Clean Technologies and Environmental Policy (2023) 25:2353–2366
https://doi.org/10.1007/s10098-023-02510-6

ORIGINAL PAPER

Adapting to energy storage needs: gaps and challenges arising from the European directive for the electricity internal market

Constantinos Papouis[1] · Angeliki Kylili[1] · Paris A. Fokaides[1,2]

Received: 22 November 2022 / Accepted: 17 March 2023 / Published online: 28 March 2023

Abstract
The increasing integration of renewable energy sources into the electricity sector for decarbonization purposes necessitates effective energy storage facilities, which can separate energy supply and demand. Battery Energy Storage Systems (BESS) provide a practical solution to enhance the security, flexibility, and reliability of electricity supply, and thus, will be key players in future energy markets. Directive 2019/944, which focuses on common rules for the internal market of electricity, provides a regulatory framework for the deployment of energy storage facilities. However, several gaps and challenges remain regarding the implementation of the directive, particularly in insular energy systems with immature storage infrastructures such as Cyprus, an EU Member State. This study examines these challenges and gaps by investigating the case study of Cyprus while also presenting the handling of energy storage in other European countries such as Germany and Poland. The primary aim of this study is to identify gaps in the legislation regarding energy storage and potential bottlenecks or monopolistic approaches that could hinder the widespread deployment of BESS under the liberalization of the energy market. In light of several BESS technologies available in the market, the study focuses on lithium-based technologies, which account for the largest share of the BESS market and are projected to grow at the highest compound annual growth rate by 2030. Therefore, the authors concentrate on Lithium BESS. The study highlights the crucial role of storage facilities in transforming the power generation sector by shifting toward renewable sources of energy. As such, the study emphasizes the importance of effective regulatory frameworks in enabling the deployment of BESS, particularly in insular energy systems. Overall, this study sheds light on the gaps and challenges facing the deployment of BESS, providing valuable insights for policymakers and stakeholders to design effective regulatory frameworks to facilitate the widespread adoption of BESS.

Keywords Energy storage · Battery energy storage system · Electricity internal market · European Union · Transmission system operator · Distribution system operator

Introduction

As the share of renewable energy sources, in the energy mix of the EU Member States (MS) in general, will continue to grow in the coming decades, Battery Energy Storage Systems (BESS) can offer a cost-effective solution that will enhance the security, reliability and flexibility of electricity supply. This increasing demand for renewable sources of energy, mainly driven by decarbonisation targets and the smart cities outlook of the European Union, in conjunction with advancements in battery storage technologies has made BESS a very attractive solution for the successful fulfilment of these environmental targets (Barik et al. 2022). The inherent limitation of power production via renewable sources of energy, namely wind and solar energy is that the periods of peak production are not matched by periods of peak demand. With the introduction of BESS, energy produced during the periods of peak production, can be stored and used during the periods of peak demand, in central, decentralized or off-grid applications. Fokaides et al. (2020a, b). As electricity prices rise, the need for diversification of energy sources, particularly for residential consumers, becomes increasingly pressing. Oprea and Bâra, (2023) Due to the great diversification of electricity markets to meet the requirements of modern power systems, determining the financially optimal

✉ Paris A. Fokaides
eng.fp@frederick.ac.cy

[1] School of Engineering, Frederick University, Nicosia, Cyprus

[2] Faculty of Civil Engineering and Architecture, Kaunas University of Technology, Kaunas, Lithuania

transaction structure as a producer has become difficult. Oprea et al. (2020)

The European Commission, in line with its energy and climate targets, seeks to facilitate the introduction of energy storage facilities in the European energy markets. The European Directive 2019/944 establishes common rules for the generation, transmission, distribution, energy storage and supply of electricity, and consumer protection provisions, with the purpose of creating truly integrated competitive, consumer-centered, flexible, fair and transparent electricity markets in the Union (European Commission 2019).

Given this background, this study aims to shed light on the essential legislative elements relevant to energy storage, which need to be introduced in EU MS energy markets legislation in order to satisfy the provision of the European Directive. The scope of this study is the analysis of the Electricity Market Rules of the Republic of Cyprus, an EU MS with premature facilities for energy storage and insular energy system (Cyprus Distribution System Operator (DSO), 2020) regarding the necessary provisions related to energy storage facilities as stated in European Directive 2019/944 for the identification of gaps in the national energy storage legislation, as well as the time horizon for the transposition of the legislation. The findings of this report will work as a tool for the policy- makers and significant key players of the Cypriot electricity market, to understand the importance of BESS, but foremost to make it as easily accessible to all interested parties in a free market.

The analyses in this report are framed by several research questions. Particularly the study aims to address the benefits and costs of introducing Battery Energy Storage Systems (BESS) in the National Electricity Market as well as to analyze the related costs and charges of energy storage facilities. This study also aspires to provide justified responses related to the analysis of the European and National Legislation Regarding Energy Storage Facilities, based on the provisions of the European Directive 2019/944 for energy storage owners and energy storage facilities. The study also attempts to compare the Energy Storage Implementation in European Countries, giving special emphasis on the current version (2.2.0) of the Electricity Market Rules of the Republic of Cyprus and the rightful transposition of the European directive. The study aims to shed light to the gaps and discrepancies identified in the proposed national and European legislation in relevance to energy storage.

In order to address these questions, the European policy and the proposed policy in Cyprus were analyzed. In particular, this report compares the Consolidated Version 2.2.0 of the Electricity Market Rules (Cyprus Distribution System Operator (DSO), 2020) focusing on energy storage facilities with the European Directive 2019/944 and also presents what prevails in other mature markets, including Germany and Poland and how these countries have dealt with the topic of introducing energy storage facilities into their energy market. A cross-matching exercise between the provisions of the European legislation and the proposed national legislation has led to the identification of the gaps and discrepancies in the elements of the proposed national electricity market rules in relevance to energy storage.

Materials and methods

The methodology of this study was based on field research, consisting mainly of literature review, as well as on the analysis of relevant legislative documents, for the extraction of the required conclusions, elaborated in the study. Personal interviews were also conducted with competent officers. Particularly with regard to the definition of the benefits of BESS in electricity markets, as well as for assessing the cost of energy storage facilities, a total of 143 studies were reviewed and analyzed, of which 42 are cited in the end version of the study. The studies were retrieved from Scopus, an abstract and citation database. The search criteria were limited to specific terms, as well as journals and years, in order to capture the most relevant references.

With regard to the interpretation of the analyzed legislative documents, information from the web portal of the European Commission, as well as of the Republic of Cyprus were conducted. Specifically, for the latter case, and for confirming the defined gaps in the legislative framework, personal interviews with competent officers were also conducted, to confirm the identified gaps. The study was also presented to competent officers of the Ministry of Energy, Commerce and Industry of the Republic of Cyprus, the competent authority for the transposition of the European Acquis in the field of Energy, and relevant feedback and suggestions were also considered (Fig. 1).

Fig. 1 Study methodological approach

Theoretical background

Battery energy storage systems (BESS)

The fastest growing battery technology is lithium-ion (Li-ion) batteries, which refers to the material of the cathode. Lithium-ion batteries are part of the Lithium-based battery family as presented in Fig. 2.

A typical power range for Li-ion batteries is between 1 kW – 100 MW and a typical energy range < 200MWh. The growing popularity of Li-ion batteries is based on the numerus advantages they offer, which include among others long service life combined with compact and maintenance-free design. In addition, Li-ion batteries offer high energy efficiency and operation at a state of low charge (IRENA 2017). More importantly, Li-ion batteries allow the design of flexible storage systems as they are scalable and can easily satisfy any voltage, power and energy demand. This technology is ideal for smart applications where accurate management and control of energy storage is required, however this comes at the cost of more complex control electronics. Chen et al. (2020). The popularity of Li-ion technology is expected to increase even further as current research on the field is expected to increase the available energy density and service life while the overall price of batteries is expected to drop significantly as a result of economies of scale due to mass production (Paliwal et al. 2020; Nisar et al. 2021). This will also lead to the development of a variety of alternative system designs (Liu et al. 2021).

Li-ion batteries satisfy the required 50% average recycling rate, and recycled materials can reduce the demand for extraction of primary metals which are on high demand in numerus industries (Lyu et al. 2020). Due to the rapid growth of Li-ion battery's market share, recycled material from volumes currently collected—sold at a period when the Li-ion market share was insignificant—do not match the quantities needed for the production of batteries available on the market today; as a result, due to its expansion, this segment is currently a net 'taker' of raw materials (Chiang et al. 2017).

Services and benefits of energy storage facilities

Energy storage through the use of batteries is expected to play a dominant role in future energy systems both for on-grid and off-grid applications offering various services that allow grid stabilization and renewable energy integration (Fig. 3). One of the main advantages of battery systems in general is the flexibility they offer by being able to be installed at every grid level, i.e., generation, transmission, distribution or self-consumption. Furthermore, battery storage can be implemented without the need of complex infrastructure, are easily scalable and mobile, and can be installed in low-risk and environmentally friendly conditions (Wakihara 2001).

The lack of flexibility is one of the main obstacles that EU's electricity systems will have to overcome, as a result of the growing fraction that renewable energy sources have on the energy mix. This issue becomes more apparent in isolated systems, and for systems that heavily depend on thermal power plants with limited flexibility. By making a system more flexible, through the introduction of dedicated storage, a significant reduction in the need for peak power generation can be achieved as well as an increase in the base load capacity factor (Weiss et al. 2021). An additional advantage is the reduction of starts and ramping required of thermal power plants, hence decreasing expenses related to their operation and maintenance (Zhang et al. 2021).

Bulk energy services for large renewable energy facilities

Batteries allow the owners of solar photovoltaics (PV) or wind generators to store the energy produced—when it is inexpensive and when it would be uneconomic to supply it to the grid—and then to release it when prices are

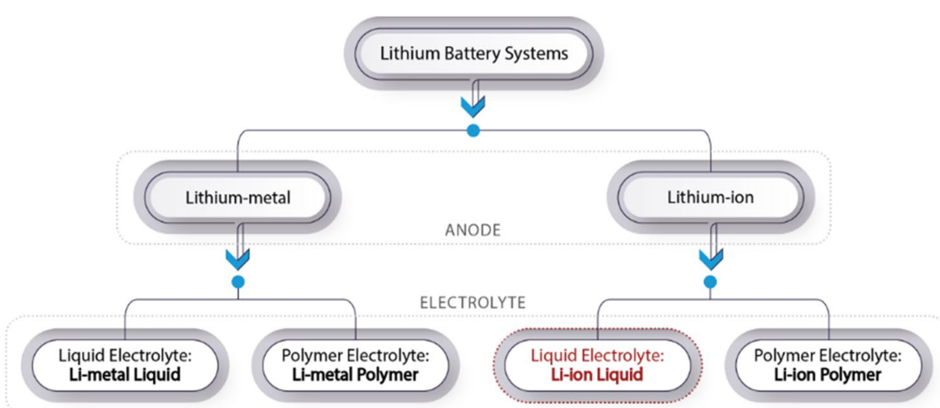

Fig. 2 Lithium battery family

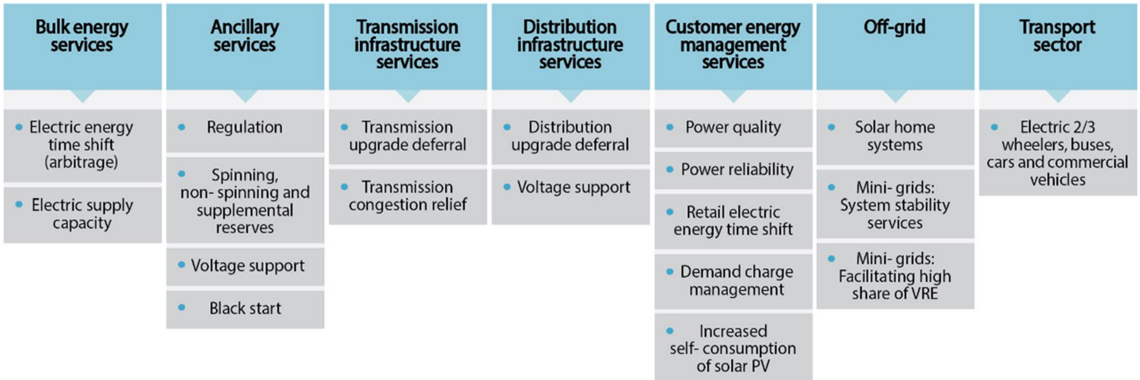

Fig. 3 Range of services that can be provided by electricity storage

higher (Kebede et al. 2022). In order to be feasible, arbitrage requires electricity prices to be free to fluctuate (Ibrahim et al. 2021). At times when renewable power generation exceeds local demand and there is insufficient network capacity to export the surplus energy to another region, dedicated storage can reduce the need to curtail wind and/or PV generators (Zhang and Yang 2021). Also, in some isolated systems—also directly relevant to insular energy system—variable renewable generation may need to be curtailed by the system operators to avoid instability at a system level because a percentage of synchronous generation is required to maintain stable operations (Smolenski et al. 2022). Overall, the effect is that every single PV panel or generation system injects more energy into the grid when it has a battery. This results in a reduced need for new central station generation capacity (Freire-Barceló et al. 2022). Variable renewable generation, combined with energy storage, represent a fixed generation capacity which can be valued on capacity markets. Additionally, storage devices can compensate for the destabilizing effects of variable generation on grid stability; they enable wind and solar generators to contribute to primary and secondary reserves respectively (Fokaides et al. 2020a, b). For such functions, storage can be either associated directly with generation devices, or can otherwise be connected to the grid.

Transmission and distribution services at grid level

Energy storage with batteries have the ability to guarantee grid stability in various ways. The ancillary services that storage facilities can offer are essential for the integration of intermittent and distributed renewable energy sources (Abbas and Chowdhury 2021). Batteries have the ability to store or supply energy, in milliseconds, in order to balance a grid, prevent frequency instabilities, and resolve momentary fluctuations in generation and loads (Stanelyte et al. 2022). Moreover, batteries offer reserve capacity to the grid that can replace the traditional reserve power generation units. Following an event of total power supply failure or in islanding situations, the use of BESS is needed to restart and to supply the required power to the grid (Venegas et al. 2021).

In addition BESS provides load leveling to low-voltage grids and also help prevent fatal overloads (Kryonidis et al. 2021). BESS give the opportunity to grid operators to shift load toward base load periods, thus reducing peak demand, and to reduce the maximum currents flowing from the high voltage grid through constrained grid assets (Badanjak and Pandžić 2021). The ancillary services provided by BESS improve the operational conditions of the grid as well as its stress resistance, it expands its capacity and makes its operation more responsive, reliable as well as secure. Furthermore, storage minimizes line congestion as well as line loss by moving electricity at off-peak hours (Ortega-Arriaga et al. 2021). Energy storage can thus prolong the life of infrastructure which is already in operation, and remove the need for additional investments in transmission or distribution system upgrades (Baecker and Candas 2022).

Customer energy management services

The use of energy storage can also be beneficial for smaller systems, for example a single household, when used in conjunction with renewable energy systems. The combination of BESS and renewables can maximize electricity production and self-consumption from about 30% to around 60–70%. This optimizes the overall efficiency of renewable energy production and minimizes the need for power use from the grid (Ali et al. 2021). Furthermore, BESS can decrease inverter distortion which optimizes the injection into the grid (Aliero et al. 2021).

Utilization of BESS in energy and capacity markets

The utilization of BESS in energy markets is expected to be focused in two main applications:

- Ancillary services (Voltage regulation and Frequency response)
- Behind-the-Meter (BTM)energy storage.

Ancillary services

Voltage Regulation is achieved by ensuring adequacy in the static and dynamic supply of reactive power which can be affected by a number of factors. The most suitable factors to be regulated by the Transmission System Operators (TSOs) are the reactive power produced or absorbed by the power generation units or the electricity storage facilities (Kumar and Palanisamy 2020). The TSO has to ensure that during operation, the voltage of the transmission system at the connection points are within the desired limits and has to maintain the required reactive power regardless of any changes in the operating conditions, for example changes in demand (Kylili et al. 2020). For this reason, it is necessary to implement measures that will allow the energy storage systems to be able to adjust their power output as well as additional voltage adjustment measures that affect energy storage facilities. Every energy storage facility is obliged to operate under the constant control of the Automatic Voltage Regulator or other means of voltage control in order to maintain a constant voltage at the exit of the facility (Shaw-Williams et al. 2020).

Frequency regulation during normal operation and during disturbance periods is essential for the safe operation of the system (Alshehri et al. 2019). As a result, the TSO has to operate the system in a way that ensures that the frequency is properly controlled and maintained within the desired limits at any moment. The total power capacity reserved for the frequency containment during periods of disturbances in the power balance is called the Frequency Containment Reserves (FCR). Since frequency can deviate either upwards or downwards, FCR can either be specified as "upward balancing" or "downward balancing" (Ribo Perez et al. 2021). FCRs can be achieved with automatic corrections of the frequency deviations by automatically adapting the power output of the inverter of energy storage facilities. Specifically, a local inverter controller adjusts the active power—frequency curve (P–f) of the power generation units.

Behind-the-meter energy storage

In addition, one of the main applications of BESS is expected to be their utilizations as Behind-the-Meter (BTM) energy storage for renewable energy systems projects (Nazari et al. 2022). Their main function will be to supplement the required electrical energy from the produced or the supplier to the final consumer. This will provide the benefit of avoiding the supply of energy at the wholesale price (Gandhok and Manthri 2022).

Cost and related charges of energy storage facilities

When compared to other battery types, Li-ion is a relatively new technology with great margin for future cost reduction. This expected reduction in cost is going to be driven mainly from greater production volume, optimization of performance resulting from improvement in design and material use and finally from competitive supply chains. Barbry et al. (2019). Table 1 presents the predicted reduction in capital cost for Li-ion based storage facility investment.

One of the main barriers to the expansion of energy storage investments are gaps in the EU legislation. Such gaps allow the application of grid fees both during charging, where energy is taken from the grid, as well as during discharging. where energy is supplied into the grid (Fokaides et al. 2014a, b). This problem of double grid fees is a major factor for energy storage investors in countries where taxation is applied both for generation and consumption (Ribeiro et al. 2017).

Given the importance of energy storage facilities in the future of the power generation sector, the government needs to offer incentives to attract relevant investments. In some European countries, special tariffs have been established to incentivize investments in storage facilities (IRENA 2017):

- Germany: For pump-storage power stations a grid fee exemption is possible for 10 years if the amount of

Table 1 2018 findings and 2025 predictions for Li-Ion Battery storage investment (US Department of Energy 2019)

	Li-ion battery	
	2018	2025
Capital cost—energy capacity [USD (EUR)/kWh]	271 (252)	189 (176)
Power conversion system (PCS) [USD (EUR)/kW]	288 (268)	211 (196)
Balance of plant (BOP) [USD (EUR)/kW]	100 (93)	95 (88)
Construction and commissioning [USD (EUR)/kWh]	101 (93)	96 (89)
Total project cost [USD (EUR)/kW]	1876 (1745)	1446 (1345)
Total project cost [USD (EUR)/kW]	469 (436)	362 (337)

Currency conversions are based on the rate 1 USD = 0.93 EUR storage-energy has increased by 5% minimum. Additionally, there is a grid fee reduction for customer with an exclusive usage of storage (not less than 20% of yearly power price).

- Italy: Energy withdrawals for generation plants auxiliary services and for hydro pumping storage plants are exempt from transmission and distribution fees.
- Serbia: Pump storage facilities are not subject of transmission tariff for the load they consume.

Documentation and understanding of EU policy on energy storage

The main aim of Directive 2019/944 is to ensure affordable, transparent energy prices and costs for consumers, a high degree of security of supply and a smooth transition toward a sustainable low-carbon energy system (European Commission 2019). This is fulfilled by establishing common rules for the generation, transmission, distribution, energy storage and supply of electricity, together with consumer protection provisions, with a view to creating truly integrated competitive, consumer- centered, flexible, fair and transparent electricity markets in the Union. This directive lays down key rules relating to the organization and functioning of the Union electricity sector, in particular rules on consumer empowerment and protection, on open access to the integrated market, on third-party access to transmission and distribution infrastructure, unbundling requirements, and rules on the independence of regulatory authorities in the Member States. It also sets out modes for Member States, regulatory authorities and TSO to cooperate toward the creation of a fully interconnected internal market for electricity that increases the integration of electricity from renewable sources, free competition and security of supply.

Directive 2019/944 defines 'energy storage' as the final use of electricity to a moment later than when it was generated, or the conversion of electrical energy into a form of energy which can be stored, the storing of such energy, and the subsequent reconversion of such energy into electrical energy or use as another energy carrier. Considering the focus point of this report is energy storage, this section discusses the Articles of this directive, which are directly relevant to the provisions for energy storage and/ or refers to the electricity market participants that own, develop, operate or manage energy storage facilities. Energy Storage is specifically referenced in the following articles, also illustrated in Fig. 4.

In the following subsections, the adaptation of the EU policy on the energy storage and internal market in selected EU Member States is presented.

The federal Republic of Germany

The purpose of the German Renewable Energy Sources Act (EEG 2017) (The Federal Republic of Germany, Federal Ministry for Economic Affairs and Climate Action 2017) is to promote sustainable energy sources with minimal environmental impact in order to protect the environment, reduce the use of fossil fuels as well as reduce the cost of energy supply. The review of this Act has indicated that preconditions exist for the exclusion of electricity storage facilities from double burden of the EEG surcharge.

In the case of grid energy which is used during an off-setting period with the intend to be temporarily stored in a electrical, chemical, mechanical or physical storage facility, the claim to payment of the EEG surcharge is less in this off-setting period. This reduction applies provided that the full EEG surcharge has been paid for electricity which is produced with the electricity storage installation to the extent that the electricity is injected to the grid system and supplied through a balancing group. For electricity which is supplied to be temporary stored in an electrical, chemical, mechanical or physical storage facility, the burden of the EEG surcharge is not applied to the extent that the energy stored in the storage facility is not taken out again (storage loss). In the case where electrical energy, for which different levels of the EEG surcharge apply, is used in the storage facility, the obligation to pay the EEG surcharge does not apply for energy loses during storage, in the ratio to one another of the various quantities of electricity consumed.

The offsetting period within the meaning of the above is the calendar year. In the case where electricity generated with a storage facility in a calendar year is not solely injected into the grid or if its solely used by the operator, the off-setting period is the calendar month. The reduction in the EEG surcharge is limited to a maximum consumption of 500 kWh in the electricity storage installation per kWh of installed storage capacity per calendar year.

The entitlement to payment of the EEG surcharge is only reduced according to the above paragraph if the electricity storage operator has fulfilled the reporting requirements and provided that the preconditions are adhered to at all times by means of calibrated metering devices (or smart metering systems) and a documented calculation which takes account of the offsetting periods. The documentation of the preconditions is provided to the grid system operator for each calendar year for electricity which is generated with the electricity storage installation by that electricity storage operator.

The Republic of Poland

The Polish Chamber of Energy Storage Association (PIME) published a complete study outlining the current status of the Polish electricity storage market which presented the

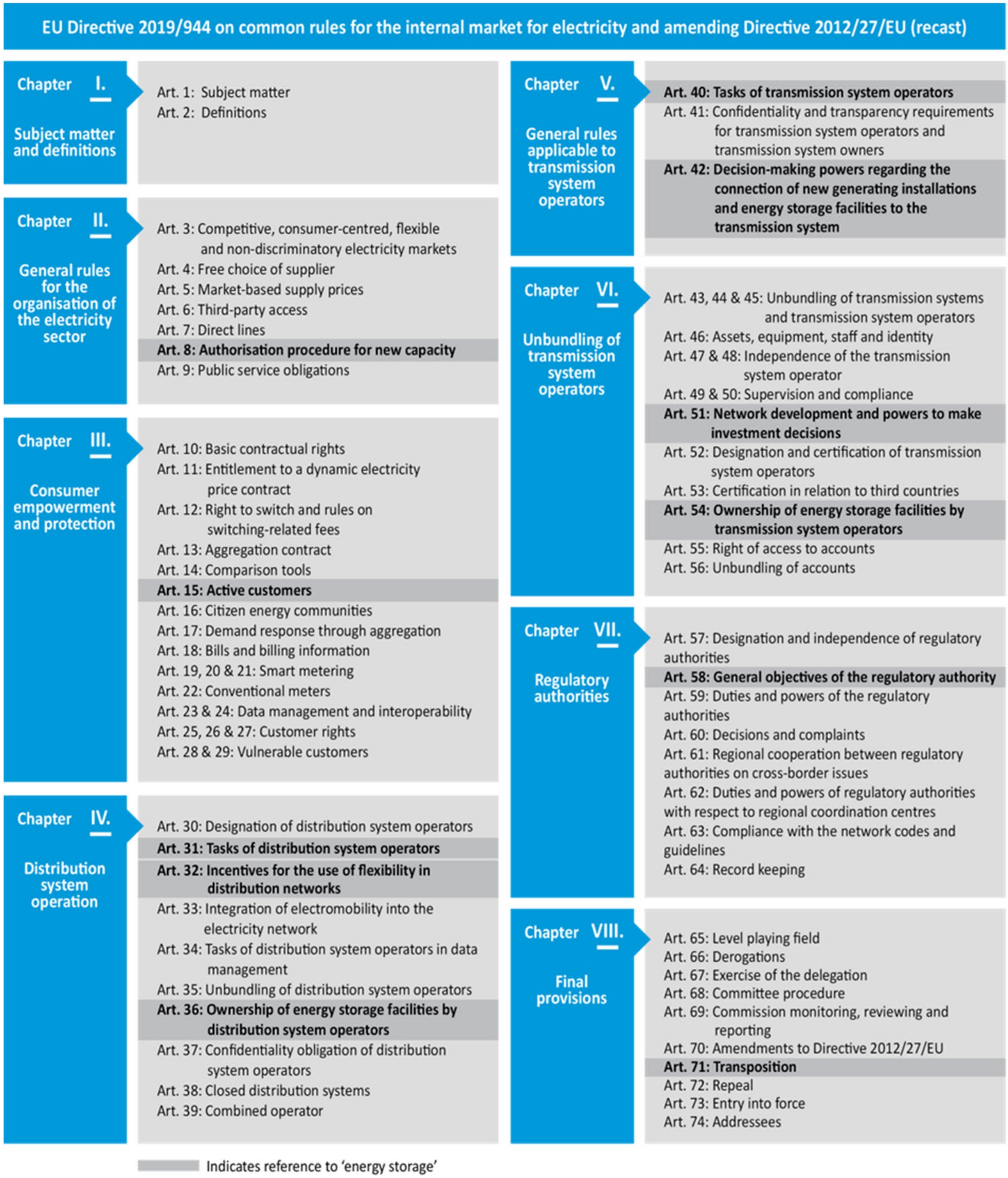

Fig. 4 Gaps identified in the national legislation with relevance to the articles of EU Directive 2019/944 regarding energy storage

needs of the market, a description of the available technologies and specific recommendations concerning the Polish market (Central Europe Energy Partners 2019). This report was the result of a series of workshops, where investors, network operators and other professionals participated, that took place between 2017 and 2019 as part of the PIME. The study concludes that the further development of energy storage technologies and the use of large-scale energy storage in

Poland are conditioned by the adoption of legislative actions in the following areas:

Area I—clarifying the status of energy storage on the energy market

With regard to this area, the following solutions are suggested:

i. Clarification of the legal definitions of "energy storage system" and "electricity energy storage" in order to prevent interpretation doubts and to limit the services that energy storage facilities can provide to only the support of unstable generation of RES.
ii. Regarding the construction of energy storage facilities, priority should be granted to investors that are not involved in the operation of distribution systems. This objective can be accomplished by statutory specification of locations, after which TSOs and DSOs will be allowed to create their own energy storage.
iii. Permit the provision of services from energy storage facilities to the network operators in a liberalized market. In particular, energy storage operators should be able to offer voltage regulation services to TSOs and DSOs.

Area II—elimination of barriers to the construction of energy storage

Measures that enable the construction of energy storage facilities by entities other than the DSO could include:

i. Minimizing the concession obligations when introducing of energy from storage to the network.
ii. Establishing favorable conditions for connecting energy storage facilities to the grid, for example setting clear rules for connecting warehouses to the network and possible preferences regarding the maximum processing time for applications and connection fees, along with safeguarding storage priority for connection before other production facilities.
iii. Enabling the widespread use of storage capacity of electric vehicles, as an energy source of the network. A viable scenario could be that this power aggregation from numerous individual vehicles can be implemented by charging service providers.

Area III—reducing the costs of energy storage and creating incentives for their construction

At the operational level, the following solutions should be considered for decreasing the operating costs of energy storage facilities, at least in the initial development period of energy storage infrastructure in Poland:

i. Energy which is introduced into energy storage facilities should be subject to reduced or no distribution fees. Full exemption can be applied in the case of variable charges whereas reduction coefficients on the based on the facility efficiency can be applied in the case of fixed charges.
ii. Exemption of electricity introduced into energy storage from financing fees.
iii. Exemption of electricity introduced in energy stores from the obligation to submit certificates of origin for redemption, including certificates of origin from a RES and energy efficiency certificates.
iv. Exemption from excise tax on electricity entering the warehouse and electricity consumed in connection with the storage process.
v. Expanding the offer of the National Fund for Environmental Protection and Water Management to non-returnable forms of investment support for the construction of energy storage facilities of any storage technology (i.e., mechanical, electrical, biological, electrochemical, thermal, chemical, etc.).

The United Kingdom

The Revised Protocol on Ireland and Northern Ireland, as stated in Article 9 of the Withdrawal Agreement, focuses on the Single Electricity Market. Its aim is to ensure that this market can function smoothly despite the UK's departure from the EU and the subsequent end of its obligation to abide by EU regulations. The article stipulates that the UK, specifically Northern Ireland, must continue to follow Union law that governs electricity markets. Therefore, the UK is responsible for incorporating these rules into its domestic legislation. To this end, the UK government's Department for the Economy has conducted a consultation regarding the adoption of the 2019/944 Directive.

The UK government's consultation document, Chapter 3, outlines proposals related to energy storage. Specifically, it highlights that the 2019/944 Directive addresses energy storage in Articles 36 and 54. These articles establish the ownership requirements for energy storage facilities for DSO and TSO respectively. Additionally, Article 8 mandates energy storage capacity as a criterion for evaluating the level of generating capacity. Article 15 provides active customers with storage facilities certain protections, while Articles 31, 32, and 40 require DSOs and TSOs to ensure that energy storage operators can participate effectively in the market and guarantee the availability of services from storage facilities.

The Consultation acknowledges that the DSO and TSO in Northern Ireland do not currently possess any energy storage facilities. However, an increasing number of energy storage units are being authorized for connection to the Northern Ireland grid. As technology advances, storage is expected to become an increasingly popular solution for energy demands. As an emerging technology, the Department recognizes the need for a regulatory and legislative framework for energy storage. Such a framework should be developed through a thorough policy analysis process to ensure an appropriate level of consideration.

The government's initial step in establishing a regulatory and legislative framework is to make energy storage a licensable activity. This necessitates a legislative amendment to prohibit unlicensed storage operations and would necessitate primary legislation. Subsequently, the Utility Regulator can grant necessary licenses. However, the Directive's energy storage requirements only obligate the TSO and DSO to ensure market access and service provision, not the energy storage operator. Therefore, creating a licensing system for energy storage beyond the Directive's requirements is unnecessary. As a result, the Department proposed that an appropriate policy framework should be developed as part of the Energy Strategy and primary legislation introduced at that stage to implement the Strategy.

The UK government recognizes that policy development is required for Article 32, Article 36, and Article 54, which relate to Incentives for Flexibility, Ownership of Energy Storage Facilities by DSO, and Ownership of Energy Storage Facilities by TSO, respectively. It is not possible to legislate these by 31 December 2020 and will require a longer timeframe. The government is interested in exploring battery storage's potential in implementing virtual power plants, which aim to optimize generation and consumption by a network of decentralized units and storage systems, including wind farms, solar parks, CHP units, and flexible consumers. The objective of a virtual power plant is to reduce the grid load by smartly distributing power during periods of peak demand.

Consolidated Version of Electricity Market Rules—Republic of Cyprus

In this section the conditions of energy storage for the case of the Republic of Cyprus are presented. Cyprus constitutes a unique case, which needs further examination. Particularly the Republic of Cyprus operates an insular energy system, with no interconnection with other energy systems. Also, the size of the system is small (peak capacity of 1,2 GW), which does not allow the development of large scale, feasible infrastructure (Fokaides et al. 2014a, b). At the same time, the energy system of Cyprus is considered to be premature in several of its aspects, related to infrastructure for energy storage and energy management, as well as related to the operation of an open market. Despite the fact that since the entrance of the Republic of Cyprus the electricity market was supposed to transpose to a free market, only in early 2022 a second supplier offered services on the island (Kylili et al. 2015).

Cyprus has the peculiarity of being a small and isolated energy system, as an island-state with subtropical climate conditions, resulting to an arid environment, with less water resources that would allow the case of hydro-pump as an energy storage method. Also, storage facilities are mainly required close to large RES units, such as big PV farms and wind farms. Under these conditions, batteries seem to be the only feasible system on the island, as they offer modularity, require less infrastructure and are not environmentally related with regard to the available resources.

For the purposes of understanding how energy storage is proposed to be introduced in the energy system of the Republic of Cyprus, the revised Consolidated Version 2.2.0 of the Electricity Market Rules with regard to energy storage were analyzed (Cyprus Distribution System Operator (DSO),2020). The main aspects of the framework are the following:

- The first article sets out the general provisions of the Rules, the control procedures and the relevant market management system, specifies the responsibilities of the Market Officer, the TSO and DSO, the requirements for accession of new contracting parties to the market, the conditions for the termination or expulsion of contracting parties and in particular the provisions relating to infringements
- The second article sets out the definitions used in the Rules.
- The third article sets out the obligation of the Participants to have a Generation Account, RES and CHP Account, Responsible Balancing Body Account, Installation of Electricity Storage Account, Response or Demand Account, and the elements that should be included in these accounts.
- The fourth article specifies the obligation to register metering devices and the information to be recorded, the obligation to notify the Responsible System Administrator when metering devices are transferred to another Contracting Party, and the assignment of responsibility for the Clearing of Deviations of each Responsible Balancing Entity to a Responsible Balancing Body.
- The fifth article defines the general provisions of the Auxiliary Services and the Contingency Reserve and the remuneration of the Balancing Service Providers for the provision of Auxiliary Services.
- The sixth article provides general information on Bilateral Contracts, sets out the submission of the Non-Availability Statements by the Producers for their generation units, by the Storage Facility Operators for the electricity

storage facilities they represent and by the RES and CHP producers for their own RES units and CHP units greater than 1 MW.

- The seventh article determines general information on the Pre-Day Market, the link between the Forward Market and the Pre-Day Market, the rules for submitting tenders and the process of clearing the Pre-Day Market, as well as the required liquidity measures in the Pre-Day Market.
- The eighth article identifies the principles of the balancing system and energy, the link between the Pre-Day Market with the Balancing Market.
- The ninth article sets out the role of the Transmission System Operator in the Real Time Balancing Market.
- The tenth article provides general information for handling Purchase Invalidity situations in the event of non-availability of the Market Management System
- Purchasing Insolvency situations in the event of a state of emergency being declared by the TSO, according to the provision of the Transmission and Distribution Rules, are analyzed in the eleventh article.
- The twelfth article specifies the obligation to install the metering devices for clearance purposes as well as to register metering devices.
- Article thirteen describes the accounting records of the Purchasing Officer, the Participant's Pre-Day market accounts and the Participant's Purchase Accounts
- The fourteenth article sets out in an Annex the procedures for the periodic conciliation of liquidation calculations after new or revised liquidation data becomes available.
- The fifteenth article provides a summary of references related to other chapters of the rule, the requirements for the Market Officer to have market information available, and the requirements for the TSO to have available information on the market and operation of the system.
- The last article determines the Forward Market and the Pre-Day Market schedules, defined the Balancing Market, and the schedule of deviations clearance, invoicing and payment procedures.

Definition of gaps and discrepancies of proposed legislation

In this section, the gaps that exist in the t Consolidated Version 2.2.0 of the Electricity Market Rules relating to electricity storage and electricity storage facilities, are identified. The identification of the gaps is necessary for transposing rightfully the European directive in the Cyprus law and implementing appropriately the recent market design legislation and in particular regarding system flexibility and the uptake of different sources of flexibility, focusing on electricity storage. Gaps in the current version of the Consolidated Version 2.2.0 of the Electricity Market Rules have been identified with reference to the following Articles, also illustrated in Fig. 4:

According to the Article 15 of the directive, consumers are at the center of the Energy Union and all consumers across the EU are entitled to generate electricity for either their own consumption, store it, share it, consume it or to sell it back to the market. This Article gives to all customers an "active role" instead of "protection". With this change, the legislative framework should make it easier for any market participant to become more involved in the energy system. The 'Transmission and Distribution Rules' provisions that the DSO must process the customer's request (customer of any unit) and provide connection conditions within reasonable time limits, as published by the DSO in the document "Citizen Map". The Consolidated Version 2.2.0 of the Electricity Market Rules also specifies that the energy storage facility operators and the energy storage representatives, in addition to the introduction or storage of energy can provide several services simultaneously, including acting as wholesale suppliers, without having to obtain the respective License from Cyprus Energy Regulatory Authority (CERA) and can participate in the market both as receiving participants and delivering participants. However no specific or additional reference is made in the Consolidated Version 2.2.0 of the Electricity Market Rules nor the 'Transmission and Distribution Rules' for active customers that own an energy storage facility, as specified in the revised Directive 2019/944 about:

- not being subjected to double charges, including network charges, for stored electricity remaining within their premises or when providing flexibility services to system operators; and
- not be subjected to disproportionate licensing requirements or fees.

Articles 31, 32 and 40 require DSO and TSO to ensure that operators of energy storage can effectively participate in the market and ensure availability of services from storage facilities. In the national legislation, this is accomplished by introducing the rights of energy storage owners throughout the Consolidated Version 2.2.0 of the Electricity Market Rules and 'Transmission and the Consolidated Version 2.2.0 of the Electricity Market Rules regarding incentives for promoting the uptake of different sources of flexibility, demand response or energy storage nor the role of the DSO has been revised to provide them with the capability of developing such incentives.

The Consolidated Version 2.2.0 of the Electricity Market Rules recognizes that there is a need for a regulatory and legislative framework for energy storage, which should be based on an appropriate level of policy consideration. Therefore, the Consolidated Version 2.2.0 of the

Electricity Market Rules makes energy storage a licensable activity. Nevertheless, the Electricity Market Rules do not set requirements around ownership of energy storage facilities by DSO and TSO, according to *Articles 36 and 54* respectively. The only restriction made for the DSO and TSO is that they have no production capacity or have the right to trade energy Distribution Rules'. Yet, with reference to Article 32, no additional provisions have been introduced in for profit. Accordingly, the revised Electricity Market Rules will require a change to the DSO and TSO license to prevent ownership unless a derogation is deemed appropriate under certain conditions.

The 'Transmission and Distribution Rules' specify that the DSO may refuse to grant permission for the connection of a new generating installation or an energy storage facility or require a revision of the design and technical parameters of the generating installation or the energy storage facility to ensure conformation of the safety and quality standards of supply, satisfying the provisions of *Article 42*. Yet, it is not clearly stated that the DSO is not allowed to refuse the connection of a new generating installation or energy storage facility on the grounds of:

- possible future limitations to available network capacities, or
- because it would lead to additional costs resulting from the necessary capacity increase in system elements in the close-up range to the connection point. With regard to *Articles 51, 54 and 58* concerning, energy storage, the role of CERA is also determinant as it is given the authority to facilitate access to the network for new generation capacity and energy storage facilities by removing barriers that could prevent access for new market entrants and is also responsible for monitoring investment in generation and storage capacities in relation to security of supply. These responsibilities of CERA are not updated in either in the Consolidated Version 2.2.0 of the Electricity Market Rules nor the 'Transmission and Distribution Rules'.

Figure 5 resumes the gaps identified in the national legislation with relevance to the articles of EU Directive 2019/944 regarding energy storage.

Cyprus is expected to alter its insularity with the EuroAsia Interconnector, the construction of which was launched in 2022 and which is expected to be in operation in 2026. EuroAsia Interconnector is a Project of Common Interest of the EU, concerning a 2 GW electricity interconnector between Israel, Cyprus, Greece and Europe. The EuroAsia Interconnector is a leading European, labeled as an EU "electricity highway" connecting the national electricity grids of Israel, Cyprus and Greece through a 1,208 km subsea HVDC cable. The Republic of Cyprus is anticipated to achieve a symbiotic environment with neighboring members through the EuroAsia Interconnector.

Making BESS more attractive: future challenges

As Battery Energy Storage Systems (BESS) become more widespread and essential for integrating renewable energy sources into the grid, it is important to consider potential limitations and challenges that may arise in the future.

One major limitation is the cost of BESS technology, which can be prohibitive for some investors. Additionally, the lack of clear regulatory frameworks and standardized business models for BESS systems can also hinder investment.

To make BESS systems more attractive for investment, several strategies can be considered. First, reducing the cost of BESS technology through advances in manufacturing and economies of scale can make them more affordable and accessible. Additionally, governments and regulatory bodies can create clear policies and incentives to encourage investment in BESS, such as tax credits, subsidies, and feed-in tariffs. Standardizing business models and contractual frameworks can also create more certainty and reduce risk for investors.

Another potential solution is to explore innovative financing models, such as energy storage as a service (ESaaS) or leasing models, which can help overcome the high upfront capital costs associated with BESS installations. By adopting these strategies, BESS systems can become more attractive for investment, leading to greater adoption and integration into the grid. This, in turn, can help accelerate the transition to a more sustainable and resilient energy system. However, it is important to continually monitor and address potential limitations and challenges as BESS systems continue to evolve and grow in importance.

Conclusions

The purpose of this study was the documentation of significant aspects of energy storage policy in the EU, through the documentation and analysis of several relevant parameters. In its theoretical section, the study justified the benefits of introducing BESS, as well as the related costs for this policy. The current EU policy on energy storage, based on the analysis of the relevant directive on common rules for the internal market for electricity, was also presented. The study also attempted to present the current status of the adaptation of this policy in selected member states, focusing on the cases of Germany and Poland, as well as of Cyprus, an insular energy system with poor infrastructure on energy storage. The analyses of this study concluded that the Consolidated Version 2.2.0 of the Electricity Market Rules of the Cypriot

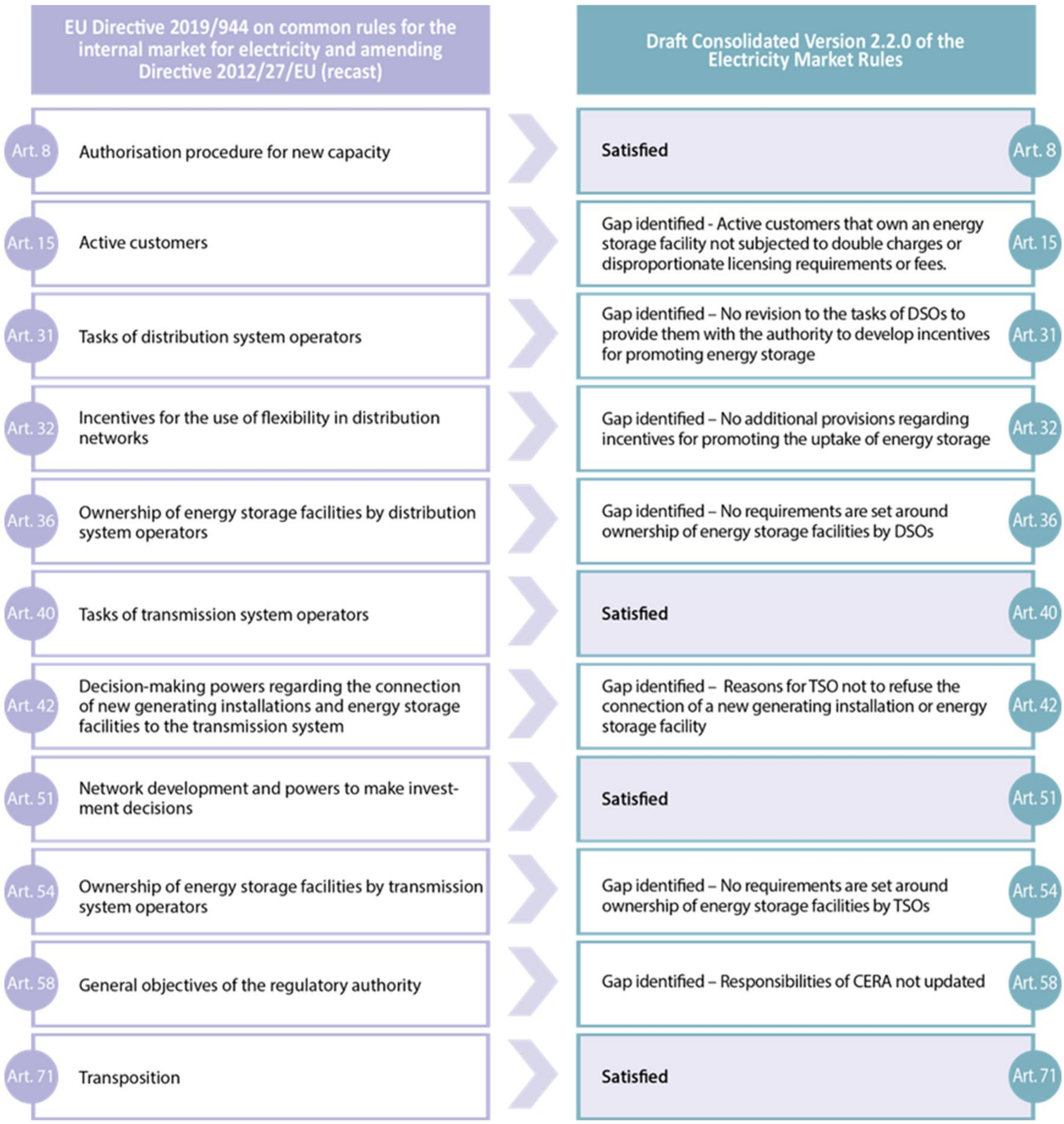

Fig. 5 Gaps identified in the national legislation with relevance to the articles of EU Directive 2019/944 regarding energy storage

DSO does not transpose rightfully the European directive in the Cyprus law, nor is expected to implement appropriately the recent market design legislation and in particular regarding system flexibility and the uptake of different sources of flexibility, by exploiting the potential of energy storage. It has been identified that in the Consolidated Version 2.2.0 of the Electricity Market Rules no reference is made regarding double charges or disproportionate licensing requirements and fees of active customers that own energy storage facilities. Furthermore, no additional provisions have been introduced regarding incentives for promoting energy storage nor has the role of the DSO been revised to provide them with the capability of developing such incentives. In addition, no requirements are stated which are associated with the ownership of energy storage facilities by DSO and TSO and is not clearly stated that the DSO is not allowed to refuse the connection of a new generating installation of energy storage facility on the grounds of possible future limitations to available network capacities or because it would lead to additional costs. Finally, it was identified that the responsibilities of CERA need to be updated in the Consolidated Version 2.2.0 of the Electricity Market Rules to include the role and authorities regarding energy storage facilities. Lessons learnt from the directive assessment, resume to the need of the adaptation of its content to the needs and requirements of insular energy systems, with lack of suitable infrastructure for its swift integration, such as the case of the Republic of Cyprus. Also, the required conditions for enabling the development of smooth symbiosis between energy production, storage and collaboration between member states should be elaborated in a more specific way. Practical implications for future use of BESS include their integration with renewable energy systems to store excess energy and supply energy when renewables are unavailable. The deployment of BESS can help balance the grid by providing ancillary services such as frequency regulation and voltage support. Innovative business models and regulatory frameworks should be implemented to ensure that BESS is financially attractive for investors, such as offering revenue streams from grid services and providing long-term contracts.

Author contributions CP and AK: wrote the main manuscript text and prepared all figures. PF: reviewed the manuscript.

Funding This research was funded by Aerotricity Ltd.

Data availability Not applicable.

Declarations

Conflicts of interest The authors declare no conflict of interest.

References

Abbas AO, Chowdhury BH (2021) Using customer-side resources for market-based transmission and distribution level grid services–a review. Int J Electr Power Energy Syst 125:106480. https://doi.org/10.1016/j.ijepes.2020.106480

Ali M, Prakash K, Hossain MA, Pota HR (2021) Intelligent energy management: evolving developments, current challenges, and research directions for sustainable future. J Clean Prod 314:127904. https://doi.org/10.1016/j.jclepro.2021.127904

Aliero MS, Qureshi KN, Pasha MF, Jeon G (2021) Smart home energy management systems in internet of things networks for green cities demands and services. Environ Technol Innov 22:101443. https://doi.org/10.1016/j.eti.2021.101443

Alshehri F, Suárez VG, Torres JLR, Perilla A, van der Meijden MAMM (2019) Modelling and evaluation of PEM hydrogen technologies for frequency ancillary services in future multi-energy sustainable power systems. Heliyon 5(4):e01396. https://doi.org/10.1016/j.heliyon.2019.e01396

Badanjak D, Pandžić H (2021) Distribution-level flexibility markets—a review of trends, research projects. Key Stakehold Open Quest Energ 14(20):6622. https://doi.org/10.3390/en14206622

Baecker BR, Candas S (2022) Co-optimizing transmission and active distribution grids to assess demand-side flexibilities of a carbon-neutral German energy system. Renew Sustain Energy Rev 163:112422. https://doi.org/10.1016/j.rser.2022.112422

Barbry A, Anjos MF, Delage E, Schell KR (2019) Robust self-scheduling of a price-maker energy storage facility in the New York electricity market. Energy Econ 78:629–646. https://doi.org/10.1016/j.eneco.2018.11.003

Barik AK, Jaiswal S, Das DC (2022) Recent trends and development in hybrid microgrid: a review on energy resource planning and control. Int J Sustain Energ 41(4):308–322. https://doi.org/10.1080/14786451.2021.1910698

Central Europe Energy Partners (CEEP) (2019). CEEP Report Q2 (57) 2019. Energy storage for future energy systems and EU role/ initiatives. Available from: https://www.ceep.be/www/wp-content/uploads/2019/07/CEEP_Report_Q2_2019_final_03.pdf

Chen T, Jin Y, Lv H, Yang A, Liu M, Chen B, Xie Y, Chen Q (2020) Applications of lithium-ion batteries in grid-scale energy storage systems. Trans Tianjin Univ 26(3):208–217. https://doi.org/10.1007/s12209-020-00236-w

Chiang YH, Sean WY, Wu CH, Huang CY (2017) Development of a converterless energy management system for reusing automotive lithium-ion battery applied in smart-grid balancing. J Clean Prod 156:750–756. https://doi.org/10.1016/j.jclepro.2017.04.028

European Commission (2019) 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 (Text with EEA relevance)

Cyprus Distribution System Operator (DSO) (2020). Electricity market rules. Version 2.2 May 2020

Fokaides PA, Christoforou EA, Kalogirou SA (2014a) Legislation driven scenarios based on recent construction advancements towards the achievement of nearly zero energy dwellings in the southern European country of Cyprus. Energy 66:588–597. https://doi.org/10.1016/j.energy.2013.12.073

Fokaides PA, Miltiadous IC, Neophytou MKA, Spyridou LP (2014b) Promotion of wind energy in isolated energy systems: the case of the Orites wind farm. Clean Technol Environ Policy 16(3):477–488. https://doi.org/10.1007/s10098-013-0642-2

Fokaides PA, Apanaviciene R, Černeckiene J, Jurelionis A, Klumbyte E, Kriauciunaite-Neklejonoviene V, Pupeikis D, Rekus D, Sadauskiene J, Seduikyte L, Stasiuliene L, Vaiciunas J, Valancius R, Ždankus T (2020) Research challenges and advancements in the field of sustainable energy technologies in the built environment. Sustainability 12(20):8417. https://doi.org/10.3390/su12208417

Fokaides PA, Panteli C, Panayidou A (2020b) How are the smart readiness indicators expected to affect the energy performance of buildings: first evidence and perspectives. Sustainability 12(22):9496. https://doi.org/10.3390/su12229496

Freire-Barceló T, Martín-Martínez F, Sánchez-Miralles Á (2022) A literature review of explicit demand flexibility providing energy services. Electric Power Syst Res 209:107953. https://doi.org/10.1016/j.epsr.2022.107953

Gandhok T, Manthri P (2022) Economics of stationary energy storage systems: driving faster adoption for behind-the-meter applications in India. J Clean Prod 330:129610. https://doi.org/10.1016/j.jclepro.2021.129610

Ibrahim ID, Hamam Y, Alayli Y, Jamiru T, Sadiku ER, Kupolati WK, Ndambuki JM, Eze AA (2021) A review on Africa energy supply through renewable energy production: Nigeria, Cameroon, Ghana and South Africa as a case study. Energy Strategy Rev 38:100740. https://doi.org/10.1016/j.esr.2021.100740

IRENA (2017). Electricity storage and renewables: costs and markets to 2030. Available from: https://www.irena.org/publications

Kebede AA, Kalogiannis T, Van Mierlo J, Berecibar M (2022) A comprehensive review of stationary energy storage devices for large scale renewable energy sources grid integration. Renew Sustain Energy Rev 159:112213. https://doi.org/10.1016/j.rser.2022.112213

Kryonidis GC, Kontis EO, Papadopoulos TA, Pippi KD, Nousdilis AI, Barzegkar-Ntovom GA, Papanikolaou NP (2021) Ancillary services in active distribution networks: a review of technological trends from operational and online analysis perspective. Renew Sustain Energy Rev 147:111198. https://doi.org/10.1016/j.rser.2021.111198

Kumar GB, Palanisamy K (2020) A review of energy storage participation for ancillary services in a microgrid environment. Inventions 5(4):63. https://doi.org/10.3390/inventions5040063

Kylili A, Afxentiou N, Georgiou L, Panteli C, Morsink-Georgalli PZ, Panayidou A, Papouis C, Fokaides PA, The role of remote working in smart cities: lessons learnt from COVID-19 pandemic. Energy sources part a recovery utilization and environmental effects. https://doi.org/10.1080/15567036.2020.1831108

Kylili A, Fokaides PA (2015) Competitive auction mechanisms for the promotion renewable energy technologies: the case of the 50 MW photovoltaics projects in Cyprus. Renew Sustain Energy Rev 42:226–233. https://doi.org/10.1016/j.rser.2014.10.022

Liu J, Wang J, Ni Y, Zhang K, Cheng F, Chen J (2021) Recent breakthroughs and perspectives of high-energy layered oxide cathode materials for lithium ion batteries. Mater Today 43:132–165. https://doi.org/10.1016/j.mattod.2020.10.028

Lyu P, Liu X, Qu J, Zhao J, Huo Y, Qu Z, Rao Z (2020) Recent advances of thermal safety of lithium ion battery for energy storage. Energy Storage Mater 31:195–220. https://doi.org/10.1016/j.ensm.2020.06.042

Nazari ME, Fard ZM (2022) A novel heuristic optimisation algorithm for solving profit-based unit commitment for thermal power generation with emission limitations. Int J Sustain Energ 41(6):675–698. https://doi.org/10.1080/14786451.2021.1971979

Nisar U, Muralidharan N, Essehli R, Amin R, Belharouak I (2021) Valuation of surface coatings in high-energy density lithium-ion battery cathode materials. Energy Storage Mater 38:309–328. https://doi.org/10.1016/j.ensm.2021.03.015

Oprea SV, Bâra A (2023) Mind the gap between PV generation and residential load curves: maximizing the roof-top PV usage for prosumers with an IoT-based adaptive optimization and control module. Expert Syst Appl 212:118828

Oprea SV, Bâra A, Preotescu D, Bologa RA, Coroianu L (2020) A trading simulator model for the wholesale electricity market. IEEE Access 8:184210–184230

Ortega-Arriaga P, Babacan O, Nelson J, Gambhir A (2021) Grid versus off-grid electricity access options: a review on the economic and environmental impacts. Renew Sustain Energy Rev 143:110864. https://doi.org/10.1016/j.rser.2021.110864

Paliwal NK, Singh AK, Singh NK (2020) Energy scheduling optimisation of an islanded microgrid via artificial bee colony guided by global best, personal best and asynchronous scaling factors. Int J Sustain Energ 39(6):539–555. https://doi.org/10.1080/14786451.2020.1735387

Ribeiro Gonçalves JA, Neves LP, Martins AG (2017) Multiobjective assessment of distributed energy storage location in electricity networks. Int J Sustain Energ 36(6):577–591. https://doi.org/10.1080/14786451.2015.1066787

Ribó-Pérez D, Larrosa-López L, Pecondón-Tricas D, Alcázar-Ortega M (2021) A critical review of demand response products as resource for ancillary services: international experience and policy recommendations. Energies 14(4):846. https://doi.org/10.3390/en14040846

Shaw-Williams D, Susilawati C, Walker G, Varendorff J (2020) Towards net-zero energy neighbourhoods utilising high rates of residential photovoltaics with battery storage: a techno-economic analysis. Int J Sustain Energ 39(2):190–206. https://doi.org/10.1080/14786451.2019.1668394

Smolenski R, Szczesniak P, Drozdz W, Kasperski L (2022) Advanced metering infrastructure and energy storage for location and mitigation of power quality disturbances in the utility grid with high penetration of renewables. Renew Sustain Energy Rev 157:111988. https://doi.org/10.1016/j.rser.2021.111988

Stanelyte D, Radziukyniene N, Radziukynas V (2022) Overview of demand-response services: a review. Energies 15(5):1659. https://doi.org/10.3390/en15051659

The Federal Republic of Germany, Federal Ministry for Economic Affairs and Climate Action (2017) Renewable energy sources act (EEG 2017). Available from https://www.bmwk.de/Redaktion/EN/Downloads/renewable-energy-sources-act-2017.pdf?__blob=publicationFile&v=3

US Department Of Energy (2019). Energy storage technology and cost characterization report, HydroWires. Available from: https://www.energy.gov/eere/water/downloads/energy-storage-technology-and-cost-characterization-report

Venegas FG, Petit M, Perez Y (2021) Active integration of electric vehicles into distribution grids: barriers and frameworks for flexibility services. Renew Sustain Energy Rev 145:111060. https://doi.org/10.1016/j.rser.2021.111060

Wakihara M (2001) Recent developments in lithium ion batteries. Mater Sci Eng R Rep 33(4):109–134. https://doi.org/10.1016/S0927-796X(01)00030-4

Weiss M, Ruess R, Kasnatscheew J, Levartovsky Y, Levy NR, Minnmann P, Stolz L, Waldmann T, Wohlfahrt-Mehrens M, Aurbach D, Winter M (2021) Fast charging of lithium-ion batteries: a review of materials aspects. Adv Energy Mater 11(33):2101126. https://doi.org/10.1002/aenm.202101126

Zhang M, Yang XN (2021) Administrative framework barriers to energy storage development in China. Renew Sustain Energy Rev 148:111297. https://doi.org/10.1016/j.rser.2021.111297

Zhang S, Liu Y, Fan Q, Zhang C, Zhou T, Kalantar-Zadeh K, Guo Z (2021) Liquid metal batteries for future energy storage. Energy Environ Sci 14(8):4177–4202. https://doi.org/10.1039/D1EE00531F