Interoperability in Energy Systems: Identifying Challenges and Innovations in Metering Operations and Data Sharing in Germany

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Abstract

The transition of the German energy market towards digitalization and smart grid integration presents both challenges and opportunities in smart metering operations and data sharing. This paper examines the complexities of interoperability among energy market participants, emphasizing the need for robust data handling frameworks as competition increases. Key findings suggest that while submetering is underutilized, its integration into the smart metering infrastructure could enhance its degree of utilization. The analysis underscores the importance of standardized communication infrastructures and indicates that star-shaped communication models as well as enhanced Web-APIs offer promising solutions for efficient data flows regarding near-real-time grid status data. Ultimately, the paper advocates for collaborative data exchange through cloud-to-cloud solutions, prioritizing data protection and trust among stakeholders.

Abbreviation	Description	Abbreviation	Description	Abbreviation	Description
API/ REST API	Application Programming Interface / Representational State Transfer API	ESP	Energy Service Provider	mMD	Modern Metering Device
APN	Access Point Name	GCP	Grid Connection Point	MsbG	Metering Point Operation Act (last change: 2025/02/21)
BDEW	German Association of Energy and Water Industries	GWA	Gateway Administration	OMS	Open Metering System
BNetzA	German Federal Network Agency	HAN	Home Area Network	SMGW	Smart Meter Gateway
BSI	German Federal Office for Information Security	HCA	Heat Cost Allocator	SM-PKI	Smart Metering Public Key Infrastructure
CBA	Control Box Administration	HCO	Heating Cost Ordinance	SMI	Smart Metering Infrastructure
CLS-CA	Controllable Local System – Communication Adapter	ID	Identification Number	TAF	Tariff Application Case
DER	Distributed Energy Resource	LMN	Local Metrological Network	UI	User Interface
DSO	Distribution System Operator	LV	Low Voltage	UCI	User Consumption Information
(a/p)EMP	(Active/Passive) External Market Participant	LoRaWAN	Long Range Wide Area Network	VDE FNN	Network Technology/Network Operation Forum at Association for Electrical, Electronic and Information Technologies
EMS	Energy Management System	MaKo	Market Communication	WAN	Wide Area Network
EnWG	Energy Industry Act (last change: 2025/02/21)	(b/c)MPO	(Basic/Competitive) Metering Point Operator	iMSys	Smart Metering System

1 Introduction

In recent years, the German energy market has experienced significant changes, particularly in the metering sector. Standardly divided into basic and competitive metering point operators ((b/c)MPOs), new MPOs entered the market, creating a divers actor landscape [1, 2]. This shift places additional pressure on distribution system operators (DSOs), who must now engage in the low voltage (LV) grid with an increasing number of actors during system operation, with most networks ranging from 11 to 30 cMPOs [3]. However, also MPOs are required to facilitate meter data access to additional parties. Officially enabled by the so-called energy service provider (ESP), a new market role since December 21, 2020, tasked with data handling aligned with end-customer agreements, as evidenced by the 159 ESPs registered at the German Association of Energy and Water Industries (BDEW) at time of writing this article [4, 5].

Additionally, submetering remains a niche market, with ongoing discussions about its integration into the smart metering infrastructure (SMI) [2]. The differentiation between localized considerations and external property control, as discussed by [6], and remote access to distributed energy resources (DERs) via smart metering systems / "intelligente Messsysteme" (iMSys), highlighted by [7], further emphasize the evolving nature of the energy market. The differentiation between localized considerations and external property control, as discussed by [6], and remote

access to DERs via iMSys, highlighted by [7], further emphasize the evolving nature of the energy market. Moreover, cloud-to-cloud services emerge as a crucial component for facilitating seamless data exchange among various market participants. This paper seeks to explore these dynamics and propose solutions to the emerging challenges.
Chapter 2 provides background on the roles of various market participants and discusses relevant regulatory frameworks such as §14a of the Energy Industry Act / "Energiewirtschaftsgesetz" (EnWG). It follows Chapter 3, which outlines the paper's approach to identify and analyze high-level system architectures to exchange metering data in the German SMI, while Chapter 4 presents the corresponding results. In Chapter 5, the results presented are discussed and the strengths and weaknesses of the architecture are highlighted. Finally, Chapter 6 summarizes the key findings and future directions for stakeholder engagement and data-driven services.

2 Background

Efficient stakeholder involvement is crucial for IT system integration in the energy system, with key roles played by basic metering point operators, competitive metering point operators, distribution system operators, and SMI suppliers. These stakeholders ensure proper installation, market competition, grid stability, and compliance with security standards [8].

2.1 §14a EnWG

The government has introduced last resort control measures for controllable consumer assets over 4.2 kW due to increased electrification in mobility and heating in the lower voltage grid. Starting March 1, 2025, DSOs must publish information on these measures on the joint internet platform "VNB-Digital" in accordance with §14a EnWG [9, 10]. To this date, none of the German DSOs have applied the new mechanism in accordance with the platform's data base.
The grid-oriented control model aims to improve grid observability using iMSys metering data, specifically tariff application case / "Tarifanwendungsfall" (TAF) 10 values from smart meter gateways for state estimation [11]. Despite §14a EnWG related industry standardization officially activities recognized by the German Federal Network Agency / "Bundesnetzagentur" (BNetzA) [12, 13], challenges may remain in accessing TAF 10 values, affecting operational efficiency.

2.2 Cross-sector Submetering

Cross-sector submetering is an essential part for Germany's energy transition, as detailed in the national SMI roadmap [14]. This roadmap aims to transform the energy grid into a smart grid through phased modernization across sectors such as electricity, gas, water, and heating. Regarding heating, as one example, since December 1, 2022, exits the obligation for metering installations in the context of heating costs billing – like heating costs ordinances (HCOs) – to be connectable with a SMGW [15].

2.3 The German MaKo

Market communication / "Marktkommunikation" (MaKo) in Germany involves structured interactions among market actors like DSOs, energy suppliers, MPOs and ESPs, and processes like DSOs assigning identification numbers (IDs) for network locations with controllable §14a EnWG assets [16].

2.3.1 Universal Ordering Process

On November 21, 2022, the BNetzA published specifications for handling control actions and grid status access related to smart metering systems, known as the universal ordering process ("Universalbestellprozess") (BK6-22-128) [17, 18]. The BNetzA's decision focuses on required MaKo changes to implement §14a EnWG data exchanges. Like the first Web-API service in the German MaKo for control signals of DSOs and energy suppliers as well as the possibility to request meter data from the responsible MPO via the MPO's backend or directly from the iMSys as a system operator, energy supplier or ESP. This includes grid status data, only available for system operators, as one example of type 2 meter data.

2.3.2 Web API Services

A web application programming interface (Web-API) facilitates communication between different software applications. As of April 1, 2023, a representational state transfer (REST) API for the universal ordering process was initially introduced, aiming for control command processing within six seconds [19]. Beginning April 3, 2024 [20], all MPOs are required to implement the Web-API for their locations [21]. All transmissions via the Web-API necessitate the German Federal Office for Information Security / "Bundesamt für Sicherheit in der Informationstechnik" (BSI)'s Smart Metering Public Key Infrastructure (SM-PKI) for authentication and authorization [18]. It uses the "JavaScript Object Notation" [22] to implement the industry requirements set by the BDEW EDI@Energy expert group, which are publicly available in [23].

2.4 The German SMI

Since the rollout of Germany's smart metering infrastructure in 2020, two main development paths have emerged [24, 25]. One path enables the receipt of (non-)validated meter data via the local metrological network (LMN) of the SMGW, while the other focuses on secure remote-control SMI rollout, driven by §14a EnWG and the need for improved grid congestion management in the low voltage grid additionally related to §9 Renewable Energy Sources Act [26]. The SMI's TAF 10 grid status data is crucial for the underlying grid observability in system operation, requiring modern metering devices (mMDs) with grid functionalities connected to the LMN of a SMGW (LV grids) [12].

2.4.1 Overview of Key SMI Components

The SMGW is the central communication unit of an intelligent metering system, integrating into the technical and

organizational environment [27]. Derived from the protection profile, the guideline details how the SMGW communicates across various networks (**Figure 1**).
It operates across the LMN to interact with utility meters for various resources and communicates securely in the wide area network (WAN) with the gateway administrator and authorized market participants. Additionally, the SMGW interfaces with the home area network (HAN) to enable services for local devices, supporting energy management and home automation.

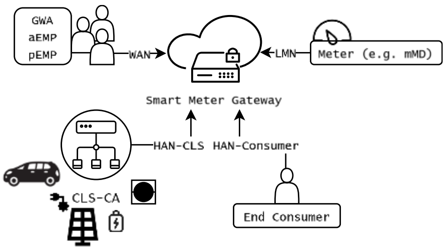

Figure 1 German SMI environment (simplified); according to [27]

Key SMI components as well as their function are listed in **Table 1**. The components are relevant for visualisation of low voltage smart grid environment in context of this paper.

Table 1 Overview of German SMI components

Component	**Short description**
SMGW	Smart meter gateway, the secure communication unit as part of the German smart metering system, e.g. responsible for the exchange of metering data, as defined in BSI-TR-03109-1 and the SMGW's protection profile [11, 27]. To date, the direct DERs' control feature of the SMGW is under development [28].
mMD	Electronic measuring device that records consumption, production as well as grid data and transmits it to the SMGW via the LMN (according to BSI-TR-03109-1 [11]).
CLS-CA	Communication adapter (CA) for controllable local systems (CLS) is located in the SMGW's HAN-CLS and operates a secure communication channel via the SMGW – a CLS proxy channel – to connect to different systems in the WAN. Official requirements are set in the BSI-TR-03109-5 [11].
§14a EnWG controllable consumption unit *(short: §14a EnWG asset)*	Consumption units with an installed capacity of usually above 4.2 kW and the capability to be controlled (like an electric vehicle charger or a heat pump). An owner can decide, if the entire grid connection point (GCP) shall be controlled by the DSO, or only the §14a EnWG assets. Further details can be found in [13].
aEMP system	If a backend system uses the CLS proxy channel functionality of a SMGW to connect with a CLS-CA in the HAN-CLS, it will be called an active external market participant (aEMP) system. [27]
pEMP system	A passive EMP (pEMP) operates a backend system to connect via the WAN to a SMGW for the purpose of receiving registered metering data sourced from the LMN. [27]
CBA system	Control box administration (CBA) system for managing and monitoring the control boxes – CLS-CA for DERs' remote control – connected to a SMGW. [29]
GWA system	Gateway administrator (GWA) system - main task is the secure operation of the SMGW as defined in BSI-TR-03109-6 [11].
Breakout gateway	In the context of this paper the breakout gateway allows the secure entry resp. exit into a access point name (APN) mobile network, typically applied in the SMGW's WAN by a responsible MPO [30].

2.4.2 Target Model of a Star-shaped Communication

Star-shaped communication is a method where data from an intelligent metering system is forwarded directly to external market participants via a central gateway, the SMGW, as defined in §60 Metering Point Operation Act / "Messstellenbetriebsgesetz" (MsbG). This approach enables the direct transmission of (non-)billing-related metering data and CLS connections to third parties [30].
This implementation is technically more challenging and has not yet been realized at scale. Most current iMSys-data continues to be processed via the MPOs' backend systems [19]. Nevertheless, during the transition phase in accordance with §75 MsbG, starting in 2026, the BSI will evaluate the potential implementation of a larger-scale star-shaped communication as intended with the first introduction of the MsbG in 2016.

2.5 Cloud-to-cloud solution

The integration of cloud-to-cloud services within existing regulatory frameworks, such as cross-sector submetering, is crucial for overcoming interoperability challenges and enhancing data sharing in the energy sector. Access to metering data is essential for various stakeholders in both regulated domains, like billing, and non-regulated areas, such as flexibility and energy services. Access to metering data often is a prerequisite for further services from different organisations. There is an ecosystem of actors and digital services that can collaborate and provide value based on this kind of data.
However, since metering data in the residential sector is considered personal information, it is subject to protection under the European General Data Protection Regulation [31], requiring customer consent for data processing by third parties. Data protection and IT security must be maintained throughout data value chains, even outside the regulated smart metering infrastructure. The emerging role of the "permission administrator" and the establishment of a

Common European Energy Space highlight current European regulatory efforts to facilitate trustworthy and collaborative data exchange.

2.5.1 Permission Administrator

The European Commission's implementing regulation on interoperability requirements outlines the management of permissions for accessing metering data, enabling customers to manage their usage and access rights through an online portal [32]. While the specific implementation for Germany is still under discussion, the concept aims to facilitate collaborative data usage for energy service companies and may extend to submetering. However, the permission administrator is not relevant to §14a EnWG, as data provision from the MPO to the system operator is directly codified by law (EnWG, MsbG).

3 Methodology

For identifying different approaches of TAF 10 values data sourcing from a DSO perspective, as well as accessing cross-sector submetering from housing users, two general methods have been applied. On the one hand, expert knowledge has been gathered via remote workshops from active actors in the DSO, ESP, MPO, and iMSys supplier domain. On the other hand, literature has been reviewed regarding the identification of different SMI architectures and their implications.
To visually represent the identified high-level system architectures a simplified approach has been chosen to provide a general overview. It should be noted, that the visualizations do not indicate specific information flow directions between components, as both unidirectional and bidirectional flows are possible. Additional systems for managing mass data or ensuring network security are intentionally excluded to maintain clarity.

Table 2 Evaluation criteria

Criteria	**Evaluation**
Interoperability	Semantic and technical aspects according to the European Interoperability Framework [33]
Scalability	Readiness for a large rollout of smart meters taking into account the number of parties involved and underlying processes
Reliability	Identification of general issues regarding reliability at high-system level and below
Time-to-market / Implementation time	Qualitative assessment of the required period to implement a specific approach
Costs	Evaluation of implementation and system costs

For §14a EnWG, a typical low voltage control system is assumed, emphasizing communication within the SMI and its directly linked systems. Afterwards, a qualitative analysis of the high-level system architectures based on the following criteria: Interoperability, scalability, reliability, time-to-market and costs (details see **Table 2**). Additionally, the introduced methodology will also evaluate cloud-to-cloud service implementations as a means of enhancing data interoperability and access among stakeholders in the energy ecosystem.
Each criterion will be summarized according to the following categories:

1) Positive (+): Favorable aspects dominate.
2) Neutral: (o): The analysis shows no clear direction if the specific criteria cannot be met positively or negatively.
3) Negative (-): Unfavorable features of an analyzed approach dominate a criterion.

4 Results

The following chapter contains descriptions of three currently used paths in industry when reading grid status data in context of §14a EnWG, as well as results containing two options of meter data readings in the context of cross-sector submetering.

4.1 §14a EnWG – TAF 10 Data Exchange

First approach is a proprietary connection (**Figure 2**). The DSO uses a grid control system that can read the TAF 10 grid status data in two common ways: Path 1a via a passive EMP system or Path 1b via GWA system, both provided by the responsible DSO.
In these systems, data flows from installed measurement systems along the power grid to the control centre. The proprietary nature of the connection suggests that it may rely on specific vendor technologies or protocols that are not standardized across the industry, potentially limiting interoperability with other systems or components outside of the proprietary ecosystem [34]. The proprietary connection must be carefully managed to maintain data integrity, security, and reliable communication between various grid components and market participants. It will most likely be usually viable for basic MPOs, who are closer related to the DSO's system environment.
Second method describing star-shaped communication alternates the communication paths from **Figure 2** as it transfers the pEMP system for TAF 10 values into the DSO's domain (**Figure 3**). This communication method is particularly relevant, as it enables system operators to receive grid status data directly from a local smart metering system. However, it should be noted that this approach requires an additional, costly pEMP system on top of the one on the MPO side for standard meter data access. Star-shaped communication is anchored in the Metering Point Operation Act and ensures that MPOs offer system operators access to grid status data. On top of that, the current German MaKo already supports this path. However, if the MPO applies an APN – a typical pattern in the German SMI – this infrastructure requires a breakout gateway to provide access for the additional DSO's pEMP system.

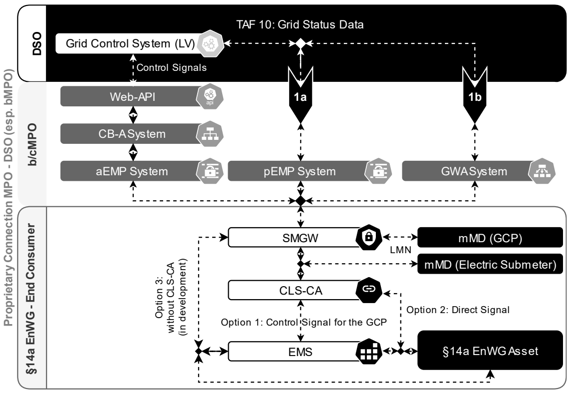

Figure 2 Common proprietary connection options (own figure based on [29, 34])

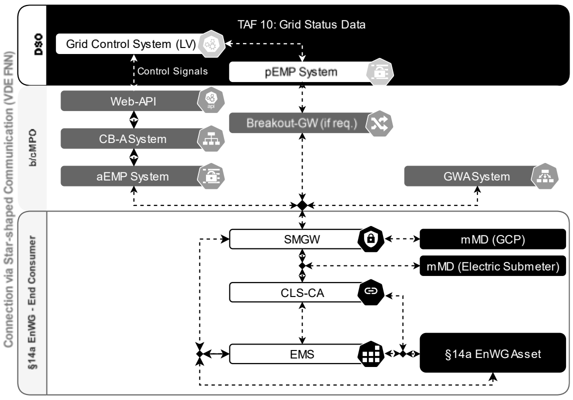

Figure 3 Connection via star-shaped communication (own figure oriented after [29, 30])

Third and final method for grid status data transfer in context of §14a of the Energy Industry Act is connection via Web-API (**Figure 4**). The Web-API connection, similar to proprietary connection 1a, utilizes the MPO's pEMP system to communicate the grid status data via an extended Web-API service of the existing control path, which could simplify the interaction between different systems in the energy sector, enabling streamlined processes and improved data sharing among market participants.

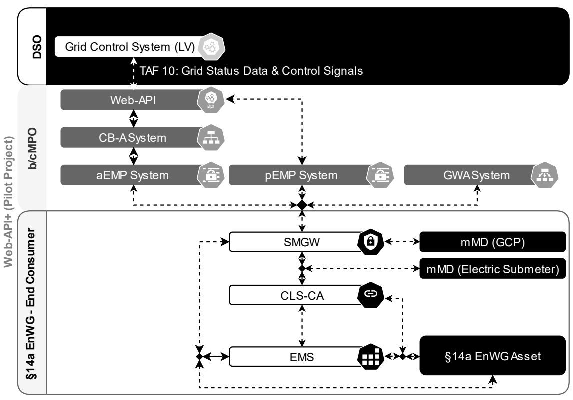

Figure 4 Extended Web-API of the current MaKo (own figure partially sourced from [29])

While this approach could reduce operation costs, it is outside of current regulation in Germany. Beyond this, it only has been developed as a pilot by [35].

4.2 Cross-sector Submetering

The **Figure 5** shows the various components and their interactions in the context of cross-sector submetering. At the top is the owner or tenant, who has several applications, including the user-interface (UI) application for user consumption information (UCI) and the UI billing application. These applications are connected to a (cross-sector) submetering provider's central backend system. If this system requires on-site cross-sector submetering data, the provider will use its own aEMP system. The MPO's aEMP system, in this case, is only for control purposes in use.

Behind the SMGW, in the local facility, the additional aEMP will connect to a CLS-CA. This local system will aggregate data from multiple devices, like the cold/hot water meter, the heat meter as well as heat cost allocators (HCAs). Typical communication standards applied here are the Open Metering System (OMS) specification, Long Range Wide Area Network (LoRaWAN) and Mioty.

The main differences lie in their use cases and technology. OMS is tailored for utility metering, focusing on device interoperability. LoRaWAN emphasizes long-range, low-power communication for Internet-of-Things devices, while Mioty can be used as an alternative approach [36].

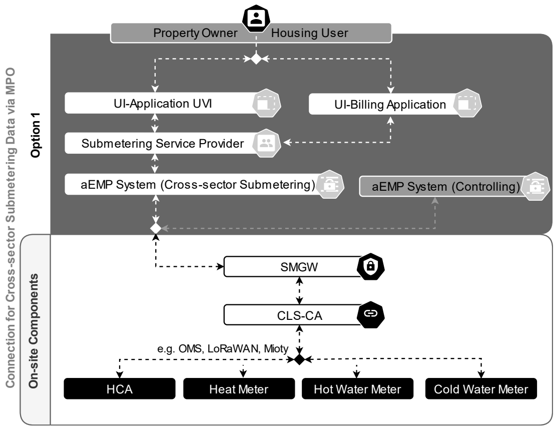

Figure 5 Cross-sector submetering via a dedicated aEMP-system to communicate with a CLS communication adapter (Option 1)

Alternative communication pathway redirects the data communication to the pEMP system for cross-sector submetering, which is under the MPO domain (**Figure 6**). Downsides are the restrictions of the LMN with a limited number of devices as well as complex configuration issues between both parties involved. In addition, it is unlikely that the German MaKo will soon support standard cross-sector submetering data exchanges. However, advantages like the enforced interoperability via OMS and privacy benefits exist due to strict records by the SMGWs of all data transfers.

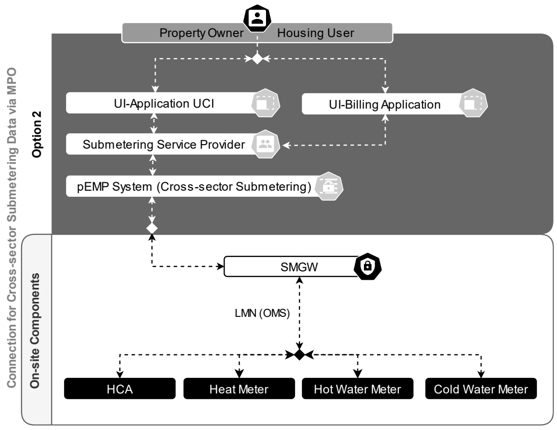

Figure 6 Cross-sector submetering via the LMN of a SMGW and the existing MPO backends (Option 2)

5 Discussion

The following section contains a comprehensive evaluation of the implementation alternatives analysed and presented in the previous Chapter 4, highlighting the strengths and weaknesses of each approach (**Figure 7**).

In discussing the key takeaways from the current regulatory and market considerations, it's evident that a proprietary solution is not favoured under §14a EnWG. Instead, the star-shaped communication model aligns well with the latest SMI design approach driven by the MsbG and corresponding MaKo processes, offering a structured and cohesive system. However, if market demands dictate a need for lower costs and a faster rollout by reducing complexity, the backend approach with an extended Web-API could be a viable alternative. Especially, if a DSO already relies heavily on cloud-based LV grid control systems.

Regarding cross-sector submetering, the regulatory environment currently does no longer mandate the use of the LMN for cross-sector submetering. Additionally, the absence of a straightforward and secure method for transmitting cross-sector submetering data to various parties presents a challenge. Given these constraints and the dominance of non-SMI communication, particularly in scenarios like heating cost settlement in multi-family homes, the market is likely to lean towards the first option, provided the overarching conditions are favourable. The challenge remains to devise a system that integrates seamlessly without relying solely on the SMI's restrictions.

Furthermore, the analysis reveals that cloud-to-cloud services could mitigate some of the operational challenges faced by DSOs and MPOs, facilitating more efficient data exchange and management.

5.1 Energy Data Space

The European Commission anticipates that cross-organizational data processing will create significant value and growth opportunities in the data economy, particularly through the development of a data space in the energy sector [37]. This infrastructure will facilitate trusted data sharing between organizations and their cloud services, making the integration of metering data into Energy Data Spaces highly relevant for numerous use cases.

A data space comprises multiple participants and their systems interacting under a common set of rules, relying on unified identity management for trust and mutual authentication. The dedicated "Data Space Protocol" [38] standardizes communication and contract negotiations for data usage policies, enabling trusted data exchange through a control plane that checks and negotiates access and usage policies. Additionally, federation services like cataloguing facilitate data exchange, with a blueprint for the "Common European Energy Data Space" outlined by the "int:net" project [39].

	§14a EnWG			Cross-sector Submetering	
	Proprietary Connection DSO-MPO	Connection via star-shaped communication	Web API+	Option 1	Option 2
Interoperability	(-) highly dependent on the chosen backend systems	(o) (-) Interoperable access via breakout gateways (APNs) needs validation (+) SMGWs support multiple communication paths and MPs	(+) EDI@Energy expert group can regulate Web-API developments (mandated by the BNetzA)	(o) Focus on interoperable connections allows proprietary submetering activities, avoidin the need for interoperability with different meters (LMN)	(+) OMS standard for various metering devices will be encouraged if scaled SMGWs' LMN enforces standard data models
Scalability	(-) Requires specific solutions for each system Needs in-depth DSO-MPO discussions outside of the offical processes (MaKo)	(+) (+) Corresponding MaKo process exists since October 2023 (+) Current legislation supports this approach	(o) (+) Web-API can be easily scaled (backend system) (-) Regulation emphasizes star-shaped communication for SMI's security and privacy reasons	(+) CLS-CAsupports various local connections (e.g. LoRaWAN, Mioty) Scalability issues can be handled by the submetering provider's backend and CLS-CAdesign	(-) LMN limitations Data exchange between MPO and metering service provider not in standardized MaKo Direct B2B communication required
Reliability	(o) depends highly on the specific set-up	(+) Direct connection with SMGW allows low latency for faster state estimation Breakout gateway is a bottleneck	(o) Web-API is the bottleneck DSO depends on MPO's SMI (control and observability) if only TAF 10 values are used	(+) Most components are controlled by the submetering service provider More reliable techologies on side (e.g. LoRaWAN)	(o) Highly dependent on the interface between MPO and submetering service provider LMN restrictions apply (esp. wireless M-Bus)
Time-to-market/ Implementation Time	(+) (+) Has been done already (-) viable solution in most cases only for bMPOs	(o) (-) First large-scale star-shape application in German SMI may face unknown bstacles (e.g. with APNs) (+) MaKo processes exist	(+) Pilots are already underway General Web-API infrastructure is in place or in development	(+) Standardization of aEMP and GWAsystems is underway (DKE) Implementation has been completed	(-) Submetering as part of MaKo seems unlikely soon; energy data space may be a solution LMN interface developments for SMGWs are time-consuming for non-state-of -the-art submetering
Costs	(o) depends highly on the specific set-up	(o) (-) Higher operation costs due to additional pEMP system (DSO) (+) Standard MaKo processes	(+) (o) First pilot implementations (+) Low operations costs by using the same Web-API infrastructure	(o) (-) Additional backend system is required (aEMP) (+) Clear responsibilites and reduced technical complexity lower costs	(o) (+) Leveraging existing infrastructure to save costs (-) Complexity could cause additional costs

Figure 7 Evaluation of approaches by criteria

Interoperability within and across Data Spaces is being developed based on the European Interoperability Framework [40] which defines four levels: legal, organizational, semantical, and technical interoperability [41].
Key challenges include integrating the identity management of the German smart metering infrastructure into a harmonized European system, as foreseen by “eIDAS 2.0” and developing a common European metering data model based on the CIM data model, which will require significant effort from German market partners.

5.2 Innovations

The expected developments in the energy market are set to introduce innovations, such as collaborations between DSOs and start-ups for AI-based data analysis aimed at real-time network status determination and predictive maintenance [42]. This collaboration could extend the trust framework beyond regulated energy companies into the non-regulated domain, allowing for the technical implementation of regulatory requirements. Furthermore, cloud services from MPOs will become vital as trusted sources of timely metering data and a single point of truth for market partners within a future “Energy Data Space”.

6 Summary & Outlook

In summary, the study identified key challenges and innovations in metering operations and data sharing within energy systems. Particularly, grid status data access for system operators, like in the context of §14a EnWG for DSOs, a Web-API approach could enable benefits as an additional option to the current star-shaped communication method.
In a nutshell, the findings underscore the importance of interoperability, particularly concerning the integration of cross-sector submetering and sector coupling into the upcoming smart grid infrastructure. The role of data-driven services is increasingly significant, necessitating robust business and value-sharing models to harness their full potential.
Looking ahead, a stakeholder workshop is planned to take place to further evaluate these findings and gather diverse insights. This workshop will be pivotal in refining our understanding and exploring practical implementations of the proposed solutions.
The emergence of collaborative data exchange, facilitated by cloud-to-cloud solutions, presents new opportunities for energy management. These developments highlight the need for standardized frameworks and secure data handling practices, ensuring all stakeholders can benefit from the evolving energy landscape.

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