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Published in:
Energy Strategy Reviews

DOI:
10.1016/j.esr.2024.101477

Published: 01/07/2024

Document Version
Publisher's PDF, also known as Version of record

Please cite the original version:
Eisele, P., Carrilho, F. A. N., Bojja, D., Pelote, P., & Valderrama, C. (2024). Readiness of demand response technology for Spanish Energy Communities. *Energy Strategy Reviews*, *54*, 1-12. Article 101477.
https://doi.org/10.1016/j.esr.2024.101477

Energy Strategy Reviews 54 (2024) 101477

Contents lists available at ScienceDirect

Energy Strategy Reviews

journal homepage: www.elsevier.com/locate/esr

Readiness of demand response technology for Spanish Energy Communities

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ARTICLE INFO

Handling Editor: Dr. Mark Howells

Keywords:
Balanced readiness level assessment
Energy communities
Energy transition
Decentralized grid

ABSTRACT

Demand response (DR) and Energy Communities are highlighted as two key means to facilitate the energy transition in Europe by providing flexibility to the grid in a decentralized way. This paper uses a theoretical framework, the balanced readiness level assessment, to review five social and techno-economic dimensions regarding the status of demand response technology, emphasizing key challenges and opportunities. Focusing specifically on Energy Communities in Spain, issues such as the split-incentive problem in technology investments, market rules favouring large generators, and the imperative for improved coordination in the electricity market and network operations are identified as significant hurdles to further DR development. A balanced readiness level score of 7.25 is assessed for Spanish energy communities, composed of a 9 for the technological, a 7 for the regulatory and the acceptance, and a 5 for explicit and 7 for implicit market readiness level.

The application of the balanced readiness level assessment methodology is novel to the energy industry and does not only prove the value it can create in this sector, but also provides insights for policymakers and stakeholders navigating the dynamic landscape of Demand Response for Spanish Energy Communities.

1. Introduction

Considering the increasing threat of climate change and energy dependency, the European Union (EU) has set directives to transition to clean and locally available renewable energy. Counteracting the challenges that electricity generation from intermittent, renewable energy resources and increasing electrification rates of several end use sectors bring along, the provision of flexibility is required to balance potential mismatches between electricity supply and demand in the power system. To obtain this flexibility, demand response (DR) and energy communities (ECs) have been identified as a promising technology and concept, respectively.

In this regard, Energy Communities are highlighted as one of the central means to facilitate a cost-efficient integration of sustainable energy solutions on a local level. The EU has defined the Renewable Energy Directive II [1], followed by the Internal Electricity Market Directive [2] and Regulation as part of the Clean Energy for all Europeans Package [3], differentiating between Citizen Energy Communities and (CECs) and Renewable Energy Communities (RECs).

Energy Communities promote local energy use, empowering the community and fostering social impact. They play a crucial role in advancing renewable energy adoption by coordinating decentralized resources, offering flexibility services for a reliable and cost-effective electricity supply, and maintaining grid stability. This model is gaining traction in Europe, enabling diverse participants like local organizations, neighbours, and public authorities to actively contribute to the transition to renewable energy [4].

Equally to ECs, the demand-side of the power system is specified by the EU as a tool to facilitate the unions energy transition. Thereby, the EU defines demand response as: “*the capacity to change energy usage by end-use consumers (including residential) from their normal or current consumption patterns in response to market signals, such as time-variable energy prices or incentive payments, or in response to acceptance of the consumer's bid, alone or through aggregation, to sell demand reduction/increase at a price in gas and electricity markets or for internal portfolio*

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https://doi.org/10.1016/j.esr.2024.101477
Received 9 February 2024; Received in revised form 12 June 2024; Accepted 24 June 2024

List of abbreviations

AMI	Advanced metering infrastructure
ARL	Acceptance Readiness Level
BRL	Balanced Readiness Level
BRP	Balance Responsible Party
BSP	Balance Service Provider
CAGR	Compound annual growth rate
CEC	Citizen energy community
CNMC	Comisión Nacional de los Mercados y la Competencia' ('Spanish National Markets and Competition Commission')
DER	Decentralized energy resources
DR	Demand response
EC	Energy community
EDR	Explicit demand response
EU	European Union
HP	Heat pump
IDR	Implicit demand response
MRL	Market Readiness Level
ORL	Organizational Readiness Level
PVPC	Precios voluntarios para el pequeño consumidor ('Voluntary price for the small consumer')
PVPC	Photovoltaic
RDL	Royal Decree Law
REC	Renewable energy community
RRL	Regulatory Readiness Level
TOU	Time-of-use
TRL	Technology Readiness Level

optimization, or bilaterally." [5].

To facilitate the integration of DR in the power system, the EU has set a framework that must be transitioned by every member state into national law: This framework consists of the Electricity Directive (2019/994/EU) [6], the Commission Regulation (EU) 2017/2195 [7], and the Council Regulation (EU) 2022/1854 [8]. It introduces the concepts, technologies and boundaries that are required to facilitate the European energy transition.

Further, EU regulation differentiates between the following two types of demand response [9].

- *Implicit demand response* (sometimes called 'price-based'), which refers to consumers choosing to be exposed to time-varying energy prices that reflect the value and cost of gas/electricity in different time periods.
- *Explicit demand response* schemes (sometimes called 'incentive based'), which are for 'freeing up' electricity to react to a network constraint or high energy prices.

Combining energy communities and demand response provides a pivotal mean to harness the technological capabilities of decentralized energy resources (DERs) and contribute to a more sustainable, stable, and cost-efficient European energy system. However, despite these possibilities, no large-scale application of DR in the context of ECs can be seen until now. To enable companies and institutions to tackle this problem, this paper provides a multi-dimensional analysis of the readiness of demand response technology to be integrated in an energy community management scheme, focusing on Spain as a case study.

The scientific aim of this research is to look beyond the technological aspects, and, by using the balanced readiness level (BRL) assessment methodology, also assess the regulatory, market, and acceptance readiness level of the technology. As a result, the study enables a more comprehensive assessment of the readiness of DR in Spanish energy communities. Moreover, by including a guideline on how to assess the organizational readiness level, a tool for companies and institutions is developed that can be used to evaluate opportunities and challenges for the adoption of the technology.

As the BRL assessment methodology was originally developed for technologies in the agricultural sector, the novelty of this research lies in the application of the methodology for the analysis of a technology in the energy sector. Thereby, it is proven that the methodology can also provide useful insights in other areas.

For this purpose, the paper first introduces the case study scope, followed by a description of the BRL assessment methodology. Then, the state of the art is summarized, leading over to the presentation and discussion of the analysis results.

2. Case study: demand response in Spanish Energy Communities

According to Koltunov et al. [10], there are nearly 4000 ECs are currently registered in Europe. Spain is recognized among EU member states, having relatively few ECs (40) but the highest average number of members per EC (6,841). In contrast, all other countries, except Finland, have an average membership of fewer than 1000 member per EC. Authors also found that due to the high renewable energy potential in Spain, especially for PV power plants, the number of ECs is constantly growing [10].

In Spain, financial support for the creation of energy communities is facilitated through several mechanisms, including the 'Next Generation EU' funds available via Order TED/1446/2021, which provides a regulatory basis for aid under the incentive program for singular pilot projects for energy communities. Additionally, the MITECO's Recovery, Transformation and Resilience Plan (PRTR), approved in June 2021, offers stimulus packages to promote and support these communities. Financial models vary, with top-down strategies involving agreements between large energy companies and municipalities offering shared self-consumption and lower risks for members, as seen in the CaixaBank and Edinor model, while bottom-up models, like the partnership between Fiare BancaEtica and Som Energia, involve initial uncertainty and seek to include new entities such as municipalities or surrounding companies [11].

Typically, Spanish ECs operate by adopting cooperative or participative association statuses, where each member has one vote, and working groups are formed to address internal objectives. In many cases, the assembly creates a governing body, democratically elected among all members, in charge of executing their objectives and managing the community [11]. However, ECs can adopt other configuration, being the three main types: consumer-owned renewable ECs, community energy cooperatives and virtual ECs.

To aid in managing energy communities, companies have been developing multiple products and technologies to optimize community management. To demonstrate the EC competitive landscape in Spain, Table 1 collects several Spanish companies that address these types, presenting their innovative and sustainable energy practices.

Connecting the concept of ECs with demand response technology, IRENA defines power-to-heat, electric vehicles, and smart appliances as possible sources for demand-side flexibility within the commercial and residential sector [27].

Based on the definition of DR within the European Union mentioned before, three applicable scenarios have been created to assess the readiness level of DR in Spanish energy communities. These scenarios have been selected, as they display the currently most popular application, optimization of self-consumption (Scenario I) [10], as well as the two EU-defined DR schemes: implicit DR (Scenario II), and explicit DR (Scenario III) [9].

Table 1
Example companies dealing with ECs in Spain.

Project/ Company	Type of DR	Description	Reference
Senda	Implicit DR	• Support for creation, development, & management of local EC's. • Legal assistance, technical modelling & funding • Platform: project planning, (access to consumption and savings data)	[12]
QUIXOTIC	*DR for optimization of self-consumption*	• QUIXOTIC 360 (subscription platform) and SaaS platform for energy community management • Automation features for streamlined processes. • Regulatory updates • Real-time data access for energy suppliers	[13]
Flexidao	*DR for optimization of self-consumption*	• RESpring (RE Monitoring Software) designed for Corporate Energy Buyers • Two implementations: Renewable Energy analysis and Procurement Software.	[14,15]
StemyEnergy	*DR for optimization of self-consumption*	• Flex Community App: management and access energy consumption data from anywhere	[16]
Elecsum	Implicit DR	• Photovoltaic self-consumption market • PV solution design and installation • App: control production, monitor savings, and access billing information • Customer engaging (customers who offer roof space for PV installations)	[17]
Ampere Energy	Implicit/Explicit DR	• Technology partner for energy communities • Offer a diverse range of battery technologies. • SEMS ONE intelligent energy management device • Software solutions, including SEMS Technology, MyAmpere & Ampere (intelligent energy storage, consumption control and community energy management)	[18,19]
Nnergix	*DR for optimization of self-consumption*	• RE analysis services, distributed solar photovoltaic, • Solar Sentinel Platform: monitoring and support for the automation and maintenance of collective solar self-consumption (photovoltaic systems)	[20]
Bamboo	Explicit DR	• Energy optimization platform • AI-powered solution for flexibility management and forecasting, day-ahead trading, and real-time flexibility operation, • Energy assets optimization and operating costs reduction	[21,22]
EnergyPool	Explicit DR	• Demand-side management solutions, covering consulting services, energy management strategies and innovation support. • Customers: utilities, renewable energy system operators, energy consumers and energy storage • Energy Resources optimization	[23–25]
Plug&Chain	Implicit/Explicit DR	• Collective self-consumption management in local EC • Web application: simulation and optimizing of energy balances. • Data security (blockchain technology)	[26]

2.1. *Scenario I: DR for optimization of self-consumption (community-internal)*

This first, most simple scenario refers to optimizing the self-consumption of electricity generated within a local energy community. Thereby, it is tried to align the energy consumption of controllable loads within the EC to follow the power supply of community-owned power generators. Thus, demand response can be used to reduce the amount of electricity that is drawn from the grid during periods of high demand.

2.2. *Scenario II: implicit demand response*

Scenario II extends the scheme of scenario I by the possibility to include dynamic electricity tariffs, as defined for the implicit, price-based type of DR. Thus, this scenario is applicable when the EC-internal, self-generated electricity is either not sufficient to cover the entire demand, or when it is not possible to sufficiently align electricity supply and demand, and hence, power is fed into the grid. In both scenarios, however, additional electricity needs to be withdrawn from the grid which leads to costs for the EC. By integrating dynamic electricity tariffs in the demand response scheme, these costs can be minimized.

2.3. *Scenario III: explicit demand response*

Scenario III, based on explicit DR, expands the concepts of scenarios I and II, involving load aggregation and active participation in ancillary service markets, such as frequency balancing. In contrast to implicit demand flexibility, which is based on tariff incentives for electricity consumption according to time, explicit demand flexibility requires consumers to actively adjust their energy use in response to system requirements, offering remuneration in return. Nonetheless, small residential or commercial consumers require an aggregator to facilitate their market participation [28].

3. Methodology: balanced readiness level (BRL) assessment

This analysis uses the BRL Assessment approach, which, was developed by Vik et al. [29], to provide a multi-dimensional assessment for companies or societies to evaluate the readiness of a technology, acknowledging a balanced consideration of five different factors: Technology development, market readiness, regulatory preparedness, social acceptance, and end-user integration. Compared to other methodologies, the BRL assessment stands out due to its comprehensive nature offering regulators and companies a more thorough evaluation of a technology's readiness for implementation. Consequently, the analysis allows decision-makers to make better-informed decisions by giving insights into significant interdependencies of the analysed dimensions for technology adoption. For example, a high technology readiness level alone may not be enough if the regulatory landscape is not prepared or there is no social acceptance for a technology.

For the individual readiness level assessments, each dimension is structured into nine levels, which thereafter contain a set of questions. Thereby, the individual dimensions are defined by Vik et al. [29], as follows.

- The **Technology Readiness Level** (TRL) scale is typically used to evaluate a technology's performance, reliability, and manufacturability.
- **Regulatory Readiness Level** (RRL) is a metric to evaluate the maturity of regulatory requirements and approvals for a particular technology or product. Specifically, the RRL allows to assess the level of regulatory preparedness for a particular product, process, or technology by measuring the degree of alignment with the regulatory requirements, the completeness of regulatory documentation, and the readiness of the regulatory agency to review and approve the product.
- The **Market Readiness Level** (MRL) is a method of evaluating the level of market demand and acceptance for a new technology or product.
- The **Acceptance Readiness Level** (ARL) specifically focuses on the readiness of end-users to accept and effectively use the new processes or technologies. It considers factors such as training, communication, and change management strategies that have been put in place to prepare people for the change.
- The **Organizational Readiness Level** (ORL) is a method of evaluating an organization's readiness to adopt and implement a new technology, process, or system.

Applied, this methodology combines two fundamental parts, which are integrated in the overall structure of this paper, as shown in Fig. 1.

In the first part, an exhaustive literature review allows an analysis of the readiness within the five dimensions. In the second part, the approach and questionnaire established by Vik et al. [29], is used to assess the specific readiness level. This method involves a series of specific questions to assess their level of readiness. For example, if the question 'Are the necessary approvals/permissions close to be given?' (question for RRL of 7) can be answered with 'Yes.', but 'Does use and production of the technology fulfil general requirements?' (question for RRL of 8) with a 'No.', a technology qualifies for a RRL of 7. Combining these levels, the BRL approach provides decision-makers with a detailed and informed perspective, facilitating effective decision-making in the adoption of technologies.

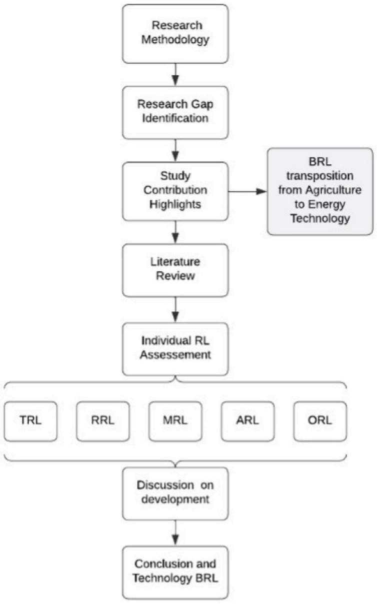

Fig. 1. Methodological structure of the BRL analysis for energy communities in Spain.

The five dimensions and their corresponding levels are illustrated in Fig. 2, while the full questionnaire developed by Vik et al. [29], can be found in TableS3 in the supplementary information.

3.1. State of the art of BRL assessment

The synthesis of literature on the readiness of demand response in the context of energy communities in Spain encompasses a multifaceted array of studies, each contributing distinct facets to this expanding field. While published literature usually focuses on one aspect, the BRL assessment offers a more thorough evaluation. Yet only the original paper introducing the BRL assessment by Vik et al. [29] is sticking to the methodology.

Transitioning into the domain of demand response readiness, several papers underscore the significance of assessing technological, market, and system readiness. Notably, Crosbie et al. [30], introduces the Demand Response Technology Readiness Level, offering means to evaluate technological readiness within building stock-oriented DR programs. Additionally, Nolan and O'Malley [31] delves into methodologies employed for evaluating the value and impact of demand response on power systems, encapsulating various integration studies and methodologies used to assess the effectiveness of demand response in the grid context.

Expanding the geographical scope, several studies focus on readiness assessments of demand response in specific countries. For instance, Freire-Barceló et al. [28], scrutinizes the integration of electricity demand flexibility in European countries, emphasizing barriers and facilitators in countries like Germany and France. Ruostetsaari [32] concentrates on Finnish citizens, probing their attitudes towards demand response and prosumerism in alignment with energy policy, highlighting the relevance of socio-political factors in readiness assessments.

Radenković et al. [33], in their 2-fold approach develop a demand response IOT business model for the Serbian market and test its customer readiness. Awareness about the positive environmental impact led to high interest in new technology.

In Freire-Barceló et al. [34], authors' review and clarify the umbrella of terms used in demand flexibility in literature and classifies mathematical models for EDF participation in ancillary services and congestion management.

Crosbie et al. [35], study a scalable cloud-based DR solution for blocks of buildings and review the proposed Demand Response Technology Readiness Level. In the pilot sites UK, Romania, France and Italy, the case study of shows few advantages but also challenges of incorporating a new system to existing one.

This paper describes comprehensive balanced readiness level to facilitate better insights for policymakers and stakeholders.

Nolan et al. [36], identify the key challenges and uncertainties of DR and how they impact the widespread implementation of demand response.

Conchado et al. [37], estimated the benefits of DR for Spain and concluded that the monetary benefits for individual households maybe less compared to the system of DR participants thus small incentive to engage in DR programs. This aids our research of DR and its readiness as their study was based in Spain.

Furthermore, Conchado et al. [37], and Freire-Barceló et al. [34], offer insights into the readiness of demand response initiatives within the specific context of Spain, assessing economic and environmental impacts alongside the optimization frameworks within the Spanish electricity system.

This literature review encapsulates a diverse spectrum of studies, covering readiness assessments, demand response evaluations, and geographical-specific analyses, collectively contributing to a comprehensive understanding of readiness levels and demand response

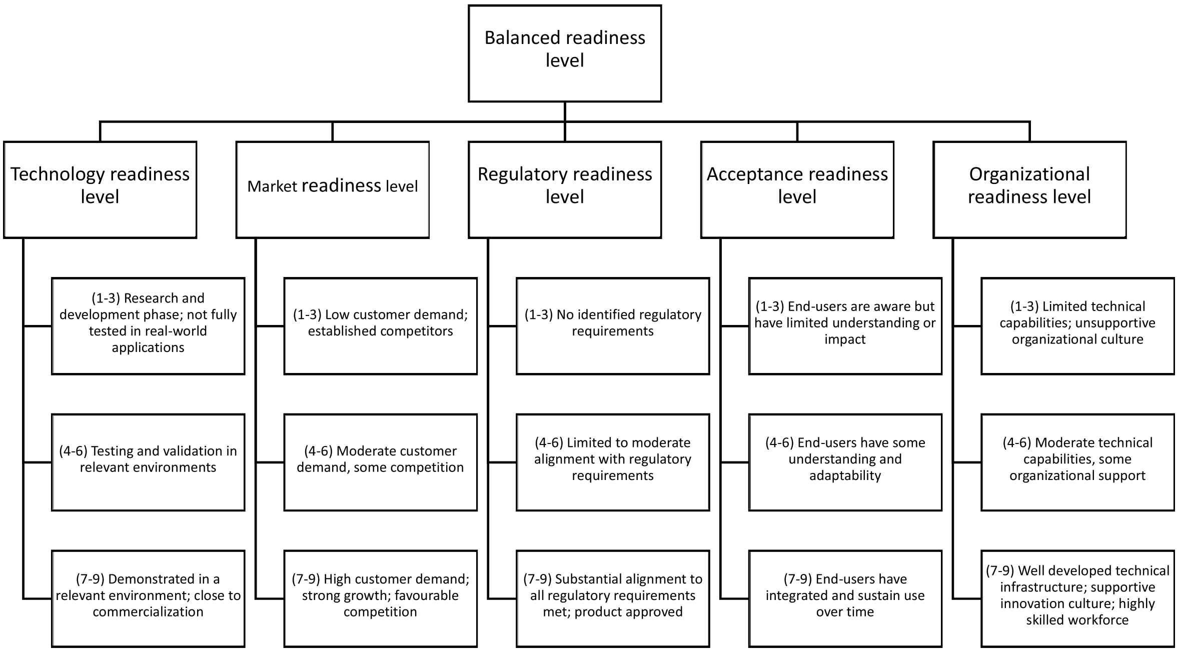

Fig. 2. Balanced readiness level assessment, derived from Vik et al. [29].

dynamics within the energy landscape.

4. Results and discussion

For the analysis of the TRL, MRL, RRL and ARL dimensions, extensive literature research has been carried out. Then, a categorization in the respective balanced readiness level has been executed, followed by a justification why the level was chosen. For the ORL, an overview of the most relevant parameters and critical constraints is given as a guideline for companies and institutions developing products or policies related to DR.

4.1. Technology readiness level assessment

The TRL of demand response technology in Spanish ECs can be stated as level 9. Thus, literature provides four main components that must be useable: controllable loads, advanced metering infrastructure (AMI), control, and optimization algorithms [38].

In this regard, IRENA specifies three types of loads for demand-side flexibility within the residential and commercial sector which are available, namely power-to-heat, electric vehicles, and smart appliances [27]. These technologies can be integrated in a DR scheme to manage and shift energy consumption to off-peak times, reduce peak demand, and improve overall grid reliability, contingent on the availability of suitable infrastructure and aggregation services.

Secondly, to effectively harness the flexibility potentials of these appliances within a managed energy community, AMI at the participants' sites, and smart control and optimization algorithms are required:

AMI is defined as a system that enables two-way communication between electricity consumers and their utilities, providing both parties with real-time data on electricity consumption and generation [39]. AMI typically consists of smart meters installed at the consumer's premises, a communications network that links the meters to the utility's data centre, and data management software that collects, stores, and analyses the data [39]. As a result, AMI allows utilities to monitor and manage electricity demand, reduce peak load, and improve energy efficiency more accurately.

Moreover, Yaghmaee et al. [40], compare distributed and cloud-based demand response AMI architectures. Thereby, DR is managed by local controllers at individual customer premises in the distributed architecture, while in the cloud-based architecture, DR is coordinated by a central cloud-based platform. The authors use simulations to compare the two architectures in terms of their effectiveness in reducing peak demand, their ability to handle various types of DR events, and their scalability. They find that both architectures are effective in reducing peak demand, but the cloud-based architecture is more scalable and can handle a wider range of DR events. If such a cloud-based control structure is wanted, Yaghmaee Moghaddam and Leon-Garcia [41] propose a IoT-based model for transactive energy management systems. As shown in Fig. 3, an IoT architecture collects real-time energy consumption data from homes and uses it to balance demand and reduce costs for customers. The architecture consists of three layers: An IoT layer to collect data from homes, an edge layer to pre-process and aggregate data before sending it to the cloud, and an application/cloud layer for permanent data storage, batch processing, and connection to the energy market. Communication between the layers is based on REST protocol and OpenADR, an open-source protocol for Automated Demand Response, is used for stable communication with flexible loads. The architecture provides faster response time to consumption variations and reduces processing capabilities in the cloud, while allowing for demand response applications.

While AMI is required to actually operate and execute demand response, advanced *control and optimization algorithms* are implemented to optimize the DR scheme [42]. Such specialized software and communication systems are used to monitor and manage demand response programs, ensuring that electricity usage is optimized during peak periods while minimizing disruption to consumers.

In this regard, literature provides many examples for predictive control and forecasts of demand respond schemes: For example, Pallonetto et al. [43], provide an overview on numerical models and available control algorithms for DR programs, and Amato et al. [44], introduces a Dual-zone economic model predictive control of residential space heating for demand response. According to Zhao and Magoulès [45], building energy models can be categorized in Detailed white box, Simplified white box, Reduced order, and Black box models [45]. Also, an algorithm for quantifying hourly DR potentials is described by Müller and Möst [46]. The authors express that DR can significantly smooth out fluctuations in the residual load which leads to a decrease in peak

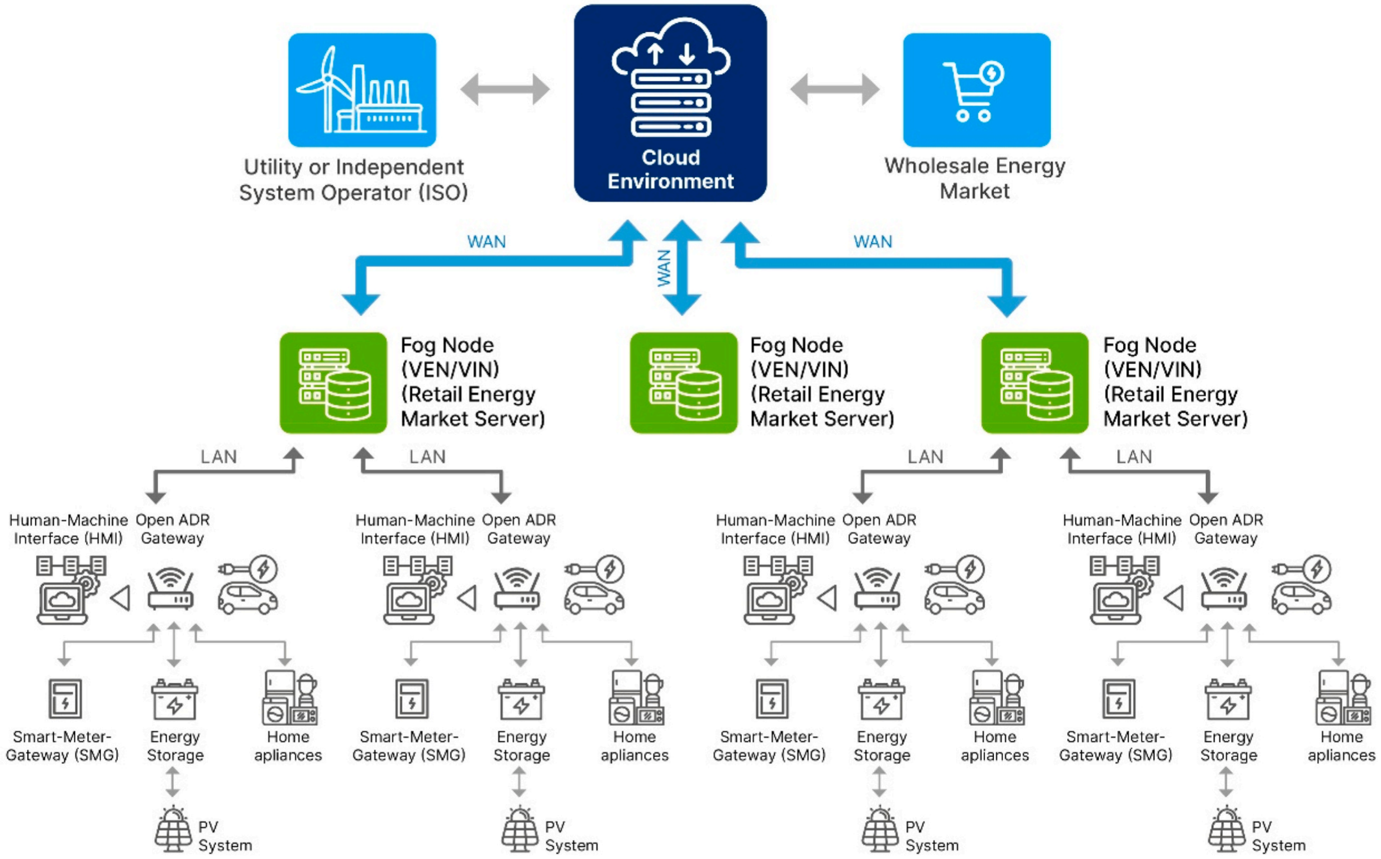

Fig. 3. Architecture of the application for transactive energy management [41].

demand and a higher utilization rate of RES. However, it is highlighted that DR is only able to balance short-term fluctuations rather than integrating large amounts of surplus renewable energy over extended periods due to its limited flexibility. To address this issue, additional flexibility options such as energy storage are necessary as they can offer greater flexibility than DR. Pallonetto et al. [42], show how an intelligent algorithm powered by machine-learning reduces costs related to electric heating by up to 43 % by integrating EV charging, PV power and TOU tariffs in an optimization model for a single commercial building.

Finally, the technological readiness is proven by use cases in other countries. While the majority is still provided by the industrial sector, such as the aggregated 733 MW in the asset pool of NEXT Kraftwerke, a VPP [47], there is also an increasing number of controllable loads within the residential and commercial sector. For example, the Swedish company FLOWER Infrastructure Technologies AB, a VPP, has an aggregated asset pool that also includes more than 6000 EV chargers to participate on the balancing markets [48]. EDF is managing more than twelve million electric hot water heaters and storage devices in France to mitigate peak loads of the power system [49]. However, although there are several approaches to also include smart appliances of the residential sector in Spain [43], no viable, operating businesses have been found during the elaboration of this manuscript.

4.2. Regulatory readiness level assessment

Assessing the RRL, Spanish regulation showed clear progress of following the European guidelines and integrating a functional DR scheme in its regulation. However, especially small loads are still excluded from the participation on various markets, resulting in an overall RRL of 7.

To assess the regulatory readiness level of DR in Spain, a thorough research and assessment of Spanish laws and regulations has been executed and listed below in chronological order (Table 2).

Summarized, it can be stated that Spain is working towards a more suitable regulatory framework for the implementation of DR in the electricity system. As stated by smartEn [60], a new capacity market proposal was being developed by the Spanish government, which has received feedback from the Spanish market regulator, the ‘Comisión Nacional de los Mercados y la Competencia’ (CNMC) and finally was set into use by publishing RDL 17/2022 [57]. The law focuses on generation assets, storage, and demand response, and includes a main tender with a five-year duration and secondary adjustment tenders lasting one year. While the participation requirements are technology-neutral, there are limitations for demand units, which must consume at least 51 % of their normal demand between 00:00 and 8:00.

However, this requirement excludes smaller demand units and contradicts the goal of using distributed resources during congestion periods. Additionally, RDL 17/2022 does only specify the framework for specific active Demand Response. Regular ancillary services, such as normal participation on daily balancing energy markets or supporting congestion management are still not possible for aggregated, small loads. Yet, as required by the European regulations 2019/994 and 2017/2195, Spain must include these options in their market framework, in the future. As per today, however, no specific date for the deployment of such law has been found during the elaboration of this assessment.

4.3. Market readiness level assessment (MRL)

Assessing the MRL of DR within the context of Spanish ECs, three aspects are considered: Market size and growth, competition, and market accessibility. Thereby, a significant difference between the implicit demand response (level 7) and explicit demand response (level 5)

Table 2

Overview of regulations impacting DR in Spanish ECs.

Title	Description	Ref.
Law 24/2013 of the Electricity Sector, modified by Royal Decree-Law 23/2020	• Encourages small consumer involvement in Demand Response while outlining the role of independent aggregators in combining electricity from diverse sources for trade within the electricity production market, aiming to improve efficiency and load curve management.	[50, 51]
Royal Decree 216/2014	• Establishes the methodology for calculating the PVPC, the voluntary prices for small consumers, of electrical energy and their legal contracting regime.	[52]
Royal Decree 244/2019	• Governs the administrative, technical, and economic aspects of self-consumption of electrical energy. • Permits the formation of Energy Communities comprising multiple self-consumers. These communities can collaboratively manage their energy demands and engage in the electricity market, including participating in Demand Response initiatives. • Introduces the concept of an aggregator for Energy Communities. This aggregator acts as an intermediary between the Energy Community and the electricity market, facilitating their involvement in various programs, including Demand Response initiatives.	[53]
Law July 2021	• Article 4 establishes INECP as a strategic tool aligning Spain's energy and climate policies with EU objectives for 2021–2030. • Further underscores the importance of Demand Response, integrating it into Spain's energy transition by prioritizing efficiency, renewable adoption, and consumer engagement within the energy market.	[54]
Resolution of December 11th, 2019, issued by the National Commission of Markets and Competition	• Aligns with EU Regulation 2017/2195 and outlines terms and conditions for Balance Service Providers (BSP) and Balance settlement Responsible Parties (BRP) within Spain's electrical system. • Defines rules for balancing imbalances in the electricity market and delineates responsibilities for balance responsible parties. • Establishes procedures for the settlement of imbalances, aiming to ensure a well-functioning Spanish electricity system with transparent and clear rules. • Subsequent Resolution on December 10th, 2020, to facilitate compliance with the established rules, ensuring the effective management of imbalances within the Spanish electrical system.	[55]
Resolution of December 10th, 2020, issued by the National Commission of Markets and Competition	• Defines key terms for market participants like BSP, BRP, enabling demand and storage participation in balancing services, and allowing contractual delegation of balancing responsibilities. Mainly: • OP 3.8 outlined tests for facilities to join the electrical system's managed services. • OP 7.2 automated secondary regulation for maintaining system frequency. • OP 7.3 to manage active power reserve balancing for system stability.	[56]
Royal Decree-Law 17/2022 – Annex II "Active Demand Response Service"	• Addresses scarcity situations of balancing reserves by acquiring additional resources beyond standard European balancing services. • Addresses the key aspect's objective and scope for balancing, introduction of definitions and operation mechanisms, and activation and settlement processes. • First demand response auction in October 2022, excluding small businesses and households due to a minimum capacity of 1 MW.	[57]
Plan + Energy Security	• bolsters energy efficiency in the public sector and households, while specifically targeting active Demand Response to improve flexibility and resilience within the energy system in response to the energy price crisis resulting from the conflict in Ukraine.	[58]
Royal Decree-Law 18/2022	• requires electricity suppliers to include average consumption data for consumers in the same area on bills up to 15 kW, fostering responsible energy use. • mandates energy-saving recommendations on bills, empowering consumers to manage demand effectively and reduce energy costs.	[59]

becomes clear.

4.3.1. *Market size and growth*

Several sources state a growing capacity and monetary demand for demand-side flexibility on a global, European, and Spanish national level. For instance, the IEA states that in the Net Zero Emissions scenario about 25 percent of the required flexibility will be met via DR and battery storage in 2030 [61]. In addition, they forecast that globally about 250 GW of DR capacity will be available from the building sector and another 50 GW from EVs in 2050, thus increasing by factor ten as per 2020 only around 25 GW were available from buildings and 0 GW from transport, respectively. Other sources state a global DR market of 70,6 billion USD in 2029 with a compound annual growth rate (CAGR) of 17.1 percent from 2022 [62], or a projected Growth Rate of 6.2 % until 2032 from 2022 [63]. The latter, Future Market Insights, also estimates the European share to be about 24.1 percent during the period. In conclusion, the sources differ in value but all state a significant growth for the market. Thus, as a next step, it is differentiated between implicit demand response and explicit demand response.

4.3.2. *Competition*

In Spain, despite limited adoption of demand response, several market actors, are developing products to capitalize on the growing DR market. A manifesto, supported by ten companies, emphasizes the importance of demand-side flexibility for a sustainable economic recovery and reduced energy costs [64]. The signatories advocate for a National Strategy for Demand Side Flexibility, urging government and regulators to incentivize flexibility management. While some companies focus on commercial and industrial loads, others, like Voltalis, offer advanced solutions for collective self-consumption [65], DR, and flexibility services, aligning with the Clean Energy Package for a comprehensive energy transition.

However, most of the associated companies of the manifesto are not explicitly targeting DR in the context of ECs. Rather, they seem to focus on commercial and industrial loads (sympower), the provision of forecasting, optimization, and trading algorithms to third party companies (bamboo energy) [64]. Others, such as Voltalis seem to offer more advanced solutions for collective self-consumption, DR, and other flexibility services [65].

4.3.3. *Market accessibility*

Regarding the MRL, it must be differentiated between implicit and explicit DR.

Concerning implicit DR in Spain, consumers have been encouraged to shift their electricity usage based on the retail price at a given time, through a voluntary, regulated, dynamic tariff called the Voluntary Price for Small Consumers, the '*precio voluntario para el pequeño consumidor*' (PVPC) [52]. Since June 2021, the PVPC separates the days into three consumption periods, the peak period, the flat period, and the valley period, thus linking hourly wholesale prices with retail tariffs, but covering only the energy component of the bill. Under this new, so-called 'PVPC 2.0 TD invoicing framework,' consumers now have the option to select two different contracted power capacity periods based on their energy usage. One period will apply during the valley period, while the other will be applied during the peak and flat periods. According to the REE, almost 40 % of eligible residential consumers were on the PVPC tariff as of 2022 [66]. In this regard, Spain differs from other European countries as it has implemented an opt-out scheme which sets that the selection of such time of use (TOU) tariff as the default option when choosing an electricity supplier. And hence, the TOU user share is significantly higher than in other countries.

In contrast to the implicit DR, however, Spain has a less developed explicit DR scheme than other large countries in Europe [61,62]. Thereby, this scheme is different from implicit demand response, which affects the demand curve, as explicit demand response represents a change in the supply curve. In theory, customers can flex their demand and sell it into the wholesale market in competition with offers from generators, in exchange for a financial reward. As stated before, aggregators usually manage this for smaller consumers who cannot participate directly in the market. An aggregator can be an independent entity or a supplier that uses demand-side flexibility to earn revenues in the market or minimize costs. For instance, the in 2022 newly implemented active demand response service is excluding smaller participants. Therefore, only sixteen participants with facilities consuming 1 MW or more took part in an online auction organized by Red Eléctrica. The service, which is regulated by current legislation in RDL 20/2022 [67] and 17/2022 [57], ensures continuity of supply during situations when there is a lack of balancing energy that can be activated manually in the system. However, this aspect is also likely to change with the introduction of the independent aggregator in Spain by mid-2023 [68].

Evaluating the market accessibility in the context of DR, some overlap with the RRL assessment exists. Specifically, however, Spain's active demand response service, governed by RDL 20/2022 [67] and 17/2022 [57], had limited participation in 2022, with just sixteen facilities (1 MW or more) joining Red Eléctrica's online auction. This service, vital for power supply continuity during energy imbalances, is a key component of the government's Plan + Seguridad Energética. Despite efforts to involve demand-side services, regulatory changes favour larger loads, setting higher market response levels. As stated in the RRL, the industrial sector, driven by high energy consumption and potential savings, embraced demand response technology. However, recent regulatory shifts restricted participation in balancing markets; new measures are expected by mid-2023.

On the other hand, the MRL of DR technology for small consumers is low. There is still limited awareness and understanding of demand response among small consumers, which has resulted in a lack of demand for these programs. However, the government is taking steps to address this issue by promoting demand response programs to small consumers through education campaigns and other initiatives. So, it is shown in ENTSO-E's report on prequalification requirements for providing balancing services, that especially for small (aggregated) units there are still either high barriers or it is not possible at all to participate in the market [69].

4.4. *Acceptance readiness level assessment (ARL)*

To assess the ARL of demand response, literature research allows to highlight the most relevant motivators, incentives, and factors for increasing the willingness to participate in DR schemes. In summary, they lead to an ARL of 7.

4.4.1. *Implicit demand response*

Muratori and Rizzoni proposed a decentralized dynamic energy management framework for optimizing the scheduling of residential appliances, including in-home charging of electric vehicles, using dynamic programming to minimize a cost function [70]. The proposed framework allows for implicit and explicit demand response. Implicit DR is achieved through the optimization of individual household energy usage, which could lead to peak demand reduction and improve integration of renewable resources. This framework could be integrated into the management of Energy Communities, which could potentially provide even greater benefits for energy management and optimization.

The decentralized dynamic energy management framework proposed by Muratori and Rizzoni provides a tool for studying energy policy solutions and developing effective residential demand response programs [70]. This indicates that the implicit DR technology has a high ARL and can be accepted for implementation. The integration of this framework into an Energy Community management service provides a powerful tool for achieving more sustainable and efficient energy management.

4.4.2. *Explicit demand response*

Nilsson et al. [71], conducted a field experiment involving 117 households in Sweden to examine the effectiveness of demand response strategies in reducing residential electricity consumption during peak periods. The study found that all three demand response strategies, namely critical peak pricing, peak time rebate, and the combination of these two were effective in reducing peak electricity consumption, with the combination strategy being the most effective. The study indicates that explicit DR technology has a high ARL and can be accepted for implementation. It is evident that demand response strategies, such as critical peak pricing or peak time rebate, can reduce peak electricity consumption, making it effective in demand management.

4.4.3. *Implicit and explicit demand response*

Sridhar et al. [72], analysed the motivators of residential consumers to participate in direct load control DR. The study identified three distinct consumer groups: adopters, followers, and neutral, with different motivators for enrolling in direct load control DR programs. Adopters are more interested in technology and prefer smart home automation, while followers prefer local generation and are influenced by contacts. Neutral consumers do not have a specific preference. Age group 60+ preferred home automation, men preferred home automation over financial and environmental gains, women preferred environmental gains over financial gains, and those with higher education preferred environmental gains over financial gains.

Avau et al. [73], presented a case study that analysed the impact of different distribution tariff structures on prosumers with photovoltaic (PV) panels, a heat pump (HP), and a battery. The study found that the distribution tariff type impacts the operation of distributed energy resources and the cost of energy.

The studies by Sridhar et al. [72], and Avau et al. [73], suggest that both implicit and explicit DR technologies have a high ARL and can be accepted for implementation. However, the findings suggest that demand response programs need to be tailored according to different consumer groups' preferences, and the integration of DR technology into an Energy Community management service could provide even greater benefits for energy management and optimization.

Although the studies reported in literature propose a rather high ARL of DR technology, some limitations remain. The authors are agreeing that residential consumers may be hesitant to participate in DR programs due to concerns about inconvenience, discomfort, or unpredictability. However, by incorporating uncertainty into bidding models, aggregators can better account for the risks and benefits of DR participation and make more accurate bidding decisions. This can then ultimately lead to more efficient use of energy resources and lower electricity costs for both the aggregator and the consumers. In addition, the importance of considering the perspective of both the aggregator and the residential consumers when designing DR programs is often highlighted, as it can help increase the likelihood of consumer acceptance and participation.

As a result, most studies suggest that the key to successful implementation of DR technology is to ensure that it is user-friendly, convenient, and does not compromise the comfort or convenience of households. The authors propose a user-friendly interface that allows homeowners to adjust their energy consumption according to their comfort preferences. This approach ensures that households remain comfortable while contributing to the overall energy flexibility of the grid. The studies further highlight the importance of engaging and compensating consumers in the design and implementation of DR programs to increase acceptance and adoption. By involving households in the process and providing them with user-friendly tools and interfaces, DR technology can be implemented successfully without compromising household comfort or convenience.

As stated before, however, this literature review can only be seen as a guideline for the ARL of DR technology in Spain. As no surveys have been found in the elaboration of this assessment, it cannot be stated with certainty that Spanish consumers feel and behave similarly.

4.5. *Organizational readiness level assessment (ORL)*

Assessing ORL for DR technology requires evaluating the company's capabilities, resources, and culture to adopt and implement DR technology successfully. Thus, this section's objective is to motivate companies and institutions to investigate the points mentioned below when aiming for the implementation of new DR schemes or business models in Spain.

Leadership commitment: The company's leadership should demonstrate a commitment to DR technology adoption by allocating resources and providing support.

Internal capabilities: The company's technical and operational capabilities must be sufficient to support DR technology deployment. This includes IT infrastructure, data management, and analytics capabilities.

Regulatory environment: Regulatory policies and standards play a crucial role in DR technology adoption. The company must be aware of the regulatory requirements and standards related to DR.

Financial resources: Adopting DR technology requires significant investment, and the company must have the financial resources to support the adoption.

Implicit DR is automatic and does not require customer involvement. Explicit DR requires customer participation and action to reduce energy consumption during peak periods. Skills and resources required to develop a product based on DR include expertise in software development, data management, energy management, and customer engagement. Technical developments needed for DR technology adoption include advanced analytics, machine learning, cloud computing, and real-time data processing.

Companies can internalize some DR technology development and deployment tasks, while others can be outsourced. Internalizing tasks such as product design and development, energy management, and customer engagement can be beneficial to the company. Outsourcing tasks such as IT infrastructure, data management, and analytics can reduce costs and increase efficiency. The associated costs of adopting DR technology depend on several factors, such as the size of the company, the complexity of the DR program, and the level of automation. Costs associated with DR technology adoption can include hardware and software costs, consulting fees, training costs, and ongoing maintenance costs. However, the benefits of DR technology adoption, such as reduced energy costs and improved energy efficiency, can outweigh the costs in the long term.

Finally, a summary of the implementation of the BRL framework on the integration of Demand Response is collected in Table 3.

Table 3
BRL for Spanish Energy Communities summary.

Dimension	RL	Description	Reasoning
TRL	9	Actual system proven functional in natural environment	• Technological requirements are fulfilled and working in other countries. • Most important components, controllable loads, AMI, control, and optimization algorithms are existing. • Communication protocols REST and OpenADR are specified. • Completed smart-meter roll-out in Spain. • Examples: FLOWER in Sweden, EDF in France
RRL	7	Necessary approvals for use are 'just around the corner'	• European framework stands and forces Spain to integrate it in national law. • PVPC enables implicit DR. • Explicit DR is already possible for industrial loads. • Participation for smaller loads in balancing markets not yet possible
MRL	5 (EDR) 7 (IDR)	Business Model(s) described/Customers confirm progress or improvement	• DR Market is large and growing. • Implicit DR is widely adopted in European comparison. • Explicit DR is only moderately developed, due to regulatory limitations
ARL	7	The technology is partially seen as controversial	• Implicit DR in Spain receives one of the highest acceptance rates within the EU (PVPC) • Research on the acceptance of explicit DR in other countries shows that if a bilateral development of a product evolves, the acceptance is high
ORL	?	The assessment of the ORL is required to be individually conducted per company.	Specific assessment required of: • Leadership commitment • Internal capabilities • Future observation of regulatory environment • Financial resources

5. Discussion

Assessing the readiness levels of Demand Response (DR) in Spain reveals both progress and persistent challenges across regulatory, market, acceptance, and organizational dimensions, while it scores perfectly technologically.

The Regulatory Readiness Level (RRL) is at 7, indicating alignment with European guidelines through laws such as Law 24/2013 and Royal Decree 244/2019. However, bottlenecks remain, particularly the exclusion of smaller loads due to a 1 MW minimum capacity requirement in Royal Decree-Law 17/2022, limiting broader market participation and integration of distributed resources.

The Market Readiness Level (MRL) for implicit DR is also 7, supported by the 'precio voluntario para el pequeño consumidor' (PVPC) dynamic tariff. Nonetheless, limited consumer awareness and understanding hinder broader adoption. Explicit DR scores a lower MRL of 5, constrained by an underdeveloped market infrastructure and stringent prequalification requirements that restrict participation to larger consumers.

The Acceptance Readiness Level (ARL) is similarly rated at 7, with studies demonstrating effective DR strategies and potential integration within Energy Communities. Yet, concerns about consumer inconvenience and discomfort highlight the need for user-friendly interfaces and engagement strategies. Without specific surveys on Spanish consumers, these insights serve as guidelines rather than definitive conclusions.

The Organizational Readiness Level (ORL) is to be determined by each company individually. Yet, the proposed guideline allows institutions to do so efficiently by emphasizing the necessity for leadership commitment, strong internal capabilities, compliance with regulatory standards, and sufficient financial resources. It is shown that companies need expertise in software development, energy management, and customer engagement, with a mix of internalizing and outsourcing tasks to enhance efficiency. Despite initial costs, the long-term benefits of DR adoption include reduced energy costs and improved efficiency, making it a viable strategy for energy management in Spain.

6. Conclusion

The balanced readiness level assessment of demand response technology for Spanish Energy Communities shows an overall BRL score of 7.25, with the ORL to be evaluated individually by interested organizations. Although Energy Communities in Spain have only slowly emerged in comparison to other European countries, recent regulatory changes have contributed to accelerated growth and significant business and climate mitigation potentials. In addition, DR is at the threshold of entering the large-scale market if some last barriers are removed. While relevant technological aspects are proven to be ready for use and the acceptance, market and regulatory framework for implicit demand response are established and accepted by society, explicit demand response still faces regulatory and acceptance issues. Thus, to exploit the flexibility potentials of explicit DR, suitable regulation for the aggregation and participation of small loads on energy and flexibility markets in Spain are required. Likewise, companies that aim at bringing the growing flexibility potential of Spanish Energy Communities to market must ensure that business models sufficiently remunerate and emotionally involve consumers.

The novel application of the BRL assessment methodology to a technology within the energy sector strongly underscores the importance of evaluating the readiness of energy technologies from a multi-dimensional perspective. The analysis indicates that only by considering all dimensions can emerging technologies, such as DR, be successfully and widely implemented.

In the future, the authors recommend to continuously monitoring the advancements of DR technology across all BRL dimensions. Additionally, they postulate that the application of the BRL assessment methodology can significantly contribute to the development of other technologies and advocate for this multi-dimensional approach in future applications.

CRediT authorship contribution statement

Philipp Eisele: Conceptualization, Methodology, Formal analysis, Visualization, Writing – review & editing. **Filipa Alexandra Na Carrilho:** Data curation, Methodology, Writing – original draft. **Divya Bojja:** Resources, Methodology, Writing – original draft. **Pedro Pelote:** Investigation, Methodology, Writing – original draft. **César Valderrama:** Supervision, Writing – review & editing.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Data availability

Data will be made available on request.

Acknowledgements

We would like to acknowledge the Catalan Government for the project 2021-SGR-GRC- 00596. Additionally, the authors acknowledge the Open Innovation – Research Translation and Applied Knowledge Exchange in Practice through University-Industry- Cooperation (OpenInnoTrain), Grant agreement number (GAN): 823971, H2020-MSCA-RISE-2018-823971. Finally, authors thanks to Peter Hagström from KTH and Bilal Fares from UPC for their valuable support and guidance.

References

[1] European Commission, 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. https://eur-lex.europa.eu/legal-content/EN/TXT/HTML/?uri=CELEX:32018L2001&from=EN, 2018. (Accessed 3 December 2022).

[2] European Commission, 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, 2019.

[3] J. Lowitzsch, C.E. Hoicka, F.J. van Tulder, Renewable energy communities under the 2019 European Clean Energy Package – governance model for the energy clusters of the future? Renew. Sustain. Energy Rev. 122 (Apr. 2020) 109489 https://doi.org/10.1016/J.RSER.2019.109489.

[4] In focus: energy communities to transform the EU's energy system. https://energy.ec.europa.eu/news/focus-energy-communities-transform-eus-energy-system-2022-12-13_en. (Accessed 12 November 2023).

[5] P. O. of the E. Union, Regulatory Priorities for Enabling Demand Side Flexibility, Dec. 2020, https://doi.org/10.2833/410530.

[6] European Commission, 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, 2019.

[7] European Union, COMMISSION REGULATION (EU) 2017/2195 of 23 November 2017 establishing a guideline on electricity balancing. https://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:32017R2195&from=EN, 2017. (Accessed 6 December 2022).

[8] Boletín Oficial del Estado, Reglamento (UE) 2022/1854 del Consejo de 6 de octubre de 2022 relativo a una intervención de emergencia para hacer frente a los elevados precios de la energía. https://www.boe.es/buscar/doc.php?id=DOUE-M-2022-81456, 2022. (Accessed 25 April 2023).

[9] L. Van Nuffel, J. Yearwood, The potential of electricity demand response. https://www.europarl.europa.eu/RegData/etudes/STUD/2017/607322/IPOL_STU(201)607322_EN.pdf, 2017. (Accessed 22 April 2023).

[10] M. Koltunov, et al., Mapping of energy communities in Europe: status quo and review of existing classifications, Sustainability 15 (10) (May 2023) 8201, https://doi.org/10.3390/su15108201.

[11] L. Losada-Puente, et al., Cross-case analysis of the energy communities in Spain, Italy, and Greece: progress, barriers, and the road ahead, Sustainability 15 (2023) 14016, https://doi.org/10.3390/SU151814016 vol. 15, no. 18, p. 14016, Sep. 2023.

[12] Comunidades energéticas - senda. https://www.senda.green/. (Accessed 30 March 2023).

[13] QUIXOTIC 360 - Plataforma para Comercializadoras Energéticas. https://www.quixotic360.com/. (Accessed 30 March 2023).

[14] FlexiDAO | renewable energy monitoring software. https://www.flexidao.com/. (Accessed 30 March 2023).
[15] RESpring | renewable energy monitoring software | FlexiDAO. https://www.flexidao.com/respring. (Accessed 30 March 2023).
[16] Stemy energy. https://www.stemyenergy.com/. (Accessed 30 March 2023).
[17] Elecsum – apps on google play. https://play.google.com/store/apps/details?id=com.elecsum.app&hl=en_IE&gl=US&pli=1. (Accessed 30 March 2023).
[18] Ampere energy | communities. https://ampere-energy.es/es-es/solutions/communities. (Accessed 30 March 2023).
[19] AMPERE ENERGY, SEMS one. https://ampere-energy.es/es-en/our_systems/sems_one. (Accessed 30 March 2023).
[20] NNERGIX | advanced analytics for renewable energies | barcelona. https://www.nnergix.com/. (Accessed 30 March 2023).
[21] Platform - bamboo energy. https://bambooenergy.tech/en/platform/. (Accessed 1 November 2023).
[22] About - bamboo energy. https://bambooenergy.tech/en/about/. (Accessed 1 November 2023).
[23] Home. https://www.energy-pool.eu/en/. (Accessed 1 November 2023).
[24] Services for electricity end-users. https://www.energy-pool.eu/en/end-users/. (Accessed 1 November 2023).
[25] Energy management: global asset, cost & market optimisation. https://www.energy-pool.eu/en/energy-management-and-cost-optimisation-software-energy-pool/. (Accessed 1 November 2023).
[26] Plug:Chain – ARCbcn. https://arcbcn.cat/en/plugchain/. (Accessed 2 November 2023).
[27] IRENA, DEMAND-SIDE FLEXIBILITY for POWER SECTOR TRANSFORMATION - Analytical Brief, 2019.
[28] T. Freire-Barceló, F. Martín-Martínez, Á. Sánchez-Miralles, A literature review of Explicit Demand Flexibility providing energy services, Elec. Power Syst. Res. 209 (Aug. 2022) 107953, https://doi.org/10.1016/j.epsr.2022.107953.
[29] J. Vik, A.M. Melås, E.P. Stræte, R.A. Søraa, Balanced readiness level assessment (BRLa): a tool for exploring new and emerging technologies, Technol. Forecast. Soc. Change 169 (Aug. 2021) 120854, https://doi.org/10.1016/j.techfore.2021.120854.
[30] T. Crosbie, J. Broderick, M. Short, R. Charlesworth, M. Dawood, Demand response technology readiness levels for energy management in blocks of buildings, Buildings 8 (2) (Jan. 2018) 13, https://doi.org/10.3390/buildings8020013.
[31] S. Nolan, M. O'Malley, Challenges and barriers to demand response deployment and evaluation, Appl. Energy 152 (Aug. 2015) 1–10, https://doi.org/10.1016/j.apenergy.2015.04.083.
[32] I. Ruostetsaari, From consumers to energy citizens: Finns' readiness for demand response and prosumerism in energy policy making, Int. J. Energy Sect. Manag. 14 (6) (Apr. 2020) 1157–1175, https://doi.org/10.1108/IJESM-11-2019-0001.
[33] M. Radenković, Z. Bogdanović, M. Despotović-Zrakić, A. Labus, S. Lazarević, Assessing consumer readiness for participation in IoT-based demand response business models, Technol. Forecast. Soc. Change 150 (Jan. 2020) 119715, https://doi.org/10.1016/J.TECHFORE.2019.119715.
[34] T. Freire-Barceló, F. Martín-Martínez, Á. Sánchez-Miralles, A literature review of Explicit Demand Flexibility providing energy services, Elec. Power Syst. Res. 209 (Aug. 2022) 107953, https://doi.org/10.1016/J.EPSR.2022.107953.
[35] T. Crosbie, J. Broderick, M. Short, R. Charlesworth, M. Dawood, Demand response technology readiness levels for energy management in blocks of buildings, Buildings 8 (2018) 13, https://doi.org/10.3390/BUILDINGS8020013, vol. 8, no. 2, p. 13, Jan. 2018.
[36] S. Nolan, M. O'Malley, Challenges and barriers to demand response deployment and evaluation, Appl. Energy 152 (Aug. 2015) 1–10, https://doi.org/10.1016/J.APENERGY.2015.04.083.
[37] A. Conchado, P. Linares, O. Lago, A. Santamaría, An estimation of the economic and environmental benefits of a demand-response electricity program for Spain, Sustain. Prod. Consum. 8 (Oct. 2016) 108–119, https://doi.org/10.1016/J.SPC.2016.09.004.
[38] P. Siano, Demand response and smart grids—a survey, Renew. Sustain. Energy Rev. 30 (Feb. 2014) 461–478, https://doi.org/10.1016/j.rser.2013.10.022.
[39] L. Suárez-Ramón, J.M. Carou-Álvarez, Advance metering infrastructure in smart grids, in: Encyclopedia of Electrical and Electronic Power Engineering, Elsevier, 2023, pp. 327–333, https://doi.org/10.1016/B978-0-12-821204-2.00013-1.
[40] M.H. Yaghmaee, A. Leon-Garcia, M. Moghaddassian, On the performance of distributed and cloud-based demand response in smart grid, IEEE Trans. Smart Grid 9 (5) (Sep. 2018) 5403–5417, https://doi.org/10.1109/TSG.2017.2688486.
[41] M.H. Yaghmaee Moghaddam, A. Leon-Garcia, A fog-based internet of energy architecture for transactive energy management systems, IEEE Internet Things J. 5 (2) (Apr. 2018) 1055–1069, https://doi.org/10.1109/JIOT.2018.2805899.
[42] F. Pallonetto, M. De Rosa, D.P. Finn, Impact of intelligent control algorithms on demand response flexibility and thermal comfort in a smart grid ready residential building, Smart Energy 2 (May 2021) 100017, https://doi.org/10.1016/j.segy.2021.100017.
[43] F. Pallonetto, M. De Rosa, F. D'Ettorre, D.P. Finn, On the assessment and control optimisation of demand response programs in residential buildings, Renew. Sustain. Energy Rev. 127 (Jul. 2020) 109861, https://doi.org/10.1016/j.rser.2020.109861.
[44] V. Amato, M.D. Knudsen, S. Petersen, Dual-zone economic model predictive control of residential space heating for demand response using a single heat meter, Energy Build. 281 (Feb. 2023) 112759, https://doi.org/10.1016/j.enbuild.2022.112759.
[45] H. Zhao, F. Magoulès, A review on the prediction of building energy consumption, Renew. Sustain. Energy Rev. 16 (6) (Aug. 2012) 3586–3592, https://doi.org/10.1016/j.rser.2012.02.049.
[46] T. Müller, D. Möst, Demand response potential: available when needed? Energy Pol. 115 (Apr. 2018) 181–198, https://doi.org/10.1016/j.enpol.2017.12.025.
[47] NEXT Kraftwerke, Power scheduling. https://www.next-kraftwerke.com/products/power-scheduling. (Accessed 30 March 2023).
[48] FLOWER, EV charging. https://www.flowertech.se/ev-charging. (Accessed 30 March 2023).
[49] Hinchliffe Prestat, Radvanyi, Lancel, Edf experience in developing ANDOPERATING energy storage in T&D grids, in: CIGRE GCC, Oct. 2017. Oman.
[50] Boletin Oficial del Estado, Royal Decree-Law 23/2020, of June 23, which approves measures in the field of energy and in other areas for economic reactivation. https://www.boe.es/eli/es/rdl/2020/06/23/23, 2020. (Accessed 4 December 2022).
[51] S.O. Gazette, BOE. Real Decreto-ley 23/2020, de 23 de junio, por el que se aprueban medidas en materia de energía y en otros ámbitos para la reactivación económica, 2020.
[52] Boletín Oficial del Estado, Real Decreto 216/2014, de 28 de marzo, por el que se establece la metodología de cálculo de los precios voluntarios para el pequeño consumidor de energía eléctrica y su régimen jurídico de contratación, 2014.
[53] Boletin Oficial del Estado, Real Decreto 244/2019, de 5 de abril, por el que se regulan las condiciones administrativas, técnicas y económicas del autoconsumo de energía eléctrica. https://www.boe.es/eli/es/rd/2019/04/05/244, 2019. (Accessed 4 December 2022).
[54] Boletín Oficial del Estado, Ley 7/2021, de 20 de mayo, de cambio climático y transición energética. https://www.boe.es/eli/es/l/2021/05/20/7/con, 2021. (Accessed 25 April 2023).
[55] Boletín Oficial del Estado, Resolución de 11 de diciembre de 2019, de la Comisión Nacional de los Mercados y la Competencia, por la que se aprueban las condiciones relativas al balance para los proveedores de servicios de balance y los sujetos de liquidación responsables del balance en el sistema eléctrico peninsular español. https://www.boe.es/eli/es/res/2019/12/11/(7, 2019. (Accessed 25 April 2023).
[56] Boletín Oficial del Estado, Resolución de 10 de diciembre de 2020, de la Comisión Nacional de los Mercados y la Competencia, por la que se aprueba la adaptación de los procedimientos de operación del sistema a las condiciones relativas al balance aprobadas por Resolución de 11 de diciembre de 2019. https://www.boe.es/diario_boe/txt.php?id=BOE-A-2020-16964. (Accessed 25 April 2023).
[57] Boletín Oficial del Estado, Real Decreto-ley 17/2022, de 20 de septiembre, por el que se adoptan medidas urgentes en el ámbito de la energía, en la aplicación del régimen retributivo a las instalaciones de cogeneración y se reduce temporalmente el tipo del Impuesto sobre el Valor Añadido aplicable a las entregas, importaciones y adquisiciones intracomunitarias de determinados combustibles. https://www.boe.es/eli/es/rdl/2022/09/20/17/con, 2022. (Accessed 25 April 2023).
[58] Govierno de Espana, Plan +Seguridad energetica. https://www.miteco.gob.es/es/ministerio/planes-estrategias/seguridad-energetica/221011_planse_octubre2022_tcm30-546389.pdf, 2022. (Accessed 4 December 2022).
[59] Boletín Oficial del Estado. Boletín Oficial del Estado, Real Decreto-ley 18/2022, de 18 de octubre, Article 9, por el que se aprueban medidas de refuerzo de la protección de los consumidores de energía y de contribución a la reducción del consumo de gas natural en aplicación del "Plan + seguridad para tu energía (+SE)", así como medidas en materia de retribuciones del personal al servicio del sector público y de protección de las personas trabajadoras agrarias eventuales afectadas por la sequía, 2022 [Online]. Available, https://www.boe.es/eli/es/rdl/2022/10/18/18/con. (Accessed 4 December 2022).
[60] A. Pinto-Bello, The smartEn Map - Resource Adequacy Mechanisms, 2022.
[61] IEA, Demand response - technology deep dive. https://www.iea.org/reports/demand-response, 2022. (Accessed 23 April 2023).
[62] Industry Research, Global smart demand response market forecast: analysis of industry trends and opportunities | 2023-2030. https://www.industryresearch.co/global-smart-demand-response-market-23480711, 2023. (Accessed 23 April 2023).
[63] Future Market Insights, Demand response market. https://www.futuremarketinsights.com/reports/demand-response-market, 2022. (Accessed 23 April 2023).
[64] sympower, Manifesto for the development of demand side flexibility in Spain. https://sympower.net/manifest-for-the-development-of-demand-side-flexibility-in-spain/. (Accessed 25 April 2023).
[65] Voltalis, Voltalis solutions. https://group.voltalis.com/en/solutions. (Accessed 25 April 2023).
[66] red eléctrica, Voluntary price for the small consumer (PVPC). https://www.ree.es/en/activities/operation-of-the-electricity-systemvoluntary-price-small-consumer-pvpc. (Accessed 23 April 2023).
[67] Boletín Oficial del Estado, Real Decreto-Ley 20/2022, de 27 de diciembre, de medidas de respuesta a las consecuencias económicas y sociales de la guerra de Ucrania y de apoyo a la reconstrucción de la isla de La Palma y a otras situaciones de vulnerabilidad. https://www.boe.es/buscar/act.php?id=BOE-A-2022-22685, 2022. (Accessed 23 April 2023).
[68] ENTSO-E, ENTSO-E Balancing report 2022. https://ee-public-nc-downloads.azureedge.net/strapi-test-assets/strapi-assets/2022_ENTSO_E_Balancing_Report_Web_2bddb9ad4f.pdf, 2023. (Accessed 23 April 2023).
[69] ACER, Wholesale electricity market monitoring 2021 - prequalification processes for the provision of balancing services. https://www.acer.europa.eu/Publications/ACER_Prequalification_BAL_Services.pdf, 2022. (Accessed 23 April 2023).
[70] M. Muratori, G. Rizzoni, Residential demand response: dynamic energy management and time-varying electricity pricing, IEEE Trans. Power Syst. 31 (2) (Mar. 2016) 1108–1117, https://doi.org/10.1109/TPWRS.2015.2414880.
[71] A. Nilsson, D. Lazarevic, N. Brandt, O. Kordas, Household responsiveness to residential demand response strategies: results and policy implications from a

Swedish field study, Energy Pol. 122 (Nov. 2018) 273–286, https://doi.org/10.1016/j.enpol.2018.07.044.

[72] A. Sridhar, et al., Residential consumer preferences to demand response: analysis of different motivators to enroll in direct load control demand response, Energy Pol. 173 (Feb. 2023) 113420, https://doi.org/10.1016/j.enpol.2023.113420.

[73] M. Avau, N. Govaerts, E. Delarue, Impact of distribution tariffs on prosumer demand response, Energy Pol. 151 (Apr. 2021) 112116, https://doi.org/10.1016/j.enpol.2020.112116.