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Profitability analysis on demand-side flexibility: A review

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A R T I C L E I N F O

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A B S T R A C T

Flexibility has emerged as an optimal solution to the increasing uncertainty in power systems produced by the continuous development and penetration of distributed generation based on renewable energy. Many studies have shown the benefits for system operators and stakeholders of diverse ancillary services derived from demand-side flexibility. Cost-benefit analysis on these flexibility services should be carried out to determine the profitable applications, as well as the required adjustments on energy market, price schemes and normative framework to maximize the positive impacts of the available flexibility. This paper endeavors to review the main topics, variables and indexes related to the profitability analysis on demand-side flexibility, as well as the influence of energy markets, pricing and standards on revenue maximization. The conclusions drawn from this review demonstrate that the profitability of flexibility services considerably de-pends on energy market structure, involved assets, electricity prices and current ancillary services remuneration.

1. Introduction

The continuing development of Distributed Generation (DG) is revolutionizing how electrical power grids are designed and operated [1,2]. In power systems with a high penetration level of distributed renewable energy, the uncertainty over generation must be handled carefully to avoid reliability and Quality of Service (QoS) losses [3,4].To address this uncertainty, power system flexibility emerges, from technical point of view, as the most efficient solution to face scenarios with high variability [5], but requires more studies to demonstrate its economic viability.

Taking into account that diverse authors define flexibility as the energy system reaction capacity to accomplish its energy objectives at a modest cost despite the variability from both demand and generation [6–8], the scientific community has increased efforts to discover existing and potential flexibility, assets able to produce controllable generation and consumption (flexibility sources), current and new ancillary services based on demand-side flexibility, and cost-benefit analysis features (profitability indicators, time-frame, standpoints, etcetera) for applications and projects with flexibility sources. With respect to cost-effectiveness studies and considering that the flexibility required by the System Operator (SO) was traditionally supplied by conventional generators, as well as huge consumers e.g., big industries or malls [5], and moreover, demand-side flexibility has recently grown strongly, two analysis approaches can be distinguished in the literature. On one hand [9,10], have proposed top-down (generation-side) approach, which generation-side flexibility is investigated. Energy systems with Conventional Generators (CG) [11–13], Large Energy Storage Systems (ESS) [14–16], Power System Coupling.

(PSC) [17–19], and Cross-Border Interconnections (CBI) [20–22] are handled as flexibility sources from generation part where important findings on flexibility exploitation has been drawn. On other hand, demand-side flexibility is investigated from Bottom-Up approach point of view, which flexible end-users [23,24], Virtual Power Plants (VPP) [25,26], Small and Medium Energy Storage System (SM-ESS) [27,28], Electric Vehicle Installations (EVI) [29,30], Demand Response Flexibility (DRF) [31,32] and Distributed Generation (DG) [33],

[34] are the flexibility sources that attract more attention.

Not only flexible sources and ancillary services based on demand-side flexibility (e.g., con-gestion management, investment deferral, peak shaving, valley filling, among others [5,35]) impact on the profitability analysis but also the energy and electricity markets and pricing schemes play a relevant role to create favorable conditions for profitable flexibility applications. For in-stance, an optimized operation of Local Energy Community (LEC) for flexibility purposes is presented in

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Nomenclature

BRP	Balancing Responsible Party BUFS Bottom-Up Flexibility Sources
CAPEX	Capital Expenditures
Co2	Carbon Dioxide
CAES	Compressed Air Energy Storage CG Conventional Generators
CBA	Cost-benefit Analysis
CBI	Cross-Border Interconnection
DAM	Day-Ahead Market
DRF	Demand Response Flexibility
DGS	Diesel Generator Sets
DER	Distributed Energy Resource
DG	Distributed Generation
DMES	Distributed Multi-Energy Generation Systems
DPVG	Distributed Photovoltaic Generation
DER	Distributed Energy Resource
DoD	Non-optimal Depth of Discharge
DPVG + HP	Distributed Photovoltaic Generation with Heat Pumps
DSO	Distributed System Operators
DWPG	Distributed Wind Power Generation
EV	Electric Vehicle
EVA	Electric Vehicle Aggregator
EVI	Electric Vehicle Installations
EMS	Energy Management System
ESS	Energy Storage System
FLM	Flexibility Markets
FP	Flexibility Projects
FS	Flexibility Services
FRP	Flexible Ramping Products
GHG	Greenhouse Gases
HEMS	Home Energy Management System
ICCS	Information, Control and Communication System
IRR	Internal Rate of Return
IRENA	International Renewable Energy Agency IoT Internet of Things
IDM	Intraday Market
LESS	Large Energy Storage Systems
LCOE	Levelized Cost of Energy
LCCA	Life Cycle Cost Analysis
LEC	Local Energy Community
LEM	Local Energy Market
LFM	Local Flexibility Market
LSO	Local System Operator
LV	Low Voltage
MCP	Market Clearing Price
MV	Medium Voltage
NPV	Net Present Value
O&M	Operation and Maintenance
OPEX	Operation Expenditure
PHS	Pumped Hydro Storage
PP	Payback Period
PV	photovoltaic Panels
PTR	Physical Transmission Rights
PSC	Power Sector Coupling
PTG	Power-to-Gas
QoS	Quality of Service
RPM	Ramping Products Market
RTM	Real-Time Markets
RES	Renewable Energy Sources
SOC	State of Charge
SCADA	Supervisory Control and Data Acquisition
SO	System Operator
ToU	Time-of-Use
TDFS	Top-down Flexibility Sources
TLC	Traffic Line Concept
TLM	Traffic Line Mechanism
T&D	Transmission & Distribution
TSO	Transmission System Operator
USEF	Universal Smart Energy Framework
VoLL	Value of Lost Load
V2G	Vehicle-to-Grid
VPP	Virtual Power Plant
WP	Wind Power

Ref. [36], while a model of Local Energy Market (LEM) for Virtual Power Plant (VPP) has been addressed in Refs. [25,37]. Moreover, recent research have reviewed the profitability of flexibility [5] in diverse cases of study, for example, Vehicle-to-Grid (V2G) applications [38], Energy Storage System (ESS) in residential and industrial applications [39,40], demand response for end-users and aggregators [41] and cross-border power interconnection projects [20,21], among others. However, all of them focus only on a particular context, without accurately addressing the whole range of cost and benefits applicable in each case, as well as the time-frame, analysis standpoints, and suitable profitability indicators regarding each application.

According to the aforementioned, this paper reviews the profitability assessment methods applied to case studies of flexibility applications. Besides, a review of main flexibility services and sources, timelines, standpoints, and profitability indicators have been carried out. This work gathers the potential improvements to the cost-benefit analysis methods that allow giving more clarity at the moment to evaluate whether a specific flexibility project is profitable or needs suit-able funding. Additionally, this study proposes an organized method to classify all the information reviewed dividing it by categories and points of view, making possible to prove the diversity of concepts, case studies, and applications. The remainder of the paper is structured as follows: flexibility sources and services are described in Section 3. Section 4 and 5 describe the markets and pricing linked to the flexibility. The existing revenues and costs schemes along with view-point and timeline profits are categorized and examined in Section 6. A review of the profitability indexes is done in Section 7. Later on, an analytical review and discussion on profitability results for the bottom-Up flexibility sources are exposed in Section 8. Lastly, conclusions are drawn in section 10.

2. Methodology

Within the scientific community, innovation and new concepts and theories move quickly, and in terms of demand-side flexibility, content variability is especially diverse, as multiple technologies, configurations, services, and sources exist. of flexibility, as well as regulatory frameworks that determine energy markets and prices and regulate more or less some activities. Accordingly, a methodology is needed to navigate within these various terminologies, case studies, approaches, and analysis contexts in order to find valuable information to be classified and debated. In this section, the methodology that has been conceived for this work is mentioned:

- Design of the review: Bearing in mind that flexibility on the demand side is a recent line of research, which involves technical solutions to challenges related to the increase of variable renewable energy sources in the electricity grid, developments in terms of optimization, control and monitoring, testing of new technologies, profitability of use cases, among others, has a high diversity. To handle this challenge, a three-stage search has been planned and executed. Each of these are discussed in the following items. As general elements to each of the three searches, some criteria have been used. In the first place, a list of concepts and keywords has been prepared by the authors of this article as basic elements for the literature search. These concepts are part of the baseline to which a conceptual extrapolation is carried out to mobilize terms in various concepts towards a common field in which to allow the development of the objectives proposed in this work [42]. With this list of concepts and keywords, together with the selection of appropriate databases for topics related to energy, flexibility and demand management, Boolean operators and plural and singular terms have been applied to key concepts with the aim of capturing the more valuable works, taking into account that the key words and concepts are mentioned in the scientific articles implicitly or explicitly [43]. Second, 2019 was defined as the initial publication date, as a date on which the articles can be valued by the scientific community and their discussion has been possible. This date was extended according to the results of the second search. Third, works in English have only been skimmed due to the inconvenience of translating concepts between languages. Finally, a summation of the concepts and key terms present in the abstract as well as in the title was carried out in order to list the articles according to the relevance for a given pair of concepts [44].

- Primary search: With the initial list of concepts and keywords, a first search is oriented towards review articles on particular key topics, such as auxiliary services, flexibility ser-vices, flexibility sources, virtual power plants, energy markets, price schemes. This search aims to affirm and expand the list of keywords, recognize the correlation between them, recognize characteristic definitions of particular regions such as the Nordic, Iberian, European, Asian-Pacific and North American countries. In this search, the sources and flexibility services have been reflected, as well as the various types of markets, price schemes, regulations, costs and benefits, standpoint and time-frame of profitability and indicators of economic viability.
- Secondary search: This review of articles was carried out to classify the majority of the articles according to the relevance method that was mentioned above. In this stage, the most extensive, articles are prioritized in which some mention of costs and benefits has been made, since many papers only focus on technical performance or only mention energy savings, in terms of the electricity bill. Energy but not on the costs associated with its operation, management, monitoring, control and communication. Additionally, no investment analysis or financing methods are made, which are basic to carry out an adequate profitability analysis.
- Tertiary search: Finally, the third stage of the search revolved around specific case studies in which a profitability analysis is carried out with at least some basic conditions represented in: analysis of costs and benefits during the useful life of the assets, time-frame and standpoint of the analysis, flexibility source, flexibility service or services evaluated, energy market and clear and precise price structure, and comparable profitability indica-tors over time. As a result of the previous stage, the period for starting publication of the articles was extended to 2015, given the articles in which a CBA has been successfully completed.

3. Flexibility sources and services

The inclusion of generation, storage and control capacities into the current power system requires the development of flexibility sources and services. As stated above, various sources have been classified and studied by numerous authors, which are summarized in this section. Some elements must be taken into account to describe each flexibility source properly. Firstly, a distinction between control and management functions and the belonging of the flexible assets has to be carried out, since profitability analysis from each stakeholder is unlike. In addition, many papers have put much attention to the role of a relevant entity, named aggregator. The aggregator is in charge of the management of the flexible resources and represents on behalf of the end-users in front of energy markets, e.g., Day-Ahead Market (DAM) or Intraday Market (IDM). Some authors attribute operator and retailer functions to the aggregator. Conversely, other authors just assign roles of manager and controller of its devices and installations. That debate is still conditioning all the existing profitability analyses.

According to European directives (REDII 2018/2001, arts. 21–22) [45], the aggregator could execute functions as an energy supplier, BRP, flexibility service provider, and balancing service provider [46]. For this paper, the aggregator only manages and controls its portfolio devices and takes decisions with the acceptance of the prosumers, DSO, SO or BRP. Fig. 1 depicts a summary of the flexibility sources, considering that this paper only focuses on Bottom-Up Flexibility Sources (BUFS). Each flexibility source will be linked to the services discovered in the review.

3.1. Bottom-Up Flexibility Sources

BUFS involves the flexibility provided from the demand-side of the power system. Flexible end-user, microgrid, VPP, Electric Vehicle (EV), Distributed Generation (DG), Demand Response (DR), and Energy Storage System (ESS) are flexibility sources more commonly mentioned in the literature. In this section, each BUFS is described, together with its main variations and flexibility services. For the sake of summarizing, Table 1 shows a compilation of the references found in the literature regarding to each flexibility source and service.

3.1.1. Flexible end-users

Flexible end-users are defined as a specified LEC in which ESS, DG, loads, control, and protection devices are interconnected through a Home Energy Management System (HEMS), involving only a single end-user (residential, commercial, industrial, or official) [23,24]. End-user controls their flexible assets and take decisions according to their objectives (savings in electricity bills, improving the energy supply or reduction in their environmental footprint) [24,48,66]. Flexible end-users are divided depending on whether possess energy storage capacities e.g. batteries or EVs, DG (Prosumers) (e.g. Photovoltaic Panels (PV) or microturbines), or none of them [49,67] (see Fig. 2).

Flexible end-users encompass from small residential consumers to large factories or commercial customers, which establish an extensive power capacity set according to energy consumption, assets and available control facilities [67]. In spite of this, flexible end-users can positively impact in the demand behavior (peak shaving and valley filling) [24,47], increasing the self-consumption level [47], as well as in voltage regulation [58,64,65] and congestion management of the distribution

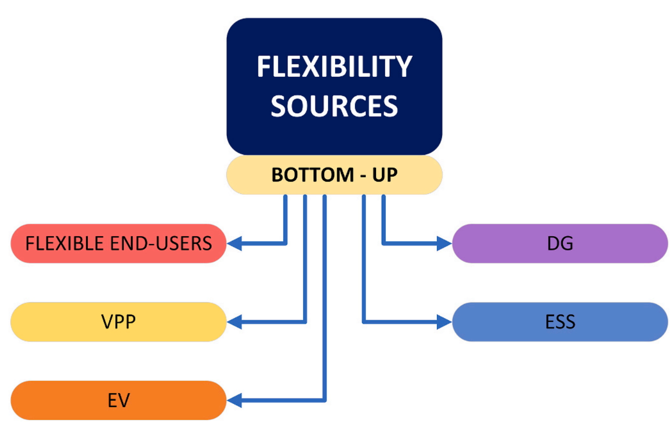

Fig. 1. Flexibility sources.

Table 1
Flexibility services for type of flexibility source.

Flexibility Services	Flexible End-users	VPP	ESS	DG	EV
Energy Trade	[24,47], [41,48]	[23, 49], [50]		[51]	
Price Arbitrage	[39,47]	[23, 52]	[53, 54]		
Peak Shaving Valley Filling	[24,39], [41,48], [32]	[23, 49], [55]	[53, 56], [57]		
Frequency Regulation	[24,47], [41,58]	[46, 49], [50, 55]	[53, 59]		[38, 60]
Voltage Regulation	[24,61]	[46, 49], [50]	[53, 59]	[62]	[60]
Spinning and Non- Spinning Reserves	[58]	[46]	[59]		[38, 60]
Reduction CO_2 emissions		[23]			
Reduction losses	[61]	[63]	[57, 59]	[62]	
Self- consumption	[24,64], [32,41], [61]	[23, 46], [49, 50], [63]	[56, 59]	[51]	[60]
Investment Deferral		[46, 55]	[53, 59]	[51]	
Congestion Management	[24,65], [61]	[46]	[53, 59]	[51]	[38]

lines [24,65]. Mainly, the above services reduce the end-user energy bill, improve the companies' competitiveness and resilience, and diversify incomes. Such benefits could not achieve without the flexibility exploitation. There are services such as Green-house Gases (GHG) emissions reduction and renewable energy penetration level rise, which have not been studied enough and their impacts accurately measured. Likewise, aggregators can accumulate prosumer' capacities to offer frequency regulation products [65], reduction of network congestion, or even trade with energy in following years [4].

3.1.2. *Virtual power plants*

As mentioned before, an aggregator could be included to optimize the management of DG, prosumers, storage devices, and loads at a massive scale in the grid. Such aggregation can be carried out physically (microgrids) [23], preserving only a single bidirectional connection point with the utility, or using an aggregation of dispersed assets linked to VPP with multiple bidirectional connection nodes [25]. [26] defines VPP as a distributed generation aggregation, where small units could perform as a conventional generator within of the power grid, as well as control itself as a single entity. For that reason, the aggregator role becomes essential.

As with flexible end-users, VPP are classified according to storage, generation, and demand response capacities [26], the aggregation process nature (prosumers', microgrids' or demands' aggregations), as well as the type of VPP configuration (fixed or flexible), given that, for instance, coalitions have shown to be an optimal design of VPP for certain applications [23]. Fig. 3 depicts a VPP based on prosumers and microgrids in dynamic coalitions.

As seen in Fig. 4, VPP could supply flexibility services such as frequency and voltage control [22,69] energy reserves [69,70] and price arbitrage [52]. Besides, congestion management and demand response capacities can be empowered concerning the flexibility potential of each VPP or microgrid participant [22,69]. It is worth mentioning that VPP and microgrid follow the management model around the Traffic Line Concept (TLC), which accomplishes with energy commitments of the VPP and provides flexibility to the external agents (DSO, TSO, or BRP) depending on the state of the distribution network and energy market [46].

3.1.3. *Electric vehicle installations*

Undoubtedly, EV is part of the necessary energy transition. An important part of the polluting emissions are attributed to transport and it is also one of the most backward sectors in the electrification process in several countries, even in the most developed ones [29]. There are four main types of EV [29,30] (hybrid, plug-in hybrid, fuel cell, and battery), which are handled as a unique category in this paper. In essence, EV provides flexibility according to its capacity to store energy and use it efficiently [71,72]. Flexible end-users and VPP include EV as a fixed storage device, which is also used as part of their flexible installations taking into account their schedule and load restrictions. On the contrary, in this section, the EV is incorporated within an aggregation structure, which has important differences from VPP in terms of operation and management strategies, distribution of profits, control and monitoring schemes, and available facilities. In addition, authors have highlighted the EVs' particular and significant impact on the grid due to the electrification of the transport sector as well as in terms of

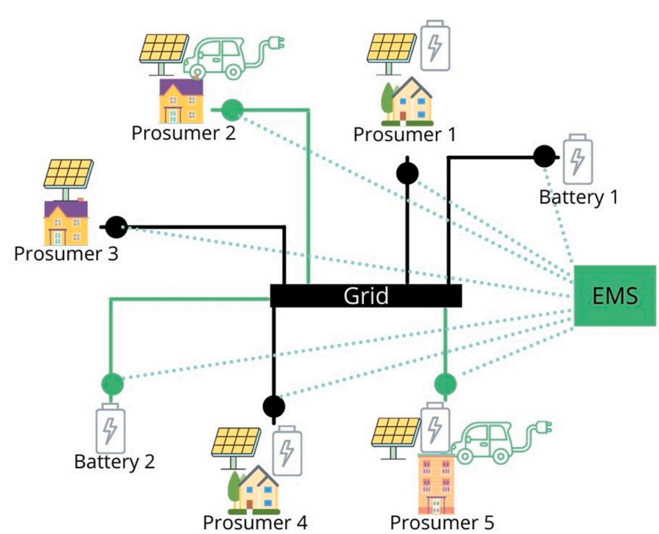

Fig. 3. VPP based on prosumers and microgrids with Energy Management System (EMS). Own preparation with pictures from Canva [68] from Note: Figure shows the activation of flexibility sources (green), e.g., prosumers, to respond a flexibility request.

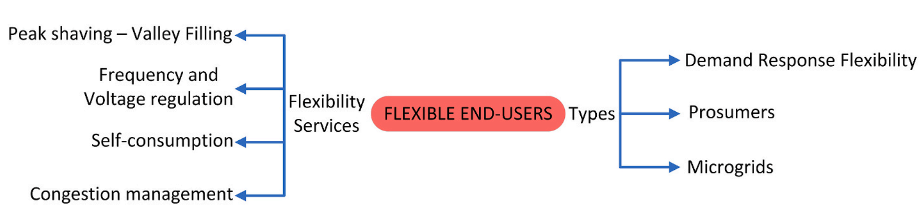

Fig. 2. Flexibility services of flexible end-users.

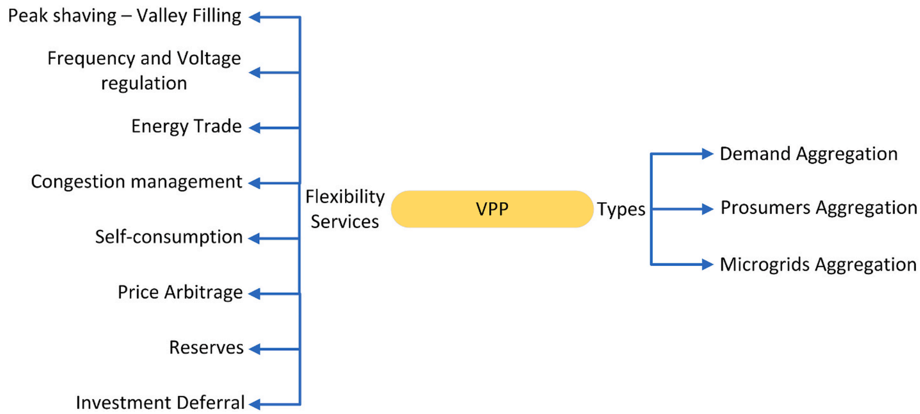

Fig. 4. Flexibility services of VPP.

cost-effectiveness analysis as a relevant vector in the energy transition. For instance Ref. [30], identifies a method to constitute EV coalitions for charging and discharging cooperation. An aggregated model for EV fleets and their provision of frequency regulation in a power system is presented in Refs. [30,73]. On the other hand, mixed virtual eligible units are tested in Ref. [60] to assess possible participation in balancing services in Italy and their profitability for end-users. In addition, research works have incorporated electrical installations such as electric parking lots [74], charging stations [75] or mobile energy distributors [76] as flexible devices able to augment the flexibility potential of the EV.

Nowadays, it is still not clear the entity in charge of controlling and managing each EV aggregation model noticed before. Therefore, an Electric Vehicle Aggregator (EVA) is used in this paper. Consequently, aggregation agents should seek benefits for EV owners, end-users, investors, and itself. Such benefits come from participation in balancing and regulation ser-vices [30,77], reserve markets [78], congestion management [38] or even self-consumption at reduced tariffs [60]. Fig. 5 summarizes the flexibility services associated with the Electric Vehicle Installations (EVI).

3.1.4. *Energy storage systems*

The expansion of flexibility services has been a consequence of the continuous growth of the ESS, which has diminished the capital costs and boosted the efficiency in general terms [56,79]. Moreover, various technologies have placed on the market competitive storage products avail-able for multiple applications. For instance Ref. [40], examines applications, Cost-Benefit Analyses (CBA), and markets of mechanical, electrochemical, electrical, thermal, and chemical energy storage systems, testing the profitability of each one for flexibility services provision. Pumped hydroelectric energy storage, sodium-sulfur, lead-acid, and Li-ion Batteries have been checked to measure value for ancillary services and price arbitrage in Nordic power market [27,28]. Excluding case studies that could entail flexibility sources as flexible end-users, microgrids, VPP, or EVI, ESS, this section aims to refer the devices connected directly to the distribution level [80]. has shown that distribution-system-connected energy storage avoids substation and feeder upgrades, and also extends transformer life and reduces network losses. In contrast to Ref. [80], ESS located inside a power substation ensures stable and reliable power support to their customers [81].

As seen in previous sections, flexibility benefits are offered as services in energy markets. ESS competes, along with VPP, for furnishing distribution asset investment deferrals [79,82] and congestion management support [83]. Likewise, ESS and EVI can influence in end-user consumption curve and hence, peak shaving and valley filling, as well as frequency and voltage regulation, are flexibility services they can offer [81]. Measuring the benefits and designing the services are still the biggest challenges currently, given that they are conditioned to the location and sizing, as well as the domain of the ESS devices (aggregator, DSO, investors, among others) [84]. In conclusion, ESS can provide multiple flexibility services, which are stated in Fig. 6:

3.1.5. *Distributed generation*

Concerns on global warming have fostered the evolution of DG or Distributed Energy Re- sources (DER) in recent years [85,86]. [86,87] define DG as small generation units connected to distribution networks or customer side, where electricity production is carried out close to consumption centers. DG encompasses the Wind Power (WP), PV, fuel cells, micro, and small gas turbines, energy storage devices, among others [85,86]. Concerning flexibility potential, the aggregation of Distributed Photovoltaic Generation (DPVG) [88] and Distributed Wind Power Generation (DWPG) [51] along with heat pumps [9,89], involve case studies with major flexibility capacity and hence, major attention in the current literature. It is worth mentioning that, as stated, flexible end-users, microgrids, and VPP includes PV and WP facilities, as well as any small DG connected to the client-side for this reason, this section only considers the distribution-system-connected appliances.

Both [33,90] recommend the usage of VPP to manage and model distributed generation devices, where the domain of the asset is still a tough topic, because of utility, DSO, TSO, private investor or aggregator could be interested in flexible assets [88]. Each stakeholder may meet their objectives and benefits since the growth of the social welfare of the entire power system must be sought. Part of the flexibility services supplied by DG in power systems are depicted in Refs. [33,34,89] goes from balance and regulation of the voltage and frequency to congestion management and price arbitrage (Fig. 7). Applications of

Fig. 5. Flexibility services of EVI.

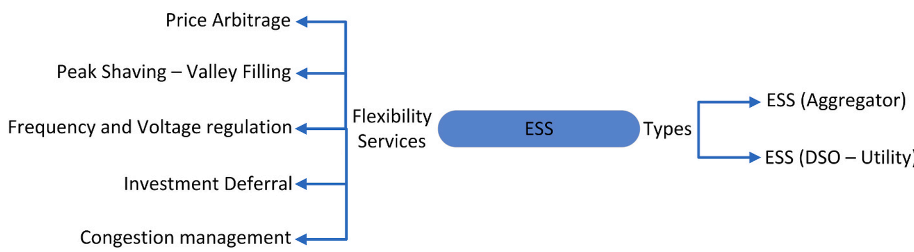

Fig. 6. Flexibility services of ESS.

self-consumption also are tested [87]. Fig. 8 shows a typical distributed photovoltaic generation attached to a medium-voltage distribution grid.

4. Energy markets

Energy markets encompass the whole energy transactions, which seek to supply the projected demand employing the prognosticated generation. Those transactions are traded in a certain period time before delivering [91]. In general, electric power trading is mainly made up of at least two markets (Day-ahead Market (DAM) and Intraday Market (IDM)), which can be found throughout all markets in the world. On the one hand, the energy market traces the energy produced by generation units with the demand of the end-users. On the other hand, the energy market negotiates packages of auxiliary services that guarantee the stability, reliability, and quality of the electricity service throughout the entire network [92].

For flexibility purposes, models for Local Energy Market (LEM) and Real-Time Market (RTM) are proposed in Refs. [37,46,93]. Additionally, diverse Flexibility Markets (FLM) models have been researched in recent years [46]. For ancillary market side, when profitability analysis is carried out for flexibility applications, secondary [49,60] and tertiary control [38],

[61] are commonly used in the assessments. Ancillary market, based on capacity [46], Ramping Products Market (RPM) [36], uncertainty reserve and real-time regulation [12], are also mentioned to optimize the balancing services provision and maximize the profits of the flexibility sources and its stakeholders. In Fig. 9, a summary of energy markets is depicted including both existing and future energy markets.

4.1. *Profitability in energy markets for BUFS*

As mentioned before, evaluating the profitability of the BUFS leads to analyzing the energy market structure and pricing schemes, together with services and products that will be traded between the stakeholders, as seen in section 3. Thus, energy markets found in the literature, regarding to the profitability of BUFS are listed in Tables 2 and 3:

4.2. *Profitability in new energy markets for BUFS*

In the literature, there are some energy market features in discussion regarding to the flexibility of the power system. First, flexibility can be managed both global and locally through LEM, where can either be composed by diverse market segments, or create new markets to trade these services (e.g., FLM, RPM, Capacity Markets (CM), among others). This subsection will examine the proposed new market models.

4.2.1. *Local energy market*

Local Energy Market (LEM) aims to be a framework that allows transactions of flexibility services between different flexibility sources and their participants (flexible end-users, aggregator, EV owners, ESS owners, or DSO), empowering to the end-users about their consumption and energy excesses [37,46]. This new market would have three components as follows:

- Energy: On this market, the energy exchange between flexible end-users or aggregators would be possible, as well as transactions with DSO, when needed, generating a set of benefits in all levels of the grid. In addition, local services can be put in available to avoid local grid problems.
- Capacity: This segment market aims to remunerate the capacity of flexibility source to be available over a given time horizon. The capacity payments reduce the payback period of distributed generation, stabilize long-term price signals and support the decarbonization of the electrical power grids.
- Flexibility: Flexibility spans the services orientated towards the punctual request by DSO, TSO, or BRP such as congestion line support, voltage regulation, backup supply, among others. These services could be paid both for energy or capacity.

[37,46,50] have mentioned LEM features. The role of a new entity, named aggregator, acquire relevance considering that aggregator can contract global and local services with DSO, TSO, or BRP on behalf of prosumers. The usage of the Traffic Line Mechanism (TLM) to regulate the energy exchanges between local entities is one of the main features of LEM operation.

4.2.2. *Flexibility market*

The development of the flexibility concept, together with the evolution of the distributed generation and energy storage system along with the power system, has fostered the debate around a flexibility market, where both generation-side and demand-side response can be traded. In the literature, diverse approaches to flexibility market are distinguished. First, the local approach is addressed by Refs. [95,96] where flexibility is seen as a local resource with high spatial resolution. Generally, both flexibility suppliers and buyers are traded in a local environment, with the mediation of aggregators, DSO, TSO, or even local system operators. These entities control and oversight the flexibility transactions at a local level. On the other hand [97], defines

Fig. 7. Flexibility services of distributed generation.

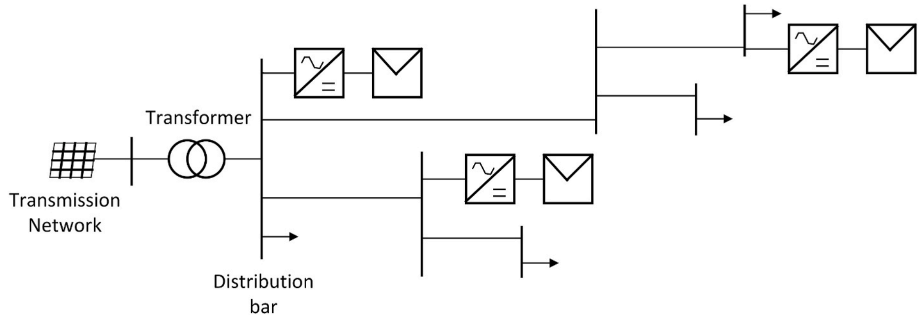

Fig. 8. Distributed photovoltaic generation (PVDG).

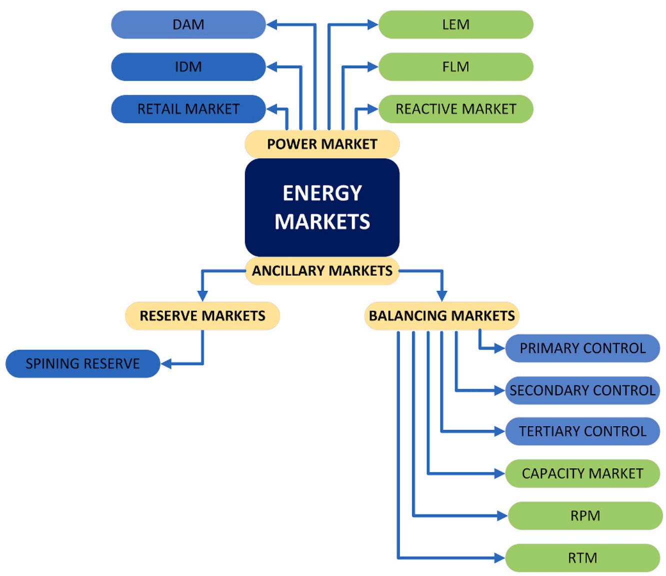

Fig. 9. Existing (Blue) and future energy markets (Green).

Table 2
Existing Energy markets involved in profitability of BUFS.

Energy Markets	Flexible End-users	VPP	ESS	DG	EVI
DAM	[24,47], [41,65], [32,48], [61]	[23,46], [48,50], [52,55], [63]	[53,54], [56,59]	[51,62], [88]	[38,60]
IDM	[47,58], [48,65]	[23,46]			
Secondary Control	[41,61]	[49,55]	[59]		[38,60]
Tertiary Control	[58,61]	[52,55]	[56,59]		[38]
Spinning Re-serve		[52]	[59]		
Retail Market	[39,47], [64]	[63]			

flexibility as a global resource, which should be traded into both existing markets (ancillary, balancing, and intraday markets) and new flexibility markets. Within existing markets, several settings should carry out for exploiting power system flexibility.

4.2.3. Capacity and reactive market

Nowadays, system operators are in charge of the reliability of the power system. In order to guarantee long-term adequacy, operators need enough investments in new generation capacity, which are obtained through the capacity market. The participants in the capacity market are

Table 3
Future Energy markets involved in profitability of BUFS.

Energy Markets	Flexible End-users	VPP	ESS	DG	EVI
RPM					[94]
LEM		[46,50]	[57]		
Capacity Market		[46,70]			[60]
Flexibility Local Market	[41,95], [61]	[46]		[51]	[96]
Reactive Power Market		[52]			
RTM			[54]		

rewarded either based on capacity payments or in a capacity auction, depending on the energy policy of the country. Generally, only conventional generators, interconnectors, and large energy storage system owners are participants in capacity markets, but multiple authors have already recommended to include the renewable generation units in this market as a condition to accomplish the 2030 environmental target [70]. Capital payments are incurred years ago or at the same time where energy is delivered. Such payments permit to reduce the payback period of the non-conventional energy projects, including flexibility applications [46], as well as to as-sure long-term price signals. Capacity payments could be funded through avoided costs such as expanding investments, extra generation capacity, or congestion costs.

Reactive market is one of the new markets proposed by Ref. [56], where reactive power bids and offers are submitted into reactive market located sequentially later of the DAM and spinning reserve market. In the VPP case tested by Ref. [56], an optimal bidding strategy is found, which maximizes the VPP arbitrage opportunities in the energy markets and increases the expected profits. Reactive market aims to foster the investments in reactive power capacities of the flexibility sources, as well as to improve its reactive products according to the new challenges of the power system.

4.2.4. Ramping product market

Flexibility is described in terms of energy, power, actuation time, and ramping capacity [94]. shows a set of Flexible Ramping Products (FRP) provided by EV, which could offer in a new energy market. Given that traditional ramping products sources, such as gas plants, flywheels, and compressed air, provide FRP expensively, alternatives as EV and ESS can be profitable. RPM can be linked to the capacity market to incentivize the investments in flexible generators units, also it can become part of traditional markets in both market mechanism and pricing scheme [98]. This new market boots investments in the ramp capacity of the flexibility sources, impacting positively on the power system reliability and deferring the execution of regulation services.

5. Pricing

As shown in Section 4, energy market and energy pricing come to form part of an economic environment with high influence on the profitability of the flexibility applications, thus a review about energy pricing schemes is mandatory. According to the conclusions by many authors, energy pricing has to evolve from bidding zones to bidding nodes [12], as this could be the optimal solution for congestion issues or efficiency problems in transmission lines [38,51]. Nodal pricing is established according to distributed generators connected to the transmission and distribution lines, their limitations, among other aspects, which offer personalized incentives for new capacities. Additionally, availability, ramping features, or capacity could be included in the same market-clearing strategy, or conversely addressed standalone way.

5.1. Profitability in energy pricing for BUFS

Profitability assessment of the flexibility applications involves studies of the impacts of the pricing on expected profits. For BUFS, this question is addressed by authors according to two different approaches (see Tables 4 and 5).

In most EU members, DAM uses a once-per-day uniform-price auction to obtain spot and forward prices for market participants. Flexibility sources such as flexible end-user [47], VPP [23,52], demand response [48], distributed generation [62] and electric vehicle installations [60] uses spot and forward price in the CBA. Intraday and ancillary markets operate with the same auction mechanism, but with the trading time along the day. Pricing related with biding prices are employed by Refs. [38,41], for measuring the payments for providing regulation services to the grid. Otherwise, maximum and minimum historical accepted prices for up/down regulation services are included in the profit calculation process in order to improve the estimation accuracy [38,60]. On the new market side, the authors mention pricing schemes for each market. For instance, capacity market and reactive market apply capacity unit price [41] and reactive power product price [52].

Secondly, flexible end-user, VPP, demand response, and ESS case studies are tested based on retailer tariffs. Time-of-Use (ToU) [24,53], power subscription [47], critical peak pricing [41] and energy [48] and power-based [56] are commonly seen in flexibility projects. In these cases, flexibility sources are only interacting with the available utility and marketers in the connection point. For that reason, it could be more accurate than using prices from wholesale markets. Profitability surveys without clarifying on price nature are scavenged in Refs. [49,52], causing un-certainty on research findings.

Table 4
Pricing and tariff used in BUFS applications related to energy markets.

Pricing	Flexible End-users	VPP	ESS	DG	EVI
Spot Price	[47,48]	[23,46], [50,52], [63]	[54]	[51,62]	[38,60]
Feed-In Tariff	[48]	[49]			[38]
Locational Price	[32]				
Real Time Price	[39,65]		[54]		
Dynamic Pricing	[32]	[63]			
LEM Energy Price		[46,50]	[57]		
Historical Up/Down Prices					[38,60]
Regulation Prices	[41]				[38]
Regulation Bid prices	[58]	[50]			
Capacity Unit Price	[41]				[60]
Spinning Reserve Price		[52]			
Reactive Power Price		[52]			

Table 5
Pricing and other tariff used in BUFS applications for retail energy market.

Pricing	Flexible End-users	VPP	ESS	DG	EVI
ToU Tariff	[39,47], [24,41], [32]	[46]			
Energy Based	[47,48]		[53,56]		
Power Based	[47,64]				
Subscription Price	[47]		[56]		
Critical Peak Pricing	[39,41]				
Retail Price	[24,39]	[49,50], [52,63]			[38]
Energy Price for ESS		[23]			
EV Charge - Discharge Price					[38]
Wind Power Price				[51]	
Price kWh Reduced	[41]				
Gas and Thermal Price		[49]			

5.2. New energy pricing for profitability of the flexibility

In order to find suitable solutions to the challenges that high penetration of renewable energy could cause to the power systems, research efforts have been done in the land of new energy markets and hence, new pricing schemes. The foremost proposals will be discussed in this section as follows:

- Nodal and zonal prices: It is expected that energy markets are moving from zonal to nodal (locational) prices, or at least toward hybrid pricing, which has proved that generate more surplus difference than nodal pricing solution [99], as nodal scheme could be affected by cross-border interconnections between power systems. Nodal pricing has a direct impact on the activation of flexible resources in vulnerable nodes, given that flexibility sources are located at the end of the feeders with low marginal price activation. The aforementioned was tested by Ref. [100] for twelve low voltage prosumers in Genk, Belgium.
- Local energy market prices: As shown in Table 4, authors have developed both particular and general local energy prices [23]. estimates energy price provided by ESS within of prosumer coalition. In this case study, this price is agreed upon between the ESS owner and the aggregator. Likewise, EV owners could define energy price for charging or dis-charging of the battery, according to the flexibility consumer requests [38]. For distributed generation systems, a particular tariff is established for wind energy or photovoltaic energy, including it into local energy markets [51]. In Refs. [46,50], a price of energy injected from local energy community into the network is included, which is defined by the aggregator, marketer, DSO, or an agreement between them.

6. Cost-benefit analysis

The cornerstone of profitability analysis is CBA [14,79]. This kind of analysis is widely sundry, in where a lot of variables and considerations are taking into account from numerous standpoints, concepts, and meanings. For instance, some authors broadly divide costs either between fixed and variable or between short and long-run [11]. Likewise, revenues should be also properly measured through different approaches. Also, it is important to consider that each cost and benefit are related to flexibility services, time fame to profitability (short or long period), and standpoints of the analysis (e.g., aggregator, flexible end-users, DSO, TSO, BRP, or to all the stakeholders). For this reason, this section begins with standpoints and timelines of the profitability. Afterward, costs and benefits will be defined, classified, and organized in order to facilitate the profitability analysis of each flexibility source and its applications.

6.1. Standpoints to profitability

As mentioned previously, profitability analysis has to spin around one or more participants or power systems as a whole. Each profitability analysis standpoint entails particular cost and revenues chains, as well as bidding strategy, energy pricing, and operation modes, all of them with the aim of maximizing the profits of each member. Market features and regulations affect more strongly to the flexible end-users than to the aggregator or the DSO and vice-versa. For that reason, Table 6 is shown the preferences in the literature to select the different existing standpoints.

Given that, the end-users acceptance is required to carry out the most flexibility projects, flexible end-users are usually selected to check the convenience of certain applications related with microgrids and VPP [46], demand response programs [32,41,48] and ESS [53]. Safeguarding a proper comfort level, remaining fair energy prices, and ensuring information privacy are key elements for end-users, besides preserving and increasing the profits from its flexibility (e.g. self-consumption and reliability). In addition, as shown in Table 6, profitability of the aggregator is also analyzed in Refs. [38,48,50]. Distribution System Operator (DSO) is also included within the profitability assessments for flexible end-users [47], microgrids [50], ESS [53] and DG [51,62]. References seek to measure the DSO profits to prove the positive impacts that the flexibility on Transmission and Distribution (T&D) Networks and profitability and suitability of the DSO investments could do in these projects.

As a complement to the above, possible investors should have certainty of the expected profitability in terms of quantity, period time, and specific conditions [53,59]. Examining the profits throughout the power system as a whole must be a guideline where all participants can be aware of their benefits. [47,101], have applied the above standpoint, but it can be very complex and have implicitly relevant uncertainty levels.

6.2. Timeline to profitability

Within the cost-benefit analysis, a pertinent factor to consider is timelines. Timeline defines a period time in which the sum of cost and benefits should be conducted. Such period time is correlated with two project features, investments and operation time of Flexibility Services (FS). Investments are split into short, medium, or long terms, each of them has a given minimum level of profitability to be considered as profitable. Each investor defines their payback period, internal rate of return, risk level, or Net Present Value (NPV). Indexes will be addressed in the next section. Additionally, flexibility services are also executed in short (15 min or less) or long times (from 6 h onwards). Flexibility services behave variably over time. For example, balancing services provided by electric vehicle batteries are cheaper in long period time than in short periods, since EV battery has a high wear-and-tear cost due to continuous charge and discharge cycles. The opposite situation occurs with demand responses programs, which are commonly used in real-time balancing services. Considering the above, this paper shows a review of the timelines of the profitability analysis in Table 7.

In this paper, two timelines period are distinguished in the literature to measure the profitability of the flexibility projects. On the one hand, analysis process in which the entire economical useful life of the project is included [14,53,56]. Such survey must consider the installed de-vice lifetimes, life cycle cost, depreciation and interest rate, as well as the proper forecast models for energy prices, degradation factors, the acceptance rate for bids, evolution of the consumption and generation, and instinctive changes on regulation. On the other hand, multiple flexibility ap-plications are tested in short terms, for instance, during the first-year financial impact, the project behavior can be compared with a base case [102]. Short terms for profitability assessment periods are beneficial for low intensity investment projects, given that risk and uncertainty levels must be carefully tackled and flexibility services are usually provided in brief delivery times in comparison with lifetime project [15,24,62].

6.3. Revenues

A proper measurement mechanism of the revenues, in terms of profitability, is a crucial part. When flexibility is examined, products and services offered by providers towards consumers, are put in a certain energy market. The main revenues for flexibility sources come from the trading of these products and services, which were mentioned in section 3. Finally, the incentive for renewable energy installation, preferential and differentiated taxes, subsidies, investment supports, compensation and reward rates, and other financial incentives are also classified as revenues, given that increase the profitability of the projects. As mentioned, the above categories are seen in the literature. Therefore, this section intends to address the types of revenues that flexibility

Table 7
Time Frame involved in profitability of BUFS applications.

BUFS	Short-Time	Long-Time
Flexible End-users	[24,32,39,41,48,64]	[39,47]
VPP	[23,50,52,63]	[46]
ESS	[54]	[53,56]
DG	[62]	[51]
EVI	[38,60]	

Table 6
Standpoint analysis in profitability of BUFS applications.

BUFS	Flexible End-users	Aggregator	EV Owner	DG Owner	DSO	External Investor	VPP
Flexible End-users	[39,47], [24,58], [41,64], [32,48], [61]	[03] [48],			[47]	[47]	
VPP	[23,63]	[50,63]			[50]		[52]
ESS	[53,56]		[54,59]		[53,57], [59]	[53,59]	
DG				[51]	[51,62]		
EVI		[38]	[60]				

projects generate and to show the way they have been defined and gauged by authors.

6.3.1. Flexibility products and services revenues

As mentioned before, the most revenues of the flexibility projects are flexibility products and services traded on new and traditional energy markets. Every flexibility source has their capacity to provide certain flexibility products or services. Therefore, the analysis of the revenues must be done case-by-case. Additionally, revenues appear within an economic context with the relevant influence of the markets and pricing schemes. Thus, profits can be situated in one or another market.

- Energy Sales: Going through the whole flexibility sources and their products and services, energy sales are a common denominator. As shown in Table 8, each flexibility source de-fines the envisaged energy sales between their stakeholders and external agents such as DSO, TSO, and BRP or market auctions. Although energy trade being a monopolized activity, exclusive of marketers or system operators, authors dare to suggest an energy trade in undistinguished directions. Virtual power plants and microgrids possess a larger amount of the energy exchanges, including the multiple interactions with existing and new markets, energy sales into DAM [52] and LEM [50]. Energy sales between end-users and aggregators, as well as with retailer or DSO are described into [23,49], respectively. Likewise, energy exchanges in demand response and distributed generator flexibility-providers between end-users and retailers, as well as with DAM, are studied in Refs. [48,51,62]. Electric vehicles have barged into power systems as relevant actors. From an energy sales point of view, authors have simulated EV participation on DAM [60], as well as energy exchanges with retailers and DSO [38]. As stated in previous sections, each energy sale or exchange works over pricing schemes and market processes (e.g., auction, bilateral agreement, etcetera). Commonly, consumers install distributed generation devices to obtain savings in electricity bills through increasing self-consumption. This same concept is applied in energy communities, which intend to encounter the proper level of internal consumption with storage and generation capacity, as well as flexible load and management tools. Flexible end-users and Virtual Power Plant (VPP) include a rate of self-consumption as revenue in the CBA and also in energy storage devices, where are used as a complement to the renewable energy sources, for example, storing energy in peak production period and discharge it in minimum generation period or peak demand hours [56].
- Revenues from capacity: Both capacity market and existing markets with capacity payments, the capacity becomes a relevant revenues sources for flexibility projects. Every flexibility source could be remunerated regarding capacity, but authors have only investigated this kind of revenue in flexible systems with storage devices [46,52,60], and demand response programs [41].
- Regulation Services: As seen in Table 9, regulation services are supplied by almost all the flexibility sources in this present paper. Revenues from accepted up/down bids in balancing or regulation markets are quantified in the total profits of VPP [50,52], demand response [41], ESS [53] and Electric Vehicle Installations (EVI) [38,60]. In contrast [41,53], discuss the regulation services in terms of payments per kWh reduced and for peak shaving and valley filling effects on the demand curve, respectively.
- Reserves: Operational, spinning, no-spinning, replacement, and frequency control reserve are some kinds of reserves that have been addressed in the literature. Bottom-Up Flexibility Sources (BUFS) can indeed gather significant capacity for reserve but its revenues have not yet been completely measured.

Table 8
Revenues from energy sales.

BUFS	Energy Sales in DAM	Energy Sales in IDM	Energy Sales in Retail Market	Energy Sales to End-Users	Self-consumption Energy
Flexible End-user	[24,48]		[39]	[48]	[39,64,65]
VPP	[23,49], [52,63]		[49,50]	[50,52], [63]	
ESS	[54]	[54]			[56,57]
DG	[51]			[62]	
EVI	[38,60]			[38]	

Table 9
Revenues from regulation and ancillary services.

BUFS	Regulation Services Sales	Payments for PS and VF Services Sales	Payments for kWh reduced
Flexible End-user	[41]		[41]
VPP	[50,52]		
ESS	[53]	[53]	
EVI	[38,60]		

6.3.2. Benefits

In order to model the indirect positive impacts of the flexibility sources in the power system, several benefits have been modeled by authors in the CBA. These benefits could be seen as

Flexibility products or services, but conversely, they are presented as positive consequences of the available flexibility execution. In this section, and according to Table 10, a large variety of benefits are described as follows:

- Investment deferral and congestion management: DSO and TSO must invest in new distribution and transmission lines, as well as in upgrade assets such as transformers, protection elements, cables, and structures. As seen in section 3, flexibility source can defer investments, producing savings in a certain period on the one hand, and improvements in the competitiveness and solvency of the system operators on the other hand. Distributed generators and storage devices contribute significantly to the investment deferral and hence, authors have estimated their revenues [51,53]. Here, revenues reflect the investment difference between the base case planning horizon and a new one with flexible sources. Additionally, system operators and utilities can attain savings in terms of lost opportunity cost, given that investment deferrals free up funds for new business or strategic expenses. This saving in the opportunity cost is accounted as revenues as well. Contrary to grid investment deferral, congestion management is measured in short terms as are punctual grid congestion due to unexpected events or demand peaks during the day. Generally, its remuneration is given by pricing agreements between suppliers and system operators.
- Other benefits: About Renewable Energy Sources (RES), there are two benefits that authors have been addressed. Green certificates and reduction in the RES capacity-based premium. The high penetration of Distributed Energy Resources mainly based on Renew-able Energy produces undoubtedly emission polluting savings. Few authors have delved into an estimation of these emissions, proposing future research to develop this revenue that could be very meaningful. Just, in Ref. [12] an assessment is carried out through saving in fuel

Table 10
Revenues from flexibility benefits.

BUFS	Upgrade Investment Savings	Battery Waste Reduction
VPP		[55]
ESS	[53]	
DG	[51]	

consumption in conventional generators. Apart from that, reducing the RES capacity-based premium represent benefits for end-users since such subsidies would be eliminated or transferred to others sectors, such as power-to-gas, EV charging terminals, microgrids, among others [17].

6.3.3. Incentives

As a formula to stimulate investments in renewable energy, numerous countries have created subsidies and incentives to impact positively on energy project profitability [60]. has proved the great influence of tax burden on profitability and has pointed out some changes needed to maximize profits. For instance, when PV, VPP, ESS, distributed generators, and EVI [60] yield energy to the network some taxes such as transmission cost (transmission service, enhancement charge, among others) should be suppressed for DAM and ancillary services. Even authors handle financial incentives for installing storage [59], shifting loads [47], installing RES or DER [17], supporting investments on energy projects [12], as well as tax incentives for foreign investors [103] or taxes credits for RES [11]. The aforementioned incentives can be considered as revenues, given that they diminish the cost and encourage the profitability [61] (see Table 11).

6.4. Costs

This section exposes the most common costs used in Cost-Benefit Analysis (CBA) of flexibility projects, discussing definitions, measurement methods, as well as highlight some considerations when assessing the profitability. With the objective of putting in order the costs and avoiding both gaps and overlaps, the present paper proposes to group costs regarding to flexibility products and services, investments, Operation and Maintenance (O&M) expenses, penalties and taxes, degradation, and other additional expenditures. Likewise, the previous categories will be considered in the description costs as well.

6.4.1. Flexibility product and services costs

In order to provide flexibility products and services, a set of costs are incurred by flexibility sources. Authors have addressed the costs as a whole and around specific services. For instance, it is common to find in the literature investment deferral cost or congestion management cost as global cost for these services, where Operation and Maintenance (O&M) and capital cost are included implicitly. Besides, costs are defined within a certain activity such as energy purchases, up/down bid production, or installation cost. This section, some cost categories used in the literature will be mentioned and some consideration about them will be commented.

- Energy Purchases: Undoubtedly, all flexibility sources manage the energy and fuel consumption cleverly, from end-users to conventional generators. Energy purchases are part of proper energy management and a high profitability. Therefore, multiple papers have researched the better way to model energy purchases in each flexibility source taking into account energy market features and regulations. The energy purchases can also be seen as either external; energy exchanges with external agents such as system operators, aggregators or end-users into energy markets, or internal; energy exchanges between participants of a same flexibility sources. According to Table 12, for external energy purchases side, all flexibility sources, described in Section 3, participate in DAM [24,38,48,49,52,53,60], IDM [54], AM [60] and retail market [41,47,56] to procure electricity for consumption, price arbitrage and shifting load. In the same way, distributed generators include the cost of demand in the distribution system, in terms of the total end-user's consumption connected to the T&D network [62]. In regards to internal energy purchases, it is important to point out that these energy exchanges depend on the profitability standpoint (e.g., flexible end-user, aggregator, DSO). Therefore, energy exchanges between end-users, aggregators [48], Electric vehicle batteries [38], and distributed generators are contained in profitability assessment.
- Investment Deferral Cost: Investment deferral costs are mainly formed by the expenses of the grid enhancement and per-kilometer cost of the feeder type [51]. The first value is related to the investment in the grid due to increased maximum load. Meanwhile, in-vestments in feeders, located in a certain zone, are only counted in the second item. The reduction of previous upgraded costs, during a fixed planning period, represents the possible revenues from investment suspension.
- Congestion Cost: Generally, system operators conduct reports about T&D networks con-gestion which are based on congestion cost [53] and the cost of losses (active and reactive) [52,62]. Savings in congestion cost and T&D Networks losses represent the main bene-fits flexibility sources can offer to the system operators [63].

Table 11
Revenues from incentives and subsidies.

BUFS	EU Incentives for REC/CIC	Investment Support	Capital Subsidy	Self-consumption bonus
Flexible End-user	[47]	[39]	[39]	[39]
VPP	[46,103]			
ESS		[59]		

6.4.2. Marginal costs

For flexibility sources able to produce energy from distributed generators or ESS, calculating marginal cost is the most common way to set a price for that energy. As seen in Table 13 [50,52], define the marginal cost of active and reactive power injected into the grid by VPP or ESS, which encompass all costs related to energy production and its bidding into the market. Another approach is used by Refs. [51,54], where is mentioned a production cost involving the capital, operating, and maintaining expenses as a whole. The new flexibility from conventional generators is also seen in terms of marginal cost for regulation services and uncertainty reserve activation, which have been studied by Refs. [5,41].

6.4.3. Capital cost

The investments required to carry out and start up a flexibility project are commonly named capital cost [53]. On the one hand, databases are employed to estimate capital cost as a unit energy cost [56,59], excluding transport, installation, custom charges, among other items. On the other hand, procurement cost for inverters [59], capacitor bank [52], distribution transformers [51], second hand EV batteries [55], among other assets are included in the sum of costs (Table 14).

6.4.4. Operation and maintenance cost

Operation and Maintenance (O&M) Cost corresponds with the necessary expenditures to operate, maintain, manage and repair assets, devices, facilities, and the system as a whole. Some manufacturers and technical institutions like IRENA define references values for (O&M) cost, but there are items that incorporate the above expenses in the literature. In Table 15 is stated the most used O&M variables in the literature. Bottom-Up Flexibility Sources (BUFS) and ESS's maintenance impact strongly on profitability, since both storage devices capital and O&M costs are higher than other asset expenditures in VPP, microgrids, ESS, and EVI [52].

6.4.5. Energy storage devices degradation

With the decreasing of the ESS capital and operation expenditures, storage devices are being installed throughout the power system, mainly on the demand-side. Installing energy storage devices implies a set of costs, which must be carefully modeled so that CBA can carry out with

Table 12
Costs for energy purchases.

BUFS	Energy Purchases in DAM	Energy Purchases in Retail Market	Purchased Energy in AM	Energy Purchases to the EV Users	Energy Purchases from end-user by aggregator	Energy Purchases from aggregator by end-consumer	Cost of demand in distribution system
Flexible End-user	[24,48]	[39,47], [64,65], [32,41]			[48]	[48]	
VPP	[49,52], [63]	[50]					
ESS	[53,54]	[56,57]	[54]				
DG							[62]
EVI	[38,60]		[60]	[38]			

Table 13
Marginal production costs.

BUFS	Marginal cost	Short-run cost	Production cost	Variable Cost	Fixed cost of the technology	Reactive Power injection or absorption cost
Flexible End-user	[39]	[39]				
VPP	[50]			[52]	[52]	[52]
ESS	[54]		[54]			
DG	[51]					

Table 14
Capital costs.

BUFS	CAPEX	Second- hand Batteries	Capacitor bank	New Distribution Transformers	Power electronics inverters	Replacement Cost BESS	Replacement Cost EV battery
Flexible End-user	[39, 47], [41]					[24]	[24,39]
VPP	[46,52]	[55]	[52]				
ESS	[53, 56], [59]						
DG	[51,62]			[51]	[59]		

Table 15
Operation and maintenance cost.

BUFS	O&M Cost	ESS Maintenance Costs
Flexible End-user	[39]	
VPP		[52]
ESS	[53,56]	
DG	[51]	

enough accuracy and effectiveness. In the literature, ESS capital costs are usually included in the CAPEX of flexibility projects, using the database from recognized institutions (e.g., IRENA, IEA). On the other hand, O&M costs are estimated either with the same databases or according to technical assumptions or designers‘ expertise. Concentrating the attention on the O&M, in Table 16 can be seen the diverse costs derived from the ESS implementation in flexibility projects. Inside O&M costs, there are three types related to the flexibility services: degradation cost from utilization, Non-optimal Depth of Discharge (DoD) and State of Charge (SOC), and additional self-discharges [24]. These costs are characterized as follows:

- Degradation cost from utilization: Together with ESS degradation by aging and nominal utilization, extra depletion appears because of frequent charge-discharge cycles. Authors have applied algorithms to model this degradation, which depends on cycle frequency, length, and characterization [79]. Also, according to Refs. [50,55], a frequent charge-discharge cycle affects the efficiencies for both charging and discharging devices during time.
- Self-discharge: The self-discharge is an effect of storage devices, where some energy is lost due to internal chemical reactions. Increasing the charge-discharge cycle implies an increase of the self-discharges due to aging acceleration [38,55].
- Non-Optimal Depth of Discharge (DoD) and State of Charge (SOC): Irregular charge-discharge cycles for flexibility services can produce additional stress on the cycle-aging of storage devices, given that during flexibility services, storage devices can charge and discharge

Table 16
ESS degradation cost approaches.

Degradation Cost	Flexible End-users	VPP	ESS	EVI
Loss Factor for Charging /Discharging	[24,47]	[23]	[56]	[38,60]
Self-discharge Coefficient		[55]		[38]
Efficiencies (losses) Charging/Discharging EV Station		[50,55]		[38]
Charging/Discharging Cost		[23,46]		
Degradation for Cycling	[39]	[23,55]		[38]
Non-optimal DoD	[24]			
Non-optimal SoC	[24]			
Over-charge and Over-discharge	[24]			
Frequent charge-discharge Cycles	[24]			

at low cycle depth also, a very high or very low SOCs, which degrade the store unit lifetime expectancy [24].

6.4.6. Penalties and taxes

As on expenditures, penalties and taxes have a negative impact on profitability of the flexibility projects, given that, they reduce the profit margin of the project. As seen in Table 17, penalties can be seen as a useful tool to model undesired situations such as charging the storage device at peak hours [54], amount of load curtailment [51], power factor deviation [52] or failure to com-ply upward/downward regulation commitments [41], as well as to sit variable and undermined costs, for instance; risk management cost [23], non-optimal DoD [24] or forecasting uncertainty costs [23], and others costs mentioned in Table 18.

Besides, the tax policy of governments also influences profitability. There are taxes in electricity tariff, which repay distribution and transmission activities of the system operators, as well as charges and fees that reflect environment and energy policies. Network fees are relevant in BUFS since these are differentiating factor in life-cycle cost [39,63].

6.4.7. Information, Control and Communication System cost

Information, Control, and Communication System (ICCS) plays a key role in flexibility project management. In order to guarantee a well-managed of flexibility project, data from energy consumption, electricity prices forecasts, weather conditions, among others. These variables must be continuously overseen and readily available. ICCS costs, control technique, and communication language are aspects with larger deficiencies. Certainly, metering and communication costs, together with cost for managing flexible and inflexible loads are deployed in EVI and VPP cost analysis [50,52,60]. Such costs are defined in terms of retailer prices and several upward or downward actions.

6.4.8. Additional costs

Together with traditional cost categories, which have been seen in previous sections, aspects as lost load, star-up and shutdown costs, insurances, depreciation, installation and commissioning costs, engineering and design costs, among other expenses must also be taken into account into CBA. The consequences of a power supply interruption in a certain power system or network are quantified by Value of Lost Load (VoLL). Start-up and shutdown costs are expenses and charges related to the interruptions, e.g., when the generation unit begins or stops energy production. All energy assets suffer obsolescence, decay, wear and tear effects, independently of the operational regime of the asset. Low-value assets typically include depreciation in O&M cost, as well as in replacement cost.

7. Profitability indicators

The probable provision of flexibility services in the power system has augmented the number of papers about technical and economic analysis of possible flexibility applications. To assess the economic feasibility, authors have been using a set of indicators that involves both economical metrics and profit or saving indexes. Net Present Value (NPV), Payback Period (PP), Internal Rate of Return (IRR), and LCOE are the most employed economical metrics. As for profits and savings, authors express them through the net profits, operational profits, and profit increase rate. It is worth noting that the above profitability indicators are calculated and shown distinctively. For instance, profits are expressed in terms of revenues per flexible end-user per hour, per euros/kWh, per day, or even per year, depending on the profitability time frame of the feasibility evaluation. As in profits, savings and economical metrics can be also been in multiple forms. To summarize all above, Table 19 presents the most used indicators in the literature, classified by flexibility sources:

Table 17
Penalties related with Flexibility Projects.

BUFS	Power fac- tor penalty	Load curtailment penalty	Energy imbalance Penalty	Penalty for DR commitment failures	Penalty for charging in peak hours
Flexible End-user				[41]	[39]
VPP	[52]		[46]		
DG		[51]			
EVI			[60]		

Table 18
Taxes and Fees related with Flexibility Projects.

BUFS	Network Fees
Flexible End-user	[39]
VPP	[63]

7.1. Net present value

NPV is an economic instrument used to contrast investments, in this case; flexibility application projects, where different revenues and costs streams are observed within their lifetime [47,53,103]. According to NPV mathematical representation, the summation of the difference between revenues and costs is linked via discount rate selected by investors or holders as the lowest profitable rate of return. Positive and negative values of NPV indicates the profitability level of a certain project. Broadly, together with another indexes, investors prefer projects with the highest NPV.

For flexibility projects, NPV is applied in projects with VPP as flexibility source, where positive NPV is found as a way to rank diverse investing strategies [103]. ESS makes use of NPV to quantify the positive impact of the ESS operation on consumers and system operators [53]. Here, net profits and costs are estimated to obtain a total net present value. Besides, NPV is also a useful tool to define which ESS technology is more proper to produce savings, increasing self-consumption or replacing the Diesel Generator Sets (DGS) [56].

Table 19
Profitability indicators.

Indexes	Flexible End-users	VPP	ESS	DG	EVI
Profits	[48]	[23, 52], [63]	[54, 59]	[51]	[38]
Operational Prof-its		[50]			
Average Revenue Increase Rate		[23]		[62]	
Savings Of Costs	[39,47], [24,64], [32,41]				[60]
Savings DSO Losses			[57]	[62]	
Reduction Total Cost of Power Grid Upgrade				[51]	
Reduction Peak Load			[57]		
NPV	[39]	[103]	[53, 56]		
IRR			[53]		
Payback Period			[53, 59]		

7.2. Payback period and internal rate return

Payback Period (PP) and Internal Rate of Return (IRR) are metric decisions, that reveal the length of time required to recover the original investment and break-even point of the project, respectively. PP is relevant since it contains information on liquidity rates and risk management in high uncertainty projects. Meanwhile, IRR indicates the break-even point where the flexibility project generates revenues for the holders or investors. The usage of PP and IRR in CBA has some drawbacks. Authors affirm that residual value should be included in the analysis. The residual value embraces the foreseen value of the assets at the end of their service life. Besides, frequent investments and diverse lifespans of significant assets generate mistakes in the PP and IRR calculation. Similarly, IRR is inconvenient to reciprocally analyze exclusive projects.

According to Table 19, PP and IRR are implicated in flexibility projects with energy storage systems, mainly electrochemical batteries. A recurrent query on ESS installation at Medium Voltage (MV) and Low Voltage (LV) grid is the charge/discharge strategy. PP and IRR help in the decision-making process not only for charge/discharge strategy but also charge/discharge and proper ESS capacity [53].

7.3. Levelized Cost of Energy

Levelized Cost of Energy (LCOE) is one of the essential indicators for the creation of energy projects. LCOE is defined as the net present value of cost per generated unit during the lifetime project. Different initiatives of coupling power sectors are evaluated through LCOE. Water storage and desalination plants are ranked according to resulting LCOE [101]. LCOE aims to assure the participation of the flexibility facilities into energy markets, which would guarantee revenues for investors, end-users, and, in overall, the social welfare of the society. On the other hand, the impact of batteries on additional flexibility provision to the power system is examined through LCOE value, taking into account the context of isolated zones [104].

7.4. Savings

Benefits expressed in savings are commonly employed by authors in papers on flexibility projects. Savings are grounded on a base case in which the costs are previously estimated. For example, flexibility sources as flexible end-users [24] and demand response programs [32] reach savings in the electricity bill for end-users, which are calculated in percentage terms per year, an hour, or during the lifespan. Besides, EVI estimates the reduction in costs of the EV charging and discharging process [60]. Distributed generators as flexibility sources have a perspective somewhat different, since the savings and cost reduction are oriented towards generation upgrade cost [51] and reinforcements in the T&D networks.

7.5. Profits

Numerous authors have contemplated to the profitability in terms of profits. Profits can be classified in different ways. Firstly, according to the payees of the profits; for instance, end-user' profits produced by VPP are shown in Ref. [23], as well as aggregator' profits from EV flexibility are found in Ref. [38]. On the other hand, profits regarding to assessment period are also identified in the literature (e.g. per hour [23], per day [38] an per year [48,52]) [23,51,62]. organize profits regarding to a profit increase rate based on; the distribution network, distributed generation unit, or VPP, respectively.

7.6. Others indicators

Nowadays, with the evidence of progressive global warming, environmental indicators have gained recognition in scientific research. When CBA is executed, indexes such as reduction in environmental damage cost are neglected, but also have been included in projects with large energy storage systems such as PHS, CAES, or Hydro Reservoir Storage (HRS) [14]. LESS supports increasing renewable electricity generation and supply balancing services to the grid.

8. Analysis and discussion

This section identifies and quantifies the profitability of different demand-side flexibility sources throughout case studies tested in the literature. Several findings in the energy markets, cost-benefit analysis, business models, flexibility service portfolios, and profitability indicators are found concerning the measurement, harnessing, and maximization of the flexibility potential. Additionally, multiple trends and challenging points are identified regarding to the development of flexibility.

8.1. Flexibility services

Together with the development of the power system flexibility, new and traditional ancillary services provided by flexible assets and sources have been discussed in the literature. As stated in section 3, each bottom-up flexibility source possesses a certain flexibility services portfolio, which could be profitable in given economical and normative frameworks. Additionally, profitability' time frame and standpoint should be considered to obtain valuable results. According to the number of papers, Fig. 10 shows the relation between flexibility services and BUFS based on source profitability level and short-time analysis.

As seen in Fig. 10, frequency and voltage regulation are the most attractive ancillary ser-vices examined by authors to be supplied by demand-side flexibility according to the number of references in the literature (Table 1). According to the frequency and voltage thresholds, event deviation in time and intervention period, BUFS should have enough reaction capacity, as well as control and communication capacities to receive and send proper signals from SO. The above aspect is overlooked in the literature, as well as the capacity limits to participate in regulation ser-vices have already been mentioned in this work. Taking into account the aforementioned, VPP, large microgrids and ESS are the sources with major references in terms of regulation services. For these sources, regulation services prices, power capacity, ramping rate and operational cost are the relevant factors to compete with the current regulation suppliers. The ESS degradation cost by frequent and unusual usages is determining element to use EV batteries as flexible source.

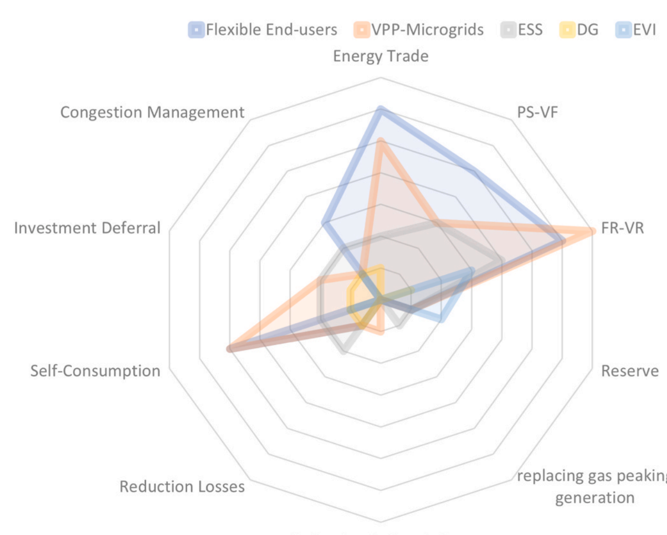

Fig. 10. Profitability of Flexibility services of BUFS.

Multiple flexibility services are provided by VPP and flexible end-users. One of them is self-consumption, which constitute a priority for all BUFS and a first optimization level in the energy management. Self-consumption, besides of peak shaving and valley filling, are good both the flexible end-users and grid, and represents a supplementary benefit generated by flexibility, since consumption is moved peak hours outside and articulate with the DG and consumption profiles of the aggregation' partners, for instance, in VPP. These services around the end-user' consumption and their incomes are marked as basic profit level, which could be enough for commissioning of some flexibility applications or as value of opportunity cost for analyzing the profitability of energy excess.

With respect to congestion management and investment deferral, VPP and flexible end-users are the sources with references, where cost-benefit analysis is done, although ESS and DG also could supply suitable solutions to congestion issues, but challenges about location, size, and transfer power should be surpassed, besides of proper technical normative. On other hand, energy trade and price arbitrage are not allowed in the most EU members due to monopoly nature of the electrical sector, but several authors have exposed that trading of energy excess in wholesale, local or specialized markets would impulse the energy transition. Several studies have involved in CBA energy sales and purchases at electricity price of given market.

8.1.1. Additional services

Advance closely with the traditional ancillary services, some additional services have emerged as possible incomes for BUFS, responding a new system operators' requirement. Additional services as reduction CO2 emissions, reduction T&D losses, peak shaving in gas consumption, reducing the RES capacity-based premium and minimization of electricity' social cost have been mainly analyzed for VPP without measuring the profits of, for instance, such reductions in carbon markets or in terms of economic incentive as Emission Reduction Credits (ERCs), investments deferral, opportunity cost, among others. Therefore, the proper recognition and remuneration of these new ancillary services would boost the profitability of flexibility sources and help launch many applications. At the end, the implication level of these additional services in the CBA is determined by BUFS' size and capacity.

8.2. Energy markets

The energy markets' structure and features both existing and new ones, could generate favorable conditions for ancillary services based on demand-side flexibility. Multiple papers have exposed the main drawbacks and challenges, as well as possible changes, proposals and solutions to adapt successfully the markets to the new technologies and energetic needs of the energy transition. The main findings in the literature are analyzed in this section.

8.2.1. Existing energy markets

As expected, existing markets such as DAM, IDM, secondary, and tertiary control are widely used to evaluate the profitability of projects with BUFS. DAM and IDM belong to the electricity wholesale market, where minimum requirements, in terms of installed power, experience, and capacity, must be accomplished in order to participate in the markets. Such requirements can be seen along of EU members with particular distinctive features. Regarding to required minimum installed power, BUFS applications are tested into DAM and IDM markets without confirming the fulfilling of the access requisites. Regulation services by BUFS are also reviewed into existing balancing markets. In Ref. [38], EV charging stations are pooled to provide upward and downward regulations to the grid, where the most profitable bidding strategy is found, in terms of net profits of the EVI owners. An optimal control algorithm of ESS is discovered through performance trials of batteries into balancing market [105].

8.2.2. New energy markets

The new markets present in the literature try to promote a more favorable environment for flexibility services. The most used market is the flexibility market, which has both global and local approaches, as well as specific markets for specific participants and services. Hand in hand with the flexibility market, the LEM and capacity markets are frequently mentioned, to the extent that they seek to trade services such as reserves, voltage and frequency regulation and surplus local energy, as well as the management of congestion and shared self-consumption. RPM or RTM are specialized markets mentioned in the case studies for specific services such as price arbitrage or reservations, which have the objective of generating specific characteristics that reward certain characteristics of the flexibility sources such as ramping rate, power capacity, reaction time, controllability and manageability. Fig. 11 shows the distribution of papers by service and new market.

8.3. Pricing

As on energy markets, pricing schemes, both conventional and modern, have been delineated in the recent years to compensate adequately cost sets and investments required for implementing flexibility applications, as well as for establishing fair prices for new and traditional ancillary services, energy exchanges, power and control capacities, among others. The present section highlights the relevant aspects in this sense. Undoubtedly, the hybrid pricing model (zonal a nodal pricing mixed) is a solution to impulse the profitability of flexibility sources, since for instance, the congestion, as its investment to be overcome, has nodal impacts, which require nodal actions.

8.4. Bottom-Up Flexibility Sources

An analysis from BUFS is needed to place and concrete the overall landscape of the demand-side flexibility, given that the sources are the main actors for the flexibility exploitation, which should have a guarantee of profits to advance in this sense. The main lines of this analysis are summarized in this section.

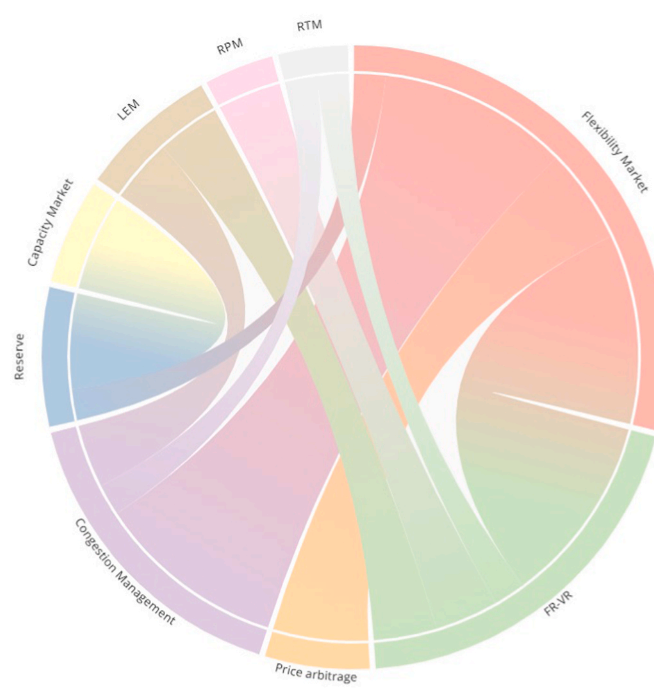

Fig. 11. New energy market for flexibility services of BUFS.

8.4.1. Flexible end-user

Residential flexible end-users possess a flexibility potential based on flexible and controllable loads such as air conditioners, lighting, heat water system (boilers), electric vehicles, and controllable household appliances. In commercial and industrial sectors, loads as datacenters, high-energy intensity machinery, and cross-sectional technologies are also manageable loads for flexibility purposes. Additionally, flexible end-users obtain additional flexibility from distributed generators coupled to the end-user facilities such as PV panels and backup generation units based on fossil fuels, as well as from storage devices such as conventional batteries, second-hand EV batteries, and intermediate or final storage stages in the production chain. Generally, flexible end-users are connected to the distribution grid at low and medium voltage levels, which principally interact with utilities and marketers, within the retail electricity market or new energy markets such as LEM or FEM proposed by authors in the literature. In terms of flexibility, for both energy and ancillary service purposes, a battery system (preferably a second-hand EV battery) combined with a photovoltaic system is more economical than other arrangements.

Secondly, the profitability of projects linked with flexibility from flexible end-users revolves around retail pricing schemes offered by marketers or utilities, and incentives impulsed by governments or regulatory entities. Authors have demonstrated that, at the actual economic and regulatory conditions, flexibility services and products are unprofitable even utilizing second-hand EV batteries. Therefore, authors have risen changes in the market and pricing structure, as well as incentives able to retributive adequately the investments. Incentives based on a dynamic retail tariff with reward mechanisms for charging and discharging storage devices, subsidies for investment or capital cost, as well as pricing schemes with payments for reducing peak demand and fair feed-in-tariff, are the most effective policy measures to improve profitability. Besides, the useable flexibility and its price into the energy market are still topics to discuss and require more research efforts. Despite the above, flexible end-users with photovoltaic panels and second-hand EV batteries with V2G technology achieve 130% of saving in the electricity bill, considering a fixed supply tariff that is equal to the retail tariff.

Thirdly, flexible end-users participate in ancillary markets to supply frequency restoration, reserve, congestion management, balance, and voltage regulation through an aggregator or a pool of prequalified units, which guarantee smart and profitable flexibility management, taking into account the risk and uncertainties present in these activities. Especially, boilers have a high regulating potential and fast ramping rate. Consequently, they are usually used for frequency restoration services, without incurring QoS losses.

From DRF side, datacenters, heat pumps, dryers, smelters, among other homogeneous and heterogeneous clusters, as well as profile loads of residential, commercial, and industrial end-users have been tested as flexibility sources in diverse energy markets and pricing schemes. Enough savings have been found to compensate the investments in demand response programs. Savings from 10.53% to 20% of the overall electricity cost can be easily seen in the literature, using retailer' prices with attractive price spread. The electricity price spread is the most significant factor for the profitability of demand response programs because it can limit the possible profits by shifting the loads from high price to low price in a period time. Undoubtedly, the energy market volatility will augment with the increase of the RES penetration. Such volatility is countered through incentive to shift loads, i.e., demand response and thus a self-cannibalism phenomenon is evidenced for demand response programs. According to that, the time frame of the profitability assessment is always short (Table 7).

Additionally, limited investments are needed to put in operation a DRF. Such investments are oriented to the ICCS procurement, marketing cost, and energy purchases. Therefore, costs must possess high accuracy grade, especially in terms of ICCS expenses, which are uncleared in the most of research works. Together with ICCS capital cost, a precise judgment on flexibility potential is crucial to determine the expected revenue. Noteworthy that four categories of the flexibility potential measurement can be distinguished in the literature (theoretical, technical, economic and practical).

8.4.2. Virtual power plant

The power and flexibility capacity aggregation from end-user, prosumers, distributed genera-tors, energy storage devices, and aggregators has been smartly intended through VPP, which are seen as a single power plant by energy market and system operators. Several case studies have probed that VPP can be profitable to supply collective self-consumption and ancillary services, achieving in certain cases a 236.4 €/day of operational profit of local energy management entity (aggregator) and an average increase of 56% in the profits of prosumers.

Many factors influence the profitability of the VPP. Initially, many authors have been proposing management models of a VPP as a condition to obtain high profitability. Flexible and fixed prosumer coalitions, nano grids, microgrids, and energy communities have risen in the literature to supply collective self-consumption and services to the system operators. Each management model has a particular profitability analysis that must be done case-by-case. Together with the management models, arbitrage and operation strategy, as well as bidding strategy are also re-viewed by authors as determining factors to maximize the profits of VPP. About regulating the internal energy exchanges and profit distribution are also considered unfinished topics. Proposals as LEM and flexibility markets are studied as an option to trade energy and flexibility services between VPP participants and external entities. These energy and flexibility services are established through compensation mechanisms, which are still under discussion.

Applying CBA to the VPP has many considerations. The degradation model of the ESS is a relevant point within the sum of costs, applying diverse degradation model as in flexible end-user, but this degradation must be included only in the CBA of ESS owner, investors, or system as a whole. The pricing schemes for both selling/purchasing energy in the grid and clearing the price of the energy produced or stored by ESS and DG is also an important topic to guarantee high profitability. Energy stored in batteries, produced by Distributed Generators units or delivered by EV must be valorized taking into account the particular cost of each energy source so that energy bids can be properly prepared.

8.4.3. Distributed generators

Distributed generation such as wind farms or photovoltaic panels has been installed along of Transmission and Distribution (T&D) Networks, augmenting the RES penetration and improving the efficiency of power systems, given that its capital and O&M cost have been diminishing in the last years. Successful cases have been found in three DG arrangements mainly, DWPG, DPVG, and DPVG with Heat Pumps (DPVG + HP). In terms of flexibility, DG has a large impact on the loss reduction of T&D Network and in the investment of the power grid upgrade, where 70.50% of diminishing can be achieved. Besides, new profits can be produced from regulation and balancing markets for both DG owners and DSO (654.77 $/day). Also, noteworthy that the LCOE of DPVG has achieved the levels of retailer prices for industrial and commercial end-users, and thus high IRR and economic benefits.

Throughout the research papers on the profitability of the distributed generators, the best location and capacity of the DG is the main trouble to the commissioning of the DG projects. Fuzzy decision-making methods, optimal planning schemes, coordinated scheduling strategy, and multiple hybrid optimization methods of size and site of DG are utilized in the literature to solve these questions. Investment deferral, congestion management, loss reduction, and other benefits depend on the optimal size and location of DG, as well as on the control technique applied to the generation unit. Power factor strategy and hierarchical control schemes have been risen to maximize the profits of DG.

Regarding CBA, DG is dependent on incentives or new pricing schemes to allow attract a large amount of flexible capacity. As in VPP and flexible end-users, flexibility and local energy markets are the economic environments where these flexibility sources can grow. In general, between revenues of the DG owners and reduction of cost of the T&D network upgrade exist an inverse relationship, which limits them mutually. Therefore, planners must balance adequately these profits to find the optimal planning solution. Finally, profitable DG projects also possess high grade of self-consumption (60%) in residential applications) to guarantee a positive NPV, depending on retail electricity price.

8.4.4. Energy storage system

ESS has a large set of applications and many sources of profits, for this reason, authors have been studying its proper incorporation to the low and medium voltage grids. In the literature fixed ESS is deployed in end-user facilities (residential, industrial or commercial), and low and medium voltage substations. 53% of internal rate of return and high NPV is effortlessly attained in projects with ESS [53,56]. Scenarios where ESS replace conventional generators as a backup power source or the usage of Li-Ion batteries under current market conditions are only profitable if ESS costs are reduced to a certain level (31% for Lead-acid or 26% for flow batteries, for instance).

The profitability of ESS is based on a proper charge/discharge strategy and sizing. Operation strategy seeks to exploit the low and high electricity prices to charge and discharge the storage devices (price arbitrage), respectively [53]. Additionally, authors have discovered a storage capacity limit, as well as a suitable charge/discharge rate in power grids, according to the kind of retail price spread and network stability values.

Given that ESS possess multiple profit sources, including all of them is a hard task. Cases studies show that distributing capacity for each flexibility service is the best way to manage and control the benefits. It is worth noting that a certain balancing market requires a reserve capacity that can't be used for other purposes. For the cost of the CBA in flexibility projects with ESS, the degradation model of ESS for irregular and frequent charge/discharge cycles is still a lack in the literature, where multiple proposals have risen but without enough experimental data. Economic metrics, in terms of IRR, NPV, and PP, are the most used to measure the profitability of ESS projects in the literature.

8.4.5. Electric vehicles installations

Industrial and residential end-users with V2G facility to connect electric vehicles could achieve savings from 35% to 47% in the electricity bill, as well as the management of EV fleet in balancing markets could produce 105 €/day in profits for the aggregator. Flexibility projects with electric vehicle facilities are profitable in most cases, but incentives and tax reductions could expand the profitability. Balancing services from EV, are limited by technical boundaries such as maximum recharging/charging powers, ramping rates and capacity of the vehicle, as well as downward and upward bid prices, and kind of technology (e.g. V2G), which must be properly selected to maximize profits; for instance, 10 €/MWh and 350 €/MWh are the most optimal price for downward and upward bids to obtain 113% of saving in electricity bill [60]. Behind bid prices and technical boundaries, an optimal bidding strategy is key in balancing and regulating markets. Preparing the regulation offers requires knowledge and expertise on energy markets, together with accuracy in the coordination between DSO, utilities, aggregators, and aggregation members (parking, recharging stations, and EV owners).

Multiple papers have put large attention on the degradation model of the battery. As mentioned before, electrochemical batteries exposed to irregular and frequent charging/discharging cycles would have less useful life than batteries with a nominal cycle. Such extra costs are currently underway, especially for second-hand EV batteries and some degradation models have been suggested as degradation could be relevant in the CBA [38,60]. Finally, business models are also checked by authors, where not only household models are assayed but also investment and financial models. Each one encompasses a set of benefits, costs, and profits distribution particularly [106].

8.5. Profitability

As stated, the profitability analysis depends of time-frame, standpoint, cost and benefits set, and profitability indicators. The most salient aspects are outlined in this section.

8.5.1. Standpoint and time frame

CBA is built based on an evaluation period and a point of view in which the benefits and costs revolve. Concerning standpoint, limited case studies have incorporated a global viewpoint, given that require a huge amount of information and complex optimization algorithms to preserve profitability to the whole stakeholders. On the other hand, flexibility projects are hardly implemented without the acceptance of the end-users, utilities, and system operators. An overview of the profits is advisable as long as allows observing the behavior of the social cost, a decrease in the social cost ensures the commitment of the parties involved and generates greater security for investors.

As shown in Table 7, short and long-term profitability evaluations can be found in the literature. A short-time frame is useful to show the convenience of operational changes, new pricing schemes, or markets, without including large investments. Besides, the first-year financial assessment allows to take decisions to improve the economic behavior of the project, without having to wait long periods time. Recovering investment require necessarily long-term analysis, given that economic metrics reflect the behavior of the net present value, benefit and cost flows, and state of returns. Life cycle analyzes are recommended for projects in which incomes are required for their start-up, including both benefits and costs throughout the useful life of all project assets including interest rates, depreciation, and residual cost.

8.5.2. Cost

Initially, the baseline of the cost analysis is electricity bill or consumption, which mark out a starting point to design flexibility solutions. In the same level, required investments for flexible assets (capital and marginal cost), ICCS, processing capacity, smart metering, primary energy (e.g., gas, carbon, biomass consumption, among others), as well as operation and maintenance cost should be contemplated in the total cost. The ESS' degradation cost has high importance in the CBA. Multiple models and procedures to measure the negative impacts can be seen in literature. The degradation reduces the battery lifetime and increase capital and maintenance cost. Several use cases reflect the large influence of the degradation in the profitability. This influence is dimmed for great flex end-users or VPP, since the rated values can be preserved. To finish the cost analysis, penalties related with power factor, load curtailment, RES spillage, energy imbalance, and failure to commitment, as well as taxes and fees, are involved in CBA to model possible undesired scenarios, no-optimal operation regimes or external cost that are not explicitly incurred in the previous costs. It is worth mentioning that both costs and revenues are accurately estimated in relation to the power and capacity of the flexibility source, since for flexible end-users' penalties are not a differentiating factor, on the other hand for large VPP, ESS or DG, all costs can be crucial in determining whether a project is profitable or requires incentives.

8.5.3. Revenues

The benefit analysis begins with the self-consumption and the revenues, in terms of savings or payments, derived by a demand smart management (peak shaving and valley filling). As mention before, this first level of profitability can be enough to guarantee feasibility for some flexibility sources. Subsequently, regulation services (frequency and voltage), as well as reserves (synchronized o no-synchronized) are examined by authors, both in current technical and economic conditions and within of new markets and pricing. Regulation and reserve are mature services with clear requirements, quantities and even historic data, which able to calculate profits easily.

As third profitability level, services as congestion management and investment deferral are studied to estimate, firstly, the whole incurred costs so that later, a tariff or price of the service can be figured out. More development of the normative is required to measure accurately the benefits by congestion management or investment deferral. Lastly, additional services are included in the benefit sum as a forecasting of profits in the future or an improvement in the operation or competitiveness (e.g., €/kWh per product). The current payments for regulation or congestion costs can be taken into account as a price reference for calculating the revenues.

8.5.4. Profitability indicators

In the literature, there are papers on profitability assessment where economic metrics are employed to measure how many profits by flexibility the flexible sources can obtain during their lifetime. On the other side, net profits and savings, during a period time, are also applied in projects with low investment intensity, essentially. According to Table 19, NPV, IRR, and PP are the most used profitability indicators in flexibility projects. Such economic metrics have several advantages for the sum of savings and profits or other indexes since these indicators measure easily aspects such as interest rates, depreciation, and different benefit and cost flows during the lifetime of the project. Besides, the recovering of the investment is more tangible than only quantifying the benefits in a certain period time, generating more security and confidence.

9. Tendencies

In this part of the analysis, a chronological review of the papers on profitability analysis of demand-side flexibility is useful to observe the trends in research on two main axes, flexibility services (Fig. 12) and flexible sources (Fig. 13).

Fig. 12 outlines that first of all, cost-benefit analyzes are becoming more frequent in the literature, showing that the authors intend to demonstrate that not only technical solutions are appropriate but that they are profitable, in some cases against the conditions. Current or others by proposing favorable future scenarios to which to arrive through changes in the current or future energy markets. Likewise, each of the flexibility services seen throughout this document is attracting more attention from the scientific community, especially auxiliary services such as regulation (frequency and voltage), reserves and power network balancing, as well as commercialization of energy surpluses and price arbitrage. Due to the increase in RES in *trans*-mission and distribution networks, congestion management and investment delays, there are also increases in the number of use cases examined, although in terms of profitability, the work carried out is proportionally scarce.

As seen in Fig. 13, The main players in flexibility on the demand side are the VPPs, which are receiving more attention, since they have sufficient power, control and monitoring capabilities to supply a broad portfolio of flexibility services and allow the addition of smaller

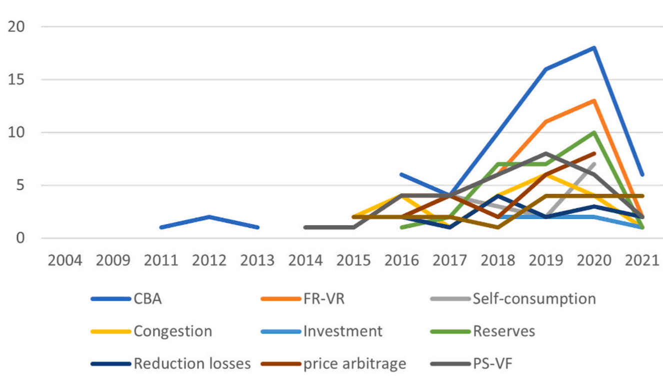

Fig. 12. Evolution of Flexibility services of BUFS.

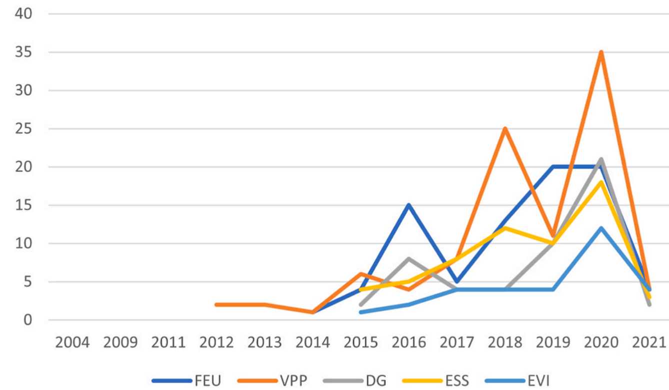

Fig. 13. Evolution of BUFS.

capacities (prosumers, demand response and microgrids) to maximize the benefits of its flexible potential. Together with the VPPs, the strategic installation of ESS and DG could generate important positive impacts on the electrical network, in terms of its operating costs, technical problems, planning and expansion, and the increasing incorporation of renewable energies. Additionally, the installations of electric vehicles, parking lots, charging stations, EV fleet, in general, the electrification of the transport sector, is also frequently examined, given its importance in the energy transition, its high mobility throughout the networks and its Storage capacity. Finally, the emergence of flexible end-users is also receiving considerable attention, to the extent that users are increasingly empowered and have greater systems of control and communication of their consumption, which could be harmonized with the new requirements of a network. Electricity with high penetration of renewable energy and with high percentages of electric vehicles.

10. Conclusions

A large deal of research has been carried out to investigate the profitability of projects based on demand-side flexibility in power systems, as evidenced by an augmenting number of applications and case studies. Due to the expected high penetration of RES and electric vehicles, the increase of the uncertainty into power system both electricity price and available power, the decreasing in the capital and O&M cost of the energy storage systems and development of the Information, Control and Communication System (ICCS), flexibility is a profitable, reliable and viable source both new incomes from balancing and regulation services to the grid and profits of the current participants. Additionally, modest changes in the existing electrical facilities would yield more flexibility in a profitable way rather than capital investment in additional capacity or network reinforcement.

In order to guarantee that both generation and demand sides flexibility projects are profitable, a CBA must be carried out. Although, CBA has been employed in certain applications to evaluate economic efficiency, there are error sources, lack, barriers, and considerations that degrade the reliability and accuracy of the profitability assessment. Therefore, this paper proposes the following considerations to take into account when profits and expenses balance are measured:

- CBA is a valuable method to evaluate the profitability of energy projects. Each analysis is initially determined by standpoints (from end-users, prosumer, aggregator, utilities, marketers, system operators or all as a whole) and time frame (short or long period time). Besides, flexibility consumers must be also kept in mind, given that they establish the flexibility services and products maximum prices, where if the total flexibility costs are higher than this maximum value, flexibility project is usually unprofitable.
- Energy markets and pricing schemes influence strongly the balance between incomes and expenses of flexibility use cases. Therefore,

CBA must properly select the energy markets, price schemes and regulations to be applied to the project. Several authors have arisen new energy markets and pricing, which must be clearly described to allow loss of reliability and assertiveness.

- Each flexibility source possesses flexibility services and products, which have a set of costs that must be incorporated into the CBA. Capital and O&M costs are the most relevant expenditures in the project, as well as the widest costs, given that authors include many costs on them. Therefore, an approach unified for these costs is mandatory, where investments from debt or equity, as well as ESS degradation cost, depreciation, ICCS costs, risk and uncertainty management cost, among other expenses must be adequately modeled.
- In order to calculate profits and expenditures in a CBA, forecasts about electricity price, consumption expected, and weather conditions must be realized, as mentioned in Sections 6.2 and 8.4.1. This information must consider the uncertainty, time frame, risk factor, and interest rates, so that CBA can preserve integrity and reliability. Neglecting the above aspects is one of the biggest sources of error in profitability calculations.
- Diverse economic metrics and indicators are used as profitability indexes, which evidence the financial well-health of the flexibility projects. Types of funding, stakeholders, flexibility products and services, flexibility feeders, and consumers could require an analysis with certain indexes (see Table 19 and Section 8.5.4). Therefore, profitability indicators should be chosen correctly in regards to the necessary information needed to make conscious decisions [14].

Declaration of competing interest

The authors declare the following financial interests/personal relationships which may be considered as potential competing interests: Jose-Fernando Forero-Quintero reports financial support was provided by Spain Ministry of Science and Innovation.

Data availability

Data will be made available on request.

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