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REVIEW

Digital platforms to support the flexibility value chain, run flexibility markets, and manage energy communities

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Abstract

Purpose of Review This paper reviews the flexibility-centric value chain (FCVC) and analyses how coordinating digital platforms along the FCVC is essential for enabling FCVC activities and supporting key actors. Based on the FCVC, the digital infrastructure needed to support flexibility provision in power systems is reviewed, with special focus on the role of energy communities (ECs) as emerging relevant actors and potential aggregators of its members.

Recent Findings We review the Grid Data and Business Network (GDBN), a platform developed by the authors to support the FCVC, with special focus on those stages of the FCVC not properly supported by existing solutions. It also analyses platforms used in local flexibility markets (LFMs), and it presents the RECreation digital platform designed to manage ECs to support the participation in flexibility markets.

Summary Digital platforms are necessary for scaling flexibility services. The GDBN offers a comprehensive approach by enabling the FCVC and facilitating interoperability with existing platforms dedicated to specific segments, such as ECs and LFMs. By addressing current limitations in platform integration, this paper contributes to a clearer understanding of how digital tools can enable an efficient flexibility ecosystem.

Keywords Digital platforms · Energy communities · Flexibility · Flexibility-centric value chain · Flexibility markets

Introduction

The European Union (EU) is urging Member States (MS) to develop regulatory frameworks that incentivize distribution system operators (DSOs) to procure cost-effective flexibility to operate and maintain their grids [1]. Flexibility, in this context, refers to explicit flexibility which is the ability to adjust energy consumption or generation patterns in response to external signals [2]. In addition, whenever possible, flexibility shall be procured through transparent, non-discriminatory, market-based procedures [1]. Renewable energy communities (RECs) and the role of active customers are also incentivized to integrate final consumers into the energy system and increase flexibility provision and renewable energy share [3, 4]. Collective self-consumption (CSC) provides a regulatory background to engage final consumers in renewable generation sharing and local energy and flexibility markets [5].

The deployment of flexibility, particularly demand-side flexibility, requires digital infrastructures capable of ensuring a secure and reliable data access and exchange between parties. Thus, over the last few years, multiple flexibility market platforms have been conceptualized and deployed to support system operators (SOs) in procuring and leveraging flexibility [6, 7], most of them in pilots or regulatory sandboxes.

More recently, in 2023, the EU DSO Entity and ENTSO-E set out a proposal for a Network Code on Demand Response which compels MS to require SOs to publish information related to flexibility procurement on a single platform at national level [8].

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Driven by the digitalisation of power grids and the deployment of smart meters, digital platforms are emerging as enablers of new markets and business models (BMs). This paper reviews the flexibility-centric value chain (FCVC) identified in [9, 10], describing the main stages needed for final consumers to become direct flexibility providers, catering to SO's needs, and introduces the Grid Data and Business Network (GDBN), a multi-tenant cloud-based platform designed for that purpose. The GDBN aims to be a low-cost and low-complexity solution, supporting small and large SOs in leveraging available flexibility capacity, to engage final consumers to unlock their flexibility potential by creating additional value for them. The GDBN links the key actors of the FCVC, including consumers, service providers (SPs) and SOs, supporting the main FCVC activities and creating new value streams. Moreover, it facilitates and promotes new activities such as pairing SPs with potential clients via interoperable protocols, enable various flexibility service providers (FSPs) to interact with different flexibility market platforms by providing interoperable interfaces to these platforms, enables flexibility activation and settlement of SOs, and support new BMs related to consumer data processing by properly marketing this data to software companies, unlocking additional value to consumers engaged in flexibility provision. These potential BMs were already identified in [11] as a preliminary step to build the FCVC.

The main contributions and sections of this paper include:

- A comprehensive proposal for the FCVC designed to boost final consumers flexibility, describing the FCVC's stages, main activities, primary and secondary actors involved, and the main mechanisms to deploy and integrate consumers into the FCVC, emphasising the collaboration between stakeholders such as consumers, SPs, and SOs.
- The GDBN as an innovative, multi-stakeholder digital platform to support the FCVC, including the conceptual GDBN architecture, its relationship with the FCVC, an assortment of supported services, key deployment and life cycle options, and BMs for its operation.
- A review of local flexibility market (LFM) platforms and flexibility products supported, commonly used by SO for flexibility procurement.
- A review of the RECreation digital platform to manage energy communities.
- A final overview on how these different digital platforms are integrated together to support the FCVC.

The flexibility-centric value chain

To the best of our knowledge, the concept of the flexibility value chain was first introduced in [12]. It addresses the use of flexibility to support both SOs, particularly for ancillary services and grid investments deferral, and integrates resources across generation, transmission, distribution, and, notably, demand-side distributed energy resources (DERs). The value chain proposed has four stages: 1) Flexibility identification: evaluate flexibility potential across the system, focusing on demand-side DERs like electric vehicles (EVs), heat pumps (HPs), and industrial loads; 2) Flexibility characterization: model and characterize DERs, including relevant features such as capacity, power limits, minimum on/down time; 3) Flexibility operation and management: DERs coordination and control, either through centralized control by aggregators or decentralized, market-based mechanisms; 4) Flexibility trading platform: a neutral body that supports flexibility needs specification, contracting, delivery, and settlement. While this proposal offers a solid base for conceptualizing and operationalizing flexibility in power grids, it overlooks the critical stage related to consumers engagement. Indeed, despite the technical, economic and environmental benefits of flexibility, the participation of consumers in its provision remains low [13], partly due to the lack of clear value propositions for these actors [14]. Closing this gap requires including stages for attracting and capacitating consumers to engage in the flexibility business.

A different framework is described in [15], where USEF proposes a flexibility value chain that defines the role of each actor in the provision of flexibility, as well as the necessary interactions between them. Here, aggregators play a central role by acquiring flexibility from consumers, aggregating it, and bringing it to the market to serve different stakeholders, including DSOs, transmission system operators (TSOs) and balance responsible parties (BRPs). To enhance the perceived value of flexibility, this proposal incorporates value stacking, allowing aggregators to deliver multiple flexibility services to various flexibility requesting parties (FRPs). However, as in [12], it overlooks consumer engagement and does not explicitly address cross-sector integration, essential for unlocking demand-side flexibility.

In [16], the authors present a high-level overview of a value chain for flexibility services. Although the proposal does not detail the specific steps involved in flexibility provision, it highlights the challenge of realising its value. It identifies four key areas that a flexibility value chain shall incorporate to successfully engage all relevant actors: 1) Revenue stacking: access to multiple revenue streams helps to reduce risks and build viable BMs, encouraging the participation in LFMs; 2) Fairness: as flexibility becomes an increasingly integral component of modern energy systems, assigning it a fair value is essential to ensure market efficiency and participation; 3) Route to market: LFMs tend to favour larger FSPs, limiting access for smaller ones, therefore simplifying entry requirements can help to unlock substantial untapped flexibility potential while ensuring service quality; 4) Non-financial value: beyond financial returns, flexibility supports low carbon technologies and sustainability goals, and so rewarding solutions which provide environmental benefits, or favouring them in market auctions, can further promote the investment in sustainable solutions.

Building on the gaps and limitations identified in the existing proposals, we propose a novel FCVC, which includes the main stages and activities for enrolling and participating in flexibility-centric BMs. This FCVC is the result of the analysis of flexibility-related BMs and of the role model identification in [11], departing from [10, 17]. It is divided in 6 main stages, as depicted in Fig. 1, mapping the main and secondary activities, and the main roles involved at each stage.

The first stage is Flexibility enablement. It involves the purchase or retrofit of DERs by consumers to unlock their untaped flexibility potential. It includes not only energy assets, such as photovoltaic panels (PV) panels and batteries energy storage systems (BESS), but also cross-sector assets, such as EVs, HPs, heating, ventilation and air conditioning (HVAC) systems, and electric water heaters (EWHs). The GDBN provides support to this stage by matching consumers with asset providers and financial partners. This facilitates DER installation and financing, thus promoting consumer participation in emerging BMs involving RECs and flexibility provision [18, 19].

The second stage, Integration/Enablement, focuses on the seamless integration of DERs into digital platforms. This includes placing metering systems, configuring energy management systems (EMS), and connecting to aggregators platforms capable of managing DERs portfolios.

The third stage, Aggregation, is essential for flexibility market participation. There, Aggregators and EC Managers optimise their portfolio of flexible DERs to bid in LFMs, and activate the flexibility selected. Thus, this stage also includes pre-qualification into LFMs, ensuring FSPs and their DERs comply with the FRP requirements.

Negotiation Preparation is the fourth, and it is where FRPs calculate and define their flexibility needs, which may also include the determination of flexibility zones [20]. Zones also help aggregators to optimize their portfolios. Secondary activities include markets performance analysis and simulation, grid forecasting, etc.

The fifth stage, Market Operation, encompasses the functioning of the LFM itself, usually through a digital platform (such as OMIE and Enedis). It includes the

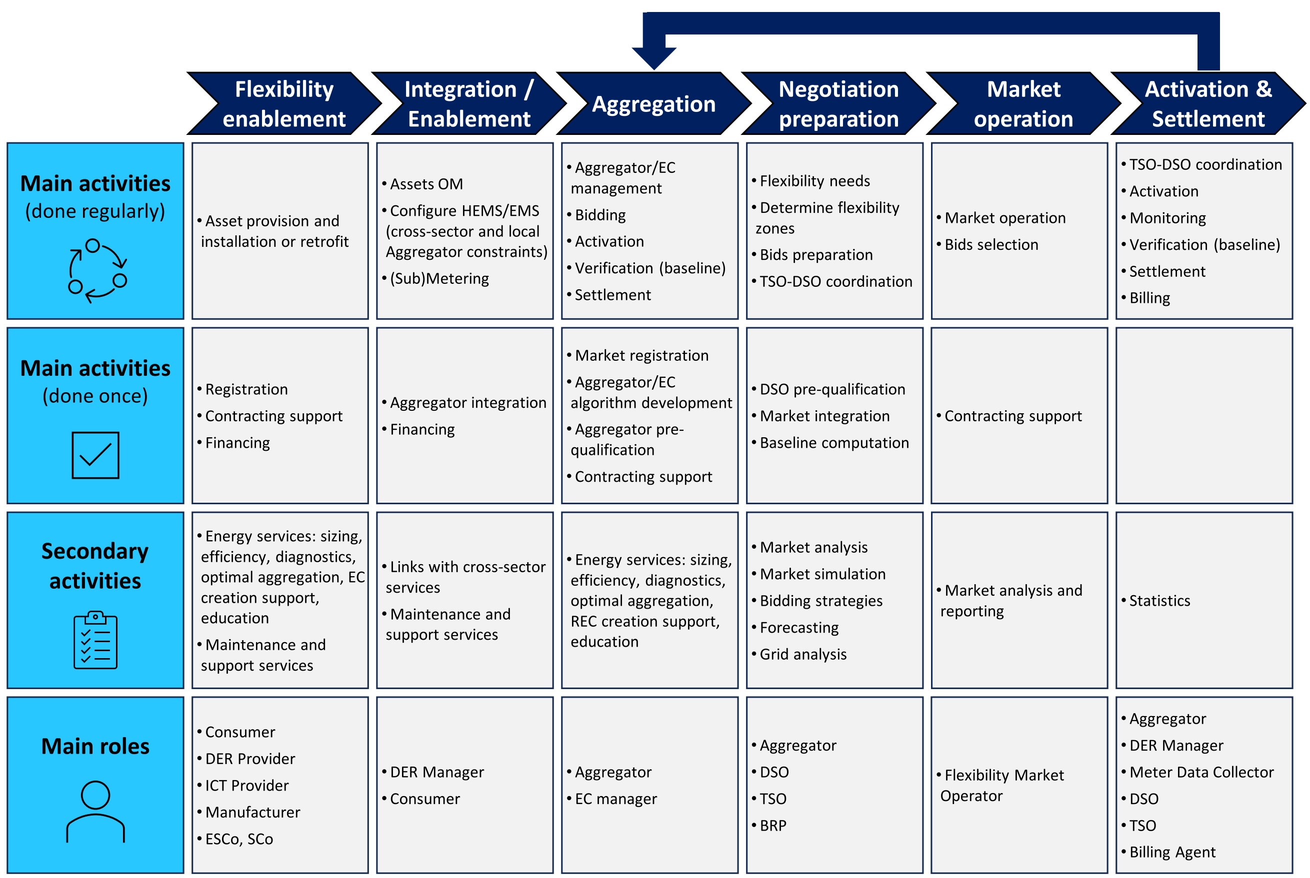

Fig. 1 FCVC stages, activities, and main roles (adapted from [10])

publication of flexibility needs online, followed by bids submission, LFM clearing, and market clearing results publication.

The final stage, Activation and Settlement, includes the activation and verification of the selected flexibility and its financial compensation. Since LFMs may lack built-in mechanisms for the real-time activation of flexibility, the GDBN can assist the SOs and aggregators in that task. Verification involves comparing the delivered flexibility against baseline and metered data, while settlement calculates the financial compensation, accounting for any penalties due to under-delivery. The GDBN support for these functions is particularly relevant for small SOs, who may lack in-house capabilities to manage these post-market processes [11].

GDBN digital platform to support the FCVC

The GDBN platform, see Fig. 2, was designed to support the primary activities of the FCVC and facilitate secondary activities for all stakeholders at each FCVC stage. The current outlook for digital platforms that fully embody this FCVC is limited. Several platforms exist that partially cover sections of the FCVC, namely: Solmatch [21] for the flexibility enablement stage; Tiko [22] and Bamboo Energy [23] for the integration/enablement, aggregation and activation stages; Piclo Flex [24], Flexible Power [25], ElectronConnect [26], Localflex [27] and NODES [28] for the negotiation preparation and market operation stages (while partially supporting the activation and settlement stage). Yet none of these platforms encompasses all the stages of the FCVC. The goal of the GDBN is to simplify processes and contractual agreements, driving participant engagement and unlocking flexibility provision. The GDBN can also integrate third-party services and digital platforms, such as existing commercial LFM platforms or REC management platforms, grid segmentation services [20], etc., while offering additional services like flexibility activation, which are not always included in LFM platforms.

The GDBN relies on a set of modules and services to ensure the support of the FCVC. The **flexibility-centric services module** includes basic services to match consumers with energy resources providers and retrofitters for enablement, to match consumers with aggregators to their flexibility to the flexibility markets. Both, short-term scheduled and the short-term dispatched flexibilities are considered at design level [10], but only short-term scheduled was yet implemented. The **value-chain services module** includes basic services to support registering and contracts management, and relevant energy and flexibility data repositories. Finally, **interoperability and data spaces module** allows as an opt-in support for interoperable and standard data interfaces available for the inclusion of stakeholders' digital platforms and external market platforms considered in each stage [29, 30]. More in-depth descriptions of the GDBN can be found in [10, 11].

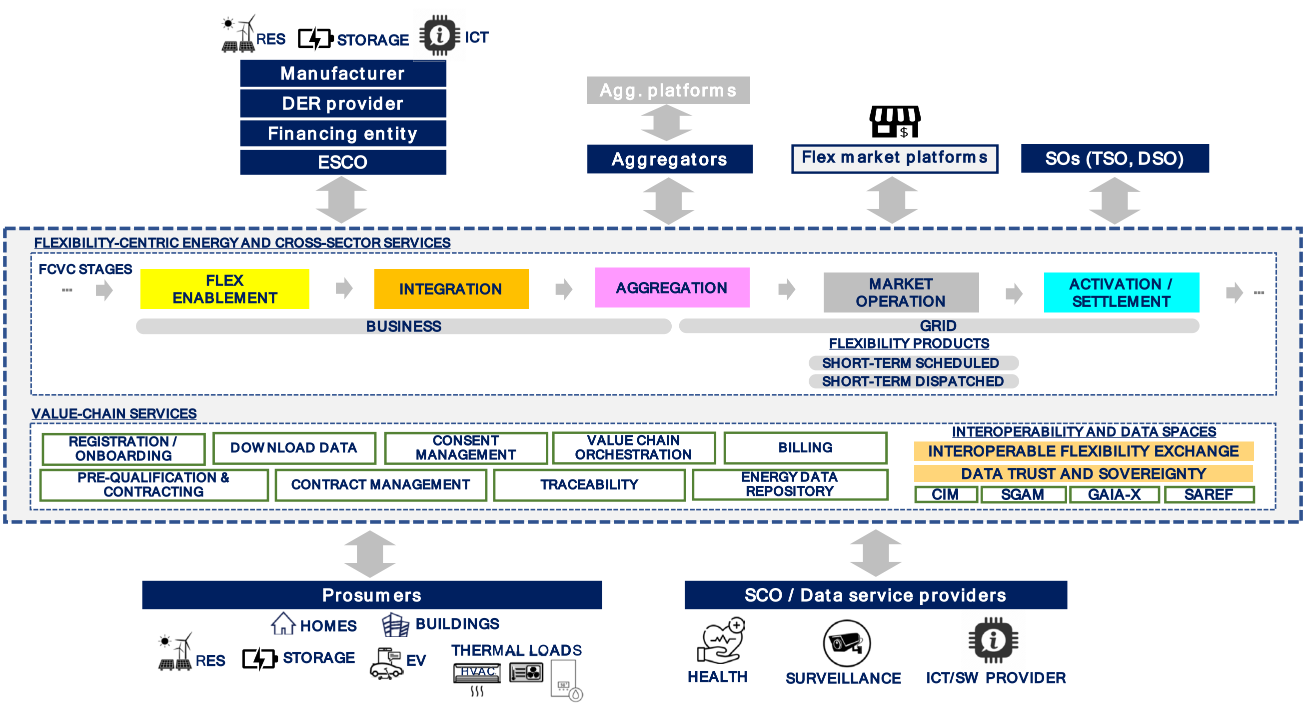

Fig. 2 Architecture of the GDBN

Local flexibility markets platforms

LFMs and the corresponding LFM digital platforms allow consumers to unlock greater value from their DERs by providing flexibility to SOs or trading with other FRPs [6]. In [31], digital platforms to support flexibility provision are classified into four groups: aggregator platforms, LFM platforms, grid platforms, and data exchange platforms. LFM platforms, which are the focus of this section, support the procurement and negotiation of flexibility products. They enable SOs to access local flexibility from small and large-scale aggregated demand, storage and generation sources, usually not accessible through traditional mechanisms such as day-ahead, intraday, capacity or balancing markets [32].

Previous works have already focused on LFM platforms and flexibility products. In [6], the authors provide an in-depth review of several platforms considering three areas: market description, structure, and market timing/implementation. However, some of the revised platforms were part of research projects, not deployed in real-world market contexts, and the study does not consider important aspects such as LFM participation levels. Moreover, given the time of publication, the analysis may no longer reflect the current operation of all platforms. Next, [33] examines a set of LFM platforms with a particular focus on identifying drivers for their success. These include addressing governance challenges, coordination mechanisms, gaming mitigation, and, most critically, reducing barriers to boost LFM participation. Nonetheless, many of the platforms analysed are no longer in operation, and the review places less emphasis on the implementation of the platforms in terms of operation and flexibility procurement and trading mechanisms. More recently, in [34] the authors provided a short review of several platforms, including both aggregator and LFM platforms, and identified relevant gaps. This analysis was complemented by a summary of the flexibility products offered, distinguishing between standardized and non-standardized products traded in the revised platforms. However, some of the platforms and products described have already suffered updates. Hence, while the works cited offer valuable insights, the rapid evolution of LFMs and products requires periodically updated analyses of their status. The following review provides a new updated comparative analysis of several LFM platforms deployed in different contexts, supporting different procurement horizons, namely long-term (LT) and short-term (ST). Specifically, it examines the end-to-end operational process of 7 platforms active across 12 countries in Europe, North America, and Oceania, as presented in Table 1.

The opening LFM platforms included in this work were first launched in the UK, namely Piclo Flex, Flexible Power, ElectronConnect, and Localflex. Indeed, the Energy Networks Association (ENA) places the UK as a global leader in the deployment of flexibility and LFMs [78], probably due to its more flexible regulation. Among those platforms, Piclo Flex has the broadest geographical reach, operating in 3 European countries, Australia, and the USA, thus spanning 3 continents. In parallel, other countries are developing their own platforms. In France, Enedis (the largest DSO, responsible for around 95% of the territory [79]) has developed its own LFM platform. Similarly, in Spain, the operator of the Iberian electricity market, OMIE, has also created its LFM platform, and NODES has deployed a platform operating primarily in Northern Europe and Canada. Additionally, a consortium of European TSOs established the Equigy crown balancing platform (CBP) [80]. Scheduled to start operating between 2025 and 2026, Equigy is expected to operate in Austria, Germany, Switzerland, Italy, Netherlands [81], enabling Aggregators [82] to provide services to DSOs and TSOs [82, 83]. However, as Equigy is not yet fully operational, the accessible information remains limited, and so the platform was not included.

To complement this review, the flexibility products traded in these platforms are listed and described in Table 2.

RECreation digital platform for the management of energy communities

Under this decentralization and digitalization context, RECs are emerging as new actors with the potential of aggregating their members for flexibility provision. RECreation is a digital platform developed by INESC TEC for the management of CSC structures and RECs [92]. RECreation integrates the tools and energy services needed to plan and operate REC under different running modes, including:

- A front end to configure the REC and show basic energy and economic indicators in its dashboard to inform the REC manager and members on the operation and performance of the REC.
- A database with structural data regarding the REC, and economic and energy data such as the opportunity costs of the REC members, consumption and generation data, and local transaction and settlement results.
- A transactions module to compute the local energy transactions and prices according to the selected BM.
- A settlement module to compute the financial compensations derived from the local energy transactions and verify the energy allocation performed by the DSO, including the grid access tariffs for the energy self-consumed. A billing guide provides, to the REC manager, all the

Table 1 Summary of the end-to-end operational process of relevant LFM platforms

Platforms	Countries	FRPs	FSPs	Pre-qualification	Procurement	Bidding window	Dispatch	Validation and settlement
Piclo Flex and Flexible Power	UK, Australia, Italy, Portugal, USA [35]	DSOs [36]	Aggregators, suppliers, large consumers, and generators [37]	Company: check FSP's profile [38, 39] Asset: check technical parameters [38, 39] and test APIs [40]	Some DSOs do LT auctions yearly [37, 39] and ST weekly [37, 39] Other DSOs do monthly auctions [40, 41]	LT auctions: ≈ 2 weeks [42] (unclear for ST auctions) Monthly auctions: few hours [40, 43]	Sent via email or API [44]	Supported by the platform. FSPs can manage meter data, obtain settlement reports, and access invoices [45] Alternatively, FRPs are allowed to use their own system and connect it to Piclo Flex [46]
ElectronConnect	UK [47]	DSOs [48]	Aggregators, generators [49]	Commercial: check FSP's profile [50] Technical: check assets parameters [50]	LT: seasonally [51] ST: weekly [52]	LT auctions: < 2 weeks [53] (unclear for ST auctions)	Sent via API [50]	Supported by the platform. FSPs submit baselines and meter data Platform verifies flexibility delivery, reports are issued, and payments are DSO pays the FSPs [47, 50]
Localflex	UK [54]	DSOs [54]	Aggregators [54]	Commercial: check FSP's profile [55] Technical: check assets parameters [55]	LT: yearly, monthly, or weekly auctions, 0.5–3 years ahead of need [56] ST: day-ahead or intraday auctions [56]	LT: 1–2 weeks [57, 58] ST: few hours [59]	Sent via email or API [60]	Supported by the platform. FSPs upload meter data from before/during delivery time, platform computes baseline, delivered flexibility, and payments. Settlement reports are issued, DSO pays the FSPs [27]
Enedis platform	France [61]	DSOs [61]	Large MV sites, aggregators [62]	Assets must be inside pre-defined grid zones and be able to receive activation signals [63]	Annual or biannual [61]	Few weeks (≈ 2 months) [63]	Sent via email or API [64]	Done by the DSO, likely off-platform (no mentions of settlement support [63, 64])

Table 1 (continued)

Platforms	Countries	FRPs	FSPs	Pre-qualification	Procurement	Bidding window	Dispatch	Validation and settlement
OMIE platform	Spain [65]	DSOs [65]	Aggregators, generators [65]	Grid: ensure FSPs assets meet technical needs [65] Product: ensure FSPs can provide flexibility as per market/product design [65]	LT: auctions from years to weeks ahead [65] ST: day-ahead or same day auctions [65]	LT: months to weeks [65] ST: few hours [65]	Sent by the DSO, not specified how [65, 66]	Done by the DSO, likely off-platform (no mentions of settlement support [65, 66])
NODES	Norway, Sweden, Finland, Belgium, Canada [67]	DSOs, TSOs [68]	Aggregators, micro-grids, BRPs [69]	Assess regulatory/financial aspects of the FSPs [70] Assess FSPs assets technical data [70]	LongFlex MaxUsage: seasonally [71, 72] ShortFlex: 1 to 3 days ahead of need [71]	LongFlex: closes 1 week before delivery [73] ShortFlex: closes 1 day before delivery [73]	Sent via message, email, API [71, 74]	Supported by the platform. It computes baselines using data provided by FSPs or SOs [75] Link with metering hub to store meter data [76] FSPs get monthly settlement notes and payments [77]

Table 2 Description of the flexibility products traded in the revised LFM platforms

Platforms	Markets (products traded)	Horizon	Product description	Remuneration scheme
Piclo Flex Flexible Power ElectronConnect Localflex	Peak reduction [84]	LT [56]	Procured in LT auctions where FSPs agree to reduce their demand during pre-defined time windows, typically during periods of high consumption. This service may be fulfilled through LT energy efficiency improvements or behavioural changes that reduce consumption, with a focus on peak demand periods [85]	Activation only [84]
	Scheduled utilisation [84]	ST [56]	Procured in ST auctions where FSPs agree to deliver flexibility during pre-defined time windows. This pre-scheduling allows DSOs to manage grid constraints in advance and provides an opportunity for FSPs that cannot participate in real-time markets. It is useful for addressing forecasted peak demands or grid reinforcement deferral [56, 85]	Activation only [84]
	Operational utilisation [84]	ST [86]	Procured in ST auctions where FSPs agree to have their flexibility activated in real time (or close to real time) based on grid conditions, with the volume of flexibility being agreed shortly before. Hence, FSPs respond dynamically to grid measurements, allowing DSOs to deploy flexibility where and when it is needed, such as in the case of unplanned events such as outages or system faults [85]	Activation only [84]
	Scheduled availability + Operational utilisation [84]	LT + ST [56]	Procured in LT auctions, FSPs agree to be available to provide flexibility during pre-defined time windows. While availability is pre-specified and non-negotiable post-contract, the actual volume of flexibility to be delivered is determined closer to real-time based on grid conditions. This enables DSOs to ensure sufficient contracted flexibility, while optimising dispatch to reflect system needs [56, 85]	Availability and activation [84]
	Variable Availability + Operational Utilisation [84]	LT + ST [86]	Procured in LT auctions, FSPs agree to be available to provide flexibility during pre-defined time windows. However, unlike in the previous product, availability can be refined closer to the delivery window. Like before, activation is determined closer to real time based on actual grid conditions. This product supports long-range forecasting while allowing refinement of operational parameters as system conditions change [85]	Availability and activation [84]
Enedis platform	With capacity reservation [62]	LT + ST[1]	FSPs agree to be available to provide flexibility during pre-defined time windows. Upon receiving an activation order issued by the DSO, the FSPs are required to deliver flexibility [62]	Availability and activation [62, 63]
	Without capacity reservation [62]	ST[1]	The FSPs do not commit to provide flexibility beforehand. Instead, upon receiving an activation order issued by the DSO, they have the option to either accept or reject the request [62], enabling a more variable and potentially opportunistic participation in the market	Activation only [62, 63]

Table 2 (continued)

Platforms	Markets (products traded)	Horizon	Product description	Remuneration scheme
OMIE platform	Availability [66]	LT [66]	FSPs agree to be available to provide flexibility during pre-defined time windows. Activation is not granted, and might be renegotiated closer to delivery [66, 87]	Availability and activation [66]
	Agreed activation [66]	LT [66]	Similar to the Availability product, also involving availability and activation terms. However, in this product, once both terms are agreed, they are not renegotiated later. Thus, it is designed for flexibility procurement when the needs can be forecasted well in advance, and activation can be scheduled ahead of delivery time [66, 87]	Availability and activation [66]
	Activation, optional availability [66]	ST [66]	Procured in ST auctions where FSPs agree to deliver flexibility during pre-defined time windows. Availability is optional, and its negotiation depends on the needs of the DSO. FSPs previously contracted in LT Availability auctions are obliged to submit offers in this market [66, 87]	Activation and optional availability [66]
	Activation [66]	ST [66]	Procured in ST auctions (typically intra-day), FSPs agree to deliver flexibility during pre-defined time windows. Unlike in the previous product, in this case there is no link to the LT market [66, 87]	Activation only [66]
NODES	MaxUsage [75]	LT [75]	Procured in LT auctions, the FSPs commit to limiting their consumption/injection to a certain level during a pre-defined time windows, meaning dispatch signals are not required. Hence, it is suitable for FSPs seeking a simple option that does not need real-time market participation [88, 89]	Availability only [90, 91]
	LongFlex [75]	LT [75]	FSPs commit to a specified availability during pre-defined time windows, subject to potential activation. FSPs offering this product are obliged to later submit ShortFlex offers in the ST market [88, 89]	Availability and activation [89]
	ShortFlex [75]	ST [75]	FSPs commit to actively change their consumption/injection levels during a pre-defined time window. Participation in ShortFlex can either stem from prior LongFlex contracts or independent ST auctions [88, 89]	Activation only [89]

[1]while Enedis does not explicitly divide its products in LT or ST, their horizon can be inferred through comparison with similar products offered by other platforms

information needed to prepare the invoices to the REC member.

- The EMS that computes the optimal setpoints of the flexible resources (pre-delivery optimization) and can also compute the optimal transactions according to predefined criteria (post-delivery optimization). When providing flexibility, it computes (with pre-delivery optimizations) the REC baseline and its flexibility bids, according to the flexibility needs, as described in [93].
- Finally, the sizing module supports the planning process by optimally sizing new resources for the REC.

The main tools and the modules of RECreation, as well as a summary of their functionalities, are presented in Fig. 3.

Two types of energy allocation modes are supported by RECreation, granting this platform the ability to adapt to different regulatory frameworks, namely pre-delivery and post-delivery allocation [94]. Pre-delivery allocation methods rely on allocation coefficients (ACs) independent of the final metered energy. Examples include the fixed ACs as specified in the Portuguese regulation, or ACs proportional to contracted power under the Spanish regulation. In contrast, post-delivery ACs are computed based on the final metered energy after delivery, and can be, for example, proportional-to-consumption, that can be automatically computed by the DSO, or dynamic ACs, computed by the REC manager from the metered energy data provided by the DSO.

Fixed and proportional ACs can be directly computed by the DSO without additional REC inputs, as in Fig. 4, providing to the REC manager (EGAC in the Portuguese regulation) the energy allocations and the metered energies. From these energy allocations, the transactions module computes the transactions that would have resulted in the same energy allocation and the transactions prices according to the price mechanism defined by the REC. Finally, the settlement module computes the internal compensations ensuring that members injecting energy are compensated by those consuming it, and the energy allocations performed by the DSO and the grid access tariffs the DSO charges to the REC to enable its verification.

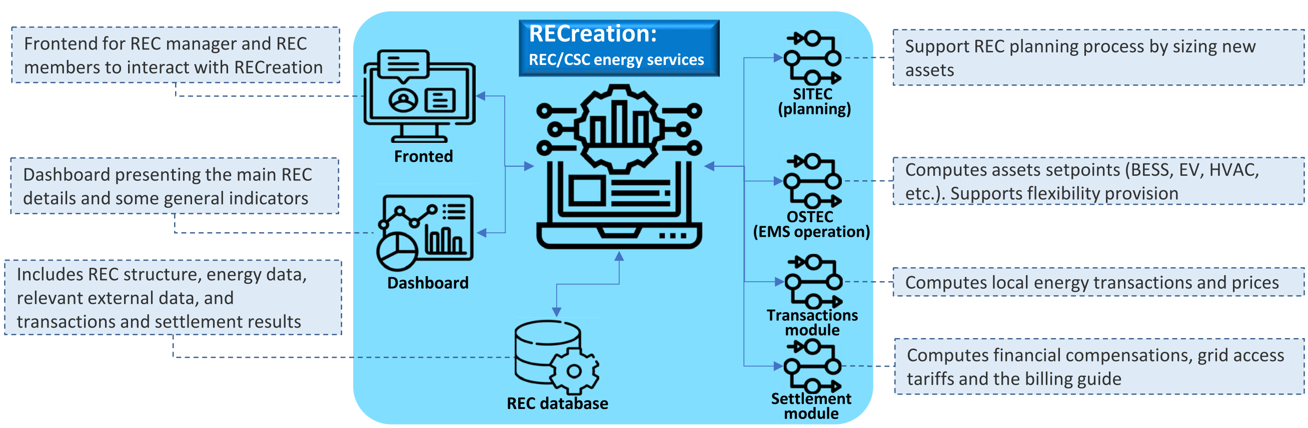

Fig. 3 RECreation: INESC TEC platform for the management of RECs

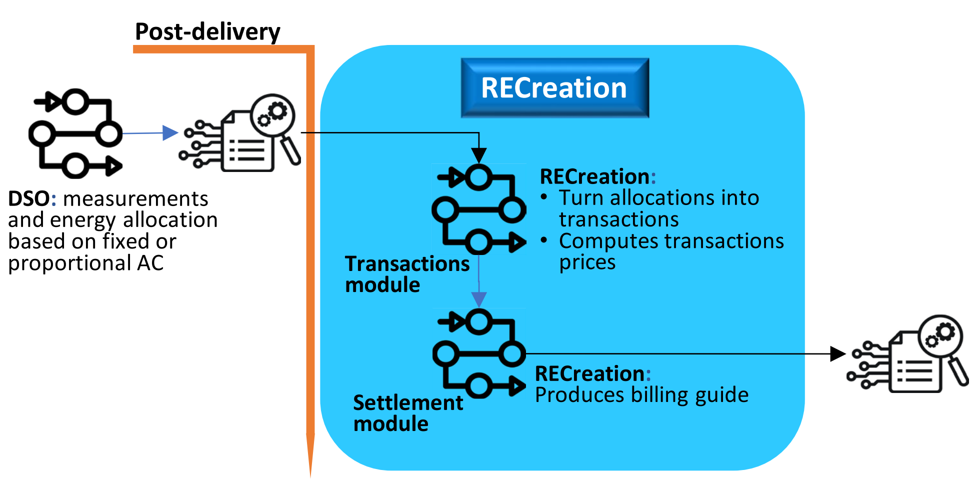

Fig. 4 RECreation operation with fixed or proportional-to-consumption ACs

When dynamic ACs are used, two different phases can be distinguished. In the pre-delivery phase, the EMS computes the optimal setpoints of the flexible assets, for example, for the day-ahead. In the post-delivery phase, the DSO shares with the REC manager the energy measurements of the members and a default energy allocation based on the proportional-to-consumption approach. The transactions module computes the optimal transactions and prices according to the selected REC BM, for example using a post-delivery pool market [5], and the dynamic ACs that correspond to these transactions, which have to be sent to the DSO to verify their values and use them to perform the final energy allocation, as in Fig. 5. Dynamic ACs offer greater flexibility compared to the other methods, allowing, for example, REC members to use the energy from their own assets before sharing the surplus with the other members, and are the most advisable ACs for the provision of flexibility, as discussed in [94]. Dynamic ACs are implemented in the Portuguese and French regulatory frameworks, among others, but not yet in the Spanish one.

When RECreation operates with flexibility provision, the EMS has a central role to compute, at pre-delivery time, the baseline, the flexibility bids, and the dispatch of the flexible assets to provide the flexibility finally committed and activated by the FRPs. The end-to-end process of flexibility provision using the RECreation platform is depicted in Fig. 6. Under this framework, the REC can behave directly as an aggregator of the REC members'resources, operating them in a centralized manner. Once the LFM is cleared, the selected flexibility is communicated for activation. The REC manager computes the final setpoints of the flexibility assets to ensure the optimal delivery of the requested flexibility. Following flexibility delivery, the local energy transactions reflecting the energy shared among REC members, while accounting for flexibility provision, and the corresponding dynamic ACs, must be calculated for the DSO to compute the final energy allocation and inform energy suppliers of the final energy supplied, reduced by the energy self-consumed. Note that, as explained in [94] or in [5], dynamic ACs allow the REC to allocate energy according to their optimal needs and dispatch decisions, effectively enabling the provision of local flexibility to LFMs, however they are not currently fully implemented in several countries, except for France. For instance, in Portugal, although the regulation adopted dynamic ACs, it still lacks a final DSO procedures definition.

Digital platforms integration

The GDBN is a digital platform developed by INESC TEC that enables stakeholder's digital platforms along the FCVC according to their profile, streamlining the technical integration processes and setting contractual agreements required for flexibility provision. It acts as an engagement driver to help unlock flexibility potential by integrating third-party services and digital platforms, including existing commercial LFM platforms or aggregators platforms to aggregate distributed resources and participate into the flexibility markets. Likewise, aggregators only need to interact with the GDBN independently on the LFM platform they want to operate, since it is the GDBN that makes the interoperable link with existing LFM

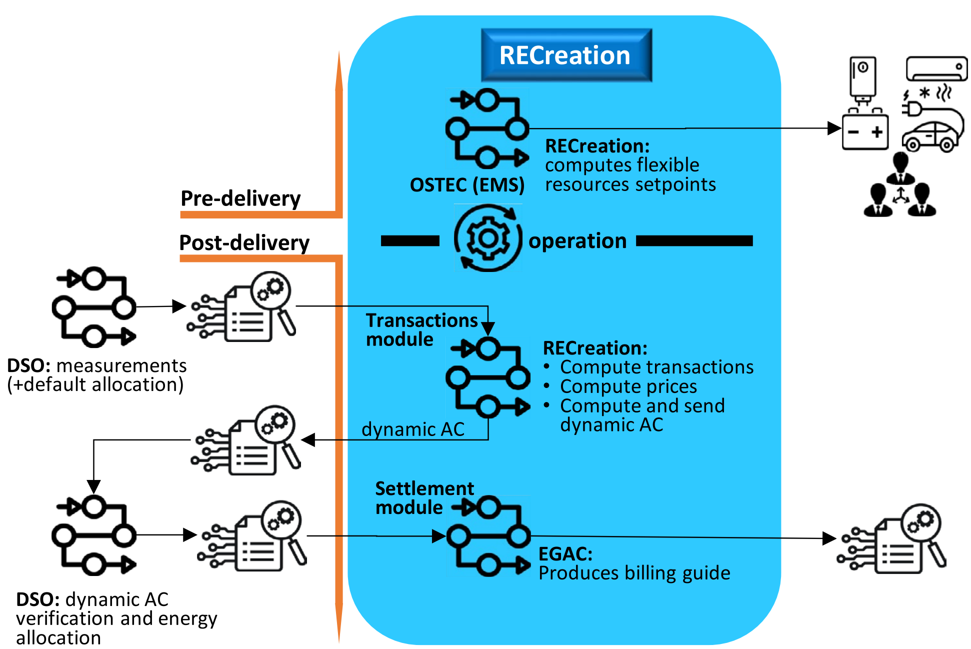

Fig. 5 RECreation operation with dynamic ACs

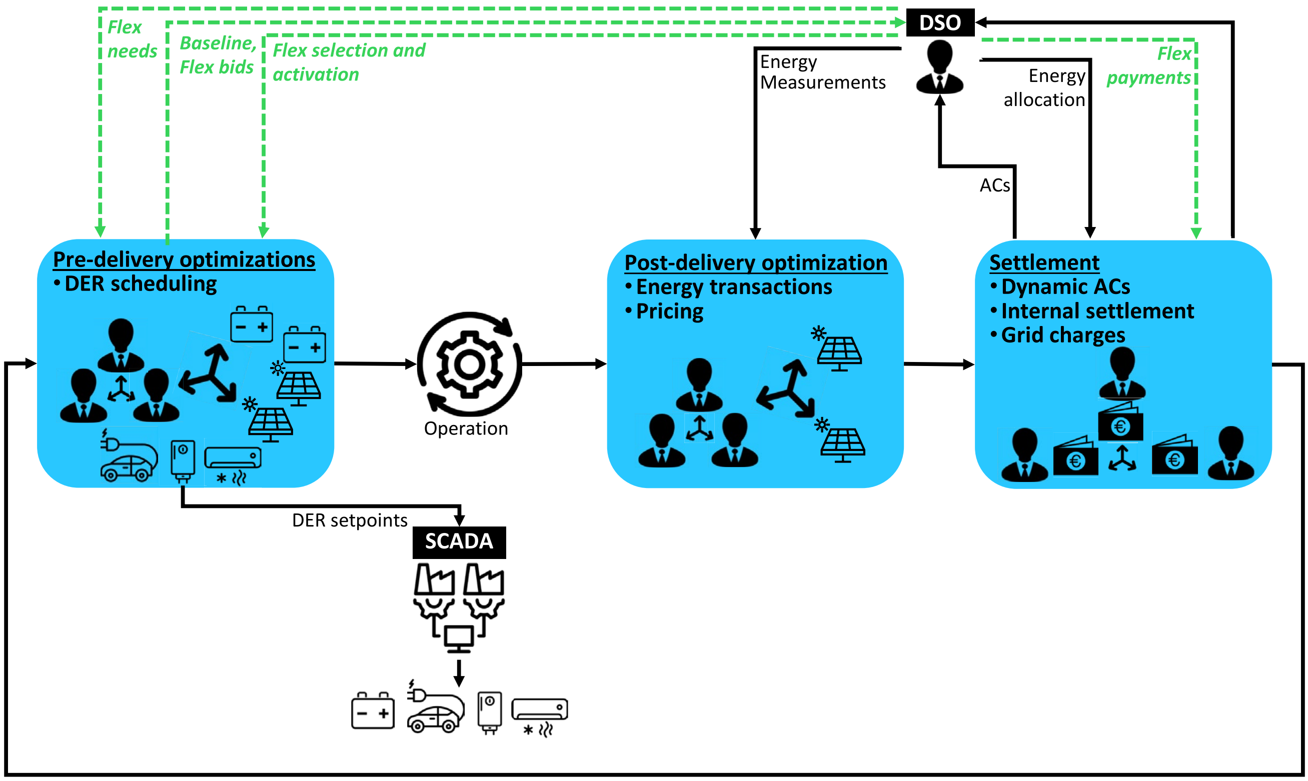

Fig. 6 RECreation: workflow with flexibility provision

platforms. An example of this integration, based on the platforms described in this work, is illustrated in Fig. 7. In this case, as a natural aggregator of the REC members, the RECreation platform acts as an aggregator that brings the REC flexibility to the market. The GDBN provides an interoperability layer so that the aggregators interact with the GDBN without the need of developing different connectors to different market platforms. Once onboarded in the GDBN, the aggregators can interact with any flexibility market supported. For simplicity, the processes of registration and pre-qualification are not shown but are described in more detail in [10]. The interoperable capacity brought by the GDBN also allows the establishment of agreement among aggregators, by enabling bilateral contracts among aggregators to be established, allowing smaller aggregators to take bids to market and then to activate and settle among them. As more LFMs are integrated, aggregators that operate in regions covered by different markets or planning expansion to other regions benefit from the GDNB through the technical interoperability and FCVC data hub available.

Conclusions

The deployment of flexibility services at a distributed scale requires a robust digital infrastructure that supports the full spectrum of activities involved in the FCVC. This paper proposed an extended FCVC framework that explicitly integrates consumer engagement and cross-sectoral integration, addressing gaps value chain models. The GDBN platform

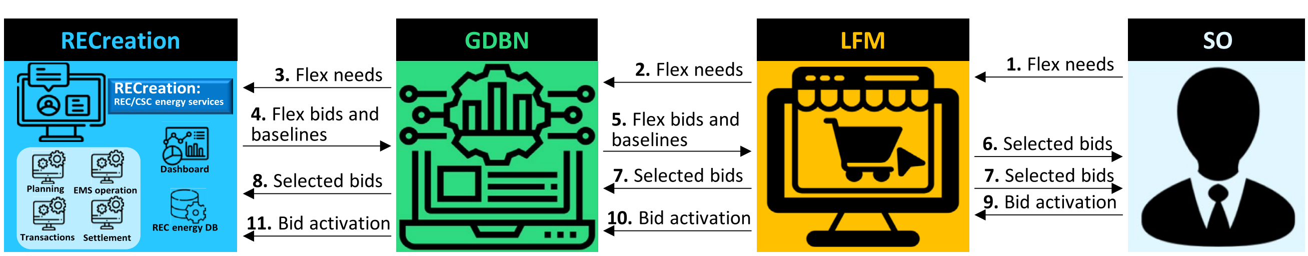

Fig. 7 Overall digital platforms integration

was introduced as a digital solution designed to orchestrate and enable the FCVC, from consumer enablement to flexibility activation and settlement. Through its modular architecture, interoperability services, and support for both commercial and community-based actors, the GDBN fosters collaboration among SOs, aggregators, and RECs.

The integration with the RECreation platform demonstrates the potential of coordinated digital ecosystems to enable energy communities to operate as effective flexibility providers. By connecting stakeholders and interactions across diverse market platforms, the GDBN reduces technical and contractual barriers, thereby facilitating greater participation in LFMs. Ultimately, the coordinated deployment of platforms like GDBN and RECreation contributes to a more inclusive, efficient, and scalable flexibility ecosystem, supporting the EU's energy transition goals.

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Data availability No datasets were generated or analysed during the current study.

Declaration

Competing interests The authors declare no competing interests.

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