B&H Electrical Engineering, Volume 20, Issue 1, 2026
ISSN:2566-3143, eISSN:2566-3151, DOI: 10.2478/bhee-2026-0017

ENERGY COMMUNITIES: OVERVIEW AND PERSPECTIVES

Eldar Hukić[1,4], Matej Zajc[2], Nermin Suljanović[3]

Abstract: By the directives of the European Union (EU), the Energy Community (EC) operates in the field of electricity production, distribution, supply, consumption management, aggregation, energy storage, provision of flexibility services, energy efficiency services, and charging services for electric vehicles. To achieve the above, it is necessary to clearly define the EC's business models, technical design, and organizational structure. This paper will clarify the similarities and differences between the concepts of renewable energy communities and citizens' energy communities through a comparative analysis. This paper provides an overview of the literature on ECs to create a picture of the current situation in this area. Likewise, the analysis of the literature gave a clear picture of who the possible members of the EC are, their mutual relations and the possible activities of the EC and the way of participating in the market. For an energy management system (EMS), the model of data exchange is given. This requires the exact mapping of EC within the SGAM, which includes communication and information standards. Also, the business models and functions of ECs are explained. For the selected use-cases, an analysis of the functionalities (activities) of the ECs is conducted.

Keywords: Energy communities, Energy community's stakeholders, business models and functionalities, data exchange

INTRODUCTION

This paper is based on the desk research of the relevant literature, existing ECs projects and documentation from research projects regarding research on ECs, existing frameworks and best practices. ECs cover a range of areas including electrical energy, thermal energy, energy efficiency, and other related sectors. This paper examines the role of ECs in the electricity sector. In traditional electricity networks large power plants are connected to the transmission network and they generate electricity which is transported and delivered to the end users by transmission and distribution network. Therefore, the generation and demand matching process, operation of electricity markets and physical control of the network is carried out on the transmission level. The distribution network has a limited passive role of supplying the end users with electricity. In modern electricity networks the role of the distribution network is change due to a rise of connected small generation units. These distributed generators (DGs) change the way how distribution network is planned, operated and regulated. Aim of the paper is to provide general overview for ECs in EU legislation, investigate possible activities and business models, show the interaction of ECs with other market players and provide information on several use-cases. Use-cases are selected for different EU countries in the way that they describe in the best possible way country's legal framework, and also to show how ECs can have very simple form as well as the most complex one.

1. ENERGY COMMUNITIES - LEGAL FRAMEWORK

1.1. EU Directives

"Clean Energy for all Europeans" package (CEP) was introduced by the European Commission to promote energy community projects and increase citizen participation. This package introduced two new definitions.

First, "Renewable Energy Communities" (RECs) were introduced in the Renewable Energy Directive II (REDII) in 2018 [1], and then, "Citizen Energy Communities" (CECs) were defined in 2019 via the Electricity Market Directive (EMD) [2]. These Directives were amended in 2024, by the Directive 2024/1711, in order to improve the Union's electricity market design [3].

[1] Regulatory Commission for Energy in FB&H, Bosnia and Herzegovina
[2] University of Ljubljana, Faculty of Electrical Engineering, Slovenia
[3] Elektroinštitut Milan Vidmar, Ljubljana, Slovenia
[4] Correspondence email: e.hukic@ferk.ba

1.2. Legal characteristics

Table I: Legal characteristics - summary

Summary of the definitions for a REC and CEC	
Article 2(16) Renewables Directive – "Renewable Energy Community"	Article 2(11) Electricity Directive – "Citizen Energy Community"
A legal entity: a) Which is based on open and voluntary participation, is autonomous, and is effectively controlled by shareholders or members that are located in the proximity of the renewable energy projects that are owned and developed by that entity; b) The shareholders or members are natural persons, SMEs or local authorities, including municipalities; c) The primary purpose is to provide environmental, economic or social community benefits for its shareholders or members or for the local areas where it operates, rather than financial profits.	A legal entity that: (a) Is based on voluntary and open participation and is effectively controlled by members or shareholders that are natural persons, local authorities, including municipalities or small enterprises; (b) Has for its primary purpose to provide environmental, economic or social community benefits to its members or shareholders or to the local areas where it operates rather than to generate financial profits; (c) May engage in generation, including from renewable sources, distribution, supply, consumption, aggregation, energy storage, energy efficiency services or charging services for electric vehicles or provide other energy services to its members or shareholders;
RECs are entitled to produce, consume, store and sell renewable energy, including through renewables power purchase agreements, to share renewable energy within the community and the access all suitable markets.	

Table I briefly summarizes the definitions for REC and CEC. The definitions for a REC and a CEC overlap, but there are a few key differences. The CEC is applicable to only electricity. The REC covers also communities engaged with for example district heating. The REC on the other hand only applies to renewable energy and the CEC does not make the distinction between renewables and non-renewables [4].

2. STAKEHOLDERS

2.1. Traditional electrical energy systems

Mapping of stakeholders represents the crucial process in the development of ECs. The relevant actors can be clustered into stakeholder groups whose representatives share the same objectives and criteria [5]. Following Table II provides an overview of the general stakeholders within the traditional energy market.

Table II: General stakeholders in traditional systems

Stakeholder	Description
Transmission System Operator (TSO)	Entity responsible for the transmission and balancing of the electrical energy on the transmission network (operation, maintenance and development)
Distribution System Operator (DSO)	Entity responsible for the distribution of the electrical energy on the distribution network, (operation, maintenance and development)
Regulator	Actor that regulates the energy markets and guarantees energy networks
Energy Supplier	Actor responsible for billing and contracting the grid operator with the consumer
Energy Trader	Actor who buys electrical energy from producers and sell it in the market
Consumer	Electrical energy end-user
Energy Producer	Entity responsible for electrical energy production.

2.2. Modern electrical energy systems

ECs may have a key role in the decentralization of the energy system. Following Table III provides an overview of the new stakeholders that can be found within the modern energy market, in regard of ECs.

Table III: New stakeholders in modern systems

Stakeholder	Description
Initiator	Initiator of the EC
External Investor	Private person or entity/NGO who invests in the EC
Insurance Party	Private entity providing insurance services to the EC
Financing Party	Private person/entity or public body providing financial support

ISSN:2566-3143, eISSN:2566-3151, DOI: 10.2478/bhee-2026-0017

EC participant	EC member
Asset Owner	Person or entity owning an energy producing or regulating unit
Engineering Office	Private entity ensuring the technical set-up and maintenance
EC decision-making body	Private or public entity responsible for ECs decision-making
Government	Public entity responsible for decision-making at higher levels
Legal Party	Private or public entity that supports the EC with legal support
Prosumer	Consumer and producer of the product or service
Aggregator (service provider)	Intermediary between prosumers and electricity markets
CPO (charge point operator)	Installs, owns, and operates charging station hardware and software
EMSP (electromobility service provider)	Connect BEV users with a CPO charger and starts and stops the charging and organizes payment.
Energy storage system operator (ESSO)	Installs, owns, and operates energy storage system hardware and software standalone or in co-operation with land or facility owners

2.3. Mutual relations between identified stakeholders

Following Figure 1 generally depicts the positions and mutual relations between identified stakeholders in regard of EC. It should be noted that sometimes the position of certain stakeholders, like supplier, grid operator or aggregator etc., can be changed in dependence of what kind of activity EC conducts and whether it is a simple EC or more complex one where EC by itself also has a role of supplier, grid operator, aggregator etc. It is also relevant to notice that some actors can be clustered into stakeholder groups if they share the same objectives and criteria.

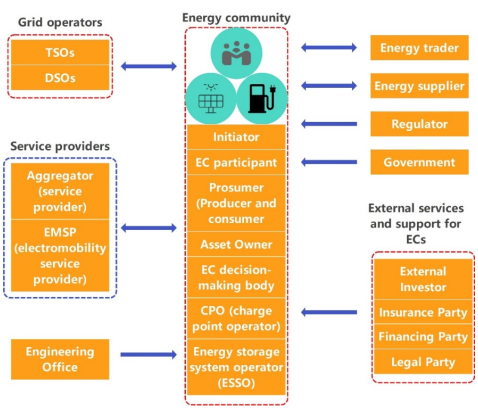

Figure 1: The positions and mutual relations between identified stakeholders in regard of EC

3. EC BUSINESS MODELS AND ACTIVITIES

3.1. EC business models

Market unbundling alongside the increase of renewable-based decentralized generation have imposed changes on the classical utilities business models (BMs). In an EC BM, two elements of production and customer management make important differences. Firstly, traditional electricity production resources are being adapted to renewable sources such as wind power and PV. Secondly, traditional consumers have transformed into prosumers, who are becoming producers and key partners in electricity generation [7]. It can be seen that intermediaries play an important role in the EC development process.

3.2. EC activities

Table IV: Activities of the ECs according to EU Directives [2], [3], [4]

Activity	Description
Electrical energy generation	Community-run production facilities produce electrical energy.
Self-consumption (Electrical energy sharing)	The produced or stored electrical energy is consumed within the community.
Electrical energy storage	Community-run storage facilities store electrical energy.
Market participation	The produced or stored electrical energy is sold to a supplier.
Flexibility services	Provision of ancillary services to support the grid operation.
EV charging	Management of charging stations.
Distribution	Management of distribution networks.
Electrical energy supply	Electrical energy is sold to customers.
Aggregation	Aggregator of Distributed Energy Resources (DERs).
Other	Financial and energy related services, consultation services, etc.

Different BMs are defined by different EC functionalities (activities). Each member state adopted a different approach and is pursuing different priorities regarding ECs and their anticipated role in the energy transition. Some member states have better approach and have more accurate definitions of ECs (in line with the EU Directives), while some don't. This fact directly influences the structure, organisational form and functionality of ECs. Consequently, ECs have different activities, positions, ways of interaction and impact on distribution network.

4. DSOS/TSOS AND ECS

4.1. DSOs/TSOs new role in regard of ECs

DSOs and TSOs should actively engage citizens in understanding the potential savings associated with joining ECs. Innovative strategies need to be developed to accommodate the growing interest in ECs. TSOs and DSOs must take a proactive role in fostering the creation of aggregation entities. By ensuring the needs of these entities in terms of grid performance are met, and ideally surpassed, they can bolster grid stability and efficiency.

4.2. The architectural integration of the ECs

The architectural integration of the ECs relates to their interaction with the grid. In some cases, ECs might need almost no support from the public power grid. Still, in a more realistic case, the use and role of transmission and distribution grids remain for stability, reliability, quality of service, and contingency management. The architectural integration of the ECs can be centralised where the TSO is the system's backbone, while the DSO usually follows the hierarchical instruction from the TSO, and decentralised where the system's robustness is increased by design because of no single point of failure [8].

4.3. Impact of ECs on the distribution network

Some researchers are pointing out that the performed simulations clearly demonstrated that the impact of ECs on the grid is not a minor issue. According to the Joint Research Centre of the European Commission [9] ECs can bring benefits, and may also pose certain challenges for the energy system. In principle, impact depends on the scale of the penetration of EC generation, ratio between produced and consumed energy, location of the generation assets etc. EC opportunities and DSO challenges are addressed in the following Figure 2.

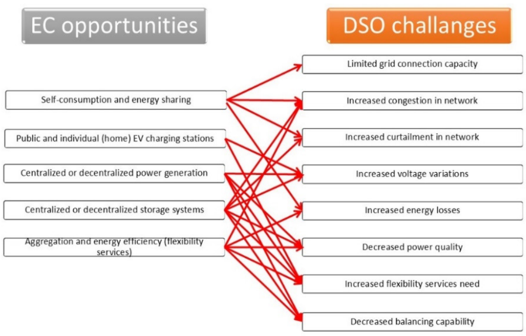

Figure 2: Summary of EC opportunities and DSO challenges they can address

4.4. Ancillary services and flexibility in distribution networks and ECs

A lot of researchers are examining the potential of ECs flexibility. Different researchers have modelled the optimization of the resources that belong to different ECs, with different assets. The results showed that there are numerous ways how ECs with their assets (resources) can provide ancillary services and flexibility [10].

Table V: An overview of the ECs assets (resources) and related ancillary services and flexibility

Assets (resources)	Ancillary services and flexibility
Energy storage systems (ESS)	- Manual frequency restoration reserve (mFRR) - Downward and upward reserves - Shifting energy consumption (DR) - Shifting energy injection
DG (PV, wind, small hydro, biomass, cogeneration etc.)	- Power generation curtailment - Manual frequency restoration reserve (mFRR) (biomass, cogeneration) - Downward and upward reserves (biomass, cogeneration)
EV charging stations	- Shifting energy consumption (DR) - Shifting energy injection (battery of electric vehicle) - Power consumption curtailment (DR)
Controllable load (CL) (HVAC, shift-able load etc.)	- Shifting energy consumption (DR) - Power consumption curtailment (DR)

5. SMART GRID ARCHITECTURE MODEL (SGAM) AND EC MAPPING

5.1. SGAM generally

The smart grid architecture model (SGAM) is a cube-like structure consisting of five different interoperability layers (component, communication, information, function, and business). The SGAM is used to analyze smart grid architectures of large systems [11].

5.2. Mapping ECs in SGAM and overall EC activity diagram

Following Figures 3 and 4 show overall EC model mapping in the SGAM and activity diagram.

To understand the position, optimal design, data exchange and necessary conditions for ECs in regard to the DSO (and TSO) and other market actors, we need to map the EC and its components in the SGAM, and create appropriate activity diagram.

ISSN:2566-3143, eISSN:2566-3151, DOI: 10.2478/bhee-2026-0017

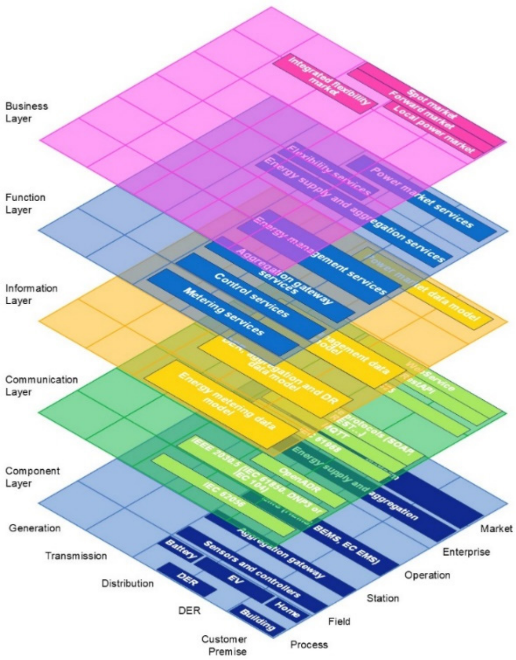

Figure 3: EC model mapping

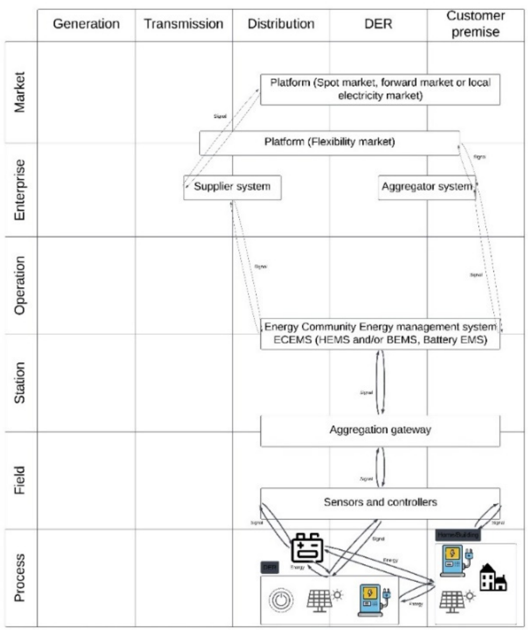

Figure 4: EC model activity diagram

5.3. ECs data exchange and smart metering

In the process of modelling and setting up an EC it is very important to have accurate data regarding the energy consumption and production of its potential members. Also, it is very important to have accurate real time data so that the EMS can operate properly. Some authors investigated the necessity of the installation of a smart meter and concluded that it is sometimes deemed necessary. This process comes with its own set of hurdles, no matter whether it is a large-scale roll-out of meters or individual installation procedures [12].

Very important enabling technology for the development of ECs and also the one that crucially needs efficient data exchange is a platform for EC energy management, EC EMS or just EMS [13].

Following Figure 4 generally depicts the data exchange block diagram in regard of EC EMS.

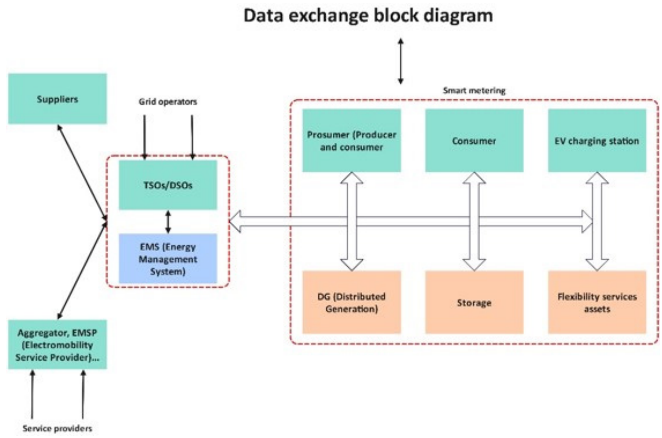

Figure 5: Data exchange block diagram

6. ENERGY COMMUNITIES SELECTED USE-CASES

6.1. Overview

To understand and address the role, functionality and position of ECs a set of use-cases is presented. Use-cases are selected from six different EU countries, from simple to the most complex ones, and in accordance to the country's legal framework. Aim is to demonstrate the existing solutions and business models in different EU countries.

Each member state adopted a different approach and is pursuing different priorities regarding ECs and their anticipated role in the energy transition. This fact directly influences the structure, organisational form and functionality of ECs. Consequently, ECs have different positions, ways of interaction and impact on distribution network.

6.2. Selected use-cases comparative analyses

Based on the provided data for the selected use-cases we see the differences between ECs that are implemented in different countries within different legal frameworks. The geographical coverage of the use-cases throughout different EU countries contributes to the variation of how ECs are integrated into the distribution network, what functionalities they have (sometimes acting like DSO) and how they interact with other market players, mainly DSOs. Following Table VI aims to identify how different ECs are organized regarding technical assets and their activities/ functionalities.

Table VI: Use-cases comparative table - assets and activities/services similarities and differences

Country / Use-case		Portugal/ Telheiras Renewable Energy Community	Spain / CEL Castellar-L'Oliveral	Italy / CER Magliano Alpi	Greece / Energy Cooperative WEnCoop	The Netherlands / Energie Coöperatie Endona	Germany / Elektrizitäts-Werke Schönau
Energy Community assets	DG units (PV, wind...)	+	+	+	+	+	+
	Energy storage system (battery, thermal…)	-	-	-	-	+	+
	EV charging	-	-	+	-	-	+
	Flexible loads (HVAC, appliances…)	-	-	-	-	+	-
	Electricity network	-	-	-	-	-	+
Energy Community activities/services	Electrical energy generation	+	+	+	+	+	+
	Self-consumption (Energy sharing)	+	+	+	-	-	+
	Market participation (trading of surplus or entire electrical energy generation)	-	-	-	+	+	+
	Flexibility services	-	-	-	-	+	-
	EV charging	-	-	+	-	-	+
	DSO role	-	-	-	-	-	+
	Retailer / trader role	-	-	-	-	+	+

7. CONCLUSION

Transposition of EU Directives regarding ECs (RECs and CECs) is very different from one EU member state to another EU member state. Each member state adopted a different approach and is pursuing different priorities regarding ECs and their anticipated role in the energy transition. This fact directly influences the structure, organisational form and functionality of ECs. Consequently, ECs have different positions, ways of interaction and impact on distribution network.

DSOs and consumer/prosumer members of the ECs are the key stakeholders. Without DSOs support and the cooperation between DSOs and ECs, the ECs cannot be implemented. Depending on the characteristics of the EC, other types of stakeholders are involved with their specific responsibilities and tasks.

It can be concluded that DSOs should be actively be engaged in the process of the design and implementation of ECs, and they should ensure that the distribution network infrastructure, primarily ICT, aligns with the ECs needs and requests. It is better to have decentralised approach in the process of integration of the ECs in the distribution network. Also, DSOs should take an active role in network operations regarding the implementation of ECs. The DSOs should manage their distribution network actively, fostering the installation of smart meters and developing the ICT infrastructure, for the purpose of optimal utilisation of the distribution network. It can also be concluded that there is no one-solution-fits-all for EC projects, and DSOs will have to be flexible and ready to adopt various frameworks to fulfil different purposes of ECs.

Integration of ECs into the distribution network has positive and negative sides. The impact of ECs on the distribution network is not a minor issue. The distribution network could suffer from increased losses, a worsen voltage profile, and an increased loading of the lines, but these issues are "normal" while integrating the DGs into the distribution network. The increased loading of the lines is the most critical one. But it is necessary to differentiate the impact of classic DG from the impact of EC, and to adopt appropriate approaches for the investigation. DGs installed and own by EC are mainly sized and controlled to maximize self-consumption within the EC. This means that the impact of the location of new EC generators is crucial and has to be investigated. Deploying generators and loads on the same feeder in urban areas (areas with large consumption) leads to lower distribution network impact.

ISSN:2566-3143, eISSN:2566-3151, DOI: 10.2478/bhee-2026-0017

The positive side of the ECs integration into the distribution network is that the DSOs can find the ECs as sources of necessary ancillary services and flexibility. Generally, the list of the EC potential in terms of ancillary services and flexibility is identified and showed, and still the potential of ECs in this field needs to be more explored.

The mapping of EC in SGAM is carried out and presented, considering both definitions from EU Directives (RECs and CECs) and taking into consideration all possible functionalities and roles. Since there is no one-solution-fits-all for EC projects, the mapping should be done for each EC project. The mapping, along with activity diagram, helps us to understand the position, optimal design and necessary conditions for ECs in regard to the DSO (and TSO). This process should be carried out in the design phase of EC project, in order to provide all necessary technical conditions for successful implementation.

The observed design of different ECs in six selected use-cases show large variations regarding the size of the EC, assets of the EC, functionalities/activities of the EC, role of the EC and integration and interaction of the EC within the distribution network. It can be concluded that in all selected use-cases DSOs are crucial stakeholders in the energy system, and they are relevant to be involved in the design and implementation process of ECs in all cases.

REFERENCES

[1] DIRECTIVE (EU) 2018/2001 OF THE EUROPEAN PARLIAMENT AND OF THE COUNCIL of 11 December 2018 on the promotion of the use of energy from renewable sources (recast); https://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:32018L2001

[2] DIRECTIVE (EU) 2019/944 OF THE EUROPEAN PARLIAMENT AND OF THE COUNCIL of 5 June 2019 on common rules for the internal market for electricity and amending Directive 2012/27/EU (recast); https://eur-lex.europa.eu/eli/dir/2019/944/oj/eng

[3] DIRECTIVE (EU) 2024/1711 OF THE EUROPEAN PARLIAMENT AND OF THE COUNCIL of 13 June 2024 amending Directives (EU) 2018/2001 and (EU) 2019/944 as regards improving the Union's electricity market design; https://eur-lex.europa.eu/eli/dir/2024/1711/oj/eng

[4] D1.2: Best practices in citizen engagement for ECs and Methodology for citizen and consumer engagement and value-based proposition design in ECs; Horizon Europe project COMMUNITAS Bound to accelerate the roll-out and expansion of Energy Communities and empower consumers as fully-fledged energy market players https://communitas-project.eu

[5] Shary Heuninckx; Geert te Boveldt; Cathy Macharis; Thierry Coosemans; Stakeholder objectives for joining an energy community: Flemish case studies. Elsevier 2022, volume 162, 112808; https://doi.org/10.1016/j.enpol.2022.112808

[7] Naimeh Mohammadi; Investigation of Community Energy Business Models from an Institutional Perspective: Intermediaries and Policy Instruments in Selected Cases of Developing and Developed Countries. Sustainability 2023, 15(10), 8423; https://doi.org/10.3390/su15108423

[8] Albana Ilo and others; Energy Communities' impact on grids, Energy Community Embedment Increasing Grid Flexibility and Flourishing Electricity Markets, Publications Office of the European Union, Luxembourg, 2024, ISBN 978-92-68-16028-2 doi: 10.2833/299800 MJ-02-24-576-EN-N. https://op.europa.eu/en/publication-detail/-/publication/0cd22fb0-1989-11ef-a251-01aa75ed71a1/language-en#

[9] Caramizaru, A.; Uihlein, A.; Energy communities: an overview of energy and social innovation, EUR 30083 EN, Publications Office of the European Union, Luxembourg, 2020, ISBN 978-92-76-10713-2, doi:10.2760/180576, JRC119433. http://catedracomunidadesenergeticas.unizar.es/wp-content/uploads/2022/06/energy_communities_report_final.pdf

[10] Emely Cruz-De-Jesús; Jose L. Martínez-Ramos; Alejandro Marano-Marcolini; Optimal Scheduling of Controllable Resources in Energy Communities: An Overview of the Optimization Approaches. Energies 2023, 16(1), 101; https://doi.org/10.3390/en16010101

[11] Deepak Kumar Panda; Saptarshi Das; Smart grid architecture model for control, optimization and data analytics of future power networks with more renewable energy. Elsevier 2021, volume 301, 126877; https://doi.org/10.1016/j.jclepro.2021.126877

[12] Shary Heuninckx; Maarja Meitern; Geert te Boveldt; Thierry Coosemans; Practical problems before privacy concerns: How European energy community initiatives struggle with data collection. Elsevier 2023, volume 98, 103040; https://doi.org/10.1016/j.erss.2023.103040

[13] Daniele Menniti; Anna Pinnarelli; Nicola Sorrentino; Pasquale Vizza; Giuseppe Barone; Giovanni Brusco; Stefano Mendicino; Luca Mendicino; Gaetano Polizzi; Enabling Technologies for Energy Communities: Some Experimental Use Cases. Energies 2022, 15(17), 6374; https://doi.org/10.3390/en15176374

BIOGRAPHY

Eldar Hukić, received his B.Sc. and M.Sc. degrees in Electrical Engineering from the Faculty of Electrical Engineering, University of Tuzla in 2004 and 2010, respectively. He is currently pursuing a Ph.D. degree in Electrical Engineering at the Faculty of Electrical Engineering, University of Ljubljana. His research interests include RES integration, flexibility services and smart grids.

Matej Zajc is a full professor at ICT department, Faculty of Electrical Engineering, University of Ljubljana. He is active in research in the field of ICT for smart networks; ICT for green transformation; Internet of Things; Ambitious intelligence; smart objects and environments; socio-technical systems. Prof. Ph.D. Matej Zajc is actively involved in activities that place the field of electrical engineering and with it the study of electrical engineering in a prominent place in the social environment.

Nermin Suljanović is a full professor and the head of the Department of Telecommunications at the Faculty of Electrical Engineering, University of Tuzla, Bosnia and Herzegovina, where he has been a faculty member since 2004. He earned his B.S. degree from the University of Tuzla in 1997 and his M.S. degree in 2001. He obtained his Ph.D. in electrical engineering from the University of Ljubljana, Slovenia, in 2004, and currently also serves as a senior researcher at EIMV, Slovenia.