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OVERVIEW OF INFORMATION AND COMMUNICATION REQUIREMENTS FOR LOCAL FLEXIBILITY MARKETS

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Abstract: This research investigates the technological underpinnings of Local Flexibility Markets (LFMs). It delves into the synergistic relationship between Information Technology (IT) and Operational Technology (OT) to ensure seamless LFM operations. A key focus is on the Information and Communications Technology (ICT) architecture, which plays a pivotal role in LFM functionality. The research addresses the critical aspect of interoperability within LFMs. It explores standardized data formats for electricity markets, the Common Information Model (CIM) for efficient data exchange, and relevant standards such as the Common Distribution Power System Model Profile (CDPSM) and the Common Grid Model Exchange Standard (CGMES). To ensure secure data exchange, the research investigates various ICT protocols and the significance of Internet of Things (IoT) protocols in enabling LFMs. It underscores the importance of a layered cybersecurity approach to protect LFM infrastructure and sensitive data. The findings of this research highlight the importance of a robust ICT architecture, coupled with secure data exchange mechanisms, to ensure the interoperability, reliability, and overall success of LFMs.

Keywords: Local flexibility market, interoperability, Common Information Model, Information Technology, Operational Technology, Information and Communications Technology protocols

INTRODUCTION

To achieve their full potential, Local Flexibility Markets (LFMs) rely heavily on interoperability – the seamless exchange of data and functionality between diverse systems and devices [1], [2]. This goes beyond technical compatibility; it fosters collaboration, innovation, and a more robust and sustainable energy ecosystem.

Interoperability acts as a catalyst for unlocking the true potential of flexibility within the LFM. Interoperability is a critical aspect of a successful LFM for several reasons. Standardized data formats and communication protocols act as a bridge, allowing a wider range of devices and systems to participate in the LFM.

Standardized data formats and communication protocols eliminate compatibility issues, allowing for smoother data exchange between market participants and system operators. This facilitates faster and more informed decision-making, leading to a more efficient market.

By adopting common standards, the need for custom data conversion tools and processes is minimized. This translates to reduced costs for LFM operators and participants when integrating with various platforms.

Consistent data formats ensure transparency across the market by enabling clear communication of essential information. This empowers regulatory bodies to effectively monitor market activity and enforce market rules, ultimately fostering trust among participants.

Interoperability empowers participants to go beyond simply trading flexibility within the LFM. Prosumers with battery storage systems, for instance, could leverage the LFM for grid balancing during peak hours while simultaneously offering surplus energy to a peer-to-peer trading platform at other times. This allows participants to maximize their revenue streams and optimize their energy use.

Standardized interfaces facilitate the seamless integration of LFMs with existing energy management systems and grid control centers utilized by Distribtion System Operators (DSOs). This holistic view of the grid empowers DSOs to make informed decisions about grid investments and leverage flexibility resources more effectively.

Developing and implementing common data formats and communication protocols can be a complex endeavor. Different stakeholders may have varying preferences and legacy systems, necessitating collaborative efforts to

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achieve universal agreement [3], [4]. Industry bodies like the Open Automated Demand Response (OpenADR) Alliance are actively establishing standardized frameworks for automating demand response programs, paving the way for greater interoperability. However, ongoing innovation in the energy sector means that standards need to be flexible enough to accommodate future advancements.

Interoperability creates additional entry points for potential cyberattacks [5], [6]. Implementing robust security measures, including encryption and access controls, across all devices and systems within the LFM ecosystem is paramount. This requires collaboration between technology providers, market operators, and DSOs to ensure a secure environment for all participants. Active collaboration between DSOs, technology providers, market operators, and consumer groups foster innovation that promotes a secure and efficient LFM environment, with clear interoperability requirements defined by all stakeholders.

By prioritizing interoperability, LFMs can unlock their full potential for creating a more dynamic, efficient, and sustainable energy future. Supporting and adhering to established industry standards for data exchange and communication protocols is crucial. This ensures a level playing field for all participants and facilitates seamless integration between diverse systems. Designing the LFM architecture with modular components allows for easier integration of new technologies and functionalities as standards and market needs evolve.

This paper deals with the technological foundations of LFMs. It examines how Information Technology (IT) and Operational Technology (OT) work together to make LFMs function smoothly. The focus is on the Information and Communication Technology (ICT) architecture, highlighting its critical role in the operations of LFMs.

The paper deals with achieving interoperability within LFMs. This includes discussions on standardized data formats for electricity markets, a Common Information Model (CIM) for seamless data exchange and relevant standards such as the Common Distribution Power System Model Profile (CDPSM) and the Common Grid Model Exchange Standard (CGMES).

To facilitate secure data exchange, the paper examines various ICT protocols and the crucial role of Internet of Things (IoT) protocols in enabling LFMs. Finally, the importance of a layered approach to cybersecurity in LFMs is emphasized.

1. INFORMATION TECHNOLOGY AND OPERATIONAL TECHNOLOGY FOR LOCAL FLEXIBILITY MARKETS OPERATION

Challenges and considerations related to IT and OT in LFM include seamless data exchange between IT and OT systems for efficient LFM operations. Standardized data formats and communication protocols are crucial for interoperability between different IT and OT systems from different vendors. Additionally, robust cybersecurity measures are essential to protect sensitive data exchanged within the LFM from cyber-attacks. Standardization of communication protocols and data formats is required for interoperability between different IT and OT systems from different vendors.

Effective interaction between IT and OT is crucial for the smooth operation of LFMs. IT is responsible for data analysis and market management, while OT is responsible for the physical implementation of flexibility measures in the grid. As LFMs evolve, continued integration and collaboration between IT and OT will be paramount for a secure, efficient and flexible electricity grid.

Secure communication channels allow IT systems to collect data from DERs, smart meters and sensors. This data is then processed and analyzed by IT systems to gain insights into grid conditions, DER availability and flexibility requirements. Based on this analysis, the LFM platform facilitates market activities, including the submission of bids and the selection of the most suitable flexibility options.

Finally, OT systems receive dispatch instructions from the LFM platform and relay them to participating DERs so they can adjust their generation or consumption patterns to meet grid needs.

A fundamental LEM architecture is given in Figure 1 [7].

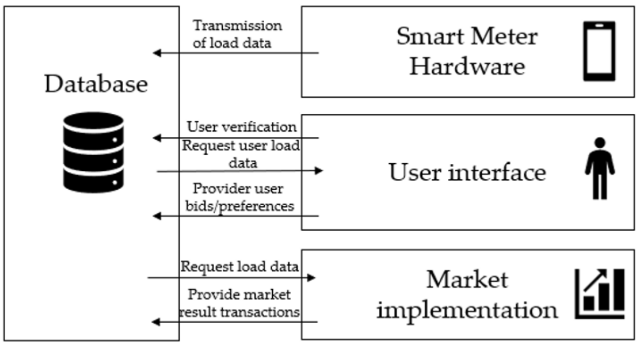

Figure 1: A fundamental LEM architecture

2. INTEROPERABLE DATA FORMATS IN ELECTRICITY MARKETS

Interoperable data formats are pivotal for seamless communication in electricity markets, particularly in LFMs. Widely adopted standards include Electronic Data Interchange for Administration, Commerce and Transport (EDIFACT) for commercial transactions (e.g., scheduling messages) and IEC 61850 for grid automation, ensuring semantic interoperability in transmission and distribution systems. The Common Information Model (CIM), defined by IEC 61968/61970, standardizes Distributed Energy Resource (DER) metadata, market data (prices, flexibility offers), and grid topology. Secure formats like JavaScript Object Notation (JSON) and Extensible Markup Language (XML), combined with semantic frameworks (Resource Description Frameworks (RDF), Web Ontology Language (OWL), SHapes Constraint Language (SHACL)), enable machine-readable data exchange while addressing security and validation needs. Resource-constrained DERs favor lightweight protocols (Message Queuing Telemetry Transport (MQTT), Lightweight Machine-to-Machine (LwM2M)), whereas organizations like IEC and ENTSO-E drive standardization to harmonize evolving technologies (blockchain, smart grids) with existing infrastructures. Standardized interoperability fosters transparency, efficiency, and trust in modern energy ecosystems.

2.1. Common Information Model: supporting interoperability within local flexibility markets

The CIM plays a significant role in supporting interoperability within LFMs. The CIM is a standardized data model for the electric power industry. It defines a common language for exchanging information about power system assets, operational data, and business processes. This standardized approach is crucial for facilitating seamless communication and data exchange between different systems and devices within the LFM ecosystem.

By adhering to the CIM standard, various systems and devices involved in the LFM ecosystem can communicate effectively. Standardized data exchange through CIM facilitates the smooth flow of information within the LFM. Flexibility offers from prosumers, real-time grid data from DSOs, and market signals can all be seamlessly exchanged in a format understood by all participants. This transparency empowers informed decision-making and streamlines market operations.

CIM facilitates seamless data exchange between diverse systems and applications within the electricity market ecosystem. This eliminates the need for custom data translations, reducing complexity and improving efficiency. The CIM standard allows LFMs to seamlessly integrate with existing power industry systems utilized by DSOs. This holistic view of the grid empowers DSOs to leverage flexibility resources alongside traditional grid management techniques, optimizing grid operations and ensuring efficient utilization of available capacity.
The modular structure of CIM allows users to select specific data models relevant to their needs. This ensures efficient data exchange while accommodating future growth and evolving market requirements. By fostering interoperability, CIM paves the way for a more open and competitive LFM landscape. New technologies and market offerings can be easily integrated, accelerating innovation and market growth. This fosters a dynamic environment that benefits all stakeholders.

The CIM standard undergoes regular updates to accommodate the evolving energy landscape. Staying abreast of the latest versions ensures continued interoperability within the LFM ecosystem.

Adopting and implementing the CIM standard may necessitate adjustments to existing systems and processes. Collaborative efforts between technology providers, market operators, and DSOs are crucial for developing CIM-compliant tools and streamlining the transition. As LFMs become more widespread, standardization efforts for LFM-specific CIM extensions are underway. This will further improve the suitability of CIM for data exchange within LFMs. Initiatives to integrate CIM with other relevant standards such as the Open Charge Point Protocol (OCPP) for the integration of Electric Vehicles (Evs) are crucial for a holistic LFM ecosystem.

IEC 61970 defines a series of communication protocols that work in conjunction with the CIM data model. These protocols define how data is formatted and exchanged between systems. Protocols such as IEC 61850 (communication for substation automation) or IEC 62351 (web services for enterprise applications) can be used for data exchange within LFMs, depending on the specific requirements.

Data structures defined in CIM can be serialized into various formats for data exchange such as XML, a human-readable format offering flexibility for data exchange or Comma-Separated Values (CSV), a simpler format for specific data exchanges.

CIM serves as a powerful tool for data exchange within the electric power industry, fostering interoperability, efficiency, and a robust foundation for effective LFMs. By leveraging CIM, stakeholders can ensure clear communication, data consistency, and a future-proof approach to a more flexible and sustainable electricity grid.

CIM enables a common language for data exchange between different LFM components, including the LFM platform, DER aggregators, and potentially the Transmission System Operator (TSO). This facilitates efficient and reliable information exchange. By adhering to a standardized data model, different LFM implementations and DER technologies can communicate seamlessly, promoting market growth and innovation.

The IEC 61970/61968 series of standards serves as a cornerstone for data exchange within LFMs. By providing a standardized and comprehensive data model, CIM promotes interoperability, scalability, and efficient communication between various LFM components. As LFMs evolve, ongoing efforts to refine and expand the

CIM standard will be instrumental in creating a robust and efficient data exchange framework for a more flexible and sustainable electricity future.

2.2. EDIFACT vs. CIM: Customised data exchange for local flexibility markets

Two well-known data exchange standards, EDIFACT and CIM, have different strengths and weaknesses when it comes to facilitating the operation of LFM.
EDIFACT is a widely used standard for business transactions that can reduce integration costs for LFM by leveraging existing infrastructure. Its adaptable structure enables customization to different business requirements through specific message types.

EDIFACT focuses on business documents such as invoices and may not cover the full spectrum of LFM data, such as technical specifications of DERs or real-time grid data. Defining customized message types for LFM data exchange within EDIFACT can be complicated and requires specialized knowledge.

On the other hand, CIM is specifically tailored to the electricity industry and provides a comprehensive data model that can accommodate the various data types that are critical to LFMs. This includes DER functions, market prices, dispatch instructions and much more. The modular structure allows the selection of specific data models relevant to LFM requirements, promoting scalability and efficient data exchange.

Compared to EDIFACT, the adoption of CIM in LFM may be lower, requiring additional investment in infrastructure and expertise. Understanding and implementing the CIM data model can be more complex compared to EDIFACT. While EDIFACT offers a streamlined approach to certain commercial aspects of LFM, it is less suitable for comprehensive data exchange due to its limited data scope. CIM's domain-specific focus and comprehensive data model, on the other hand, make it a compelling choice for LFMs. It is capable of processing the volumes of information required for market operation, network management and seamless communication between different systems.

The future of LFM data exchange will likely favor standardized data models such as CIM. This standardization will ensure consistent data representation across different LFM implementations, promoting interoperability and streamlined market operations. In addition, ongoing efforts to develop specific CIM extensions tailored to the needs of LFM will further enhance the suitability of CIM for this area.

For robust and efficient LFMs, the use of a domain-specific data exchange standard such as CIM is the most professional approach. Due to its comprehensive data model and its focus on the electricity industry, it is superior to EDIFACT in this context. In the further development of LFMs, the introduction of standardized data models will be crucial to ensure seamless communication, efficient market operation and a more robust and flexible grid.

A comparative analysis of the data exchange standards for LFMs EDIFACT and CIM can be found in Table I.

Table I: EDIFACT vs. CIM: Comparative Analysis of Data Exchange Standards for LFMs

Criteria	EDIFACT	CIM (Common Information Model)
Primary Focus	Business transactions (e.g., invoices, orders).	Electricity industry (DERs, grid management, market operations, technical data).
Strengths	Reduces integration costs (leverages existing infrastructure). Adaptable structure for business needs. Widely adopted in commerce.	Comprehensive data model (covers DERs, real-time grid data, market prices, dispatch). Modular and scalable. Domain-specific to energy systems.
Weaknesses	Limited data scope (excludes technical/real-time grid data). Complex customization requires expertise.	Steeper learning curve and implementation complexity. Lower adoption in LFM, requiring new infrastructure investment.
Data Coverage	Business documents (invoices, orders).	Technical specifications, real-time grid data, market operations, DER functionality.
Customization	Possible via tailored message types but technically challenging.	Flexible modular design (select relevant data subsets for LFM needs).
Integration Costs	Lower (uses existing business infrastructure).	Higher (requires investment in new systems and training).
Adoption in LFM	Higher for commercial transactions due to legacy use.	Growing adoption as LFMs prioritize technical interoperability.

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2.3. Common Distribution Power System Model Profile and The Common Grid Model Exchange Standard

The CDPSM is a specific application of the CIM standard that is tailored to the modeling of power distribution systems. It is a subset of the broader CIM that focuses on data objects relevant to the distribution network level. CDPSM provides a standardized method for modeling and exchanging data about distribution networks, including grid topology (lines, transformers, switches), measurement data (loads, distributed energy sources), and information on grid connectivity, and is geared towards planning and design of distribution networks, power flow analysis and voltage regulation studies, as well as outage management and restoration processes.

The CGMES is an international standard that facilitates the exchange of operational and grid planning data between TSOs. It defines a common set of data models and structures for the representation of electricity grid information that enable seamless communication and data exchange between different software applications and systems.

CGMES is based on the IEC 61970-301 standard, CIM, that provides a basic framework for the representation of power system assets, network topology and operational data. It improves interoperability by enabling seamless data exchange between different systems and applications used by TSOs. It lowers development costs by standardizing data models, reducing the need for custom development for data integration.
CGMES increases efficiency by streamlining data exchange processes and improving data quality. It facilitates regulatory compliance by supporting the implementation of network codes based on standardized data exchange. CGMES was originally developed by the ENTSO-E. It was adopted by the IEC as an international standard under IEC TS 61970-600. CGMES continues to be actively developed and maintained by the IEC.

3. FACILITATING DATA EXCHANGE IN LOCAL FLEXIBILITY MARKETS: A SURVEY OF ICT PROTOCOLS

The efficient functioning of the market depends on smooth communication and data exchange between the various players. While there is not yet a single standardized ICT protocol specifically designed for LFM, several promising options can be used to build a robust communication infrastructure. Standardized protocols define the rules for how devices and systems exchange information. Protocols that can be applied in LFM are:

- MQTT: A lightweight and efficient protocol, ideal for resource-constrained DERs to publish data and subscribe to relevant topics on the LFM platform.
- AMQP (Advanced Message Queuing Protocol): An open-standard application layer protocol designed for message-oriented communication between applications.
- LwM2M: Another lightweight protocol suitable for battery-powered DERs with efficient data exchange capabilities.
- CoAP (Constrained Application Protocol): Designed for constrained devices behind firewalls, CoAP is suitable for secure communication with DERs.
- OpenADR (Open Automated Demand Response): a protocol to allow Automated Demand Response (ADR) procedures.
- OCPP (Open Charge Point Protocol): While primarily used for EV charging management, OCPP can be leveraged for LFM integration, facilitating communication between EV charging stations and the LFM platform to control charging rates based on grid needs.
- API (Application Programming Interface): APIs are essential tools for enabling efficient and scalable LFMs. They streamline communication, automate processes, and contribute to a more optimized and flexible electricity grid. APIs simplify participation for DER providers by reducing technical barriers to entry. Clear and standardized data exchange fosters transparency and trust within the market. Automated processes through APIs lead to lower operational costs for both DSOs and DER providers.
- RestAPI (Representational State Transfer Application Programming Interface): RestAPIs adhere to well-defined architectural principles, promoting interoperability between different software systems and devices participating in the LFM. They are known for their simplicity and efficiency in data exchange. This makes them suitable for handling the frequent communication needs of LFMs, which involve many DERs and other participants. RestAPIs can be easily adapted to accommodate various data formats and functionalities required by different LFM implementations. Security features can be integrated into RestAPIs to ensure secure data transmission and access control within the LFM.
- TLS (Transport Layer Security): TLS is a widely adopted security protocol designed to facilitate privacy and data security for communications over the Internet. TLS ensures secure communication between participants in LFM. It safeguards data exchange in LFMs by: encryption, authentication, data integrity. TLS is a critical security measure for LFMs. It safeguards sensitive data exchange, fosters trust among participants, and contributes to the overall reliability and efficiency of LFMs.
- SSL (Secure Sockets Layer): SSL is cryptographic protocol that provides secure communication over a network. However, TLS is the more recent and secure version, effectively replacing SSL.
- The SCADA 104 protocol: IEC 60870-5-104

3.1. A multi-layered approach to cybersecurity in local flexibility markets

Comprehensive cybersecurity frameworks enable the implementation of robust frameworks that address data security, access control, incident response and vulnerability management, which is critical. These frameworks should be tailored to the specific needs of LFM and should be regularly reviewed and updated.

Secure communication protocols use strong encryption protocols for all communications within the LFM platform to ensure the confidentiality and integrity of data. This makes it much more difficult for attackers to intercept or manipulate sensitive information.

The implementation of Multi-Factor Authentication (MFA) adds an additional layer of security by requiring users to provide additional verification factors in addition to usernames and passwords when accessing the LFM platform. Regular scanning of LFM platforms and participating devices for vulnerabilities and the timely application of security patches are essential to minimize the risk of exploitation by attackers.

It is critical to educate all stakeholders involved in LFM, from DSOs to prosumers, on cybersecurity best practices. This will allow everyone to recognize and report suspicious activity and reduce the attack surface.

Promoting collaboration and information sharing between LFM operators, cybersecurity experts and regulators is critical. This enables a coordinated response to emerging threats and the development of more effective mitigation strategies.

The development and adoption of standardized cybersecurity frameworks and best practices for LFM will create a more uniform level of security across the market. Regulators can play a key role in promoting these standards.

Cybersecurity is an ongoing challenge that requires constant vigilance and adaptation. By implementing robust security measures, promoting awareness and fostering collaboration, stakeholders can build a secure and resilient LFM ecosystem. This paves the way for a future where LFM can thrive, empower prosumers and contribute to a more sustainable and flexible electricity grid.

4. USE CASE: INFORMATION TECHNOLOGY SYSTEM ARCHITECTURE FOR LOCAL FLEXIBILITY MARKET

The high-level IT architecture for the LFM model is shown in Figure 2. This architecture facilitates the overall feasibility of the LFM framework. It is designed to enable automatic data exchange via APIs in machine-readable XML and JSON format adapted to the semantic CIM data model.

The flexibility platform is located in the DSO's IT network and is responsible for the evaluation of flexibility offers and the creation of Merit Order Lists (MOLs). This IT platform communicates with an external LFM platform that publishes tenders for flexibility services and collects bids. In this way, a DSO only integrates with one platform and not with many flexibility service providers (FSPs). In addition, such an approach facilitates integration for FSPs, as they only need to integrate with one platform.

All systems exchange data via Enterprise Service Bus (ESB). ESB has different interfaces so that different systems using different communication protocols can communicate without additional gateways. Such an approach offers scalability, as the introduction of a new system only requires integration of the new system with the ESB.

The simulation engine is a software for analysing energy systems. Commercial software (e.g. Power Factory, SINCAL, etc.) already contains an API that can be used for automation. RestAPI can be used to retrieve grid model and grid data and to exchange data with the flexibility platform.

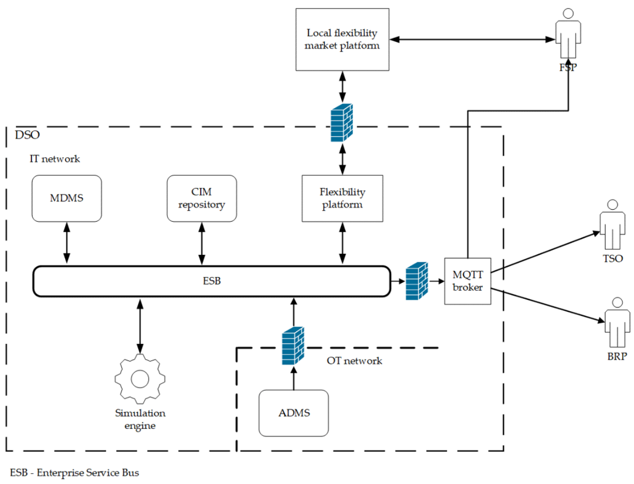

Figure 2: High-level architecture for the LFM model

As the Advance Distribution Management System (ADMS) is critical to the operation of the distribution network, it is located in an OT network with higher cybersecurity requirements. Communication between the ADMS and the flexibility platform is one-way, from the ADMS to the platform. Therefore, any data flow from the flexibility platform to the ADMS is not allowed.

If the flexibility platform creates a TLS message to prevent the activation of flexibility resources connected to the distribution grid for the frequency services (automatic Frequency Restoration Reserve (aFRR), manual Frequency Restoration Reserve (mFRR)), these messages are sent to TSOs, balance responsible parties, aggregators and other actors via the publish/subscribe method using the MQTT broker.

5. CONCLUSION

This paper has underscored the critical role of technology in enabling the smooth operation of LFMs. By examining the intricate relationship between IT and OT, highlighting the importance of standardized data formats and protocols, and emphasizing the need for robust cybersecurity, the paper has established a solid technological foundation for LFM implementation. A well-designed ICT architecture, coupled with secure data exchange mechanisms, is essential to ensure the interoperability and reliability of LFMs.

The lack of a single, standardized ICT protocol for LFM presents an opportunity for innovation and adaptation. By strategically leveraging existing protocols, exploring the potential of new technologies, and fostering collaboration to define standardized protocols, LFM stakeholders can build a secure, efficient, and privacy-preserving communications infrastructure. This will pave the way for a future where LFMs thrive and contribute to a more flexible, sustainable and consumer-centric electricity grid. For DSOs, priorities include adopting grid-centric standards like CIM for real-time data exchange, advocating for interoperability. Aggregators should focus on secure DER coordination using low-latency protocols, develop consumer-friendly tools for prosumer engagement, and align DER data with CIM extensions. Vendors must prioritize interoperability by embedding compliance with CIM and IEC standards into their solutions, while integrating cybersecurity-by-design to protect critical infrastructure.

Cross-stakeholder collaboration is essential to define unified LFM data profiles, advocate for regulatory alignment, and test hybrid systems through regional pilots. By balancing innovation with standardization, stakeholders can build LFMs that enhance grid flexibility, ensure security, and empower consumers in the energy transition.

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BIOGRAPHY

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Matej Zajc (IEEE Senior Member) is a Full Professor at the University of Ljubljana, where his research focuses on Information and Communication Technologies (ICT) and user-centred services for smart grids, vehicle-to-everything (V2X) solutions for integrating electric vehicles into power systems, and approaches that enhance active consumer participation. He currently leads the University of Ljubljana research team in the Horizon Europe project EV4EU – Electric Vehicles Management for Carbon Neutrality in Europe. He is an active member of the V2X Cluster Working Group on Business Models, the CIGRE Working Group C6.47, and serves as a co-leader of the 2ZERO Partnership Pillar 2.