

The procedure model for the development of the maturity model presented in section 2.2 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 5.1.

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.

5.3.1 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 Task 2.1. The deriving of the procedure model was done in this phase and has been already described in section 2.2. 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 in coordination with Task 6.2 to narrow down the scope. The relevance and the execution way of the workshops has already been highlighted in section 5.1.1. 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 are 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*. T

Building on the first internal IOP workshop, a brainstorming session was also held in the 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 appendix A corresponds the compilation of the Excel spreadsheet contains 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 2nd 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) [7] and Smart Grid Interoperability Maturity Model (SG IMM) [19] 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 basing on the GWAC interoperability stack which have been mentioned in section 4.1. 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 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 from the SG IMM [19] is shown in Figure 7.

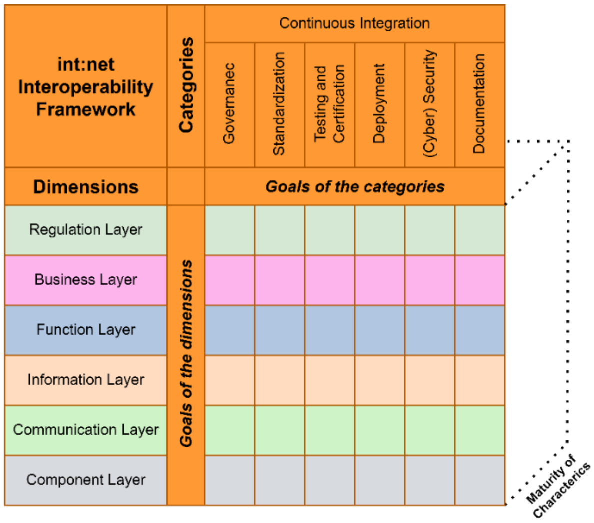

Figure 7: First draft of the int:net Interoperability Framework

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 Figure 8 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.

	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 planed 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 hod documentation	Documented in a project specification	References community standard with some customization	References a community standard without customization	Adopts an open, community standard

Figure 8: Levels and characterstics of the first draft

The **phase 5 "Assess the Maturity Model"** was realized in the expert round of the 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 can cover not 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.

5.3.2 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. The definitions of the terms categories and dimensions are identical defined in chapter 6 and described there in more detail.

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 dimensions, 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 9 visualizes the maturity model as such diagram. The sections (labeled 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.

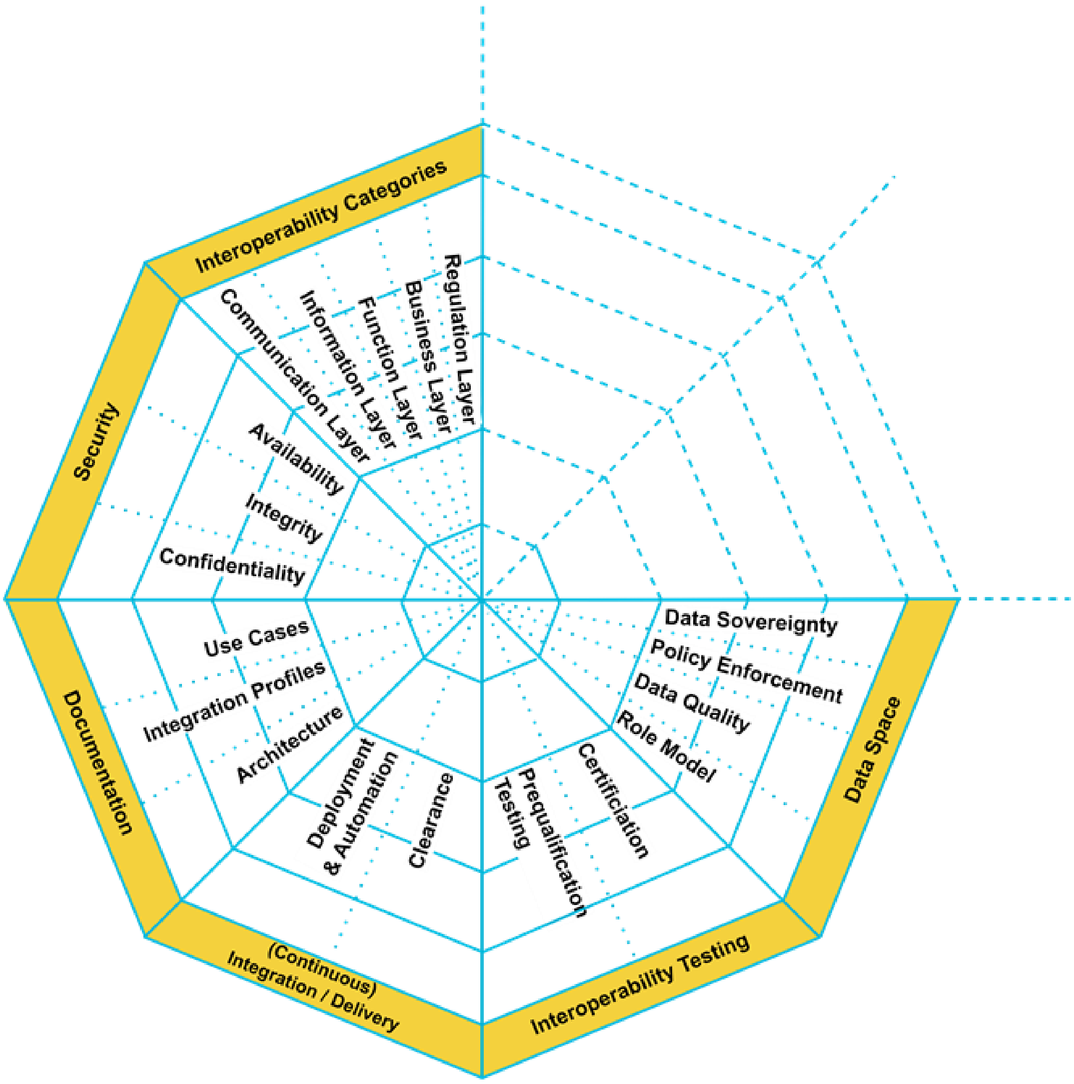

Figure 9: Second draft of the int:net Maturity Model

Like in the first iteration already done, **phase 5 "Assess the Maturity Model"** was conducted in the expert round of the 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 catalog 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.

5.3.3 Final Iteration

The final iteration represents the transition from the second iteration to the results from the next two chapters 6 and 7. In this regard, **phase 4 "Derive of the Maturity Model"** was run through again. In the final iteration, the general framework of the 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* category has 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 the T3.1 testing workshop lead by 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. The FAIR principles in particular were listed as examples in the questionnaire.

In addition to the changes within the categories, the visualization was also adapted to int:net's Cooperate Identity (see Figure 11). 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.

6 Structure of Evaluating the Maturity of INteroperability for the ENergy Transition (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 categories, 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 categories. 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.

6.1 EMINENT

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 categories 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 an 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 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. The reference architecture model used in the maturity model is the SGAM framework primary present in the (European) energy sector, which defines the domains, zones and interoperability layers found in the Smart Grid. When applying the maturity model, the system-of-interest view is classified in this framework. Regulatory interoperability represents an important consideration of the maturity model, which is why a Regulatory Layer is added to the SGAM framework under consideration. The use of other architecture frameworks (e.g., NIST Smart Grid Framework) is possible as long as a mapping of the interoperability categories, zones, and domains is feasible.

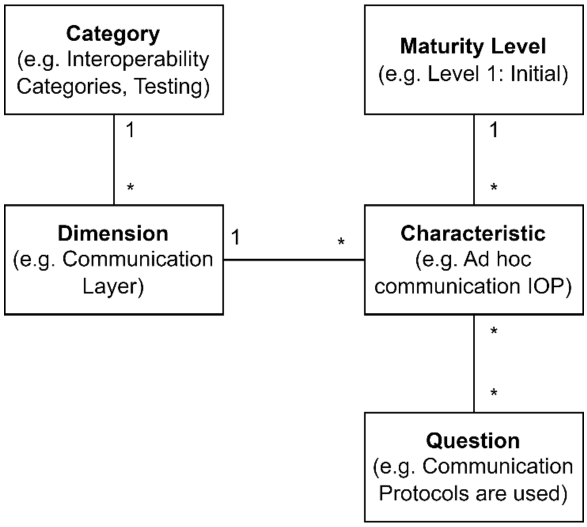

Figure 10: Components of EMINENT and their relationships

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

- **Categories:** Categories are defined as groupings or set of related dimensions, which are necessary for achieving a specific level of maturity. Categories 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 Categories are in the context of the interoperability challenges. The categories of the maturity model are defined in section 6.2. *Relationships:* A category can have different amounts of associated dimensions.
- **Dimensions:** The dimensions represent a specific area within the categories where interoperability challenges are apparent. For the dimensions, the maturity of interoperability needs to be measured. For this purpose, characteristics are representing the prerequisites for reaching a level. The dimensions of the maturity model are defined in section 6.3. *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 organization 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. Goal of the organizations 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 6.4. *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 6.5. *Relationships:* Every characteristic is assigned to one maturity level, dimensions and is assigned to at least one question of 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 way assessment way are defined in chapter 7. *Relationships:* Every question is assigned to at least one characteristic.

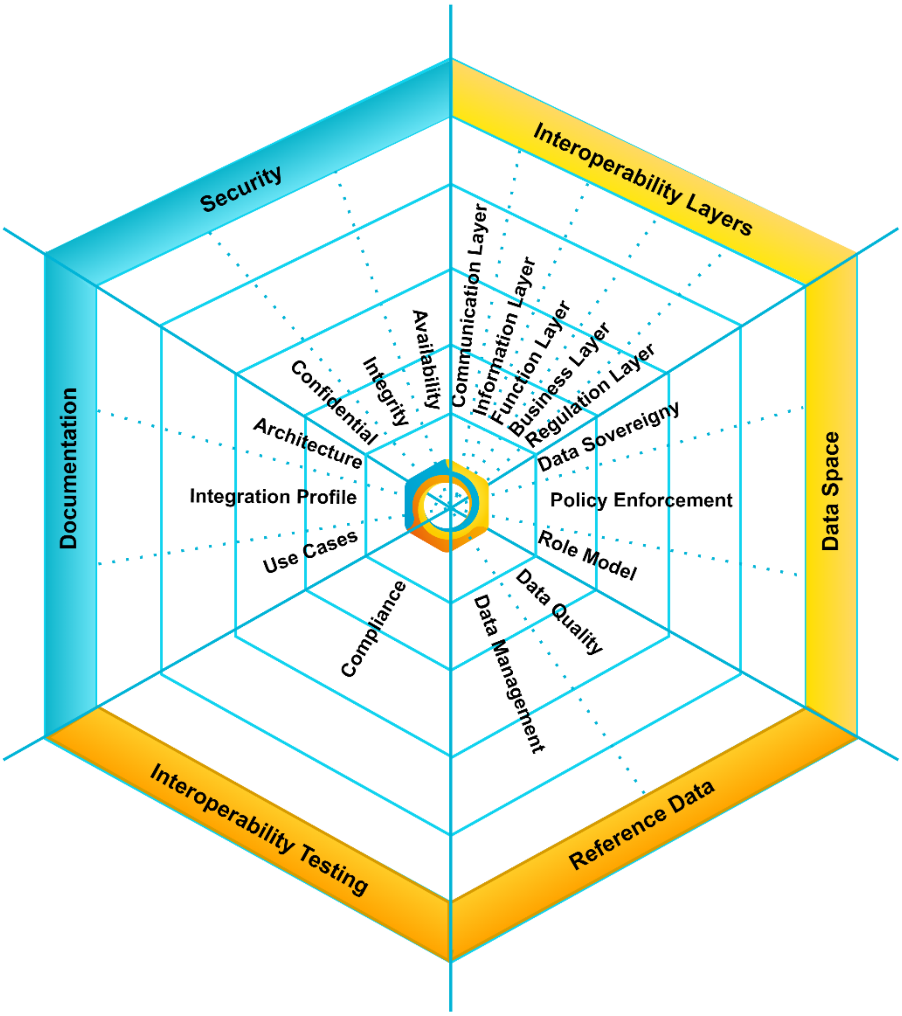

Figure 11: Framework of the int:net Interoperability Maturity Model

The framework of the int:net interoperability maturity model can be visualized as a network diagram in Figure 11. The **categories** at the outermost edge represent groupings of the associated **dimensions** labelled near the center. From the center, the areas are defined, to which the **maturity levels** are assigned in an ascending order. Implicitly, each dimension can be assigned to a maturity level by marking the area.

Not directly covered in the visualization are the **characteristics** that are given to the dimensions and maturity models in the Table 5. Characteristics represent the prerequisite that must be met to reach a certain maturity level within the associated dimension.

By answering the **questionnaire,** it is possible to determine the actual state of the company System-of-Interest. The questions are associated to the characteristics, which makes it possible to determine the maturity levels. This relationship between the defined questions and the maturity levels is further clarified in Chapter 7. Figure 12 shows an exemplary representation of an assessed community, which could used the questionnaire to determine the maturity levels of the dimensions.

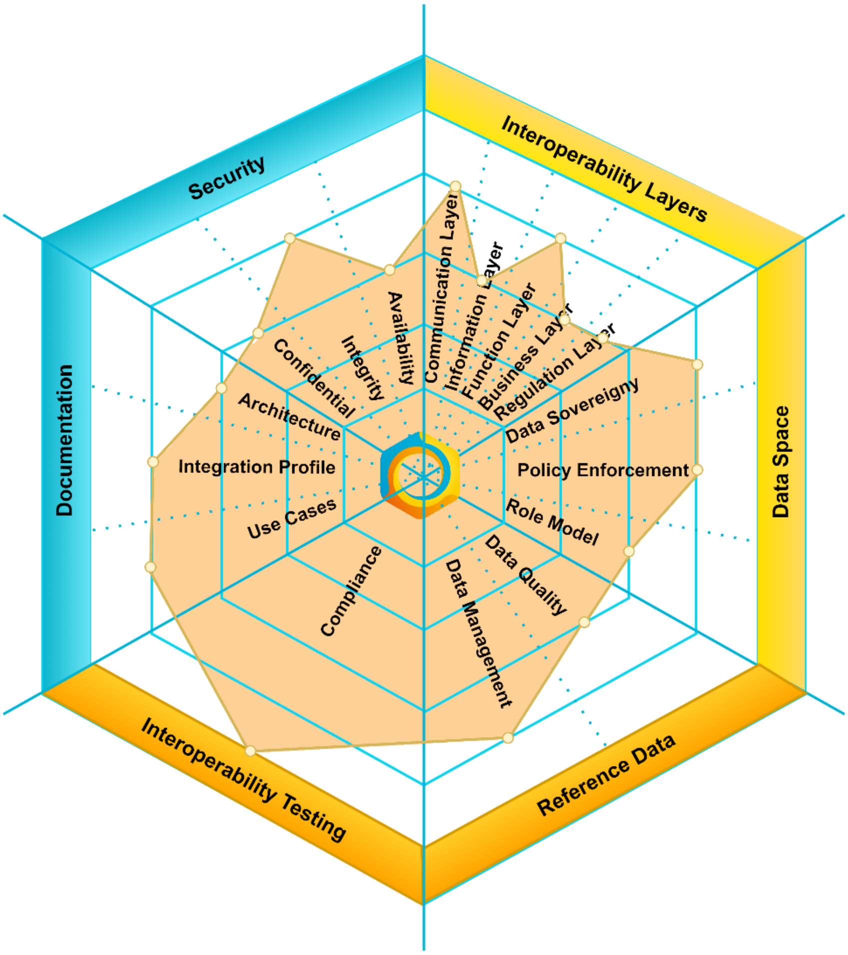

Figure 12: Exemplary representation of an assessed community according to the maturity model

The overall interoperability maturity score related to a concrete community can be calculated by summing the maturity level score of all dimensions. Consequently, the following formula can be established applicable for a community (e.g. company or for a concrete system) x:

$$score(x) = \sum_{i \in Dim.} level(i, x) \qquad max\big(score(x)\big) = 80 \qquad ratio(x) = \frac{score(x)}{max(score(x))}$$

For the example in Figure 12 the score for the community is $score(x_1) = 58$ which is a ratio of $ratio(x_1) = \frac{score(x_1)}{\max(score(x_1)} = \frac{58}{80} = 72{,}5\%$.

6.2 Categories

Categories are an essential element in the maturity models, providing a structured approach to assess the maturity of a particular area or process. Categories group related dimensions into distinct areas, allowing stakeholders to better understand the complexity of the process and identify areas of strength and weakness. The use of categories also offers a common language for stakeholders to discuss and evaluate their progress towards achieving the objective. Categories provide a framework for assessing multiple dimensions of a process and enable stakeholders to focus their efforts on areas of improvement.

This maturity model uses the categories as a grouping tool for the relevant topics within the energy sector. Here, disciplines are selected that should be implemented within the companies in the energy sector in order to achieve a high level of interoperability. Based on our work and identified requirements, the following categories are emerged for the maturity model:

- **Interoperability Layers:** A relevant category for an interoperability maturity model are the interoperability categories, which with their dimensions refer to the domain specific problems typical in the smart grid domain. *This category measures direct interoperability efforts*
- **Data Space:** This category focuses on the management and control of data, particularly in the context of a distributed system or network. It may involve defining policies and procedures for data sharing and access, ensuring data quality and integrity, and providing mechanisms for data protection and privacy. *This category measures interoperability efforts related to the integration of data spaces but also in the energy sector in general*.
- **Reference Data:** Data represents an important asset within ICT systems. Consequently, data management and quality processes must be setup to improve semantic interoperability. *This category measures interoperability efforts related to improving semantic interoperability of data.*
- **Interoperability Testing:** In this category, it involves the development and implementation of testing protocols and processes to ensure that interoperability requirements are met. This may include the creation of test cases, tools for automated testing, and the establishment of testing environments to simulate real-world scenarios. *This category measures interoperability efforts related to testing, which identifies integration failures and therefore improves consistency to standards.*
- **Documentation:** This category refers to the processes of documentation for the System-of-Concern. In the smart grid context in particular, specific standards and frameworks have emerged for documentation, which have a significant impact on the understanding of interoperability. In addition, the consideration of further documentation, e.g. user manuals, technical specifications or API documentation are aspects to be considered. Effective documentation can help ensure that systems and processes are well-understood and can be maintained and improved over time. *This category measures interoperability efforts related to documentation, which improves the awareness of the system integration in the system-of-systems and assist in the coordination with the stakeholders.*

- **Security:** This category involves the identification and management of security risks and vulnerabilities, as well as the implementation of security controls and practices to mitigate those risks in the smart grid. This may involve defining security policies and procedures, conducting regular security assessments, and staying up-to-date with the latest security threats and best practices. *This category measures interoperability efforts related to security, which envisions secure communication within the system-of-systems.*

Based on the categories, it is necessary to define dimensions that evaluate the interoperability aspects within the system-of-systems view. Conversely, this means that the interoperability to be assessed refers to the integration within the smart grid as a reference. This is also reflected in the selection of the categories, the dimensions of the characteristics and especially in the questionnaire.

6.3 Dimensions

The dimensions are concrete, specific problems that can be identified within the selection of the categories. These are more a specification of the categories and represent essential questions that are more finely granulated than the categories. Within the dimensions, characteristics are identified that require interoperability. The dimensions selected for maturity are presented below based on the categories.

6.3.1 Interoperability Layers

This category primarily considers direct interoperability difficulties within the smart grid context. The dimensions derived for the interoperability issues category are based on the layers of the SGAM framework. The component layer from SGAM was not considered because in our context this only descriptively shows the components of the community and no interoperability goals are connected. Here, the challenges of these layers are considered within the present maturity model. In addition to the original layers, a further level is considered, namely the regulation layer, which highlights the legislative challenges for ensuring interoperability. The following dimensions of the category are:

- **Communication Layer:** This dimension addresses the interoperability goals of component communication connectivity. The focus here is on interoperable interfaces for data exchange. This dimension thus provides for the use of standards that are adequate for integration within the system-of-systems.
- **Information Layer:** This dimension deals with the interoperability goals of the data exchange of components. The focus here is on interoperable data formats and models. This dimension thus provides for the use of standards that are adequate for integration within the system-of-systems.
- **Function Layer:** This dimension looks at the functions or use cases of the community under consideration. The focus here is on ensuring that the functions present in the community are interoperable with one another and that these fit the corporate goals and the components. These should use standards, common practices and agreements of the involved parties to enable integration in the system-of-systems.
- **Business Layer:** This dimension deals with the business cases of the community under consideration. Here, the business cases should be interoperable with the functions of the

community, but also with the technical and regulatory conditions. Within the business layer, standards, coordination and established approaches within the system-of-systems should therefore be taken into account.

- **Regulation Layer:** This layer represents a separate, additional dimension for the maturity model, which assumes the regulatory view of a community. Here the legislation is viewed on a regional, national, association of nations or international basis. Based on the contents of the previous layers, an agreement on the legislation side is essential. This dimension envisions compliance with the legislation to an international level in the optimum case.

6.3.2 Data Space

The subject of (Energy) Data Spaces is still under research and implementation at the time of this document. However, based on the category and its challenges, interoperability goals can be defined, which can also apply to conventional systems. Based on the processed results of the International Data Spaces Association [20], the following dimensions were developed:

- **Data Sovereignty:** This dimension refers to the authority and ownership that individuals or organizations have over their data. It encompasses the ability to control how data is collected, stored, processed and shared. Within the maturity model framework, assessing data sovereignty involves evaluating an organization's practices in data ownership and control, privacy and consent management, security and data protection, legal and regulatory compliance, and trusted data exchange. By considering these aspects, organizations can determine their level of maturity in ensuring data sovereignty and identify areas for improvement in data governance and control.
- **Policy Enforcement:** This dimension pertains to the implementation and enforcement of policies that govern the use and exchange of data within the data space. It involves defining and implementing policies that regulate access, usage, sharing, and protection of data in accordance with legal, regulatory, and organizational requirements. Assessing policy enforcement within the maturity model framework involves evaluating an organization's mechanisms for policy creation, dissemination, monitoring, and enforcement. This includes aspects such as access control, authentication and authorization mechanisms, data usage agreements, consent management, data lifecycle management, and compliance with relevant data protection regulations. By assessing policy enforcement, organizations can gauge their level of maturity in ensuring adherence to data policies and identify areas for improvement in policy implementation and governance.
- **Role Model:** This dimension refers to the establishment and adoption of standardized roles and responsibilities within the data space ecosystem. This dimension focuses on defining the roles of data providers, data consumers, data processors, and other relevant stakeholders. It includes the identification of their specific responsibilities, rights, and obligations in relation to data governance, data sharing, and data usage. The dimension entails the development of comprehensive role descriptions, clear communication channels, and mechanisms for accountability and coordination among the different actors within the data space. By implementing a well-defined role model, organizations can foster trust, collaboration and effective practices in the context of data spaces.

6.3.3 Reference Data

The category of "Reference Data" within the maturity model focuses on the management and quality of critical data assets that serve as reference points for accurate and consistent information within the energy sector. It encompasses two key dimensions:

- **Data Management:** This dimension encompasses the systematic management of critical data assets that serve as the foundation for various operational and decision-making processes. This dimension involves establishing comprehensive strategies and processes for the identification, collection, storage, maintenance, and dissemination of reference data within the energy sector. It emphasizes the importance of data accuracy, consistency, integrity, and availability to ensure reliable operations and informed decision-making. Effective data management practices within the energy sector enable stakeholders to leverage accurate and up-to-date reference data to support various activities such as asset management, grid planning, energy forecasting, and market analysis. When integrating data management, processes with the adequate handling of data should be measured.
- **Data Quality:** This dimension focuses on implementing robust data quality management processes within the data space. These processes involve data profiling, cleansing, integration, validation, and enrichment. Organizations need to establish clear responsibilities, roles, and procedures for data quality assessment and improvement. By implementing mature data quality management processes, organizations can ensure reliable and accurate data for decision-making and collaboration within the data space.

6.3.4 Interoperability Testing

Testing is an important part of both (general) software development and the energy domain via the use of specific testing strategies. An essential aspect of testing is interoperability testing, which includes compliance testing. This dimension is described in the following:

- **Compliance:** This dimension envisions testing involves assessing systems, components, and processes for prequalification testing, conformance to requirements, and certification. It ensures adherence to industry standards and regulatory frameworks. The dimension includes comprehensive testing strategies, conformance verification, certification, and robust documentation processes. Emphasizing compliance in testing enhances system trust, reliability, and interoperability, meeting regulatory and certification obligations.

6.3.5 Documentation

Documentation represents an essential point to ensure a common understanding of the (energy) community. The dimensions used represent essential aspects from the documentation and are considered and used especially in research and development projects to build up the understanding as well as analysing possible interoperability issues. These dimensions are the following:

- **Use Cases:** This dimension focuses on the development and application of (standardized) use cases to address specific industry requirements and challenges. Use cases serve as practical examples that demonstrate how different technologies, systems and processes can be employed to achieve specific objectives in the energy sector. They provide a standardized framework for defining and sharing best practices, facilitating interoperability, and promoting collaboration among various stakeholders. The standard IEC 62559 has a significant role in this dimension, providing guidelines for the creation and documentation of use cases in the energy domain. The dimension involves the comprehensive identification, documentation, and dissemination of use cases that cover a wide range of energy-related scenarios, fostering innovation, and enabling informed decision-making. By leveraging (standardized) use cases, the energy sector can enhance its efficiency, reliability, and sustainability while promoting harmonization and interoperability across diverse systems and technologies.

- **Integration Profiles:** This dimension focuses on the documentation of standardized integration profiles for seamless interoperability between different systems, devices and stakeholders. Integration profiles define the specific requirements, interfaces, protocols, and data formats that enable effective communication and collaboration among diverse components within the energy ecosystem. They serve as a blueprint for ensuring compatibility and consistency across systems, facilitating the smooth integration of various technologies and promoting interoperability at multiple levels. Robust documentation of integration profiles allows stakeholders in the energy sector to understand the technical specifications, capabilities, and dependencies of different components, fostering efficient system integration and reducing the risks of incompatibility or misalignment. The dimension entails the comprehensive development, maintenance, and dissemination of well-documented integration profiles that cover a wide range of energy-related scenarios, enabling seamless communication and collaboration among different entities within the energy ecosystem. By promoting (standardized) integration profiles, the energy sector can achieve enhanced interoperability, increased efficiency, and accelerated innovation in a rapidly evolving landscape.
- **Architecture:** This dimension pertains to the systematic and structured representation of energy systems. It involves the creation and maintenance of architectural artifacts that capture the various components, relationships, and interactions within the energy domain. Documentation in this dimension serves as a blueprint for designing, implementing, and managing energy systems, enabling stakeholders to gain a comprehensive understanding of the system's structure and behaviour. It includes the use of standardized modelling techniques and frameworks, such as the Smart Grid Architecture Model (SGAM), to ensure consistency, interoperability, and alignment with industry best practices. Effective documentation of energy system architecture (e.g. with Unified Modeling Language) facilitates efficient decision-making, promotes collaboration among stakeholders and supports the development of sustainable and resilient energy infrastructure.

6.3.6 Security

In the context of interoperability in the energy sector, security has a crucial role in ensuring safeguarding critical infrastructure and the reliable and secure exchange of information and data. As energy systems become increasingly interconnected, the need for robust security measures becomes paramount. Effective security practices encompass various aspects, including secure communication protocols, authentication mechanisms, access controls, encryption techniques, and intrusion detection systems. These measures help mitigate potential risks such as cyber threats, unauthorized access, data breaches, and ensure the integrity, confidentiality, and availability of energy infrastructure. By prioritizing security in the interoperability context, stakeholders can foster trust, resilience, and the overall sustainability of energy systems. The following dimensions are based on the primary protection goals of IT security (CIA) which are covered by the NIST IR Cybersecurity Guidelines [17]. However, Confidentiality is in sense of interoperability covered by Integrity and therefore the following are representing the dimensions:

- **Integrity:** This dimension focuses on ensuring the accuracy, consistency and trustworthiness of data and information throughout its lifecycle. Integrity measures involve the prevention of unauthorized modifications, tampering, or corruption of data, ensuring that it remains reliable and unaltered. This includes the implementation of mechanisms such as data validation, checksums, digital signatures, and secure communication protocols. By upholding data integrity, the energy sector can maintain the trustworthiness of critical information, such as meter readings, operational parameters, and control commands, which are vital for decision-making and system reliability. This dimension ensures the maintenance of (data) integrity and contributes to secure and resilient interoperability in the energy sector by protecting against unauthorized changes and ensuring the accuracy and reliability of data exchanged between different entities.
- **Availability:** This dimension pertains to ensuring uninterrupted access and functionality of critical systems and services. It encompasses measures and practices that aim to mitigate the risk of service disruptions, system failures or unauthorized access that could affect the availability of energy infrastructure. This includes implementing redundancy, failover mechanisms, backup systems and disaster recovery plans to minimize downtime and maintain continuous operation. Furthermore, it involves monitoring and response capabilities to detect and mitigate potential threats, such as cyber-attacks or physical disruptions that could compromise the availability of energy resources. By prioritizing availability, the energy sector can ensure the reliable and continuous delivery of energy services, supporting the stability and resilience of the overall energy infrastructure, which is part of the dimension to measure.

6.4 Maturity levels

Levels are representing a fundamental element in maturity models, which provide a framework for assessing the maturity of a particular area or process. The levels are used in a maturity model by categorizing the process into distinct stages or levels of development, each representing a specific set of characteristics indicative of the degree of maturity that has been achieved. The objective of EMINENT is to measure interoperability in the energy sector, which is why the levels are aligned with the measurement of interoperability efforts.

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. Since the maturity model has the requirement to use a hybrid assessment approach (in terms of progression and capability), this decision ensures capability. The realization of the progression approach is mirrored, in particular in the concrete goals and questions. The following maturity levels are used for this maturity model:

- **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.

These levels represent a basic framework for the development of concrete goals and their characteristics for the considered dimensions within the maturity model. Consequently, the concrete goals of the dimensions must be consistent with these levels across the entire maturity model.

6.5 Characteristics and goals

Characteristics are representing the observable attributes or indicators that describe a specific aspect of the process being evaluated. Defined characteristics can be used to assess the maturity of a process and identify areas for improvement. Goals represent the subjective objectives of the maturity model applicant. Consequently, in the context of our maturity model, this indicates that the characteristics represent the states to be achieved.

Characteristics are mapped to dimensions in the levels in a one-to-one relationship. The characteristics build on the definition of the levels and adapt them to the corresponding dimensions. In selecting the characteristics, the SG IMM was used as a guide for related dimensions, which also considers interoperability in the smart grid [19]. Table 5 represents the full characteristics in the form of a matrix for the intended dimensions and levels for the maturity model.

Category: Interoperability Layers	**Level 1**	**Level 2**	**Level 3**	**Level 4**	**Level 5**
Communication Layer	Ad hoc communication interoperability (proprietary)	Usage of concrete communication protocols	Usage of communication-related standards but with customization	Usage of communication-related standards without customization	The standardization of communication is being driven forward

Information Layer	Ad hoc information interoperability (proprietary)	Usage of a canonical data model	Usage of information-related standards but with customization	Usage of information-related standards without customization	The standardization of information exchange is being driven forward
Function Layer	Ad hoc function interoperability	Functions and/or use cases are documented	Functions and/or use cases are documented using community accepted techniques	Functions and/or use cases are documented using community accepted techniques without customization	The use case lead to a sustainable environment
Business Layer	Ad hoc business layer interoperability	Business processes are documented	Business processes are documented using community accepted techniques	Business processes are documented using community accepted techniques without customization	The business objective leads to a sustainable environment
Regulation Layer	Ad hoc regulation layer interoperability	EU-wide regulation interoperability	Location-independent interoperability	Location-independent interoperability with regulation support	Location-independent interoperability influencing legislation
Category: Data Spaces	**Level 1**	**Level 2**	**Level 3**	**Level 4**	**Level 5**
Data Sovereignty	Ad hoc data sovereignty	Data sovereignty processes are established	Data sovereignty processes are oriented on community approaches	Data sovereignty processes are oriented on community approaches	Continuous improvement of data sovereignty

			with customization	without customization	
Policy Enforcement	Ad hod policy enforcement	Policy enforcement processes are established	Policy enforcement is following community approaches with customization	Policy enforcement is following community approaches without customization	Continuous improvement of policy enforcement
Role Model	No role model	Role modeling processes are established and documented	Role modeling processes are integrated into the overall data management framework	Roles and responsibilities are aligned with organizational strategy and goals	Role modeling processes are continuously improved and optimized
Category: Reference Data	**Level 1**	**Level 2**	**Level 3**	**Level 4**	**Level 5**
Data Management	No formal data management	Data management processes are ensured	Data management processes are oriented on standards	Data management processes comply with the standards	Continuous improvement of data management processes
Data Quality	No formal data quality management processes	Data quality management processes are established and documented	Data quality standards and frameworks are used with customization	Data quality standards and frameworks are used without customization	Continuous improvement of data quality management
Category: Interoperability Testing	**Level 1**	**Level 2**	**Level 3**	**Level 4**	**Level 5**
Compliance	No formal testing	Prequalification testing is ensured	Declaration of conformity is ensured	Certification is ensured	Regular (re-)certification is ensured

Category: Documentation	Level 1	Level 2	Level 3	Level 4	Level 5
Use Cases	Ad hoc use case documentation	Use Case documented in a project specification	Reference community standard with some customization	References a community standard without customization	Use case management processes are ensuring continuous improvement
Integration Profiles	No integration profile management processes	Integration profiles management processes are established and documented	Integration profile standards and policies are used with customization	Integration profile standards and policies are used without customization	Integration profile management processes are continuously improved and optimized
Architecture	Ad hoc architecture modelling	Architecture in a project specification	Using a reference designation system with some customization	Using a reference designation system without customization	Adopts a open, community standard
Category: Security	**Level 1**	**Level 2**	**Level 3**	**Level 4**	**Level 5**
Integrity	Ad hoc integrity	Basic integrity is realized	Major integrity is ensured acc. smart grid guidelines	Integrity is realized acc. smart grid guidelines	Continuous improvement of integrity ensured
Availability	Ad hoc availability	Basic availability is realized	Major availability is ensured acc. smart grid guidelines	Availability is realized acc. smart grid guidelines	Continuous improvement of availability ensured

Table 5: Characteristics of EMINENT

7 Questionnaire of EMINENT

This chapter represents the second descriptive part of the maturity model. The focus here is on the application for a concrete system or a process strategy of companies via a questionnaire, which was developed based on the framework from Chapter 6. Furthermore, this chapter shows an exemplary application of the maturity model in order to illustrate it in reality and for further research tasks and projects.

7.1 Questionnaire

A questionnaire is used to record the questions for the concrete assessment of a system or the process strategy. The questions are assigned to the dimensions and the maturity level. By assigning the maturity level to the dimensions, the characteristics from Table 5 can be presented as prerequisites for achieving the maturity levels. Consequently, the assignment of questions to maturity levels also represents an assignment of characteristics. A maturity level can only be reached if and only if all the questions for a particular characteristic are answered in the affirmative. Table 6 represents the questionnaire of EMINENT.

Level 3 and 4 in particular provide for orientation to standards and guidelines. While Level 3 mostly provides for orientation to standards and guidelines, Level 4 requires stringent compliance with the standard. Here, the term "with deviations" is envisaged, which allows deviations, while "without deviations" envisages strict compliance.

				Level 1 - Initial	Level 2 - Managed	Level 3 - Defined	Level 4 - Quant. Managed	Level 5 - Optimizing
Interoperability Layers	Communication Layer	IL-CL-1	Technical communication with other systems is defined					
		IL-CL-2	Standardized communication protocols, e.g. REST, MQTT are used for all relevant data exchanges					
		IL-CL-3a	Processes are used to log version changes to the data model or profiles (e.g., via interface versioning)					
		IL-CL-3b	Technical communication integrates with the visions of participating stakeholders					

		IL-CL-3c	Energy-related standards, e.g. CIM or IEC 61850, are used **with or without deviations** for the communication/information exchange					
		IL-CL-4	Energy-related standards, e.g. CIM or IEC 61850, are used **without deviations** for the communication/information exchange					
		IL-CL-5	Culture of innovation and continuous improvement in communication/information exchange are established					
	Information Layer	IL-IL-1	Data formats for the exchange are defined					
		IL-IL-2	Canonical data models are used for the data exchanges					
		IL-IL-3a	Data exchanges integrates with the visions of participating stakeholders					
		IL-IL-3b	Standardized approach for information exchange across the organization are used **with or without deviations**					
		IL-IL-4	Standardized approach for information exchange across the organization are used **without deviations**					
		IL-IL-5	Culture of innovation and continuous improvement in information sharing are established					
	Function Layer	IL-FL-1	A distinct use case has been defined					
		IL-FL-2a	The associated information model fits the foreseen use case					
		IL-FL-2b	The use case fits to the business objective					
		IL-FL-3a	The use case integrates with the visions of participating stakeholders					
		IL-FL-3b	Standards and guidelines for designing and implementing the functions / use case are used **with or without deviations**					
		IL-FL-4	Standards and guidelines for designing and implementing the functions / use case are used **without deviations**					
		IL-FL-5	Culture of innovation and continuous improvement in the functions / use case are established					

	Business Layer	IL-BL-1a	The business objective can be realized with the regulations / policies					
	Business Layer	IL-BL-1b	The business objective can be realized with the technical possibilities					
	Business Layer	IL-BL-2	The business objective is documented					
	Business Layer	IL-BL-3a	The business objective is aligned with the all the participants					
	Business Layer	IL-BL-3b	Standards and guidelines for designing and implementing (parts of) the business objective are used **with or without deviations**					
	Business Layer	IL-BL-4	Standards and guidelines for designing and implementing (parts of) the business objective are used **without deviations**					
	Business Layer	IL-BL-5	Culture of innovation and continuous improvement in business objectives are established					
	Regulation Layer	IL-RL-1	Feasibility through the regulatory level on regional level is given					
	Regulation Layer	IL-RL-2	Feasibility through the regulatory level on country/EU level is given					
	Regulation Layer	IL-RL-3	The feasibility on the legislation is globally given					
	Regulation Layer	IL-RL-4	The policy level assures support to the project					
	Regulation Layer	IL-RL-5	The project influences the regulation level to a change in thinking					
Data Space	Data Sovereignty	DS-DS-1	Awareness of the country where data is stored is ensured when using cloud-based solutions					
Data Space	Data Sovereignty	DS-DS-2	The hosting service location serves as a motivation for selecting services					
Data Space	Data Sovereignty	DS-DS-3	Existence of data sovereignty is confirmed					
Data Space	Data Sovereignty	DS-DS-4	Coordination with the community is carried out to ensure alignment of data sovereignty policies					
Data Space	Data Sovereignty	DS-DS-5	Community-wide data sovereignty agreements are established					

	Policy Enforcement	DS-PE-1	A data management policy is defined within the organization					
		DS-PE-2	Processes are in place to actively monitor conformance to the data management policy					
		DS-PE-3	The policy aligns with standardized frameworks like DAMA DM-BOK					
		DS-PE-4	Verification is conducted with the community to determine if they have a data policy defined					
		DS-PE-5	Coordination with the community is established to ensure enforcement of the data management policy					
	Role Model	DS-RM-1	Ad hoc data management has been realized					
		DS-RM-2	Data management roles are defined and used within the organization					
		DS-RM-3	The data management roles have the necessary mandate and access to resources to align data management practices with data management policies					
		DS-RM-4	The roles align with standardized frameworks such as DAMA DM-BOK					
		DS-RM-5	Roles and responsibilities for data management are aligned with the community to ensure consistency and collaboration in data management efforts					
Reference Data	Data Quality	RD-DQ-1	Regular steps are taken to improve data quality within the organization					
		RD-DQ-2	A data quality framework is defined to guide data quality initiatives					
		RD-DQ-3	Processes are in place to address data quality issues at the processes where the data originate					
		RD-DQ-4	Interaction with the community is established to address data quality issues that span multiple organizations and technologies					
		RD-DQ-5	Community-wide data quality agreements are in place to ensure consistent data quality practices.					
	Data Management	RD-DM-1	Ad hoc data management has been realized					
		RD-DM-2	Data management processes are defined and used within the organization					

		RD-DM-3	Data management processes are oriented on established guidelines, standards and principles (e.g. FAIR principles)					
		RD-DM-4	Data management processes are compliant with established guidelines, standards and principles (e.g. FAIR principles)					
		RD-DM-5	Community-wide data management processes agreements are in place to ensure consistent data management practices.					
Interoperability Testing	**Compliance**	IT-C-1	Compliance has been generally checked					
		IT-C-2	Compliance with self-defined requirements is checked by the vendor / supplier / provider					
		IT-C-3	Compliance with relevant standards (e.g. IEC 62443) has been checked by the vendor / supplier / provider					
		IT-C-4	Compliance with relevant standards (e.g. IEC 62443) has been checked by a third party (certification body)					
		IT-C-5	Compliance with relevant standards (e.g. IEC 62443) is being checked regularly by a third party (certification body)					
Documentation	**Use Cases**	D-UC-1	Use cases are created upon request					
		D-UC-2a	Processes for creating and validating use cases are created					
		D-UC-2b	Use cases are created according to a project-specific specification					
		D-UC-3	Use cases are following a standardized approach with or without customization (e.g. IEC 62559 Use Case Methodology)					
		D-UC-4	Use cases are following a standardized approach without customization (e.g. IEC 62559 Use Case Methodology)					
		D-UC-5	Use case development processes are continuously improve by a feedback and data analysis loop					
	Integration Profiles	D-IP-1	Integration profiles are created upon request					
		D-IP-2a	The organization have a defined set of integration profiles for the use in projects					

		D-IP-2b	Processes for the integration profile management are established and documented in a project specification					
		D-IP-3	Integration profiles are defined and documented in a standard format (e.g. IHE profiles) **with or without customization,** that is accessible to all project teams					
		D-IP-4	Integration profiles are defined and documented in a standard format (e.g. IHE profiles) **without customization,** that is accessible to all project teams					
		D-IP-5	Processes for continuously reviewing and updating integration profiles based on emerging technologies and changing project requirements are established					
	Architecture	D-A-1	Architectures for the integration inside the energy system are created					
		D-A-2	A project-wide specification for architecture creation is employed					
		D-A-3	Reference architecture framework (e.g. Smart Grid Architecture Framework [SGAM]) are used **with or without customization**					
		D-A-4	Reference architecture framework (e.g. Smart Grid Architecture Framework [SGAM]) are used **without customization**					
		D-A-5	Architecture design process ensure improvement proactively based on emerging technologies and trends					
Security	Integrity	S-I-1	The organization is capable of managing data produced by third parties					
		S-I-2	The organization is capable of using external data and publishing results with the original identifiers					
		S-I-3	Globally unique and persistent identifiers are provided for the organization's data					
		S-I-4	Processes are established with interoperability partners to resolve inconsistencies in data at the data source, whether internal or external					
		S-I-5	The organization uses resilient techniques (e. g. Artificial Intelligence) that improve integrity in the longer term					
	Availability	S-A-1	The organization is aware of the 'uptime' of services that serve the data it provides and consumes					
		S-A-2	Efforts are made to align the uptime of data services consumed with the organization's availability needs					

		S-A-3	Efforts are made to align the uptime of data services provided with the availability needs of data consumers					
		S-A-4	The organization has the capability to adjust the availability of the data it provides to meet the needs of consuming business processes					
		S-A-5	The organization uses resilient techniques (e. g. Artificial Intelligence) that improve availability in the longer term					

Table 6: Questionnaire of EMINENT

7.2 Application

This section focuses with the practical application of the maturity model. Decisive for the application of the maturity model is the answering the questionnaire from the previous section. The questionnaire consists of statements that the user can agree or disagree with, enabling the evaluation of a system and/or company. In this section, an exemplary application of the question catalogue using the "Use Case" dimension of the "Documentation" category is provided. By applying the questionnaire (based on the provided example) to all other dimensions, the individual total maturity score can be determined. Additionally, the concept of presets is introduced, aiming to support the diverse perspectives of stakeholders on the maturity model.

7.2.1 Exemplary assessment

In this example for the "Use Case" dimension of the "Documentation" category, the maturity level for a given system or the company should be determined. Since the maturity levels are linked to the characteristics provided for the dimension, it is necessary to evaluate the capability of a concrete system and/or company. For reaching the highest maturity, the following conditions are to be meet:

- To reach the next higher maturity level, all previous maturity levels must be covered. Consequently, maturity levels are not permitted to be skipped.
- The maturity levels are directly linked to the characteristics (see section 6.5), which in turn are linked to at least one question (see section 7.1). All linked questions (in the sense of statements) must be agreed to in order to describe a characteristic and consequently to achieve the maturity level.

Two examples are used to illustrate the maturity assessment for the "Use Case" dimension. Table 7 shows the answers of both examples for the intended questionnaire. The *first example #1* represents a community that is implementing a consistent use case policy for an energy system. Use cases are created based on the IEC 62559-2 Use Case Template. However, some sections have been removed from the standard, which is why significant adaptations lead to a deviation from the standard. However, use cases are created once and there is no continuous feedback process. The second example represents a community that also creates use cases for energy systems, in form of a textual use case description. However, these do not follow any (project) specification and therefore also no standard. However, these use cases are constantly updated and improved at regular intervals via regulated processes.

Maturity levels and characteristics of the Dimension	**Question**	**Examplery answer #1**	**Examplery answer #2**
Level 1: Ad hoc use case documentation	Use cases are created upon request	Yes	Yes

Level 2: Use Case documented in a project specification	Processes for creating and validating use cases are created	**Yes**	**Yes**
	Use cases are created according to a project-specific specification	**Yes**	**No**
Level 3: References community standard with some customization	Use cases are following a standardized approach **with or without customization** (e.g. IEC 62559 Use Case Methodology)	**Yes**	**No**
Level 4: References a community standard without customization	Use cases are following a standardized approach **without customization** (e.g. IEC 62559 Use Case Methodology)	**No**	**No**
Level 5: Adopts a open, community standard	Use case development processes are continuously improve by a feedback and data analysis loop	**No**	**Yes**

Table 7: Exemplary answering for two different examples

According to the answers of the questionnaire for the dimension, the *maturity level "Level 3: Defined" can be assigned for example #1*. All statements up to and including the third characteristic could be agreed. For example #2, only the statement linked to the first characteristic could be agreed completely. Consequently, the *example #2 can only be granted the maturity level "Level 1: Initial"*. A partial match of the answers for the characteristic from level 2 and the complete match for the characteristic from level 5 are consequently irrelevant with respect to the conditions. The achieved maturity levels for the dimension Use Case are visualized in Figure 13 for example #1 and Figure 14 for example #2.

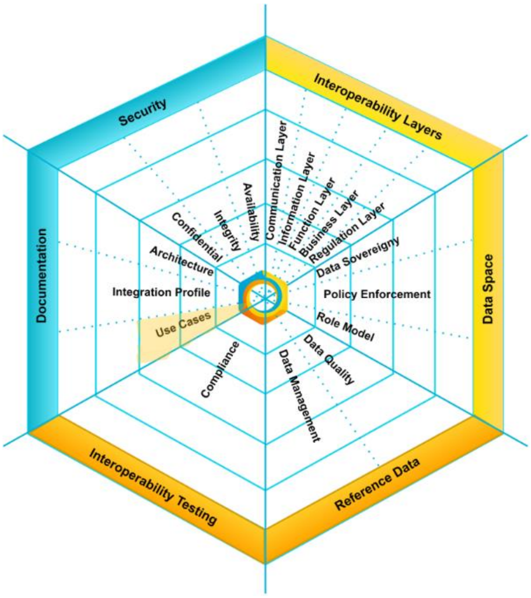

Figure 13: Spider web representation of the maturity model with maturity level drawn in for dimension use cases example 1.

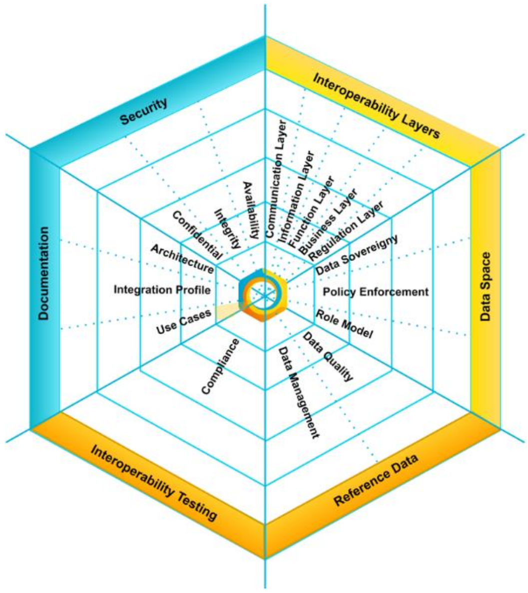

Figure 14: Spider web representation of the maturity model with maturity level drawn in for dimension use cases from the example 2

7.2.2 Presets

The maturity model is designed to be applicable to various stakeholders in the energy sector. These stakeholders include energy generation companies, transmission system operators, distribution system operators, distributed energy producers, virtual power plants, consumers, producers, standardization companies and policymakers. Each stakeholder has their unique perspective on the system, resulting in different requirements. This initial version of the maturity model serves as a *baseline version*, selecting relevant categories and dimensions based on existing frameworks, maturity models and literature. The model considers each category and dimension independently, without imposing strong dependencies between disciplines. As a result, the categories, dimensions, and questionnaire of the maturity model exhibit 'loose coupling,' promoting flexibility and the substitutability of individual components [21].

Based on the baseline versions, *presets* can be developed that are tailored to the stakeholders. These *presets* allow the selection of relevant categories, dimensions and adaptation of the questionnaire according to the stakeholder's requirements. By utilizing presets, the maximum maturity score achievable for a system changes based on the amount of selected dimensions. *Exemplary presets* will be developed in later stages of the int:net project through field evaluations of the maturity model.

8 Conclusion

Within Task 2.1, a maturity model framework was developed that can be applied domain-agonistically within the electric energy sector to assess interoperability efforts, covering the system-of-systems view. A focus point represents the consideration of interoperability issues in the sense of categories or dimensions. In the first version of the maturity model, the definition of characteristics and the developed questionnaire are used to evaluate the interoperability efforts of companies and/or systems. The questions are accompanied by examples, although they are not restricted to a specific technology.

However, research indicates some limitations and an outlook. The evaluation envisaged in this procedure model was ensured within the framework of expert rounds and workshops, which, however, is to take place with the actual users in the next instance. This will be done in cooperation with ENTSO-E and E.DSO as the EU-leading representation of the transmission system operators and distribution system operators, respectively. However, both companies were also involved in the development of the framework. The evaluation may result in additional categories, dimensions or additions to the questionnaire. The maturity model is intended to be domain-agnostic, which is why the categories and dimensions identified are generic but not relevant to every stakeholder. Therefore, the preset system has been introduced in section 7.2.2, which are intended as functionality in the maturity model framework for considering a selection of categories, domains and flexibility in the questionnaire. Concrete presets will also be developed as part of the follow-up tasks in the work package and by using the feedback of the evaluation.

9 List of Tables

10 List of Figures

11 List of Abbreviations

CIM	Common Information Model
CMM	Capability Maturity Model
CMMI	Capability Maturity Model Integration
DAMA-DM-BOK	The Data Management Body of Knowledge
DER	Distributed Energy Resources
DSO	Distributed System Operator
EMINENT	Evaluating the Maturity of INteroperability for the ENergy Transition
GDPR	General Data Protection Regulation
GWAC	GridWise Architecture Council
ICSF	Interoperability Context-Setting Framework
ICT	Information and Communications Technologies
IEC	International Electrotechnical Commission
IHE	Integrating the Healthcare Enterprise
intMM	int:net Maturity Model
IOP	Interoperability
MM	Maturity Model
REST	Representational State Transfer
SG IMM	Smart Grid Interoperability Maturity Model
SGAM	Smart Grid Architecture Model
SGMM	Smart Grid Maturity Model
TRL	Technology Readiness Levels
TSO	Transmission System Operator
UML	Unified Modeling Language
WP	Work Package

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Annex A: Collection of Maturity Models and Framework

A1. Smart Grid Interoperability Maturity Model

Name & Abbreviation:	Smart Grid Interoperability Maturity Model [SG IMM]
Author or Publisher:	GridWise Architecture Council (GWAC) [19]
Created at / Last Update:	2012
Location:	USA
Type:	Maturity Model
Description:	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:	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, semantical and pragmatical interoperability
Categories / characteristics 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	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.

A2. 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) [22]
Created at / Last Update:	Version 1.1 2014

Location:	USA
Type:	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 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

A3. Smart Grid Maturity Model

Name & Abbreviation:	Smart Grid Maturity Model [SGMM]
Author or Publisher:	Software Engineering Institute (SEI) [19]

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 to 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 most prominent representative in the smart grid context

A4. Distributed Energy Resources Integration Maturity Model

Name & Abbreviation:	Distributed Energy Resources Integration Maturity Model [iDER]

Author or Publisher:	Navigant Inc. [23]
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 the DER integration as part of the energy sector

A5. Technology Readiness Level

Name & Abbreviation:	Technology Readiness Level [TRL]
Author or Publisher:	NASA [24]
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

A6. Integrated DER Maturity Assessment

Name & Abbreviation:	Integrated DER Maturity Assessment [iDER]
Author or Publisher:	Guidehouse [25]
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 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 the DER integration as part of the energy sector

A7. Smart Readiness Indicator

Name & Abbreviation:	Smart Readiness Indicator (SRI)
Author or Publisher:	European Commission [26]
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 pursue 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. It's application on national level is optional (for now). EU institutions will probably require this to be a basis for measirung smart readiness of buildings. However, there are no specific requirements on interoperability.

A8. Industry 4.0 Readiness Indicator

Name & Abbreviation:	Industry 4.0 Readiness Index
Author or Publisher:	IMPULS [27]
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

A9. Smart Industry Readiness Index

Name & Abbreviation:	Smart Industry Readiness Index [SIRI]
Author or Publisher:	Singapore Economic Development Board [28]
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	• Connectivity • Interoperability

for int:net: *Which dimensions and/or categories are relevant for int:net?*	• 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 ability to access data across assets and systems with ease • To mitigate cyber-attacks • To have secure and resilient cyber-physical security architecture

A10. Interoperability Score

Name & Abbreviation:	Interoperability Score [iScore]
Author or Publisher:	Air Force Institute of Technology [29]
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 calcuation 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

A11. Capability Maturity Model

Name & Abbreviation:	Capability Maturity Model [CMM]
Author or Publisher:	U.S. Department of defense [16]
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

A12. Capability Maturity Model Integration

Name & Abbreviation:	Capability Maturity Model Integration [CMMI]
Author or Publisher:	CMMI Institute (ISACA) [17]
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

A13. Control Objectives for Information and Related Technologies

Name & Abbreviation:	Control Objectives for Information and Related Technologies [COBIT]
Author or Publisher:	ISACA & ITGI [30]
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

A14. 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