DELIVERABLE 2.1

IDENTIFICATION OF CONSUMER CHARACTERISTICS TO UNLOCK LOW VOLTAGE FLEXIBILITY

[1,2] Luciana Marques, [1,2] Fernando Dominguez Iniguez, [1,2] Pieter Valkering, [1,2] Marco Ortiz,
[4,5] Brian Fowler, [4,5] Anthony Ford, [3,5] Justus Böning,
[1,2] Guillermo Borragán and [1,2] Helena Gerard

[1] VITO, [2] Energy Ville, [3] KU Leuven, [4] University of Antwerp, [5] University of Hasselt

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INTRODUCTION

The Belgian energy system is transitioning to a higher level of Renewable Energy Sources (RES). This transition creates new challenges with respect to security of supply and balancing due to a higher degree of volatility and lower predictability of RES. On the demand side, electrification needed for phasing out of fossil fuels use will lead to higher average and (potentially) peak loads. At the same, a sharp increase of available demand flexibility is expected in the coming years, especially connected to the Low Voltage (LV) grid, driven by the uptake of energy technologies such as smart meters, roof top photovoltaic systems, home batteries, electric mobility, and heat pumps. The recent EnergyVille PATHS2050 scenarios, for example, show significant uptake of all these technologies from a long-term cost-optimal energy system perspective[1].

The advent of LV flexibility is further facilitated by the radical shift in the role of consumers from passive to active participants in the energy system. In particular, the Clean Energy Package introduces a framework for community energy ownership, by defining two concepts for collective flexibility: the Renewable Energy Community (REC) and the Citizen Energy Community (CEC). Consequently, LV flexibility will gain importance in the coming years and has the potential to play an important role, supporting both an adequate and operationally stable Belgian energy system.

The Alexander project aims to address several key research questions to remove existing barriers and unlock the true value of LV flexibility for the Belgian system. The ALEXANDER project Includes three core work packages (WPs). WP2 undertakes an in-depth analysis of consumer behaviour, including consumer preferences and bounded rationality. WP3 will identify technical and operational barriers for the provision of system services from LV networks. WP4 will assess the impact of the developed models and solutions for the entire Belgian energy system.

This deliverable provides the starting point for the research under Alexander WP2. It aims to identify from literature consumer characteristics to unlock the uptake of low voltage technologies or distributed energy resources (DER) and to unlock flexibility to set the stage for defining the use cases and specific aspects to consider for the discrete choice experiments of follow-up tasks. Task 2.1 has delivered three main contributions that are collated in this report. These contributions entail the use cases methodology, and two literature reviews of consumer acceptance for respectively technology adoption and flexibility provision. In this cover document, each contribution is summarized, and final reflections are given. The full contributions are appended.

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[1] https://zenodo.org/record/7614844

CONTRIBUTIONS IN A NUTSHELL

1. Use cases methodology

The first contribution provides a framework for mapping the possible use cases for flexibility in the low voltage electricity system. To this end, this contribution identifies the main components of the potential use cases in terms of the flexibility technologies that can be used, the organization models of flexibility provision, the system services offered and the remuneration mechanisms that can be applied.

Based on this framework, the use cases under analysis in the different tasks of the Alexander project (reflecting ongoing work) are presented. Key directions for use cases are the following:

- Task 2.2: A use case based on smart EV charging (uni- and bi-directional) applied to individual households
- Task 2.3: A collectively organized use case involving enhanced self-consumption and flexibility though PV and battery storage
- Task 3.1: The collective operation of residential battery storage for providing grid services
- Task 4.4: An integrated use case covering a number of technologies with broad utilization by individuals in renewable energy communities, providing both internal services to the community and external services for the grid.

2. Consumer acceptance technologies framework

For a use case to come into effect, a first step is consumer investment in the technologies underlying flexibility provision. The second contribution therefore reviews the psychobehavioral factors that play a role in the adoption of distributed energy resources (DER) by end-consumers. The energy transition relies on the increasing use of electricity generated from renewable sources and the transition of end-use sectors to electric technologies. Adoption of DERs by end-users can contribute to this transition by allowing them to generate and store their own energy and provide flexibility to the grid. However, the adoption of DERs is not consistent across the population. A systematic literature review of 47 across 3 academic databases was conducted to better understand the psychological and behavioural factors that influence the adoption of DERs. The results were organized using the variables of the theory of planned behaviour and the unified theory of technology adoption. The results suggest that psychobehavioral variables such as norms, hedonics, and control may play a more important role in the adoption of different technologies. Additionally, certain technologies have been studied more than others and certain variables are sometimes excluded from the studies of certain technologies. In conclusion, improved knowledge of user characteristics, specifically for technologies with similar intrinsic adoption factors, can be used to develop different strategies for the deployment of DER technologies.

3. Consumer characteristics for flexibility provision

The utilization of distributed energy resources is experiencing a rapid growth, providing end-consumers with the opportunity to offer flexibility to the power grid. To comprehend the impediments and motivations of flexibility provision, a systematic review of the literature was conducted including a total of 39 studies across 3 academic databases. The results revealed a set of factors that commonly affect the provision of demand-side flexibility in residential environments, which were classified into intrinsic, extrinsic, and routine-related categories. Intrinsic factors that impact flexibility include perceived risks, attitudes towards data privacy, environmental consciousness, convenience, awareness of energy consumption, perceived control, familiarity with technology, and cultural norms. Extrinsic factors, such as ownership, availability of renewable energy sources, financial incentives, climate conditions, and controllable household appliances, also play a vital role in determining flexibility provision. Finally, the routines and lifestyles of householders can influence the flexibility provision. The findings suggest several implications for promoting flexibility provision, including predictable pricing for flexible routines, community-based initiatives to enhance user participation and trust, access to technology, and customized policies and profiling based on users' intrinsic characteristics.

DOCUMENTS

1. Use Cases Methodology

Authors: Luciana Marques (VITO), Fernando Dominguez Iniguez (VITO), Helena Gerard (VITO)

Acronyms

BRP: Balancing Responsible Party
CEC: Citizen Energy Community
CM: Community Manager
ESS: Energy Storage System
EV: Electric Vehicle
FCR: Frequency Containment Reserve
G2V: Grid to Vehicle
HP: Heat Pumps
LV: Low Voltage
mFRR: Manual Frequency Restoration Reserve
PV: Photovoltaic solar panels
REC: Renewable Energy Community
SO: System Operator
TCL: Thermostatically Controlled Load
V2X: Vehicle to Others

Introduction

When considering the flexibility assets, we should not only consider the amount of flexibility they can generate but also how that flexibility can be used to support the operations of the energy system and how it can be remunerated so consumers have incentive to provide flexibility. To undertake this analysis, this report builds on the framework in Figure 1 to identify the main components of the potential use cases that could be relevant for the different tasks in Alexander.

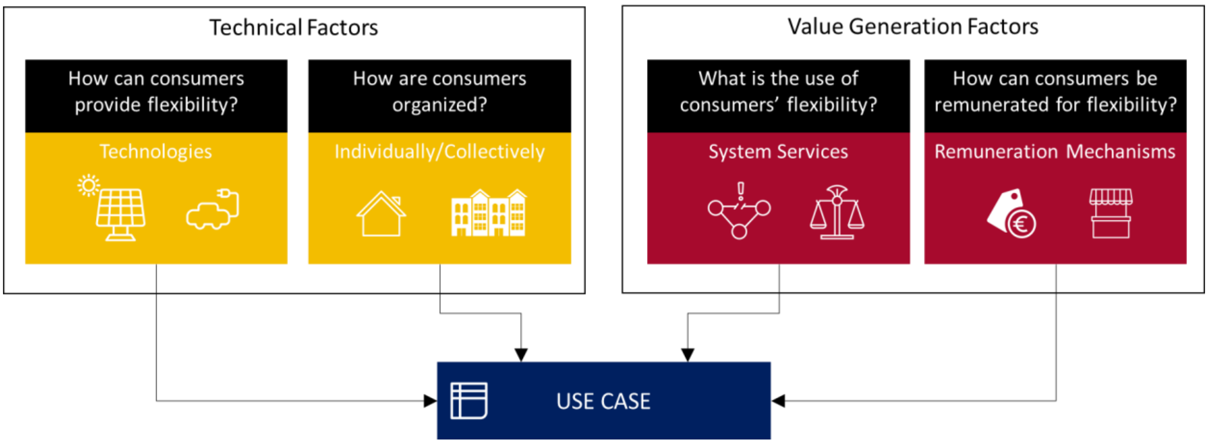

Figure 1: Designing use cases to analyze low voltage flexibility is possible through the identification of technical and value generation factors

This framework divides these components into:

- **Technical factors**: This includes the technical characteristics of the different appliances connected to the LV flexibility, which are defined according to the technologies required to make flexibility available (e.g. algorithms being used to optimize the provision of flexibility)[2], and the organization model of consumers when providing flexibility (i.e. individually or collectively).
- **Value generation factors**: This component considers the elements that affect the profitability of providing flexibility from appliances connected to the LV grid. This profitability is impacted by the type of service the flexibility can provide and the remuneration mechanism. Value generation factors will define the incentives for residential consumers to invest in/adopt such appliances to provide LV flexibility.

The different factors are discussed in more detail in the following sections.

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[2] Shewale et al., "A Survey of Efficient Demand-Side Management Techniques for the Residential Appliance Scheduling Problem in Smart Homes." provides an extensive summary of potential methodologies for the schedule of residential appliances.

Flexibility Technologies

The Alexander project will zoom in on the provision of flexibility services using assets connected to the LV electricity grid with special emphasis on residential consumers. In order to identify how residential consumers can provide flexibility, this section reviews the different technologies they can adopt. Each of the technologies available has a different potential to provide flexibility, which impacts residential consumers' decision to invest in it. These multiple technologies can be grouped into three different categories of flexibility resources:[3,4]

- **Demand-side flexibility**: able to impact the pattern and/or amount of end-users' electricity consumption.
- **Generation-side flexibility**: capable of modifying the output of power generation.
- **Storage system**: capable of bi-directional exchange of power with the network.

Inside each of these categories, many technologies can be identified. For instance, in demand-side flexibility, periodic appliances as washing machine, dryer and dishwasher can provide flexibility. Those appliances are periodically used and execute a user-initiated finite cycle. Once the cycle is started, there is no interaction with the user until its end. Although those technologies have a potential to be delayed, especially because the user does not require the cycle to be finished as soon as possible, studies have shown that they have little impact on the households' electricity use.[5,6] Moreover, they have limited seasonal effect, and are mainly used during evenings and weekends. All those aspects together limit the flexibility potential of periodic appliances.

Another example of appliances in the demand-side flexibility group are thermostatically controlled loads (TCLs). Those are appliances regulated by a thermostat that use heat inertia (with heat accumulated mainly on air and liquids) in the provision of flexibility. They can provide flexibility by altering their normal operational cycle to consume energy at different points in time.[7] There are heating ventilation and air conditioning (HVAC) systems, which can provide flexibility using multiple strategies (e.g., by adjusting the temperature, by pre-heating/pre-cooling, by modulating the energy consumption). Other TCL appliances are hot water boilers (with storage),[8] refrigerators, and freezers.

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[3] Degefa, Sperstad, and Sæle, "Comprehensive Classifications and Characterizations of Power System Flexibility Resources."

[4] A fourth category is the network-system flexibility which includes components of the network that can be used in the provision of flexibility. Because the focus of Alexander is on residential consumers providing flexibility, no further discussion will be done on the network flexibility.

[5] Fonteijn et al., "Evaluating Flexibility Values for Congestion Management in Distribution Networks within Dutch Pilots."

[6] Lucas et al., "Load Flexibility Forecast for DR Using Non-Intrusive Load Monitoring in the Residential Sector"; VITO, "Preparatory Study on Smart Appliances (Lot 33): Task 1 Scope."

[7] Conte et al., "Synthetic Inertia and Primary Frequency Regulation Services by Domestic Thermal Loads."

[8] There are versions of water heater without storage facilities. However, the use of these appliances for the provision of flexibility is limited as they could only provide flexibility by changing the set-point.

TCLs represent a big share of residential energy consumption in Europe, and they have a great potential of providing flexibility, being able to reduce consumption from 15-37% and/or shift 15-30% of load.[9] That is why many initiatives target those technologies to support the energy transition goals. For instance, at the European level, member states aim at increasing the share of renewable heating by an average of 1.1% per year. However, a binding target, as well as a supporting framework, are needed.[10] In Belgium, this has been translated into measures focusing on reducing the carbon footprint of the heating industry. For example, new constructions cannot be connected to the gas network from 2025 in Flanders[11] and from 2035 in Wallonia and Brussels.[12] Moreover, there is a (partial) ban on the installation of heating using fuel oil (stookolie) in Flanders and Brussels.[13]

The last demand-side flexibility asset reviewed in this report is lighting, which includes dimmable lights. The amount of potential flexibility provided by these appliances is a function of factors such as the geometry of the building, the weather, and occupancy profiles. An amount of 0 to 10% of the energy installed can be provided as flexibility through lighting.[14] In commercial buildings, the average lighting power curtailment is 32.6% (4.8 kW) of peak lighting demand and the duration is about 3,800 h annually,[15] representing the potential of flexibility provision. Similar information could not be found on residential demand.

In the category of generation-side flexibility, photovoltaic solar panels (PV) are the most common appliances in the residential sector. Without any storage facility, solar panels have a limited capacity to provide flexibility as the only option would be their curtailment from the system which is currently allowed in Belgium if the voltage rise in the distribution system[16]. In the last category, energy storage systems (ESSs) are appliances that use an electrochemical reaction to store energy and are based on a variety of different specific chemical systems. To estimate the amount of flexibility batteries can provide, it is necessary to consider: 1) the size of the battery; 2) the charging speed; and 3) the speed at which the battery gets depleted. ESSs can furnish 100% of its capacity (if fully charged/depleted) to the provision of flexibility.
In Belgium, these appliances are currently being subsidised by the Federal Government until 2024 (with these subsidies being decreased over time). These subsidies cover investment in batteries that go from 0 to 9 kWh (6 kWh from 2023).[17]

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[9] Luo et al., "Demand Flexibility of Residential Buildings."

[10] European Commission. Directorate General for Energy. et al., *Renewable Space Heating under the Revised Renewable Energy Directive*.

[11] https://www.vlaanderen.be/nieuwe-verwarmingsinstallatie-kiezen/geen-aardgasaansluitingen-meer-bij-nieuwe-grote-projecten#q-5a16d194-4404-4c48-9b78-e2bdfa8a5a4c

[12] https://www.bosch-thermotechnology.com/be/fr/residentiel/infos-et-conseils/legislation/#:~:text=%C3%80%20partir%20du%201er%20janvier,gaz%20%2B%20pompe%20%C3%A0%20chaleur).

[13] https://www.vlaanderen.be/nieuwe-verwarmingsinstallatie-kiezen/verbod-op-het-plaatsen-en-vervangen-van-stookolieketels and https://environnement.brussels/thematiques/batiment-et-energie/obligations/la-performance-energetique-des-batiments-peb/chauffage-et-climatisation-peb/interdiction-installations-non-durables (accessed 29/08/2022)

[14] Lucas et al., "Load Flexibility Forecast for DR Using Non-Intrusive Load Monitoring in the Residential Sector."

[15] Yu et al., "Quantifying the Flexibility of Lighting Systems by Optimal Control in Commercial Buildings."

[16] Synergrid, "SPECIFIC TECHNICAL PRESCRIPTIONS REGARDING POWER-GENERATING PLANTS OPERATING IN PARALLEL TO THE DISTRIBUTION NETWORK."

[17] Information available in https://www.energiesparen.be/thuisbatterij (accessed 03/08/2022)

Finally, electric vehicles (EVs) can also provide flexibility services to the systems. Those are vehicles powered by a battery, and they can be included in the category of storage system and/or demand-side flexibility, depending on their ability to supply energy back to the grid. EVs are moveable batteries that can provide flexibility when connected to the system, and their potential depends on the characteristics of the chargers in two dimensions. First, chargers can be privately owned or shared with other EV owners. Second, chargers can be unidirectional (Grid to Vehicle (G2V)) or bidirectional (Vehicle to others (V2X)). As an example, assuming EVs take 3 hours to charge, they can supply flexibility for 9.8 hours when connected to a private charger and for 3.5 hours when connected to a public charger.[18] Moreover, charging strategies coordinated by a centralized schedule can reduce peak demand by 14.6% to 33.7% when connected to private chargers.[19] In addition, coordinated EVs could reduce peak demand by 23.7% to 24.25%.[20] One limitation of the flexibility potential of EVs is that they are normally connected during the evening/night-time.[21]

As part of the process to decarbonize transport, in June 2022, the European Parliament adopted a proposal to set 2035 as a deadline to set zero-emissions road mobility (i.e. an EU-fleet-wide target to reduce the emissions produced by new passenger cars and light commercial vehicles by 100% compared to 2021).[22] These EU proposals have been translated into different measures by the Belgian governments:

- the Federal Government has set that after 2026, only zero-emission cars will be able to benefit from a tax reduction;[23]
- the Flemish Government has banned the sale of new cars with combustion engines after 2029 if three conditions hold: enough supply of EVs available, at affordable prices, and with sufficient charging stations;[24]

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[18] Sørensen et al., "Analysis of Residential EV Energy Flexibility Potential Based on Real-World Charging Reports and Smart Meter Data."

[19] Van Kriekinge et al., "Peak Shaving and Cost Minimization Using Model Predictive Control for Uni- and Bi-Directional Charging of Electric Vehicles."

[20] Khan et al., "Coordination of Multiple Electric Vehicle Aggregators for Peak Shaving and Valley Filling in Distribution Feeders."

[21] Khajeh, Firoozi, and Laaksonen, "Flexibility Potential of a Smart Home to Provide TSO-DSO-Level Services."

[22] Information available in https://www.europarl.europa.eu/news/en/press-room/20220603IPR32129/fit-for-55-meps-back-objective-of-zero-emissions-for-cars-and-vans-in-2035#:~:text=With%20the%20adopted%20text%2C%20which,100%25%20compared%20to%202021). (accessed 03/08/2022)

[23] Information available in https://www.leaseplan.com/en-be/car-taxes-2021-2031/ and https://news.pwc.be/the-zero-emission-company-car-as-the-new-standard/ (accessed 03/08/2022)

[24] Information available in https://www.vlaanderen.be/departement-mobiliteit-en-openbare-werken/nieuwsberichten/elektrisch-rijden-belangrijke-pijler-in-het-vlaams-klimaatplan (accessed 09/08/2022)

- the Brussels Government has announced that it will banish diesel cars in the region by 2030 and petrol cars by 2035;[25]
- the Wallonia Government has not published the date for the prohibition of these vehicles, but the 2035 limits would still apply.

Based on the discussion above, the main technologies being proposed to be analysed by Alexander are presented in Table 1.

Table 1: Technologies to be considered for the provision of flexibility

Demand-side flexibility	Generation-side flexibility	Storage system
HVAC: Heat pumps Water boilers with storage EV (unidirectional)	PV	Residential batteries EV (bidirectional)

These technologies are the ones being identified by the literature[26,27] as those providing a larger and more stable potential for flexibility. Furthermore, the development of these technologies is being supported by regulation. Lighting and periodic appliances are excluded from this analysis as they can provide a limited amount of flexibility. Furthermore, the number of uses of flexibility provided by these appliances is restricted. However, this does not imply that they should not be considered in any practical application.

Organization Model

The second aspect which impacts the technical capability/potential of residential consumers to provide flexibility is how they are organized. Two possibilities are available: individually or collectively. In the first, the consumer provides flexibility alone, by installing the chosen technologies in its own premises and/or by adopting the technologies individually. No coordination with other consumers is needed in this case. In the second, consumers provide flexibility as a group, e.g., in energy communities, apartment buildings, through aggregators. The ownership of the technologies can be shared in this case, and coordination between the participants is needed.

The collective organization model is interesting to increase the possibilities of flexibility provision by residential consumers. An individual consumer has less flexibility assets, less flexibility amount, and less market power to provide his/her flexibility to the multiple actors of the power systems. As an example, system operators (SOs) often set minimum requirements when they acquire flexibility, to facilitate their operations. Some of these requirements could constitute barriers for consumers connected to the LV grid to provide flexibility directly to the SO as: 1) the minimum quantity to be offered to the SO can be larger than the flexibility those consumers have individually available; 2) the availability time of the flexibility to be provided can be longer than residential consumers appliances can provide; 3) the SO needs both

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[25] Information available in https://www.reuters.com/business/environment/brussels-region-ban-diesel-cars-by-2030-petrol-cars-by-2035-2021-06-25/

[26] Gerard, Virag, and Bogaert, "Preparatory Study on Smart Appliances (Lot 33) Tasks 1 – 7 Reports – Supplementary Report."

[27] T. Ji and Rajagopal, "Demand and Flexibility of Residential Appliances: An Empirical Analysis."

increase and reduction of flexibility while residential consumers can individually provide only in one direction. Aggregators is one new figure growing in relevance in recent years that can collectively provide flexibility. According to the European Commission,[28] aggregation is a "function performed by a natural or legal person who combines multiple customer loads or generated electricity for sale, purchase or auction in any electricity market". As a result, the risk of their overall portfolios may be easier to manage than when managed by individual consumers. This allows higher profitable and less risk-averse positions in the electricity markets without affecting the reliability of the end-energy service for the consumers.[29]

There are different types of aggregators, depending on how they interact with upstream parties (e.g. system operators, market operators) and downstream parties (e.g. residential consumers). For instance, integrated aggregators supply energy to prosumers and have balancing responsibility, thus playing directly in wholesale markets, while independent aggregators do not have balancing responsibility and can designate a balancing responsible party for its consumers/prosumers.[30] Moreover, their role depends on their objective when grouping consumers. Some examples are[31]: they can enable economies of scale for market access by joining small generators; they can help prosumers with production and/or storage capacity to interact with other players (e.g. retailers or system operators); they can implement peer-to-peer energy trade to integrate distributed energy resources in the electricity networks. It is important to mention that, in Alexander, the role of the aggregator can be played by the retailer, given that residential consumers are more used to deal directly with retailers than with aggregators.

When managing its portfolio, an aggregator would aim at optimising the operations of the different appliances. The optimisation of these appliances can be done at different levels of the system[32] as behind-the-meter[33], at the level of the distribution grid/aggregator, or system-wide.[34] The complexity of this optimisation plays a role on the speed that flexibility is available and, as a result, on the flexibility services/products an aggregator can offer with it. Furthermore, the speed at which the flexibility is available also depends on the number of agents involved in the activation of the flexibility.

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[28] European Commission, "Directive (eu) 2019/944 of the european parliament and of the council of 5 June 2019 on common rules for the internal market for electricity and amending directive 2012/27/eu (text with eea relevance.): Pe/10/2019/rev/1," 14.6.2019. [Online]. Available: http://data.europa.eu/eli/dir/2019/944/oj.

[29] Bruninx et al., "On the Interaction Between Aggregators, Electricity Markets and Residential Demand Response Providers."

[30] Kerscher and Arboleya (2022), "The key role of aggregators in the energy transition under the latest European regulatory framework"

[31] Kerscher and Arboleya (2022), "The key role of aggregators in the energy transition under the latest European regulatory framework"

[32] Gonzalez Venegas, Petit, and Perez, "Active Integration of Electric Vehicles into Distribution Grids: Barriers and Frameworks for Flexibility Services."

[33] A HEMS or Home Energy Management System is a device that deals with controlling and optimizing the home appliances on the basis of user preferences to enhance the energy efficiency

[34] For an example of energy arbitrage see Borne, "Vehicle-To-Grid and Flexibility for Electricity Systems: From Technical Solutions to Design of Business Models."

Even if they have received significant attention in the academic and practical literature, aggregators still face challenges when participating in the flexibility markets[35] such as a lack of metering devices for reliable real-time metering and control,[36] or large critical mass required to participate in energy markets (i.e. they require a large number of consumers to deliver the minimum size of the bids). Another collective organization model is energy communities. European legislation has two definitions of energy communities: renewable energy communities (RECs)[37] and citizen energy communities (CECs).[38] Both imply open and voluntary participation and must be effectively controlled by its members or shareholders. Moreover, their primary purpose is to provide environmental, economic, or social community benefits to its members or shareholders or to the local areas where it operates rather than to generate financial profits. Based on the two definitions from the European Union, energy communities will:

- facilitate self-consumption of electricity among the members of the community,[39]
- use common assets for the provision of flexibility that can be consumed inside of the community (e.g. optimizing time of use or controlling the peak demand inside of the community). Any remaining flexibility could also be sold externally into the market.[40]

As these communities expand, additional analysis is required to quantify their effects both on the welfare of consumers and the overall efficiency of the system, and initial papers seem to indicate that there are costs reduction resulting from the operations of these communities. For example, Algarvio 2021[41] shows prosumers with small-scale solar PV could obtain an additional 8% reduction in energy costs when becoming members of a CEC.[42]

Another point that needs to be considered is that these communities can have objectives other than profit maximization[43]. To develop a deeper understanding on which one of these objectives could trigger individual consumers to join an energy community is one of the main objectives of Alexander as it will also affect how consumers' characteristics can affect the engagement of these communities in the provision of flexibility to the system. The introduction of these communities is at different stages among the different parts of Belgium. All three regions have transposed the definitions coming from the European Union, but some differences remain in terms of approach:

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[35] Eid et al., "Aggregation of Demand Side Flexibility in a Smart Grid"; Villar, Bessa, and Matos, "Flexibility Products and Markets"; D'Ettorre et al., "Exploiting Demand-Side Flexibility."

[36] Smart meters are being deployed in Belgium at different speeds. In Flanders, 80% of households are expected to have a smart meter by 2024 (https://www.fluvius.be/nl/thema/meters-en-meterstanden/digitale-meter/wanneer-krijg-ik-een-digitale-meter and https://www.vreg.be/nl/digitale-meter) while a similar level is expected to be obtained in Wallonia by 2029 (https://www.cwape.be/node/146#quand). In Brussels, there are no set targets but these meters are being implemented for new consumers, participants in energy-sharing communities and substitution of older meters (https://www.sibelga.be/en/connections-meters/smart-meters/whos-eligible-for-a-smart-meter)

[37] European Commission, DIRECTIVE (EU) 2018/2001 OF THE EUROPEAN PARLIAMENT AND OF THE COUNCIL of 11 December 2018 on the promotion of the use of energy from renewable sources (recast).

[38] DIRECTIVE (EU) 2019/944 OF THE EUROPEAN PARLIAMENT AND OF THE COUNCIL - on common rules for the internal market for electricity and amending

[39] Mendicino et al., "DSO Flexibility Market Framework for Renewable Energy Community of Nanogrids."

[40] The mechanisms aimed at facilitating this process are the focus of ongoing projects being developed by Synergrid. Additional information in http://www.synergrid.be/index.cfm?PageID=20956

[41] Algarvio, "The Role of Local Citizen Energy Communities in the Road to Carbon-Neutral Power Systems."

[42] The paper indicates that single prosumers with small-scale PC can save 16% on energy costs and if they are part of a CEC they can save 24%. Therefore, being part of the CEC would generate 8% reduction in costs.

[43] Lupi et al. "A Characterization of European Collective Action Initiatives and their Role as Enablers of Citizens' Participation in the Energy Transition." https://www.mdpi.com/1996-1073/14/24/8452

- **Flanders:**[44] Technical rules for these communities have been implemented and Fluvius aims to fully support the creation of these communities from January 2023.[45] Currently, only some options are available (e.g. if all members are inside one building).
- **Brussels:**[46] Technical rules are being developed. There is a strong push for the introduction of energy communities in Brussels which includes the introduction of special (reduced) network tariffs.[47] Sibelga has committed to promoting energy communities[48] and the local government has created an entity to facilitate the creation of communities.[49] Furthermore, legislation in Brussels has kept a pre-existing type of community: the Local Energy Communities. For these types of communities, production, consumption, storage, and sharing should take place within the energy community, and be limited to renewable energy.
- **Wallonia:**[50] No technical rules in place. An additional type of community also exists: active consumers acting collectively within the same building. These consumers do not need to create a separate legal entity but they are allowed to share their energy without entering into contact with the energy system.[51]

System Services

The multiple flexibility technologies described before can provide different types of services to the systems and their stakeholders (system operators, balancing responsible parties, aggregators, energy community manager, consumer). In this report, the possible services are presented depending on the stakeholder procuring the flexibility.

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[44] In Flanders: Energiedecreet Art. 4.8.4. Available in https://navigator.emis.vito.be/mijn-navigator?woId=83391 (accessed 18/102022);

[45] Information available in https://www.fluvius.be/nl/thema/zonnepanelen/delen-en-verkopen-van-energie and https://www.fluvius.be/nl/thema/zonnepanelen/energiegemeenschappen?app-refresh=1659709088371 (accessed 5/8/2022)

[46] In Brussels: Ordinance amending the ordinance of 19 July 2001 relating to the organization of the electricity market in the Brussels-Capital Region, the ordinance of 1 April 2004 relating to the organization of the gas market in Brussels-Capital Region, concerning road charges for gas and electricity and amending the order of 19 July 2001 relating to the organization of the electricity market in the Brussels-Capital Region and the order of 12 December 1991 creating budgetary funds for the transposition of directive 2018/2001 and directive 2019/944.Available in https://www.ejustice.just.fgov.be/mopdf/2022/04/20_1.pdf#Page113 (accessed 05/08/2022)

[47] Detailed information about the framework for these communities in Brussels can be found in https://energysharing.brugel.brussels/

[48] https://www.sibelga.be/en/about-sibelga/strategy-and-mission

[49] https://environnement.brussels/news/un-nouveau-facilitateur-pour-le-partage-denergie

[50] In Wallonie: Decree amending various energy provisions in the context of partial transposition of the directives 2019/944/EU of 5 June 2019 concerning common rules for the market electricity policy and 2018/2001/EU of 11 December 2018 on the promotion of the use of energy produced from renewable sources and with a view to adapting principles relating to the pricing methodology. Available in http://nautilus.parlement-wallon.be/Archives/2021_2022/PARCHEMIN/871.pdf (accessed 09/08/2022)

[51] Information available in https://energie.wallonie.be/de/communautes-d-energie-et-partage-d-energie.html?IDC=10295 (accessed 08/08/2022)

System operators require system services to ensure the integrity and stability of the network infrastructures as well as power quality, reliability, and security on an economic basis.[52] The main system services of interest for SOs are: [53]

- **Congestion management**: SOs need to resolve congestions in their grids (e.g., thermal limits of lines surpassed, capacity limits of transformers exceeded). This can be done by flexibility located in the affected region (e.g., rooftop solar combined with home storage).
- **Balancing**: supply and demand need to be equal in all time. This is traditionally a TSO responsibility, and many market mechanisms are already in place to support this service. The challenge here is to include flexibility from distribution systems in those markets. As this is a frequency service, available market products as aFRR, mFRR, and FCR can be used as a replacement to define this service.
- **Voltage control/reactive power control**: voltage stability is essential to ensure safe operation of all voltage levels of the grid. SOs are responsible for voltage control, and traditionally rely on the assistance of producers to feed/absorb reactive power.

Even though system operators can use different approaches to obtain these system services (e.g., investing in new capacity to reduce congestion), the focus of Alexander is on the use of flexibility to provide them. Balancing responsible parties, aggregators, retailers, or energy community managers also need flexibility. The nature of the service provided by the residential consumer to these actors will depend on the use, and some examples are: [54]

- **Self-balancing:** BRPs need to keep their portfolio balanced (production and consumption) at all times. Depending on the portfolio nature (e.g., share of renewables), BRPs have to procure flexibility to adapt their forecasts and respect their contracts. Although aggregators, retailers and energy community managers do not necessarily have the balancing obligation, this service can be of their interest to, for instance, minimize the energy purchased in wholesale markets or maximize the local use of renewable generation.
- **Portfolio optimization:** those actors procure resources/flexibility in an optimal way to determine the assets in their portfolio and the amount of production and consumption.

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[52] Carreiro, Jorge, and Antunes, "Energy Management Systems Aggregators."

[53] Classification obtained from https://www.elia.be/en/electricity-market-and-system/system-services (accessed 12 July 2022). Consistent with products identified in Villar, Bessa, and Matos, "Flexibility Products and Markets.". In its website, Elia also includes two additional system services. First, the system services provided by the outage planning agent. In these services Elia coordinate the outage planning of generation units with an installed capacity of at least 25MW connected to Elia's grid and other generation units might also be included in the contract with a view to being coordinated by Elia. Second, re-energising after a black-out: When a blackout occurs, in addition to the means available in the Belgian grid to re-energise the system, Elia contracts capability for the purpose of re-energysing the system. These services will not be considered as they will have a limited effect on the operation of residential consumers.

[54] Gonzalez Venegas, Petit, and Perez, "Active Integration of Electric Vehicles into Distribution Grids: Barriers and Frameworks for Flexibility Services."

- **Energy arbitrage:** those actors can procure flexibility according to their strategies in energy markets in order to capture value from price differences in those markets.

Finally, consumers can use their flexibility to provide services to themselves, as: [55]

- **Bill optimization:** residential flexibility can be used to reduce consumers' energy bill, based on the electricity tariffs or other remunerations as part of flexibility contracts with aggregators (e.g. aggregators provide consumers with monetary incentives to reduce or increase their consumption when needed by the grid[56]).
- **Self-consumption:** consumers' flexible appliances can be used to maximize the local use of their resources (e.g. PV generation), minimizing the need for electricity from the grid.
- **Load management:** residential consumers can use their flexibility to limit the power consumption and respect a connection capacity agreement.

The services listed above are, in fact, intertwined: depending on the technology and remuneration mechanism, the flexibility can directly or indirectly provide more than one service. This is called the value stacking potential of the flexibility. For instance, a demand-side technology as an EV can, at the same time, provide bill optimization as a response to a certain tariff and maximize self-consumption by adapting its charging profiles to the local PV generator. In some cases, the service provided to a lower voltage actor can indirectly provide a higher voltage service. For example, when an energy community manager procures flexibility for self-balancing, it can provide congestion management support to the distribution system operator by reducing the amount of energy the community purchases from (or inject into) the grid.

Remuneration Mechanisms

To obtain flexibility from residential consumers' technologies, and acquire the services discussed previously, remuneration mechanisms are necessary. Those mechanisms can be classified in four categories of highest relevance, which are reviewed in the next sections:[57,58]

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[55] Gonzalez Venegas, Petit, and Perez, "Active Integration of Electric Vehicles into Distribution Grids: Barriers and Frameworks for Flexibility Services."

[56] beuc-x-2019-016_flexible_electricity_contracts_report.pdf

[57] CEER. (2018). *Flexibility use at distribution level - A CEER Conclusions Paper.* Council of European Energy Regulators.

[58] This classification was proposed to identify the possible mechanisms available for system operators to procure flexibility, particularly from distribution systems. In this report, the classification is extended to include not only SOs, but also other stakeholders interested in buying flexibility. For instance, the tariff considered here is beyond grid tariffs, including the energy share as well. A fifth category called technical solution using grid assets, which is linked to the network-system flexibility, is sometimes included in this classification, but given that the focus of Alexander is on residential flexibility, this fifth category is not considered here.

- **Ruled-based:** mandatory provision of flexibility as a consequence of the implementation of technical requirements from connection codes that are available in last-resort or emergency situations.
- **Tariff:** the use of certain tariff structures to trigger implicit flexibility that is able to react to prices. These tariffs can include aspects such as time, direction, capacity and location.
- **Connection agreement:** specific agreements with certain grid users so that they provide a certain service needed.
- **Market-based:** market-based activation of explicit flexibilities that are able to alter power flows in all directions.

a) Ruled-based

The first category includes all types of regulated flexibility. When consumers acquire some appliances and/or when aggregators decide to operate in a market, they need to accept certain requirements set in regulation. Those regulatory requirements could include conditions that allow SOs to modify and even interrupt the operation of those appliances. For example, in Belgium the distribution system users can be disconnected from the system when voltage rises in the distribution system.[59]

When setting these mechanisms, the legislator/regulator could include compensation mechanisms. Lacking those compensation mechanisms incentivizes SOs to always use such flexibility even if alternative, more efficient, sources of flexibility are available. For instance, the Flemish government introduced, in May 2022, a regulatory framework for technical flexibility provision from low- to medium-voltage consumers. Those consumers are obliged to provided system services to distribution system operators if needed, and a compensation mechanism is foreseen.[60]

b) Tariff

The second category includes any type of tariffs designed to trigger consumers' flexibility as a reaction to price signals. As the focus of Alexander is on residential consumers, retail tariffs and feed-in tariffs are the ones reviewed in this report. The former applies to the energy consumers take from the system, while the later relates to each unit they put into the system.

The main objective of the retail tariffs is to provide consumers with incentives to consume energy efficiently, resulting in smaller bills for consumers who react to the tariff profiles. These tariffs have three main components: energy/generation costs, network tariffs, and taxes. As of June 2022, Belgium consumers have 56% of the tariff represented by the energy cost, 18% by the grid fees, 16% by taxes, and 10% by VAT.[61] The energy generation component has always reflected a larger share of the retail tariffs and this aspect has been exacerbated under the current energy crisis that has resulted in higher energy prices.

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[59] Synergrid, "Specific technical prescriptions regarding power-generating plants operating in parallel to the distribution network."

[60] https://beslissingenvlaamseregering.vlaanderen.be/document-view/62833E78479218B0ED55BA23

[61] Information available in https://www.creg.be/sites/default/files/assets/Prices/EvolPrNL.pdf

To understand the potential effects on the efficiency of the system and the applicability of these tariffs, it is necessary to consider the agent setting them. The energy component is set by the retailer of electricity, who acquires electricity (via bilateral contracts for energy, wholesale markets or self-generation) and uses it to provide consumer with their energy need. When recovering these costs, retailer can set tariffs that incentivize consumers to change their consumption pattern. An option that has been discussed in the literature is to link this price to the price on the wholesale markets to incentivize a reduction in consumption of energy during higher price periods. However, a challenge identified by the literature is that these tariffs are not widely popular now, as consumers typically place a high value on predictability and bill stability.[62] An alternative use of this component would be to allow the retailer to obtain flexibility they could trade in flexibility markets.

The network tariff is set by the system operators, who can recover their (regulated) costs from consumers. SOs can use these tariffs to facilitate an efficient use of the network. One option for these tariffs that has received attention in the literature is to link them to the condition of the network to ensure a more efficient consumption of the network.

Once these components are set by separate agents, they need to be coordinated to avoid that they counteract each other. For example, congestion in an area could happen when wholesale prices of electricity are low. Therefore, the generation component could be low which would incentivize consumption. However, at the same time, the network price could be higher to reduce congestion in the area. This results on consumers receiving mixed incentives, which could reduce the effectiveness of the tariffs being operated jointly.

When setting these components, one important aspect is to determine the periodicity of change of the tariffs.[63] By increasing the frequency of the changes in price, the objective is to manage the incentives of the consumers more closely. The literature has identified three main approaches to consider:

- **Static tariff**: Changes in tariffs are set in advance for a period of time (e.g. day and night tariffs are set constant for a year). These tariffs will not reflect the current condition of the grid but they would provide incentives to modify the consumption pattern to avoid high price periods.
- **Event-based tariffs**: Changes in tariffs will be triggered by pre-set events. For example, higher tariffs could be triggered if congestion arises in the node where the consumer is connected. These higher tariffs can be set in advance or they can be calculated as a function of the severity of the event they are trying to correct. An important feature of these tariffs is that the event should not happen very often.

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[62] Schittekatte et al., "Electricity Retail Rate Design in a Decarbonizing Economy: An Analysis of Time-of-Use and Critical Peak Pricing."

[63] Examples of test of dynamic tariffs can be observed in Li, Wu, and Oren, "Distribution Locational Marginal Pricing for Optimal Electric Vehicle Charging Management"; O'Connell et al., "Day-Ahead Tariffs for the Alleviation of Distribution Grid Congestion from Electric Vehicles."

- **Dynamic tariffs**: Charges are calculated dynamically as a function of the grid state during each period. As a result, they could be used to modify tariffs when congestion is expected in specific points of the network in a certain period.

When considering the situation in Belgium, the retail tariffs are set in a competitive market, and energy suppliers can offer a variety of contracts to consumers, with different pricing methodologies, including dynamic energy prices (tariffs)[64]. As energy suppliers must stay competitive, the available contracts in the Belgium market will depend on the behaviour of its consumers (e.g. if consumers are risk-averse and do not follow prices continuously, dynamic energy prices might not be an interesting offer).

On the other hand, network tariffs are approved/designed by regional regulators: VREG for Flanders, BRUGEL for Brussels Capital Region and CWaPE for Wallonia. These network tariffs have been, until recently, depended on a volumetric term in the distribution grid tariff. However, this has been changing in recent years, indicating that capacity and dynamic components are likely to play a more relevant role in the future:

- **Brussel region**: As part of the network tariff methodology for the period 2020-2024,[65] BRUGEL introduced a capacity-related charge (€/kW/month) in these tariffs that will be complemented by a volumetric charge. The objective of this component is to achieve the energy transition at the lowest cost, in particular by greatly reducing the need to reinforce the distribution network by 2030. In the context of a new clearing house and data platform (called Atrias), BRUGEL is examining the introduction of time differentiation in the reformed tariff design. This exercise should be finalised in the function of the new tariff methodology for the next regulation period starting from 2025.
- **Flemish region**: VREG aims at introducing a reform starting in January 2023.[66] As a result, the existing day and night tariff is eliminated and a new tariff with a capacity component (in addition to the volumetric one) is introduced. The capacity component in this new grid tariff is based on the average of the previous 12-month peak measurements. In this way, a single high peak demand during a certain month only counts for 1/12th of the invoice but is carried out for 12 months.[67]
- **Walloon region:** the current network tariffs (which are still volumetric-based tariffs) are valid until 2023.[68] CWaPE is currently undertaking a study to consider the evolution of the tariffs for the next period (2024-2028).[69]

Feed-in tariffs are tariffs that determine the remuneration prosumers receive when they sell electricity to their retailers. Currently in Belgium, these tariffs are set by the retailers and

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[64] Dynamische energieprijzen | VREG

[65] Available in https://www.brugel.brussels/nl_BE/themes/distributietarieven-12/tariefmethodologie-2020-2024-320

[66] Information available in https://www.vreg.be/nl/nettarieven

[67] Further information on these tariffs available in https://www.fluvius.be/nl/thema/factuur-en-tarieven/capaciteitstarief/gezinnen-en-kleine-ondernemingen/wat-is-het#waarom-dit-nieuwe-capaciteitstarief

[68] Available in https://www.cwape.be/node/177

[69] Available in https://www.cwape.be/node/197#travaux-prparatoires

consumers could decide to change retailer to profit of higher prices for their excess electricity. However, these tariffs can also be set in a different way. For example, in the UK these tariffs were set by Government with supplier being required to pay the set amount to their generators.[70]

These tariffs have been introduced to incentivize the uptake of renewable energies. Therefore, a fixed price is normally set to facilitate that prosumers can estimate the revenues they can obtain when considering their investment decision. However, alternative approaches are also possible. For example, to promote self-consumption, these tariffs could be reduced when there are higher wholesale electricity prices and/or congestion in the network.

c) Connection agreement

The third category includes agreements between grid users and system operators so the first provides a certain service needed by the second. In general, the service provided is indirectly remunerated by setting different capacities according to the flexibility needs of the system operator.
An example of this mechanism is the Variable Connection Capacity (VCC), designed for the management of congestion. In these contracts, consumers face a time-dependent profile for the available capacity at the point of contact. This is done by setting an on- and off-peak capacity over time (e.g. peak capacity between 12 pm and 7 am and low capacity the rest of the day). The peak/off-peak profile can be set nationally as well as regionally depending on the needs of the system.[71] VCCs were tested successfully in the project FlexPower in the Netherlands. This approach, however, moves the peak demand which could result in similar peaks in another period.[72] In Spain, these agreements are being offered for recharging electric vehicles, and consumers can decide the power (in kW) they can contract in the peak and off-peak periods of the day (set by the DSO).

These contracts have been proposed mainly to deal with grid congestion and investment deferral, but they could also be used for local voltage support, for example, by providing faster connections for EV charging infrastructure if they provide reactive power compensation.

In Belgium, these contracts are currently not in use for residential consumers. Before these contracts are applied to them, it is necessary to evaluate how they could be designed for consumers to understand their effects. Furthermore, it is necessary to identify potential interactions with other indirect mechanisms such as network tariffs.

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[70] For further information see https://www.ofgem.gov.uk/environmental-and-social-schemes/feed-tariffs-fit#:~:text=The%20Feed%2Din%20Tariffs%20(FIT,and%20exported%20by%20accredited%20installations.

[71] van Amstel, “Flexibility System Design for Electric Vehicles. Performing Congestion Management for the DSO.”

[72] Fonteijn et al., “Evaluating Flexibility Values for Congestion Management in Distribution Networks within Dutch Pilots.”

d) Market-based

A market is a place where parties gather to facilitate the exchange of goods and services.[73] When the procurement of flexibility is done through markets, the price is defined by the law of supply and demand, rather than by a regulated stakeholder (e.g. the system operator defines network tariffs and connection agreement solutions; the retailer defines energy tariffs; the regulator defines regulated flexibility obligations). The flexibility is, thus, procured explicitly by the interested actor and remunerated according to the market price. Market-based solutions for the procurement of flexibility can be divided in three types:[74]

- **Bilateral contract:** one buyer and one seller directly trade the flexibility and negotiate the price for its provision. No centralized rules defining a market for a specific flexibility product are imposed in this case. Therefore, the flexibility traded can have many different formats (e.g. flexibility asset requirements as time, capacity, among others, are freely negotiated);
- **Auction market:** one buyer opens a tender for procuring the needed flexibility, and multiple sellers offer their flexibility according to their technical-economical constraints/requirements. In this case, an specific standard flexibility product must be defined, to allow for the multiple providers to participate. No direct trading or price negotiation is possible, as a market operator is generally responsible for clearing the market and defining which sellers are selected to provide the flexibility. Centralized rules to define how the sellers are picked are imposed, which must be done with transparency;
- **Exchange market:** multiple buyers and multiple sellers enter in a centralized market to exchange the good (flexibility in this case). Again, a standard flexibility product must be defined, no direct trading or price negotiation is possible, and a market operator is responsible for clearing the market. The clearing also defines which buyers have their flexibility needs fulfilled, on top of defining which sellers are selected.

In the framework of Alexander, buyers can be system operators, aggregators, balancing responsible parties, retailers, community aggregators or any other actor interested in purchasing low voltage flexibility. In the case of sellers, the project focuses on residential consumers. However, to give a broader background on flexibility markets, this report reviews other markets where balancing responsible parties, retailers, aggregators, large generators, etc., are also sellers.

Bilateral contracts for the provision of energy are a well-set practice in the wholesale markets where generators sell their electricity directly to large consumers or retailers, but the focus here is on bilateral contracts for the provision of flexibility. These are contracts between a user of flexibility (e.g., an aggregator) and a provider of flexibility (e.g., an EV owner) to agree on the terms on which the user can have access to that flexibility and the compensation the provider will receive.[75]

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[73] Jin, Wu, and Jia, "Local Flexibility Markets."

[74] OneNet D3.1 "Overview of market designs for the procurement of system services by DSOs and TSOs"

[75] Bridge - Data management working group, "Interoperability of Flexibility Assets."

These bilateral contracts can enable flexibility procurement for medium- to long-term horizons. Moreover, they are an interesting solution when there are no sufficient conditions for market formation,[76] e.g., when there is a monopolist situation or when the nature of the flexibility need does not allow product standardization. For instance, system operators can identify in advance the flexibility requirements and contract flexibility through long-term contracts, especially when the need is frequently caused by one (or a small number of) users (e.g., a frequent and predictable congestion in an area).

In the case of low voltage consumers providing flexibility through bilateral contracts, an example is the aggregators contracts. Aggregators can set up an agreement with several consumers, with terms allowing the company to temporarily reduce their electricity consumption when the demand for electricity is high.[77] Those agreements include a negotiated remuneration mechanism, given that end-consumers are not willing to provide flexibility without compensation.[78,79]

Auction markets for the provision of flexibility are a common practice in the ancillary services[80] sector, because those services are procured by system operators, configuring a situation where one buyer seeks to efficiently procure flexibility from multiple sellers (liquidity plays an important role in the efficient procurement). For instance, transmission system operators procure balancing services through national auction-based markets to fulfil their obligations to keep the systems balanced. Nowadays, the effort in Europe is to integrate those national markets, given that the flexibility to provide balancing services does not need to have a location component: supra-national platforms such as MARI for mFRR (manual Frequency Restoration Reserve)[81] or the FCR (Frequency Containment Reserve) platform[82] were created.

Currently in Belgium, appliances connected to the LV network can only participate in the provision of one of the balancing products (i.e., FCR). However, this is likely to evolve. For a start, DSOs would require direct access to flexibility for congestion management which could result in the development of local flexibility markets, which are mentioned next.

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[76] Gonzalez Venegas, Petit, and Perez, "Active Integration of Electric Vehicles into Distribution Grids: Barriers and Frameworks for Flexibility Services."

[77] https://www.beuc.eu/sites/default/files/publications/beuc-x-2019-016_flexible_electricity_contracts_report.pdf

[78] Aman Srivastava et al. (2020) "Reducing winter peaks in electricity consumption: A choice experiment to
structure demand response programs" Reducing winter peaks in electricity consumption: A choice experiment to structure demand response programs | Elsevier Enhanced Reader

[79] Langbroek et al. (2017) "When do you charge your electric vehicle? A stated adaptation approach" When do you charge your electric vehicle? A stated adaptation approach - ScienceDirect

[80] Ancillary services refer to a range of services supporting the normal operation of transmission and distribution systems on top of the basic functions of power generation and transmission – Degefa, Sperstad, and Sæle, "Comprehensive Classifications and Characterizations of Power System Flexibility Resources."

[81] Further information available in https://www.entsoe.eu/network_codes/eb/mari/ and https://eepublicdownloads.azureedge.net/webinars/2021/MARI_PICASSO_Stakeholder_Workshop_20211202-final.pdf

[82] Further information available in https://www.entsoe.eu/network_codes/eb/fcr/

In the case of non-balancing services (e.g., congestion management and voltage control), location is an important factor, and the distribution system operators are also important buyers. Auction markets in the shape of local flexibility markets and/or flexibility trading platforms have received significant interest. These markets trade flexibility in geographically limited areas such as neighbourhoods, communities, towns, and small cities[83] (i.e., "local" can be defined broadly as going from one single substation to the whole network of a distribution company). Some examples are: GOPACS[84] in the Netherlands, NODES[85] in Norway and Sweden, and PICLO[86] in the UK.

Exchange markets for the matching between generators and consumers of energy is a well-set practice in wholesale markets. For instance, day-ahead and intra-day power exchange platforms are in place in Europe to allow energy matching of generators and large consumers or retailers. Retailers will then transfer this energy to its final consumers. Currently, there are no mechanisms for appliances connected to the LV grids to participate in these markets.[87]

In the case of low voltage consumers, local energy markets using peer-to-peer trading are under analysis. A P2P market is an online marketplace where prosumers and consumers can trade electricity[88] without an intermediary, at their agreed price.[89] Prosumers with generation appliances (including batteries) could participate in these markets to sell their flexibility (either from demand-side, generation-side or storage) and/or buy their energy needs. These markets can cover a large range of potential market structures that go from direct trade between peers (resulting in bilateral contracts) to cases where the platform matches buyers and sellers in an exchange market. These markets could constitute the base of an aggregator. For example, project Pebbles in Germany proposed a platform that operates a P2P market but any energy that is not being traded can be aggregated into a virtual power plant that can operate in the market.[90]

Alexander Use Cases

In this section, we present the use cases under analysis in the different tasks of the Alexander project. Those use cases are not definitive: they represent the current status of the work ongoing on the tasks, and they can be modified according to the developments and findings of the tasks.

Task 2.2: Analysis of the influence of individual consumers' characteristics on the

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[83] Jin, Wu, and Jia, "Local Flexibility Markets."

[84] https://en.gopacs.eu/about-gopacs/

[85] https://nodesmarket.com/

[86] https://picloflex.com/

[87] The mechanisms to allow demand response from consumers connected at the high and medium voltage are being put in place at the moment. For example, Elia has introduced the mechanisms for the transfer of energy in day ahead and intra-day markets (available in https://www.elia.be/-/media/project/elia/elia-site/electricity-market-and-system---document-library/transfer-of-energy/2020/2020_07_design_note_toe_da_id.pdf)

[88] These markets could also be used for trading flexibility. However, the focus of the literature has mainly been on the trade of electricity.

[89] IRENA, "Peer-to-Peer Electricity Trading: Innovation Landscape Brif."

[90] Further information available in Project – EN – Pebbles Projekt (pebbles-projekt.de) (accessed 8/9/22)

engagement in energy system services

EVs have potential to disrupt the grid by increasing peak electricity use. Conversely, they enable LV-users to use their vehicles' energy-storage capacity as a grid asset. While various smart charging features (enumerated in the next paragraph) have been well demonstrated in real-life pilots, consumer preferences for many of these features are less understood. We will uncover LV-user preferences for smart charging features that can provide system services using a discrete choice experiment.

In the experiment, survey-takers will imagine that they can only drive an EV that is capable of all smart charging features listed in the experiment. In this scenario, the survey-takers would be able to choose which private EV charger to buy, if they would buy one at all. Survey-takers can choose amongst devices that can have various combinations of six smart charging features: solar-exclusive charging capability (if they have rooftop solar), bidirectional charging capability (vehicle to the home and/or to the grid), dynamic load management capability (so that the charger will not push household peak electricity use past the limits of their homes' circuits, avoiding a household power outage), user-scheduled charging (via smart phone application), and/or automated smart control (by a smart-home management system or the survey-taker's retailer acting as an energy aggregator).

By finding survey-taker's preferences to adopt these smart-charging features, we can better understand consumer willingness to allow system operators to use their EV batteries as a reserve (using V2G charging) and to provide load balancing (balancing hourly energy demand distribution) and load management (keeping peak household electricity use within the limits of the home's circuits) services. In this scenario, survey-takers will consider that their energy retailer, acting as an aggregator, would compensate them for their system services through bilateral contracts between the aggregator and households. This use case is summarized in Table 2.

Table 2: Use case applied in discrete choice experiment to understand consumers' behaviour when investing in smart chargers for electric vehicles

Technologies	Organization Model	System Services	Remuneration Mechanisms
EV (unidirectional) EV (bidirectional) Both combined with smart charger (focus on the smart charging options)	Individual	Load balancing (with solar) Load balancing (balancing hourly energy demand distribution) Load management (keeping peak household electricity use within the limits of the home's circuits) Services for retailer	Bilateral contracts (contracts between consumer and retailer)

Task 2.3: Analysis of the influence of individual consumer characteristics and governance approaches on their engagement in collective flexibility concepts

Table 3: Use case applied in discrete choice experiment to understand consumers' behaviour when investing in collective PV with residential storage

Technologies	Organization Model	System Services	Remuneration Mechanisms
PV (Collective) Residential Storage	Collective	Demand Reduction (self-consumption) Flexibility Provisions (Energy flow to external aggregator)	Bilateral contracts (contracts between consumer and aggregators)

Task 3.1: Development of innovative algorithms to identify congestion points in LV network

Energy storage systems (ESSs) are well suited to provide services to the grid. Among the existing ESSs, residential batteries are increasingly studied to provide grid services. These assets can be aggregated to provide ancillary services such as frequency containment reserve (FCR) and automatic frequency restoration reserve (aFRR). Few research works study the impact probability of the flexibility provided by LV ESSs on the LV network. To address problems faced by DSOs and complete the existing literature, task 3.1 of WP3 studies the impact probability of residential batteries providing frequency ancillary services on the LV network and presents a methodology to assess the congestion probability. This use case is summarized in Table 4.

Table 4: Use case applied to analyse the impact of low voltage flexibility on the low voltage networks

Technologies	Organization Model	System Services	Remuneration Mechanisms
Residential energy storage systems	Collective (through aggregators)	Frequency Containment Reserve (FCR) and automatic Frequency Restoration Reserve (aFRR)	Bilateral contracts (contracts between consumer and aggregators)

Task 4.1: Implications for balancing

The proposed use case of this research is linked to task T4.1 of Alexander, but it is also relevant for Task 2.4: Modelling heterogeneous and non (economic) rational consumer behaviour. It includes a number of technologies with broad utilization by individuals in renewable energy communities. The considered use technologies are photovoltaic (PV) units, batteries, electric vehicles (EVs), heat pumps (HPs), and electric water boilers. Some of these technologies can have shared ownerships such as battery storage systems that can have individual and community-based ownerships. Therefore, studying both ownership schemes could be useful for remuneration or system service analysis. The focus of this research is to consider a centralized community as the main organization model. In the centralized community scheme, individuals exchange power directly with the community manager (CM). Therefore, the CM is responsible for coordinating energy exchanges and remuneration inside the community. For comparison purposes, it would be possible to consider the decentralized community model with the ability to have peer-to-peer (P2P) energy exchanges among the members. Furthermore, the community can be studied for providing possible external systems services such as load flexibility provision and storage capacity sharing services to a Balance Responsible (BRP)/Flexibility Service Provider (FSP). Also, other external services such as congestion management can be provided to system operators (SOs). Within the community, flexibility is scheduled internally inside the community to optimize the electricity bill of the members, considering the potentialities of external services. Community members can receive remuneration in different ways. Using energy-component remuneration, it is possible to purchase energy in communities at a different price than the retail market price. To incentivize the community members to inter-community exchanges, the CM typically proposes competitive electricity prices compared to the upstream supplier's price. The section option could be grid-component remuneration (SOs). In fact, future tariffication in Belgium will include volumetric [€/MWh] + capacity [€/MW] (depending on monthly peaks) components. Some regions in Belgium (e.g., Brussels), even allow for a reduction in grid fees for energy consumed locally in a community (members pay the full fee for energy purchased from the external supplier). And the last option could be remuneration for flexibility service provision to FSP/BRP. One interesting approach would be the establishment of internal mechanisms to share between members benefits coming from external flexibility provision. The use case is summarized in Table 5.

Table 5: Use case of an energy community

Technologies	Organization model	System services	Remuneration mechanism
Generation-side: Photovoltaic units Demand-side: heat pumps, electric vehicles (unidirectional), electric water boilers Storage systems: batteries, electric vehicles (bidirectional)	A Community established on an LV network, with members connected behind the same MV/LV substation. Energy exchanges within/outside the community are managed centrally by a Community Manager (CM).	**External services:** • To a Balance Responsible/Flexibility Service Provider (*): a community can help a BRP/FSP in its portfolio optimization and self-balancing, via e.g. load flexibility provision, storage capacity sharing services. • To SOs: congestion management to the distribution system operator **Internal (i.e. within community) services:** flexibility is scheduled	**For external services:** • To BRPs/FSPs: market-based remuneration to the Community Manager • To SOs: tariff, via e.g. the grid-component of the electricity bill **For Internal services**: minimization of the energy and grid components of

		internally inside the community to optimize the electricity bill (or any other utility function) of the members, taking into account the potentialities of external services	the electricity bill of members, internal sharing of the revenues obtained through external flexibility provision

(*) we suppose a market situation without Transfer of Energy (ToE), i.e. a situation in which the BRP, supplier and FSP roles are assumed by the same entity (ELIA *opt-out regime*). We consider also that the community is part of the portfolio of the BRP/FSP and does not have balancing responsibilities (very large communities, e.g. city-scale communities, which may appear in the future might have balance responsibilities themselves).

2. SCI: Consumer acceptance technologies framework

Consumers’ adoption characteristics of distributed energy resources behind the meter

[1,2] G. Borragán, [1,2] M. Ortiz, [2,3] J. Böning, [4,5] B. Fowler, [1,2] F. Dominguez, [1,2] P. Valkering, [1,2] H. Gerard

[1] Vlaamse Instelling voor Technologisch Onderzoek (VITO), Belgium
[2] Energy Ville, Belgium;
[3] KU Leuven, Belgium;
[4] Department of Engineering Management, University of Antwerp, Belgium;
[5] Centre for Environmental Sciences, University of Hasselt, Belgium;

Highlights

- A systematic literature review was conducted to understand psychological and behavioural factors of DER adoption.
- Acceleration of adoption of DERs can contribute to a faster energy transition by allowing users to generate and store their own energy.
- Results suggest that variables like norms, hedonics, and control play a significant role in adoption.
- Different DER have been studied at different degrees without a standardized framework, thus an uneven number of factors appears per technology.
- Improved knowledge of user characteristics can be used to develop strategies for upscaling DER technologies.

An SCI paper was accepted at Renewable and Sustainable Energy Reviews and can be found at https://www.sciencedirect.com/science/article/abs/pii/S1364032124004714.

3. SCI: Consumer characteristics driving flexibility provision

Prosumer's characteristics driving the provision of flexibility of distributed energy resources behind the meter

[1,2] M. Ortiz, [1,2] G. Borragán, [2,3] J. Böning, [4,5] B. Fowler, [4,5] A. Ford, [4,5] F. Dominguez, [1,2] P. Valkering, [1,2] H. Gerard

[1] Vlaamse Instelling voor Technologisch Onderzoek (VITO), Belgium
[2] Energy Ville, Belgium;
[3] KU Leuven, Belgium;
[4] Department of Engineering Management, University of Antwerp, Belgium;
[5] Centre for Environmental Sciences, University of Hasselt, Belgium;

An SCI paper 'Prosumer's characteristics driving the provision of flexibility of distributed energy resources behind the meter' is in preparation and will be available after acceptance.

Alexander