ANNEX 82

EBC
Energy in Building and Communities Programme

International Energy Agency

Review and assessment of market, policy and stakeholder participation in energy flexibility of buildings

Energy in Buildings and Communities Technology Collaboration Programme

June 2025

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Preface

The International Energy Agency

The International Energy Agency (IEA) was established in 1974 within the framework of the Organisation for Economic Co-operation and Development (OECD) to implement an international energy programme. A basic aim of the IEA is to foster international co-operation among the 30 IEA participating countries and to increase energy security through energy research, development and demonstration in the fields of technologies for energy efficiency and renewable energy sources.

The IEA Energy in Buildings and Communities Programme

The IEA co-ordinates international energy research and development (R&D) activities through a comprehensive portfolio of Technology Collaboration Programmes (TCPs). The mission of the IEA Energy in Buildings and Communities (IEA EBC) TCP is to support the acceleration of the transformation of the built environment towards more energy efficient and sustainable buildings and communities, by the development and dissemination of knowledge, technologies and processes and other solutions through international collaborative research and open innovation. (Until 2013, the IEA EBC Programme was known as the IEA Energy Conservation in Buildings and Community Systems Programme, ECBCS.)

The high priority research themes in the EBC Strategic Plan 2019-2024 are based on research drivers, national programmes within the EBC participating countries, the Future Buildings Forum (FBF) Think Tank Workshop held in Singapore in October 2017 and a Strategy Planning Workshop held at the EBC Executive Committee Meeting in November 2017. The research themes represent a collective input of the Executive Committee members and Operating Agents to exploit technological and other opportunities to save energy in the buildings sector, and to remove technical obstacles to market penetration of new energy technologies, systems and processes. Future EBC collaborative research and innovation work should have its focus on these themes.

At the Strategy Planning Workshop in 2017, some 40 research themes were developed. From those 40 themes, 10 themes of special high priority have been extracted, taking into consideration a score that was given to each theme at the workshop. The 10 high priority themes can be separated in two types namely 'Objectives' and 'Means'. These two groups are distinguished for a better understanding of the different themes.

Objectives - The strategic objectives of the EBC TCP are as follows:

- reinforcing the technical and economic basis for refurbishment of existing buildings, including financing, engagement of stakeholders and promotion of co-benefits;
- improvement of planning, construction and management processes to reduce the performance gap between design stage assessments and real-world operation;
- the creation of 'low tech', robust and affordable technologies;
- the further development of energy efficient cooling in hot and humid, or dry climates, avoiding mechanical cooling if possible;
- the creation of holistic solution sets for district level systems taking into account energy grids, overall performance, business models, engagement of stakeholders, and transport energy system implications.

Means - The strategic objectives of the EBC TCP will be achieved by the means listed below:

- the creation of tools for supporting design and construction through to operations and maintenance, including building energy standards and life cycle analysis (LCA);
- benefitting from 'living labs' to provide experience of and overcome barriers to adoption of energy efficiency measures;
- improving smart control of building services technical installations, including occupant and operator interfaces;

– addressing data issues in buildings, including non-intrusive and secure data collection;

– the development of building information modelling (BIM) as a game changer, from design and construction through to operations and maintenance.

The themes in both groups can be the subject for new Annexes, but what distinguishes them is that the 'objectives' themes are final goals or solutions (or part of) for an energy efficient built environment, while the 'means' themes are instruments or enablers to reach such a goal. These themes are explained in more detail in the EBC Strategic Plan 2019-2024.

The Executive Committee

Overall control of the IEA EBC Programme is maintained by an Executive Committee, which not only monitors existing projects, but also identifies new strategic areas in which collaborative efforts may be beneficial. As the Programme is based on a contract with the IEA, the projects are legally established as Annexes to the IEA EBC Implementing Agreement. At the present time, the following projects have been initiated by the IEA EBC Executive Committee, with completed projects identified by (*) and joint projects with the IEA Solar Heating and Cooling Technology Collaboration Programme by (☼):

Annex 1: Load Energy Determination of Buildings (*)
Annex 2: Ekistics and Advanced Community Energy Systems (*)
Annex 3: Energy Conservation in Residential Buildings (*)
Annex 4: Glasgow Commercial Building Monitoring (*)
Annex 5: Air Infiltration and Ventilation Centre
Annex 6: Energy Systems and Design of Communities (*)
Annex 7: Local Government Energy Planning (*)
Annex 8: Inhabitants Behaviour with Regard to Ventilation (*)
Annex 9: Minimum Ventilation Rates (*)
Annex 10: Building HVAC System Simulation (*)
Annex 11: Energy Auditing (*)
Annex 12: Windows and Fenestration (*)
Annex 13: Energy Management in Hospitals (*)
Annex 14: Condensation and Energy (*)
Annex 15: Energy Efficiency in Schools (*)
Annex 16: BEMS 1- User Interfaces and System Integration (*)
Annex 17: BEMS 2- Evaluation and Emulation Techniques (*)
Annex 18: Demand Controlled Ventilation Systems (*)
Annex 19: Low Slope Roof Systems (*)
Annex 20: Air Flow Patterns within Buildings (*)
Annex 21: Thermal Modelling (*)
Annex 22: Energy Efficient Communities (*)
Annex 23: Multi Zone Air Flow Modelling (COMIS) (*)
Annex 24: Heat, Air and Moisture Transfer in Envelopes (*)
Annex 25: Real time HVAC Simulation (*)
Annex 26: Energy Efficient Ventilation of Large Enclosures (*)
Annex 27: Evaluation and Demonstration of Domestic Ventilation Systems (*)
Annex 28: Low Energy Cooling Systems (*)
Annex 29: ☼ Daylight in Buildings (*)
Annex 30: Bringing Simulation to Application (*)
Annex 31: Energy-Related Environmental Impact of Buildings (*)
Annex 32: Integral Building Envelope Performance Assessment (*)
Annex 33: Advanced Local Energy Planning (*)
Annex 34: Computer-Aided Evaluation of HVAC System Performance (*)

Annex 35: Design of Energy Efficient Hybrid Ventilation (HYBVENT) (*)
Annex 36: Retrofitting of Educational Buildings (*)
Annex 37: Low Exergy Systems for Heating and Cooling of Buildings (LowEx) (*)
Annex 38: ☼ Solar Sustainable Housing (*)
Annex 39: High Performance Insulation Systems (*)
Annex 40: Building Commissioning to Improve Energy Performance (*)
Annex 41: Whole Building Heat, Air and Moisture Response (MOIST-ENG) (*)
Annex 42: The Simulation of Building-Integrated Fuel Cell and Other Cogeneration Systems (FC+COGEN-SIM) (*)
Annex 43: ☼ Testing and Validation of Building Energy Simulation Tools (*)
Annex 44: Integrating Environmentally Responsive Elements in Buildings (*)
Annex 45: Energy Efficient Electric Lighting for Buildings (*)
Annex 46: Holistic Assessment Tool-kit on Energy Efficient Retrofit Measures for Government Buildings (EnERGo) (*)
Annex 47: Cost-Effective Commissioning for Existing and Low Energy Buildings (*)
Annex 48: Heat Pumping and Reversible Air Conditioning (*)
Annex 49: Low Exergy Systems for High Performance Buildings and Communities (*)
Annex 50: Prefabricated Systems for Low Energy Renovation of Residential Buildings (*)
Annex 51: Energy Efficient Communities (*)
Annex 52: ☼ Towards Net Zero Energy Solar Buildings (*)
Annex 53: Total Energy Use in Buildings: Analysis and Evaluation Methods (*)
Annex 54: Integration of Micro-Generation and Related Energy Technologies in Buildings (*)
Annex 55: Reliability of Energy Efficient Building Retrofitting - Probability Assessment of Performance and Cost (RAP-RETRO) (*)
Annex 56: Cost Effective Energy and CO_2 Emissions Optimization in Building Renovation (*)
Annex 57: Evaluation of Embodied Energy and CO_2 Equivalent Emissions for Building Construction (*)
Annex 58: Reliable Building Energy Performance Characterisation Based on Full Scale Dynamic Measurements (*)
Annex 59: High Temperature Cooling and Low Temperature Heating in Buildings (*)
Annex 60: New Generation Computational Tools for Building and Community Energy Systems (*)
Annex 61: Business and Technical Concepts for Deep Energy Retrofit of Public Buildings (*)
Annex 62: Ventilative Cooling (*)
Annex 63: Implementation of Energy Strategies in Communities (*)
Annex 64: LowEx Communities - Optimised Performance of Energy Supply Systems with Exergy Principles (*)
Annex 65: Long-Term Performance of Super-Insulating Materials in Building Components and Systems (*)
Annex 66: Definition and Simulation of Occupant Behavior in Buildings (*)
Annex 67: Energy Flexible Buildings (*)
Annex 68: Indoor Air Quality Design and Control in Low Energy Residential Buildings (*)
Annex 69: Strategy and Practice of Adaptive Thermal Comfort in Low Energy Buildings (*)
Annex 70: Energy Epidemiology: Analysis of Real Building Energy Use at Scale (*)
Annex 71: Building Energy Performance Assessment Based on In-situ Measurements (*)
Annex 72: Assessing Life Cycle Related Environmental Impacts Caused by Buildings (*)
Annex 73: Towards Net Zero Energy Resilient Public Communities (*)
Annex 74: Competition and Living Lab Platform (*)
Annex 75: Cost-effective Building Renovation at District Level Combining Energy Efficiency and Renewables (*)

Annex 76: ☼ Deep Renovation of Historic Buildings Towards Lowest Possible Energy Demand and CO_2 Emissions (*)
Annex 77: ☼ Integrated Solutions for Daylight and Electric Lighting (*)
Annex 78: Supplementing Ventilation with Gas-phase Air Cleaning, Implementation and Energy Implications
Annex 79: Occupant-Centric Building Design and Operation
Annex 80: Resilient Cooling
Annex 81: Data-Driven Smart Buildings
Annex 82: Energy Flexible Buildings Towards Resilient Low Carbon Energy Systems
Annex 83: Positive Energy Districts
Annex 84: Demand Management of Buildings in Thermal Networks
Annex 85: Indirect Evaporative Cooling
Annex 86: Energy Efficient Indoor Air Quality Management in Residential Buildings
Annex 87: Energy and Indoor Environmental Quality Performance of Personalised Environmental Control Systems
Annex 88: Evaluation and Demonstration of Actual Energy Efficiency of Heat Pump Systems in Buildings
Annex 89: Ways to Implement Net-zero Whole Life Carbon Buildings
Annex 90: ☼ EBC Annex 90 / SHC Task 70 Low Carbon, High Comfort Integrated Lighting
Annex 91: Open BIM for Energy Efficient Buildings
Annex 92: Smart Materials for Energy-efficient Heating, Cooling and IAQ Control in Residential Buildings
Annex 93: Energy Resilience of the Buildings in Remote Cold Regions
Annex 94: Validation and Verification of In-situ Building Energy Performance
Annex 95: Human-centric Building Design and Operation for a Changing Climate
Annex 96: Grid Integrated Control of Buildings
Annex 97: Sustainable Cooling in Cities

Working Group on Building Energy Codes
Working Group on Cities and Communities
Working Group on HVAC Energy Calculation Methodologies for Non-residential Buildings
EBC Annex 36 Extension Working Group
Working Group on Indicators of Energy Efficiency in Cold Climate Buildings
Working Group on Energy Efficiency in Educational Buildings (EBC Annex 15)

Summary

There is a large potential for improving resilience in energy grids, postpone grid extension or enforcement, increase utilisation of renewable energy sources and reduce CO_2 emissions from energy production by harvesting end users' energy flexibility. Demand-side flexibility is the capacity to change energy usage and local production from normal or current consumption patterns in response to local climate conditions and grid requirements, the latter normally encouraged by changes in the price of energy over time or economic incentives (e.g. contracts with payment for offering demand flexibility). These price changes or incentives can be energy grid and market related. Energy grid operators may provide customers with grid related signals to manage net overload, minimise emissions from energy production or postpone enforcement of the grid. Price signals from the market can come from the wholesale market, e.g. day-ahead or intra-day markets. Suppliers or other commercial parties (such as aggregators that collect small quantities of end-user flexibility and give those aggregated volumes a value on wholesale markets or as ancillary service) may provide customers with price signals, e.g. when wholesale prices are very low or extremely high. The success of energy flexibility among consumers is likely to be defined by a combination of the willingness of consumers to respond to signals actively, and the availability of smart devices, smart systems and smart buildings to allow automated controls.

This document reports the findings from our collaborative, international comparisons of the state-of-the-art of energy flexibility within different countries around the world. Our focus has been on policy and regulation, price-incentive structures, business models and key factors influencing customers' willingness and possibilities for taking part in energy demand flexibility.

In terms of **policy and regulation** (Chapter 2), our international review shows great variety between countries, in terms of the extent and type of policy measures implemented. Countries with the most ambitious policies are the most advanced in deploying energy flexibility in commercial and residential buildings, which confirms that policies make a difference. However, the diffusion of energy flexibility for smaller consumers is still limited. Relatively few aggregators exist, which points to the need for more policies aimed at creating a market for flexibility. At the same time, there has been some diffusion of energy communities in a few countries, which points to the importance of considering alternative organizational approaches to activating the energy flexibility potential rather than only aggregators and market-based/commercial solutions. Finally, implicit demand response is relatively widespread in countries with dynamic pricing and Time-of-Use (ToU) pricing for small consumers (including households). This indicates that the potential of implicit demand response should not be ignored in policymaking.

Price incentives (Chapter 3) for energy flexibility are available to electricity customers in all reviewed countries, often in the shape of real-time pricing (retail). However, the penetration of price incentives varies considerably between countries, with some having a considerable number of small customers being using dynamic and/or ToU schemes, and other countries with only a small number of customers using such schemes. Our review indicates that in countries with a high penetration of price incentives, this has influenced the load profile of small consumers. The implementation of flexible pricing schemes is very limited within the gas markets, and non-existing within district heating systems.

Our literature review and own studies into the broader variety of **factors influencing energy flexibility** are described in Chapter 4. The literature review demonstrates that simulation-based studies dominate the literature on demand side management, with fewer studies based on experimental trials and full-scale rollout. This might result in methodological biases towards less valid and more 'idealistic' findings than 'real-world'

experiments. Also, the review shows that previous studies have had a dominant focus on economic and price incentives, which might reflect a more general tendency within the energy flexibility field to prioritize market-based and commercial solutions, which could be problematic as other types of approaches (such as citizen energy communities) driven by other motivations than financial gains could be overlooked in research, design and policy-making. A survey carried out in US, Belgium and Austria shows that the willingness to adjust household activities, and whereby the timing of energy consumption, varies between countries. Important factors are differences in incentives and rate structures, the time of the day and perceptions of and previous experiences with DSM. Chapter 4 concludes by observing that stakeholders have different capabilities for taking part in energy flexibility schemes, and they are affected in different ways. To some extent, their capabilities and how they are affected reflect their composition of 'flexibility capital', including financial resources. It is important to design energy flexibility programs that are inclusive and do not increase inequalities in societies. Neglecting these concerns might result in a lack of social acceptance, or even resistance to, energy flexibility schemes and the transition of energy systems.

In terms of **business models** (Chapter 5), creating sustainable and scalable business models is essential for promoting energy flexibility in buildings. Many actors or stakeholders are involved in the energy system, and business models often include several stakeholders. However, DSOs seem to play a particular key role as they serve as the primary interface for facilitating energy flexibility through their direct – and 'physically wired' – connection to customers. Another key actor seems to be aggregators. Our review of business models shows that most of these models target residential buildings (especially single-family homes), commercial buildings and mixed-use buildings. Many value propositions were identified, such as energy bill savings, new equipment/technology acquisition, financial incentives, etc. Most of the stakeholder categories shared propositions related to societal or community contributions. This shows that not only financial benefits are in focus, but also broader societal gains (e.g. CO_2 reduction or sustainability branding for companies). Dominating types of systems/equipment targeted by business models are HVAC (mainly heat pumps and air conditioners), followed by PV panels and electric batteries. The reviewed business models primarily focus on load shedding and load shifting. In terms of revenue sources, 30% of the cases involved a combination of subscription fees, equipment purchases, research funds and professional service fees. This shows that revenues often depend on a multiplicity of sources.

Table of content

Abbreviations

Abbreviations	Meaning
AEMC	Australian Energy Market Commission
AEMO	Australian Energy Market Operator
BRP	Balance Responsible Parties
CEC	Citizen Energy Community
CER	Consumer Energy Resources
DERs	Distributed Energy Resources
DESNZ	Department for Energy Security and Net Zero
DFS	Demand Flexibility Service
DNO	Distribution Network Operators
DSO	Distribution System Operator
EC	European Commission
ECo	Energy Community
EF	Energy Flexibility
EED	Energy Efficiency Directive
EPBD	Energy Performance of Buildings Directive
ESCO	Energy Service Companies
ESO	Electricity System Operator
EU	European Union
EV	Electrical Vehicle
GDP	Gross Domestic Product
MW	Megawatt
IEA	International Energy Agency
NEM	National Electricity Market (Australia)
NL	Network Level
Ofgem	Office of Gas and Electricity Markets
PSA	Pooling and Settlement Agreement
PV	Photo Voltaic
RCP	Raggruppamenti ai fini del Consumo Proprio (Own Consumption Group)
REC	Renewable Energy Community
RES	Renewable Energy Sources
RTP	Real Time Pricing

SRI	Smart Readiness Indicator
TSO	Transmission System Operator
UV	Unità Virtuali (Virtual Units)
UVAM	Unità Virtuali Abilitate Miste (Mixed Enabled Virtual Units)
WDRM	Wholesale Demand Response Mechanism

Definitions

Distributed Energy Resources: Distributed Energy Resources (DERs) refers to smaller generation units located on the consumer's side of the meter, e.g. rooftop photovoltaics (PVs).

Energy Flexibility: The Energy Flexibility (EF) of a building is the ability to manage its demand and generation according to local climate conditions, user needs and grid requirements. Energy flexibility of buildings will thus allow for demand side management/load control and thereby demand response based on the requirements of the surrounding grids. (Definition from IEA EBC Annex 67 Energy Flexible Buildings; see Jensen et al., 2017).

Resilient Energy Networks: In this context, resilient energy networks are defined as systems that are prepared for, and can withstand, the challenges associated with the transition to energy systems with a large share of Renewable Energy Sources (RES). Energy flexible buildings and communities may increase the resilience of the energy networks by reducing the stress on the infrastructure, but also by making the buildings and communities more resilient to fluctuations in the energy supply.

Energy source: Source from which useful energy can be extracted or recovered either directly or by means of a conversion or transformation process.

Ancillary services: Specialized functions that help maintain grid stability and reliability. These services include frequency regulation, voltage control, reserves and black start capabilities. Ancillary services are essential for ensuring the uninterrupted supply of electricity.

Aggregator: An aggregator means a legal entity that is responsible for the operation of several Demand Facilities by means of Demand Aggregation. (ENTSO-E, 2012).

Demand Aggregation: Demand aggregation is a set of Demand Facilities that can be operated as a single facility for the purposes of offering one or more Demand Side Response services (ENTSO-E, 2012).

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1 Introduction

This deliverable reports the findings from two subtasks in the IEA EBC Annex 82 on *Energy Flexible Buildings Towards Resilient Low Carbon Energy Systems* running from 2020 to 2025. The overall focus of Annex 82 was on how energy flexibility of buildings can contribute to future, resilient energy systems with high shares of fluctuating renewables. This deliverable builds on the work carried out in Subtask C *Stakeholder acceptance and engagement* and Subtask D *Development of appropriate implementation (business) models*. These subtasks investigated the factors influencing the realization of the energy flexibility potential in buildings, including policies and price incentives, as well as business models supporting utilization of flexibility services from buildings. The understanding of the motivations and barriers for the different stakeholders is a key input for developing boundary conditions of simulation models or innovative business models for the utilization of flexibility services from buildings and clusters of buildings. And, more broadly, this knowledge can inform policymaking.

References are collected at the end of each chapter.

1.1 Background

The foreseen large-scale deployment of intermittent renewable energy sources (RES) may seriously affect the operation and stability of energy networks, but also reduce CO_2 emissions from energy production and use. Use of RES in production of electricity is seen as the prime path to decarbonization. This, however, requires costly strengthening of the electricity grid and/or utilisation of energy flexibility. i.e., the ability to use electricity when abundant, and curtail or shift when production is low. It will, therefore, be necessary to control the energy use to ensure alignment with the fluctuating energy production. The potential energy flexibility in buildings is an attractive resource to control energy use due to the relatively limited infrastructure needed to operationalize this resource and better utilize local (distributed) production of renewable energy. Mobilizing this currently untapped resource would, therefore, allow for a larger roll-out of RES and make the energy networks more resilient through their ability to shift energy use in time.

In this context, resilient energy networks are defined as systems that are prepared for and can withstand the challenges associated with the transition to energy systems with a large share of RES. Energy flexible buildings and communities may increase the resilience of the energy networks by reducing the stress on the infrastructure but also make the buildings and communities more resilient to fluctuations in the energy supply and price.

Energy flexibility of a building is the ability to manage its demand and supply according to local climate conditions, user needs and energy network requirements. Energy flexibility of buildings is the ability to provide demand side management and/or load control, thus satisfying requirements of the surrounding energy networks and contributing to the resilience of the future energy systems, without compromising the indoor climate or healthiness in the participating buildings or communities. This can be achieved by a combination of, for example, extensive use of heat pumps, district heating/cooling networks, and smart controls, as well as appliances that can react to signals from the energy networks. Energy flexibility can also be provided through end-users shifting energy consumption actively, for instance shifting their use of appliances in time.

In the previous IEA EBC Annex 67, it was suggested that a main motivator for leveraging energy flexibility from buildings is the monetizable benefits for end-users and energy service providers. It was thus, important to investigate business models where all the stakeholders obtain some kind of monetizable benefit for providing or utilizing energy flexibility. From a strategic point of view, existing energy networks and building energy systems will require additional investment and service costs to be able to utilize the potential energy flexibility in buildings and communities. Last, but not least, examples of rules and regulations allowing stakeholders to harvest energy flexibility have been analysed and documented to serve as inspiration for less developed areas. Annex 82, and the present deliverable, add further insights to the topics identified in Annex 67 that were deemed to require further exploration.

1.2 Types of flexible energy loads

Different kinds of energy loads can be flexible (inspired by Edelenbos et al., 2015 and He et al., 2013):

- **Non curtailment load** (Base load). Not all energy consumption is changeable. The base load can be considered inelastic to signals (e.g., burglary alarm for households).
- **Curtailable (sheddable) load.** This kind of energy consumption can be switched off at given times or periods. Curtailment can happen as reduced service (e.g., switching off decorative lighting, reduced temperatures in parts of a building). The curtailed energy will not be consumed at a later point in time.
- **Shiftable load**. This energy consumption can be moved to a different time (earlier or later). In many cases, the total consumption will remain the same (e.g., when charging an electric vehicle later). If the change involves pre-heating or precooling, the total consumption may increase due to extra service levels or reduced efficiencies. Even if the total end-user demand increases, overall benefits may exist, e.g., reduced CO_2 emissions.
- **Storable load**, meaning that this kind of energy consumption can be used as usual, but the energy can be generated, transported and stored at a different time, such as when wholesale electricity prices are low. The final energy-savings effect is likely to be negative because storage is less efficient than immediate consumption. However, at a system level, there could still be primary energy savings if, for example, the process allows replacing electricity from thermal generation with wind or solar-generated electricity.

1.3 Relevant stakeholders to energy flexibility in buildings

There are several stakeholders that can utilize and benefit from energy flexibility services that buildings, especially clusters of buildings, may provide and who are essential for the design of future resilient Smart Energy Networks. For example, electricity delivery companies can use energy flexibility to avoid expanding infrastructure, which avoids additional capital costs, allowing them to provide value for their customers in the form of lower electricity bills. Companies developing business cases for products and services that will support the roll-out of Smart Energy Networks can benefit from new revenue opportunities through new product offerings. Other important stakeholders are the building owners and occupants of the buildings with energy flexibility services, as they must accept, and sometimes invest in, such services. Other types of relevant stakeholders are energy cooperatives, building caretakers, and ESCOs (Energy Service Companies), but also aggregators, utility companies, consultants, manufacturers, and local authorities. Also, policy-makers play a critical role in shaping the future of energy systems and government entities by setting energy flexibility requirements for new and existing buildings.

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2 Policy and regulation schemes as basis for energy flexibility

2.1 Introduction

In the pursuit of sustainable energy systems, the integration of distributed energy resources (DERs) has emerged as a pivotal strategy to enhance grid resilience, promote energy efficiency, and mitigate environmental impacts. DERs, encompassing production sources such as solar photovoltaics, wind turbines, and other small-scale generation units and demands like charging of EVs (electrical vehicles), heat pumps, space cooling systems, but also behind the meters batteries, hold immense potential to revolutionize the energy landscape by decentralizing power production and consumption. However, unlocking the full value of these diverse and dispersed energy assets requires more than technological innovation; it demands a robust legislative framework capable of facilitating the seamless aggregation of many small amounts of energy flexibility. When phasing out thermal power plants with their spinning reserves, the harvesting of energy flexibility through the power system becomes increasingly important.

The aggregation of energy flexibility refers to the process of orchestrating and optimizing the operational characteristics of numerous DERs to collectively respond to grid needs in real-time. By harnessing the inherent variability and controllability of DERs, energy flexibility enables grid operators to balance supply and demand, alleviate congestion, and integrate intermittent renewable resources more effectively. Moreover, it empowers consumers to actively participate in energy markets, optimize their energy consumption patterns, and reap financial rewards through demand response programs and energy trading.

Despite the promising benefits of energy flexibility aggregation, several regulatory and policy barriers impede its widespread adoption and deployment. The absence of standardized protocols for data exchange, interoperability challenges among diverse DER technologies, and unclear market mechanisms, hinder the seamless integration of DERs into grid operations. Moreover, regulatory frameworks often lag behind technological advancements, failing to incentivize investments in DER aggregation platforms or adequately compensate flexibility providers for their services.

In light of these challenges, the establishment of a legislatively robust framework emerges as a critical imperative for realizing the full potential of energy flexibility aggregation from DERs. Such a framework should encompass a multifaceted approach, addressing technical, economic, and regulatory dimensions, to create an enabling environment for scalable and interoperable DER aggregation solutions. By delineating clear rules for market participation, data sharing, and compensation mechanisms, legislators can foster a conducive ecosystem for innovation, investment, and collaboration among stakeholders across the energy value chain. Ideally the legislation should facilitate the utilization of energy flexibility from DERs by creating the right conditions, including removal of barriers. However, the legislation also must protect already involved stakeholders – especially TSOs, DSOs, electricity retailers and end-users.

This chapter explores ongoing legislative works in different countries that aim to facilitate the aggregation of energy flexibility from distributed energy resources. Drawing upon insights from regulatory experiences worldwide, this illustrates key components of an effective legislative framework and highlights the role of policy innovation in driving the transition towards a more flexible and resilient energy system. The chapter aims to inform policy-makers, regulators, industry stakeholders, and researchers about the imperative of legislative action in unlocking the value and potential of demand side flexibility for grid optimization and decarbonization efforts.

The section contains information on policies and regulation regarding energy flexibility with a focus on flexibility in buildings from the countries shown in Figure 1. The country sample includes Australia, Canada, China, European Union and selected EU member states (Austria, Denmark, Ireland, Italy and Czech Republic), Switzerland, UK and USA.

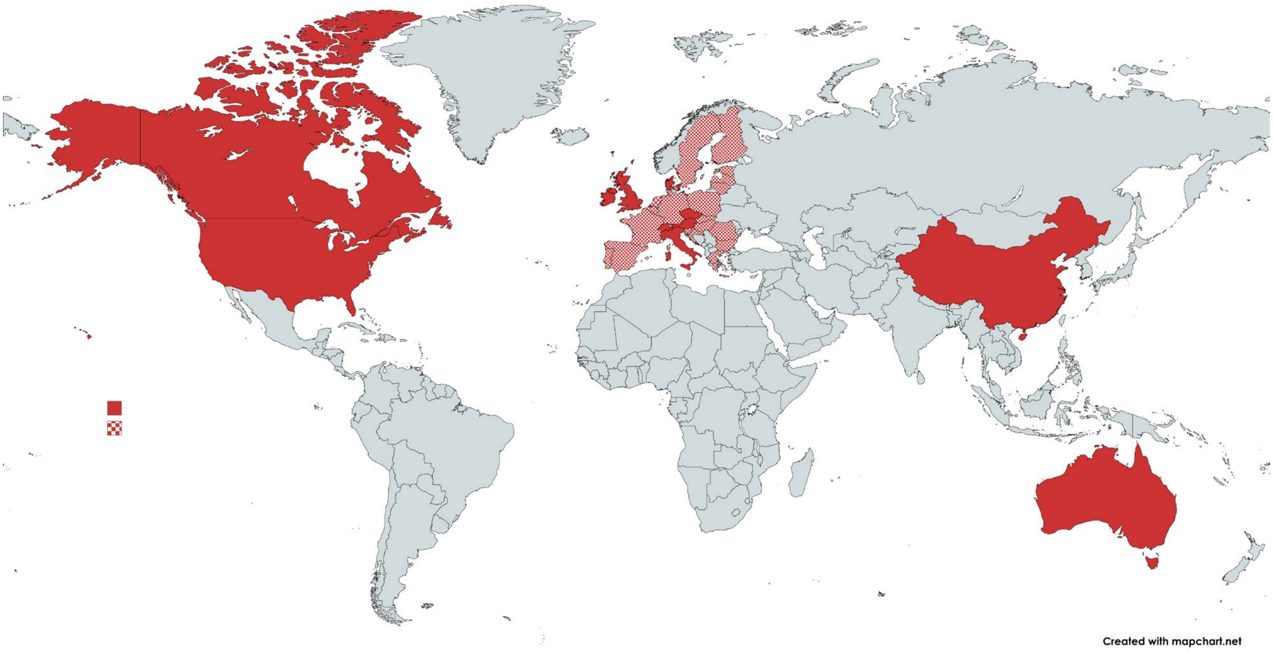

Figure 1 Countries surveyed in this chapter about policy and regulations on energy flexibility.

Aggregation of energy flexibility

Commercial demand response is relatively well established in the markets of most power grids. However, in the existing flexibility markets it is only possible to participate with units at the MW+ scale, which limits the participation to large consumers. Domestic demand response from a house can only generate energy flexibility in kW+ sizes. Households can, therefore, not directly participate in the current flexibility markets. There is a need for an entity that can aggregate many small flexibility contributions into sufficiently large volumes, which then can be offered to a flexibility market. This entity is often referred to as an aggregator.

An aggregator can for instance be a fleet-operator in charge of controlling many charging stations for EVs or many smaller heat pumps in single-family homes. However, such aggregators need to be regulated so that they do not cause problems to the performance of the energy system or to other stakeholders. For example, in the case of much surplus electricity in the grid, due to a windy day for instance, an aggregator may see a profit in increasing the demand of the many assets the aggregator is in charge of. However, this may create congestion problems at the distributed level e.g., feeder level, and thus create severe problems for the DSO (Distribution System Operator).

Another kind of aggregator is an Energy Community (ECo), which is an important entity in the EU legislation (see chapter 2.5). An ECo is a community that creates an area for internal exchange of production and usage of renewable energy. Either in the form of a) a behind the meter area, only connected to the surrounding grid via one connection, or b) where smart meters at the customers and producers are utilized to establish a virtual energy community. The DSO sees the ECo as one large customer, where the production and demand are aggregated.

The layout of the power grid and the legislation regulating the power market differs between countries and regions, and there is no ‘one legislation package’ that fits it all. The following gives examples of current and coming legislation aimed at utilizing the possible energy flexibility from DERs.

The European Union (EU) constitutes a special case. The power grids of the EU member states are interconnected, which means that a situation in Italy may influence the power price in northern Sweden. The member states, therefore, agree on overarching legislation under which the different member states have some freedom on how to implement this in their national legislation. Hence, there is a subsection in this chapter dedicated to describing the EU context, but also country-specific sub-sections describing conditions in some of the member states.

2.2 Australia

Australia’s electricity system is in transition. One-third of Australian households have installed rooftop solar PV. Collectively rooftop solar PVs is the second largest source of renewable electricity in Australia behind wind energy. According to projections from the independent system and market operator and system planner, the Australian Energy Market Operator (AEMO), Australia will have a significant uptake of Distributed Energy Resources (DERs) and renewables in the coming decades: a 4-fold increase in rooftop solar and a 6-fold increase in large scale wind and solar generation by 2050 (AEMO, 2024). In order to ensure secure and reliable operation of the grid with high levels of renewables, a right mix of flexible resources is needed to manage the grid at different time scales. AEMO expects a major part of this flexibility to come from Consumer Energy Resources (CER) that include rooftop PVs, batteries, EVs, hot water systems and air conditioning. Australian Renewable Energy Agency (ARENA) has commissioned a study that has identified a cost saving of up to 18 billion AUD$ by 2040 through utilisation of demand flexibility available from residential, commercial and industrial sectors (Briggs et al, 2023).

Electricity markets need to adapt to operation of a system with high CER uptake. As a result, there are various activities (projects and market rule amendments) under progress to support the operation of a two-sided market. This section outlines some of the key changes and developments that have either been implemented or are under consideration.

Five-minute Settlement

Australia National Electricity Market (NEM) moved from 30 minutes settlement to 5 minutes in 2021 (AEMC, 2021). As a result, electricity spot prices are settled at five-minute intervals. This is seen as a significant step to enable participation of consumer-side resources to deliver demand response and support operation of an electricity system with highly varying renewables.

Wholesale Demand Response

Australia introduced the Wholesale Demand Response Mechanism (WDRM) in 2021 to encourage all consumers with greater opportunities to participate in the wholesale market. Consumers can participate in the market through Demand Response Service Providers who aggregate the demand response and dispatch it through the National Electricity Market’s standard bidding and scheduling processes (AEMO, 2021). There is a minimum dispatchable size of 1 MW for participation. This can be achieved by individual loads or through aggregation. There is no minimum size of individual loads for aggregation. A review of the current WDRM operation is due in October 2025.

Common Smart Inverter Profile Australia

Considering the need for having visibility of CER and their active management (e.g. communicating flexible export limits), Australia has developed a communication protocol between utility servers and clients (aggregators, gateways or inverters). This protocol leverages the IEEE 2030.5 and CSIP (California's Common Smart Inverter Profile). This enables a consistent approach to the active management of CER (CSIP Aus, 2023).

CER roadmap

The CER Roadmap released in July 2024 sets the national reform priorities to build national consistency and support a harmonised approach to unleashing the full potential of CER. As part of CER roadmap, the Australian Energy Market Commission (AEMC) has been considering various rule changes as part of market reforms (AEMC, 2024):

- Activity #1: Accelerating smart meter deployment. Some states in Australia have more smart meter deployment than other states. AEMC is progressing reforms to achieve smart meter deployment across all the National Electricity Market region by 2030. These reforms address the risks associated with highly volatile prices.
- Activity #2: Electricity pricing for a consumer-driven future. AEMC is currently carrying out a review of electricity pricing, products and services. This review will examine how markets and regulatory frameworks can support the participation of consumer energy resources in the energy transition.
- Activity #3: Unlocking CER benefits through flexible trading. The Australian Energy Market Commission (AEMC) has determined changes to the electricity and retail rules to facilitate CER participation through flexible trading. Three key components of the proposed arrangement are:
    - Large consumers will be able to engage multiple service providers to manage and obtain value from their CER.
    - Energy service providers for small and large consumers will be able to offer new products and services through management of flexible CER.
    - Market participants will be able to use inbuilt technology from CER devices, e.g. EV chargers.

  It is expected that most of these rule changes will be implemented before November 2026.
- Activity #4: Incorporating price responsive resources into the National Electricity Market. AEMC have created draft rules (under consultation) to enable participation of unscheduled price-responsive resources into the National Electricity Market (NEM). This will enable consumers or parties acting on their behalf to respond to spot prices as scheduled and dispatchable resources in the electricity market. As a result, it will allow price responsive small resources to bid in the spot market either individually or in aggregation, receive dispatch instructions and earn revenues. This draft rule includes a time limited incentive scheme to drive participation in the first 5 years. This rule will enable CER participation in the market in 2026.
- Activity #5: Real time data for consumers. AEMC is considering carrying out a review of how consumers and their authorised agents can access power data in real time.

Scheduled Lite

To support participation of unscheduled loads and generators in the NEM scheduling process, the electricity market operator has proposed setting up a voluntary mechanism called Scheduled Lite (AEMO 2023). This mechanism has two modes: visibility mode and dispatch mode. Under the 'visibility' mode, participants would be able to provide to AEMO details of their price-responsiveness, allowing AEMO to incorporate an adjusted demand curve for dispatch. Under 'dispatch mode', participants with a minimum aggregation larger than 5 MW would be able to submit bids and be dispatched, but under less restrictive rules than under the Wholesale Demand Response Mechanism (WDRM).

Emergency backstop

As a means to ensure system security while operating with high levels of PV sources, some Australian states have mandated the solar emergency backstop mechanism that allows distribution companies to remotely turn down or switch off rooftop solar systems during an energy supply emergency (DEECA Victoria, 2024).

2.3 Canada

Canada's electricity sector is undergoing a significant transformation driven by five major megatrends: the integration of climate policy into energy regulation; evolving customer expectations and flexibility; the convergence of industry boundaries; increasing complexities in executing large-scale projects; and the emergence of the Energy Cloud. This transition involves the adoption of distributed energy resources (DERs) such as solar PV, batteries, and electric vehicles. These decentralized sources, powered by digital technology and cloud-based systems, enable real-time monitoring, control, and optimization of energy production and consumption, thereby enhancing grid flexibility, building efficiency, and overall energy use. As a result, there is a need for a comprehensive reassessment of legislative and regulatory frameworks to address an expanded set of issues beyond traditional considerations like price, cost, reliability, and service quality. Current regulatory regimes in Canada are not adequately equipped to handle the rapid integration of DERs and innovative technologies. Originally designed to govern centralized energy systems, these frameworks are now being challenged by new technologies that present technical possibilities previously unforeseen. The advent of smart appliances, grid-interactive efficient buildings, electric vehicles, and bidirectional energy flows, among other emerging technologies, offers opportunities to enhance electricity resource management, deliver greater value to customers, reduce overall system costs, and improve regulatory systems (Krause, 2020; NERC, 2021).

Regulatory reforms in Canada can be broadly divided into two categories: process reforms and framework reforms. Provinces such as Alberta and Ontario are leading these changes, transitioning from a predominantly centralized energy system managed by a few major players to a more decentralized model. This shift is largely driven by the increasing role of DERs and other demand-side solutions, alongside growing electricity demand (Alberta Utilities Commission, 2022; Ontario Energy Board, 2023).

In Ontario, the energy sector has become a significant contributor to DER flexibility, with over 5,000 MW of DER capacity already deployed. The potential for further expansion is substantial, particularly as more DERs are introduced to meet electrification and decarbonization goals driven by both policy and customer demand. For instance, the use of energy storage and electric vehicles as mobile storage units introduces new flexibility in energy management and pricing. These technological advancements pose a variety of challenges, not only in the physical management of the energy system but also in pricing and market entry for non-traditional participants. Ontario’s regulatory framework must be adaptive, forward-looking, and capable of handling technological and market uncertainties (IESO, 2024; Ontario Ministry of Energy, 2024).

Québec, as it embarks on a path of energy and economic transformation, increasingly prioritizes the strategic management of its electricity supply. This includes reducing overall energy consumption and exploring the flexibility of end-users, particularly during periods of high demand. With a global push towards DER flexibility integration, Quebec aims to leverage its clean energy resources and competitive rates. The Canadian public electric utility Hydro-Québec has launched its Action Plan 2035, a strategic roadmap designed to guide the province toward a decarbonized and prosperous future. The plan focuses on five key areas: 1) Enhancing service quality; 2) Empowering customers to optimize electricity use; 3) Expanding power generation capacity; 4) Fostering partnerships with Indigenous communities; and 5) Becoming an agile, innovative, and transparent organization (Hydro-Québec, 2023).

Regarding the integration of DERs at customer-owned facilities, Hydro-Québec is working to establish specific interconnection requirements for consumers while still allowing a degree of flexibility in these arrangements (Navigant Consulting, 2024). However, consumers do not have the option to choose their electricity providers. In response to the evolving energy landscape, Hydro-Québec acknowledges the need for regulatory reforms and enhanced DER interconnection standards (Hydro-Québec, 2024).

It is important to recognize that Hydro-Québec's current regulatory framework, business models, and market rules were established before the viability of DERs. Consequently, Hydro-Québec sees the need to develop mechanisms that facilitate DER flexibility and enable the local distribution system to achieve its full potential, effectively contributing to Quebec's future energy system (Navigant Consulting, 2024).

There is an urgent need to accelerate regulatory and policy reforms to support the effective integration of DER flexibility and remove existing barriers. Without timely action, the energy transition could be delayed, reducing the competitiveness of cost-effective and resilient energy solutions; particularly as Quebec and Ontario invest in expanding their electricity grids to meet the increasing demand from electrification. Failing to implement these changes risks continued reliance on traditional, bulk-level resource investments, which would weaken the business case for DERs and slow progress toward a more sustainable and adaptive energy system (Krause, 2020; Alberta Utilities Commission, 2022).

2.4 China

In a speech at the United Nations General Assembly in 2020, President Xi Jinping announced China's commitment to peak carbon emissions by 2030 and achieve carbon neutrality by 2060 through stronger policies (NDRC, 2021). A key strategy for achieving China's carbon goals is increasing the penetration of green energy. The energy structure has been continuously optimized over recent years. From 2015 to 2019, China's coal consumption i.e., coal input to electricity output, dropped from 72.2% to 68.6%, while natural gas rose from 4.8% to 5.7%, and electricity from renewable sources increased from 14.5% to 18.8%.

Policy Framework

The government has developed an extensive policy framework to enhance Demand Response (DR) and energy flexibility, crucial for modernizing the power system. A significant step was the 2023 revision of the 'Measures for Electricity Demand-Side Management' policy (NDRC, 2023), which aims to broaden participation in DR programs and integrate them with electricity markets. This was further supported by the 'Action Plan for Accelerating the Construction of a New Power System (2024-2027)' (NDRC, 2024). This plan highlights the importance of demand-side response, especially in regions facing peak load issues or challenges with renewable energy integration.

The policy emphasizes innovative approaches to active distribution network scheduling. In regions experiencing rapid growth in distributed renewable energy generation, user-side energy storage, and electric vehicle charging infrastructure, there is a push to explore new scheduling models that coordinate microgrids with the main grid. This initiative encourages local adaptation to enhance distributed resource management and improve local balancing capabilities, thus providing active support to the main grid.

Additionally, the construction of smart microgrid projects is a focal point. Local governments are encouraged to develop these projects based on specific application scenarios and regional conditions. In areas at the grid's periphery or not covered by the main grid, wind-solar-storage complementary smart microgrids are being established to enhance local power supply. Regions with favourable renewable resources are building integrated smart microgrids that coordinate source, network, load, and storage. These projects aim to increase the self-sufficiency of renewable energy generation, reduce the regulatory and absorption pressure on the main grid, and foster the development of new business models.

Pricing Strategy

The government has introduced dynamic pricing mechanisms including time-of-use, critical peak, and seasonal pricing to enhance demand response and optimize electricity resource allocation. These strategies aim to guide consumer behaviour, improve system flexibility, and support renewable energy integration by managing supply-demand fluctuations, thereby fostering a more responsive and efficient energy system.

The National Development and Reform Commission issued a notice in 2021 to further refine the time-of-use electricity pricing mechanism (NRDC, 2021). This adjustment aims to reflect the true costs of electricity during high-demand times, motivating consumers to use electricity during lower-demand periods. The notice stipulates that in areas where the maximum system peak-to-valley difference ratio exceeds 40%, the peak-to-valley raw electricity price ratio should not be less than 4:1; in other areas, it should not be less than 3:1.

The notice also introduced a critical peak pricing mechanism, requiring local authorities to implement it based on their specific conditions. The critical peak periods are determined by analysing the top 5% of load occurrences in the previous two years, with flexibility to adjust for current power supply and demand situations and weather changes. The critical peak price should be at least 20% higher than the regular peak price. This incentivizes consumers to reduce consumption when the grid is most stressed, increasing overall system resilience.

Additionally, the notice emphasizes the importance of seasonal pricing mechanisms, especially in areas with significant seasonal variations in daily electricity load or power supply-demand relationships. It encourages northern regions to develop seasonal electricity pricing policies for electric heating, aiming to reduce clean heating costs and ensure residents' winter heating needs are met.

The document also outlines the expansion of time-of-use pricing to all commercial and industrial users, except for electrified railways. It promotes the adoption of time-of-use pricing for residential users where conditions allow, gradually increasing the peak-to-valley price difference.

Furthermore, the notice establishes a dynamic adjustment mechanism for time-of-use pricing. Local authorities are required to adjust the time periods and floating ratios of time-of-use prices based on changes in local power system load characteristics and referencing electricity spot market price signals.

Pilot Programs and Local Initiatives

The State Grid Corporation of China has been instrumental in rolling out pilot programs across various provinces, significantly advancing demand response initiatives (NDRC, 2021). In 11 provinces and cities, State Grid has introduced demand response subsidy policies and innovatively conducted DR pilots based on spot markets and ancillary service markets. These efforts have resulted in a flexible load resource pool with a response capacity of 30 GW, accounting for approximately 3% of the maximum power load.

Specific regional initiatives have shown promising results. In areas such as Beijing-Tianjin-Hebei, Jiangsu, Ningxia, Gansu, Shaanxi, and Shanxi, market mechanisms have been established for user-adjustable loads to participate in power auxiliary services. By the end of 2020, over 70 user-side entities had participated in these markets, enhancing the system's peak-shaving capacity by 2.38 GW and increasing renewable energy consumption by 258 GWh. These participants earned 39.4 million yuan in auxiliary service benefits, effectively motivating user engagement in system regulation.

The demand response initiatives included a diverse set of participants – both residential, industrial and commercial enterprises. In the Jiangxi Province, for instance, residential consumers were actively involved in demand response programs through specific measures such as residents receiving subsidies for reducing electricity usage during peak times. And in regions like Zhejiang and Jiangsu, the programs expanded from industrial users to include commercial entities with smart-controlled systems like central air conditioning and energy storage facilities. The types of shifted loads were also diverse. In the residential sector, participants reduced usage by temporarily turning off or adjusting appliances such as air conditioners, electric water heaters, washing machines, and electric kettles. For instance, raising air conditioner set-point temperatures was a common method to lower energy consumption. Similarly, central air conditioning systems were a significant focus for the industrial and commercial sectors; in Jiangsu, for instance, an innovative system interconnected air conditioning units for centralized control via the "ubiquitous power internet of things", enabling real-time adjustments without compromising comfort. Finally, energy storage facilities were also used in some regions, like Zhejiang, to manage load balancing more effectively. (China Energy News, 2019, 2024)

The pilot programs have demonstrated a significant impact. Cumulatively, 175 peak-shaving and valley-filling demand response events have been conducted, reducing peak loads by 36.44 GW and increasing off-peak loads by 27.79 GW. This has played a crucial role in balancing power grid supply and demand. Moreover, through valley-filling demand response bidding and demand-side resource participation in peak-shaving auxiliary services, these initiatives have facilitated the consumption of approximately 1.8 thousand GWh (TWh) of clean energy.

Looking ahead, plans are in place to expand these initiatives. The aim is to extend demand response programs to all provinces, leveraging the experiences from successful market-based approaches. This expansion will involve establishing clear standards and procedures for determining demand response resources, standardizing agreement signing, and improving information platforms and metering devices for precise monitoring and measurement of interruptible loads. There are also plans to explore demand response bidding through these platforms.

2.5 European Union (EU)

The EU has established a framework under which the individual member states must implement their national legislation. This section describes the European framework. Examples on legislation in individual member states are shown in individual country sections in this chapter.

Current EU legislation related to energy flexibility in clusters of buildings, districts or Energy Communities, is incorporated in different directives related to i) energy in buildings, ii) the electricity market and iii) Energy Communities legislation.

Energy use in buildings is legislated for through the Energy Efficiency Directive – EED III (EU, 2023a), the Renewable Energy Directive - RED III (EU, 2023b), and Energy Performance of Buildings Directive – EPBD (EU, 2024a). However, it is the EPBD 2018 (EU, 2018) which specifically includes a flexibility provision through the development and implementation of a smart readiness indicator (SRI). The SRI quantifies how well buildings can potentially interact with the grid, including the ability to provide flexibility, optimized self-management and information related to the occupants (as explained in more detail in the below sub-section).

EU Directive 2019/944 (EU, 2019) on ‘common rules for the internal market for electricity’ specifies the requirement to provide dynamic or real time pricing (RTP) to retail customers with a smart meter. This is a key enabler for flexibility as it introduces the capability to link renewable generation surplus and shortfall, currently reflected in wholesale market prices only, with actual prices paid by consumers and thereby incentivise more flexible consumption patterns (Hanny et al., 2022). Regulation (EU) 2019/944 provides for capacity mechanisms to be used by member states for demand side measures such as flexibility and ancillary services. However, participation thresholds are typically in the MW scale, often excluding individual building participation, and market participation is therefore primarily via aggregators. Aggregator participation is set out in Directive 2019/944 also.

EU Directive 2019/944 also stipulates the general rollout of smart metering systems to all customers (with some exceptions, see Article 19). However, the actual penetration of smart meters varies significantly across member states (Geidl et al., 2022). The limited rollout of smart meters, especially among smaller consumers, effectively works as a barrier to the participation of small customers in electricity flexibility markets.

For clusters of buildings or Energy Communities (ECs), the most impactful legislation has been EU Directives defining different types of Energy Communities. The aim is to empower communities to manage energy locally and provide flexibility through measures such as balancing supply and demand at the distribution level and creating a critical mass for aggregating assets for specific demand response services, among others. Energy communities have been defined, in European legislation, through the recasts of the Renewable Energy Directive (EU, 2018b) and the Electricity Market Directive (EU, 2019). These define two distinct ECs: i) the Renewable Energy Community (REC), and ii) the Citizen Energy Community (CEC). Both types are rooted in community ownership and have organisational structures that may be used by citizens, Small and Medium Enterprises (SMEs) and municipalities to participate in activities across the energy sector. Still, RECs have a proximity requirement, i.e. participants must be geographically close.

EU Smart Readiness Indicators (SRI)

The Smart Readiness Indicator (SRI) was introduced as part of the revision of the European EPBD in 2018 (EU, 2018). It aims to further promote smart building technologies and to evaluate the readiness of buildings to adapt their operation based on external signals. More specifically, the SRI allows the rating of the smart readiness of buildings (or buildings units), meaning their capability to adapt their operation (i) to the needs of the occupant, (ii) based on signals from the grid (energy flexibility), while also (iii) optimizing energy efficiency and overall performance.

The European Commission (EC) is pushing ahead with measures in the building sector regarding intelligent technologies with a high proportion of renewable energies and energy efficiency. The assessment of the ‘smart readiness’ of a building using an indicator should also contribute to this to make it fit for the future requirements of renewable energy networks while still maintaining the needs of the users.

From 2018 to 2020, a consortium led by the Flemish Institute for Technological Research NV (VITO), granted by the EC/DG Energy, has, from two studies, presented a proposal for the SRI calculation methodology (final report – Verbeke et al., 2020). Following these studies, a decision was made at the end of December 2020 on implementing the methodology of the SRI and it came into force by EU regulation from 2021. Two SRI legal acts, the SRI delegated act, and the SRI implementing act (EU, 2020a, 2020b), have been published in the Official Journal of the EU on December 21st, 2020, and entered into force on January 10th, 2021.

This decision also started a 5-year test phase in which member states can participate voluntarily. In parallel, an 'SRI platform' for interested stakeholders and representatives of the member states has been established by EC/DG Energy (EU, 2024b). In the present revision of the EPBD 2024 (EU, 2024a), the SRI will only be required from July 2027 for large, non-residential buildings with a nominal heating or combined space heating and ventilation system capacity of more than 290 kW. For other buildings, it will be optional for the member states to introduce the SRI.

2.6 Austria

Austria has set the targets to reach 100% net renewable electricity in 2030 and carbon neutrality in 2040, and energy flexibility can play a major role to reach those goals (Bundesministerium für Nachhaltigkeit und Tourismus & Bundesministerium für Verkehr, Innovation und Tech, 2018), (Bundeskanzleramt Österreich, 2020).

Concerning implicit demand response, Austria has had time-of-use and real-time (spot market induced) pricing for retail electricity implemented for many years. As an additional measure, a new network tariff scheme has been under discussion without specific results yet, specifically for residential customers who can choose an 'interruptible' network tariff with lower charges in exchange for the possibility of disconnection from the grid in certain time windows. Concerning explicit demand response, the DSO can disconnect units from the grid due to the grid situation if this is defined in the connection contract. In December 2022, a 'demand-side response electricity saving product' was introduced by APG, the Austrian TSO, following a law on reducing electricity consumption triggered by the energy crisis in 2022. Big consumers (2 MWh in 2 hours) could offer their flexibility during peak consumption periods in an auction. The most recent auction for this product was at the end of March 2023 (APG, 2022). Furthermore, participating in balancing markets of APG in Austria is possible for volumes starting at 1 MW, through prequalified single units or pools. APG joined the crowd balancing platform EQUIGY in 2021 (Equigy, 2024). The aim is to make it easier for small-scale players to participate in the markets for balancing energy and in the redispatch portfolio (APG, 2021).

Concerning energy communities, Austria was one of the first countries to transpose the EU directives into national law in 2021. Based on the National Renewable Expansion Act and the Electricity Organization Act, both RECs and CECs can be established whereby a legal entity (usually associations or cooperatives, as they do not primarily seek financial gain) must be established for this purpose. Renewable energy (RECs) or electricity (CECs) can be produced, shared, stored, and consumed within the community and aggregation services can be provided. RECs benefit from reduced grid fees and the exemption from certain levies for electricity shared within the community. The proximity constraint is based on network levels (NL). Participants of RECs can be natural persons, SMEs, and local authorities (e.g., municipalities). Participation in CECs is not limited; however, control needs to be with individuals, local authorities and/or SMEs. Participation in both forms of energy communities is voluntary and open, and the free choice of supplier remains unaffected. The members' residual electricity suppliers are responsible for the imbalance settlement. The DSOs are responsible for energy allocation, whereby a static or dynamic allocation key (defined by the energy community individually) is used (RIS, 2024), (RIS, 2023).

2.7 Czech Republic

Regarding regulatory framework progressions in the energy sector, between 2010 and 2015, the Czech Republic experienced a surge in solar energy driven by favourable incentives. However, the system was exploited, leading to an unsustainable influx of mainly large-scale solar installations occupying vacant lands. Concerns arose regarding the resiliency of the grid but mainly overcompensation for producers, prompting the government to swiftly enact stringent regulatory changes. Retroactive subsidy cuts and installation limitations were implemented to mitigate misuse, which slowed the implementation of new renewable resources and legislative support for prosumers.

In 2022, the 'Act on Promoted Energy Sources' initiated the first revision of energy law in Czechia, primarily supporting small and medium-sized renewable energy projects. This revision, effective from February 2023, aims to reduce bureaucratic barriers for prosumers, resulting in an expansion of the permissible size for local renewable energy installations without requiring a license, increasing from 10 kWp to 50 kWp (Legal Act No. 19/2023 Sb. in Czech energy law).

The second revision of the energy law associated with this act defines the Energy Community as a legal entity, emphasizing and advancing their rights and obligations. This came into force in January 2024. It notably permits energy sharing within the community. Additionally, this revision addresses the alteration of the metering scheme. The shift from billing based on phase-specific measurements to a comprehensive measurement across all phases is proposed, simplifying the billing process for local renewables and aligning the metering system with those of other EU countries (Amendment to Act No. 458/2000 Sb. in Czech energy law). Regarding the energy community regulation, there are three new options to establish an energy community:

- **Active customers**, who can generate and share their own energy, are limited to a maximum of ten metering points. For individuals, the energy generation installation must be located on their own property, but there are no geographical limits on where the energy can be shared.
- **Energy communities** (referred to as 'občanská energetická společenství' or OES in Czech law) are limited to producing electricity from renewable energy sources and can have a broad membership base, including individuals, businesses, and local governments, with all members being equally part of the decision-making.
- **Renewable energy communities** (společenství pro obnovitelné zdroje energie, or SOZE) are allowed to invest not only in electricity but also in thermal energy from renewable energy sources. These communities have more stringent membership rules, as large enterprises cannot join, and only members living close to the community energy sources can effectively control decision-making.

The forthcoming third revision of the energy law, currently in progress and scheduled to take effect between 2025 and 2026, is set to address demand-side flexibility aggregation and trading. While the TSO code anticipates the involvement of demand-side contributions in grid balancing mechanisms, the national legislation has yet to delineate the terms and conditions governing agreements between aggregators and BRPs (Balance Responsible Parties) who represent the same endpoint of a building or device. This lack of regulation, apart from technical barriers, complicates the aggregation of small-scale demand-side flexibility. The upcoming revision aims to define the role of independent aggregators, enabling broader utilization of demand-side flexibility.

2.8 Denmark

In 2020, a parliamentary majority adopted a Danish climate law with a target to reduce greenhouse gas emissions by 70% in 2030 compared to 1990, reach 100% green electricity in 2030, and become climate-neutral no later than 2050.

All Danish buildings are equipped with a smart power billing meter from which the utilities download consumption data. All Danish customers have, based on this, the possibility to be billed according to the price of electricity for the time of use. From January 1st, 2023, the Danish DSOs were further allowed to have ToU transport tariffs, better reflecting the cost of transporting the electricity hour by hour. See section 3.1 to learn how this has affected the electricity demand of domestic end-users.

Denmark is well on the way towards becoming a green society, but the next few years will be particularly challenging as the energy system is subject to major changes. A successful green transition requires not only the production of electricity from renewable sources, but also that production and demand for electricity are balanced in the most efficient way. This ensures a cost-effective green transition while maintaining a high security of supply.

Denmark has, therefore, started to create a new market structure for the power market – called Market Model 3.0. The aim of Market Model 3.0 (Danish Energy Agency, 2021a) is the development of a flexible electricity market, and it contains 13 main recommendations and 23 sub-recommendations. Market Model 3.0 is summarized in Danish Energy Agency (2021b). Gade et al. (2022) describe the current Danish power system, the rationale behind Marked Model 3.0 and discuss challenges within the proposed framework in Market Model 3.0. The following is mainly taken from Danish Energy Agency (2021b).

Market Model 3.0 appoints five scopes of actions:

- **Action 1: All actors must be able to contribute to a flexible electricity market**.
  A first and fundamental step towards realising a flexible electricity market is ensuring a regulatory framework that allows for the widest possible group of actors to supply flexibility services on market terms. A higher total supply of flexibility is one of the preconditions for the triple objective: green transition, security of supply and affordability. It is, therefore, essential to also engage the vast number of small actors that have small consumption and production flexibility resources. For this to be efficient, it must be possible for these flexibility resources to be pooled. This task will be carried out by a new type of market actor i.e., the aggregator.
- **Action 2: A flexible electricity market must ensure a robust and balanced energy system**.
  A second crucial step is that the power system is made flexible on all levels – both in solving mismatches between supply and demand across seasons and weeks and in compensating for imbalances and errors within the day and in real time. Capacity adequacy and system security are necessary preconditions for a robust and balanced energy system. Capacity adequacy is about ensuring sufficient, flexible production capacity and interconnectors (nationally and across borders) to meet demand. System security, or robustness, refers to the system's ability to withstand outages, faults and short-circuits.
- **Action 3: A flexible electricity market must ensure a cost-effective expansion of the grid**.
  The third essential step concerns the need for local flexibility to ensure a cost-effective green transition. The transition towards a climate neutral society entails the transportation of much higher volumes of electricity. This imposes new demands on network infrastructure, as the consumption and production of electricity constantly needs to be accommodated within the at any time available network capacity.

- **Action 4: The regulation of monopolies must promote a flexible electricity market**.
  The fourth essential step is ensuring that regulation of the transmission and distribution system operators continues to support a cost-effective green transition that goes hand-in-hand with maintaining a high security of supply and affordable prices for the consumer. A well-functioning grid, electricity market, and associated power systems represent crucial aspects of the green transition, where society increasingly needs to consume electricity from green sources, which must be transported safely and efficiently through the grid. The regulation must prevent the costs of transporting electricity from becoming a barrier to the green transition while supporting the development of an integrated energy system.
- **Action 5: The market model must be forward-looking**.
  The last step is ensuring that the electricity market model continues to be adjusted and developed based on data and in line with the experiences gained in the years to come. With flexibility representing one of the keys to a cost-effective green transition with a continued high security of supply, it is important not to cease development of the market model. On the contrary, there is a need to proactively gather and share practical experiences to continuously make the necessary and data-based adjustments to the market model, so it continues to support cost-effective flexibility in the energy system.

Designing Market Model 3.0 is a work-in-progress, and many challenges remain to be solved. Gade et al. (2022) conclude: 'Market Model 3.0 is a market framework that inherently integrates the aggregator as an independent participant in the power system.' This will mitigate the barrier-of-entry for new aggregators and make it more attractive to utilize demand-side flexibility. However, aggregators face technical challenges when utilizing demand-side flexibility, such as the determination of reserve capacity and pre-qualification. By mitigating market and legislation barriers for aggregators, Market Model 3.0 gives rise to other technical challenges, such as skewed incentives for aggregators and the need for imbalance compensation. However, Market Model 3.0 is a pioneering effort by Denmark to address the green transition in the power system, which unlocks demand-side flexibility and the value it can bring to society.

2.9 Ireland

Commercial demand response is well established in Ireland, but residential demand response is in its early stages. Ireland has a target of 80% of electricity generation from renewable energy sources by 2030, which is challenging given that demand is expected to increase by 50% in the same period (SEAI, 2023). Increased demand is expected due to the electrification of transport and heating, an increase in industrial demand, primarily data centres, and a high-growth economy. In 2022, renewable generation accounted for 39% of total electricity generation with 2023 daily peaks as high as 4,653 MW, equivalent to 80-90% of typical demand (EirGrid, 2024a).

The Transmission System Operator (TSO) and Utility regulator run transmission level demand response programmes. The DS3 programme operated until 2022 for large entities and aggregators to participate in demand side services, including ancillary services, and had a minimum threshold of 4 MW for participation. This is in the process of being replaced with a new programme as part of the 'Shaping Our Electricity Future' TSO roadmap for achieving the 2030 target (EirGrid, 2024b).

Value frameworks for flexibility at the distribution level are at an early stage, but the Distribution System Operator (DSO) is starting to develop enabling mechanisms, such as flexibility tenders, which are being run on a pilot basis (ESB Networks, 2023).

Residential explicit demand response is not yet available in Ireland. The DSO is starting to introduce the concept of coupling household electricity use with renewable generation, primarily wind, through a marketing campaign ‘Is this a good time’ (ESB Networks, 2024) as part of an initiative to ‘beat the peak’. Householders are encouraged to consider energy use, e.g., through activities such as looking out the window to see if it is windy before running appliances. General energy saving tips are also communicated to users who register interest in the programme. This may be a pre-cursor to introducing energy flexibility at the residential level but the timeframe for this is not clear. The intention behind the programme seems to be a little mixed as peak reduction is identified as the main target but the messaging to consumers is around linking consumption to renewable generation.

Pricing options for residential retail electricity are still uncoupled from renewable generation. Electricity retailers have introduced some pricing options in the last few years, with limited time-of-use tariffs with up to 3 to 4 fixed price bands per day. Prices are still linked to peak demand times, e.g., the 5pm to 7pm peak load. The wholesale market has hourly pricing and a day-ahead market directly linked to wind generation (SEMO, 2024). It is unknown if household retail pricing will be linked to wholesale market hourly pricing in the future. The implementation in Ireland of the EU Directive 2019/944 (EU, 2019), which incorporates real time pricing, may result in more dynamic, generation led pricing structures.

2.10 Italy

Italy has been actively developing its electricity flexibility regulations to accommodate the growing share of variable renewable energy in its power system. The country has implemented measures to enhance system flexibility, strengthen grid infrastructure, and promote electricity storage. Regulatory efforts include initiatives by ARERA (The Italian Regulatory Authority for Energy, Networks and Environment) and Terna (the Italian TSO) to support pilot projects and facilitate the integration of demand management, distributed renewable generation, and storage systems into the ancillary services market. Since 2022, these resources have been allowed to participate in secondary frequency regulation, increasing competition and system reliability. Italy has also introduced the concept of UV (Unità Virtuali, in English: Virtual Units) and UVAM (Unità Virtuali Abilitate Miste, in English: Mixed Enabled Virtual Units), which aggregate distributed resources to provide grid services. UVAMs play a key role in congestion management, balancing services, and reserves, with ongoing efforts to expand their participation in frequency restoration. With a strong focus on smart grids and digitalization, Italy is positioning itself as a leader in modernizing power systems and advancing international collaboration in energy transition initiatives.

Regarding energy communities, RECs play a key role in Italian policies. REC represents an innovative association that brings together citizens, SMEs, local authorities, cooperatives, research and religious organizations, third-sector entities, and environmental protection associations (Ministry of Environment, 2023, 2024). These communities aim to produce and use renewable electricity within a specific geographical perimeter, exploiting the national distribution network for virtual energy sharing.

RECs mainly intend to provide environmental, economic, and social benefits to their members and local communities by encouraging renewable energy self-consumption. They contribute to the dissemination of renewable energy sources, the reduction of greenhouse gas emissions, and the strengthening of the country's energy independence.

In order to set up a REC, it is necessary to identify areas suitable for the installation of renewable energy plants and users interested in energy sharing. Then, the community must be legally established through one of the various legal forms provided, such as associations, third-sector entities, cooperatives, non-profit organizations, etc. Participation in the community can occur either in the initial phase or afterward, as provided for in the statutes and articles of the association.

Members of a REC may include producers of energy from renewable sources, self-consumers (who produce energy for their own needs and the community), and electricity consumers who do not have production facilities but can benefit from the energy produced by other members. Large companies are excluded from participation in REC but can be members of groups of renewable self-consumers.

Respecting the geographic constraint, which requires that producers and consumers are located within the same geographic area, defined by the connection to the same primary electrical substation, is necessary to be entitled to receive the incentives tariffs. Verifying this constraint is possible through a dedicated portal on the website of GSE (https://www.gse.it/en), a company owned by the Ministry of Economy and Finance entrusted with the promotion and development of renewable energy sources and energy efficiency.

State incentives for REC include an incentive tariff for virtually self-consumed energy, recognized for 20 years, an ARERA (Italian Regulatory Authority for Energy, Networks, and Environment) valorisation fee for self-consumed energy, and valuation at market conditions of energy produced but not self-consumed. In addition, for RECs located in municipalities with fewer than 5,000 inhabitants, there is a capital subsidy of 40% on the investment cost, financed by the PNRR (National Recovery and Resilience Plan). (Council of Ministers, 2022)

Production plants of various types can be included in the REC, provided they are powered by renewable sources and have a capacity of no more than 1 MW. The plants must be newly built or, in any case, put into operation after 16 December 2021 without benefiting from other incentives on energy production.

Finally, REC can include storage systems, which are incentivized by considering the stored energy as part of the shared energy within the community. Charging infrastructures for electric vehicles can also be integrated into RECs, with the energy absorbed for charging considered for calculating shared energy.

2.11 Switzerland

The new Swiss Federal Law on Secure Electricity Supply with Renewable Energy, known as Mantelerlass, introduces significant provisions regarding flexibility and energy communities in Switzerland (Federal Council, 2024a). Approved in 2024, this law will bring amendments to the Ordinanza sull'approvvigionamento elettrico (OAEl) (Federal Council, 2024b). The changes related to flexibility and energy communities are set to be approved in the first quarter of 2025 and will come into force on January 1, 2026 (Ufficio federale dell'energia, 2024).

Under the new provisions, Distribution System Operators (DSOs) can access flexibility from flexibility holders only when necessary to address local network issues, such as mitigating peak injections or utilizing storage systems for load shifting. This usage is justified to avoid costly network expansions and to maintain efficient network operations. The use of new flexibility requires the establishment of a formal contractual relationship between DSOs and flexibility holders, including contractual terms and remuneration. Additionally, DSOs are granted guaranteed rights to use flexibility strictly for feed-in management. The regulation limits DSOs' priority rights to a maximum of 3% of the annual energy produced at the connection point. Beyond this cap, DSOs may contract additional flexibility with appropriate compensation. Moreover, significant changes were defined for the management of already existing RCPs (Raggruppamenti ai fini del Consumo Proprio, in English: Own Consumption Group). In addition, prosumers will be allowed to constitute a new type of entity, the local Energy Community.

"Virtual" RCP

In an RCP, self-generated electricity is used directly within the community where it is generated. Users thus avoid paying taxes and grid usage fees. The connection to the public grid is, however, necessary and managed by a unique physical metering point: if the photovoltaic – or any other local RES-based electricity producing system – produces more than consumed, the solar energy will be fed into the public grid; if, on the other hand, production is not sufficient, the electricity will be purchased from the energy supplier, towards whom the users will be considered as one customer.

With the new law, the Federal Council requires network operators to allow so-called 'virtual RCPs'. Thus, smart metering systems can be used to set up an RCP; on the one hand, the grid operator treats them as a virtual metering point, and it makes available to the RCP the metering data required for accounting the internal consumption.

In addition, another important aspect related to the usage of the feeder lines is introduced with the Mantelerlass law: RCPs will be allowed to use the lines, including the electrical infrastructure at the connection point, if the voltage level is lower than 1 kV.

Local EC

Local EC (Comunità di Elettricità Locale) is a new type of energy community introduced in the Mantelerlass law. A group of prosumers that aims to constitute a local EC must be aware of the following requirements:

- A local EC must be located in the same area, which effectively means the same DSO
- Grid used by local ECs must not exceed 36 kV
- Concerning consumption capacity, at least 20% of power production must be installed in the local EC.

Participants in the local EC will receive a benefit in terms of a discount on the grid tariff, which is 30% if the community uses only the low voltage grid (<1 kV) and 15% if the medium voltage grid (1-36 kV) is also needed. DSOs must collaborate with the community by providing the members with all the necessary information to constitute a community (e.g., grid topology) and calculating the local EC self-consumption.

2.12 United Kingdom

As with other industrialised nations, commercial demand response is relatively well established in the UK, with large industrial consumers engaged in demand reduction programmes and interruptible contracts during peak demand periods since the 1970s, albeit at a relatively small scale. There were even some early examples of domestic time-of-use tariffs in the late 1970s; for example, the Economy 7 tariffs aimed to shift demand to off-peak nighttime use (Capper & Oxby, 2024). Legislation developed by the UK Government to privatise the electricity sector was set out in the Electricity Act 1989 (HM Government, 1990) and provided the regulatory framework for Electricity Market Reform (1990) which derestricted the sector to create a competitive market, which has ultimately led to opportunities for energy flexible markets in the commercial, industrial and domestic sectors. The reform led to a legal framework for the Pooling and Settlement Agreement: the PSA, commonly referred to as 'The Pool' (Green, 1999). Thus, creating the wholesale market that power generators can bid into, a version of which remains in operation today. It is important to note that, although there are great similarities between policy and markets across the UK, and overlap of operations, devolution of governance in the late 1990s means that conditions in England and Wales differ from those in Scotland and Northern Ireland.

Within the modern UK electricity market, the National Grid Electricity System Operator (ESO – often referred to in other countries as a TSO) are responsible for real-time balancing of supply and demand in England and Wales, along with the Distribution Network Operators (DSOs) that manage local grids, both playing a role in linking generators with consumers, via electricity supply companies and more recently, third party aggregators. In Scotland and Northern Ireland, Scottish Power Energy Networks and Scottish and Southern Energy Networks, and System Operator for Northern Ireland operate the respective networks. Regulation of the electricity market in all nations of the UK is the responsibility of the Office of Gas and Electricity Markets (Ofgem) which promotes competition whilst protecting consumers, primarily through setting price caps; although Ofgem helps to inform policy, they are not responsible for creating it (Ofgem, 2024a). They also provide the licence for operation to the ESO and their equivalents. The Department for Energy Security and Net Zero (DESNZ) review and administer energy policy for England and Wales which is dictated by central government (DESNZ, 2024). Earlier forms of Ofgem were created when the market was privatised in the 1990s.

Legislation relevant to energy flexibility markets since the privatisation in the 1990s has included the Climate Change Act 2008 (covering all UK nations), the Energy Act 2013 (updated in 2023) and the Smart Meters Act 2018. The Climate Change Act 2008 originally sets a target of reducing greenhouse gas emissions by at least 80% by 2050 compared to 1990 levels and identified the importance of flexibility in the transition to low carbon generation (HM Government, 2008); the most recent target form 2020 aims for a 78% reduction by 2035 (Committee on Climate Change, 2020). The requirement for more flexible energy use to support renewable integration is noted as part of this. More significantly for flexibility markets, the Energy Act 2013 introduced the Capacity Market, Contracts of Difference and an Emissions Performance Standard (HM Government, 2013). The Capacity Market provided payments to maintain capacity at peak times, including demand-side response incentives, with payments made for available power made even when it is not required. However, these previous policies have been criticised for favouring generator-based services, with numerous barriers to access demand reduction markets related to end-user understanding, regulatory frameworks, technical capacity and market conditions (Torriti & Green, 2019).

The Energy Act 2023 (HM Government, 2023a) included major updates relevant to energy flexibility markets, encouraging the development of demand-side response mechanisms and the creation of financial incentives for local and national flexibility markets. This has gone some way towards addressing previous concerns about the access and viability of energy flexibility services. Updates also promote smart-grid development, decentralised energy generation, clearer regulation for aggregators, dynamic pricing and flexibility incentives. It also established important standards and codes relating to technical implementation, market rules, data and consumer protection, grid integration and compliance (HM Government, 2023b). The main sections of the Act that relate to flexibility are Parts 4, 7 and 9. Innovation is encouraged including trials of new systems and services, with examples including the ‘Local Constraint Market’ being trialled by the ESO via a third-party provider (National Grid, 2024a) and the Demand Flexibility Service (DFS) (National Grid, 2024b).

Preceding the Energy Act 2023, on behalf of the government, Department for Energy Security and Net Zero (DESNZ) engaged with policy development activities building upon the ‘Smart systems and flexibility plan 2021’ (HM Government, 2021). The ‘Electric Vehicle (Smart Charge Points) Regulations were introduced in 2022 and required all domestic charge points to allow for demand response (Capper & Oxby, 2024). DESNZ also administered the ‘Interoperable demand side response programme’ providing funding to support creation and demonstration of smart appliances and their integration with energy management systems as part of ongoing policy development (HM Government, 2022).

In keeping with the energy flexibility aims described in the Energy Act 2023, Ofgem has recently appointed a third-party market facilitator to coordinate local energy flexibility services that will work with the ESO, DNOs and Flexibility Service Providers (aggregators); they will be responsible for aligning local and national flexibility markets. Ofgem has also proposed a common 'Flexibility Market Asset Registration' which will simplify the registration of flexible assets (for example electric vehicles, heat pumps and domestic battery storage), which currently have to be registered multiple times by aggregators for individual markets (Ofgem, 2024b).

Due to its obligation for real-time balancing of supply and demand, the ESO plays a major role in bringing government legislation into practice. Balancing services managed by the ESO include frequency response (used to control system frequency), reserve services (backup power generation at peak times), and the Demand Flexibility Service (DFS) (National Grid, 2024c). The DFS has been developed in line with the aims of the Energy Act 2023 and is an example of how the legislation within the act can be implemented in practice. The DFS was first introduced in the winter of 2022/23 to help offset high national peak demand; it incentivised domestic, commercial and industrial users to either reduce or shift demand in time.

During the first two years of operation, the DFS has been designated as an 'enhanced action' in addition to the existing electricity market; consultation is currently active to bring the DFS within the existing market. Large consumers meeting technical requirements can participate in the DFS directly with the ESO, smaller consumers and domestic consumers must participate through their energy suppliers. All participants must have access to half-hourly metering and have the ability to respond for a minimum of 30 minutes following instruction. The ESO provides signals to suppliers and aggregators either a day before or on the same day, customers are then asked to reduce demand to receive incentive payments (National Grid, 2024b). In its first year of operation, the DFS was reported to have reduced demand by 3.3 GWh (Capper & Oxby, 2024).

Whilst it is still considered to be an emerging market in the UK, consumers, generators and aggregators can all engage in the energy flexibility market in some form. The Smart Meters Act 2018 has played a significant role in this as it enables responses within the half-hourly settlement market. The mandatory use of a smart meter to access flexibility markets is however under review as the ESO identified this as a potential technical barrier to market development, as approximately half of UK consumers do not currently have these installed (National Grid, 2024d). In the first two years of the DFS, it was also not possible to claim incentives when engaged with other balancing services, but this restriction is also likely to be removed following the 2024 consultation exercise, to encourage providers to develop and diversify services.

In May 2024, the UK Government published a policy paper entitled 'Strategy and policy statement for energy policy in Great Britain' (HM Government, 2024); the power to define this policy strategy was originally established in the Energy Act 2013. This paper defines strategic priorities for the sector, policy outcomes and roles and responsibilities. Whilst this is a recent action, the paper cites energy flexibility as key in supporting the transition to a low-carbon energy systems and again promotes the development and deployment of technologies that can support energy flexible operations, including smart meters, storage, grid management and dynamic response and pricing.

2.13 United States of America (USA)

Residential and commercial demand response in the US is a significant resource in retail and wholesale electricity markets. Demand response capacity in US wholesale electricity markets was approximately 33 GW in 2023 and representing approximately 6% of total peak demand across all US regional electricity systems (FERC, 2023). Likewise, retail electricity markets continue to rely on demand response as a resource for balancing the power system with high renewable energy, including in California where state utility regulators established a statewide goal of 7 GW of load flexibility resources (FERC, 2023).

The Federal Energy Regulatory Commission (FERC) regulates US wholesale electricity markets and has removed barriers to demand response participation and facilitated its development through several regulatory orders. A significant source of demand response's value to the bulk power system is aggregating multiple building loads and flexible resources and providing multiple services (e.g., capacity, energy, and ancillary services). FERC Order 2222 mitigated many of the barriers to load aggregation and value-stacking by allowing distributed energy resources (DERs) direct participation in wholesale electricity markets, including addressing certain physical and operational characteristics of DER aggregation, as well as allowing participation in multiple wholesale and retail electricity market products (Forrester & Cappers, 2021). Additionally, FERC Orders 890 and 1000 established open and transparent transmission planning processes and required the consideration of DERs as potential non-wires alternatives (NWAs – a collective term for expenditure that offsets and/or removes the need to expand the transmission system) (Shen et al., 2021). This increases the value of demand response to avoid or defer transmission expansion costs.

US retail electricity markets are a patchwork of policies and regulations, which hinders translating successful demand response deployment models from one state jurisdiction to another. Generally, there have been two important areas of legislative and regulatory support for demand response in US retail electricity markets. First, several states authorize retail electricity pricing with greater unbundling of electricity services and temporal differentiation (Satchwell et al., 2020). More granular and time-differentiated pricing (e.g., time-of-use rates) that reflects the actual marginal costs of energy can enhance the customer value (e.g., bill savings) of shifting electricity demand. Customer response to time-differentiated price signals also benefits utilities by avoiding and reducing high system costs. Second, regulators are incorporating DERs in resource planning and more explicitly recognizing DER resilience and reliability benefits (Carvallo et al., 2021). This is particularly important for aggregating demand response that can be geo-targeted to minimize distribution network impacts.

2.14 Summary

Distributed energy resources (DERs) are increasingly being implemented across the World. In some countries, the penetration of such energy sources has already become substantial (like in Australia, where one third of households have rooftop PVs installed). With the increasing dissemination of DERs, such as microgeneration in households, strategies and policies to support energy flexibility become increasingly important.

The review of existing policies demonstrates a high variety between countries in terms of both the extent and type of policy measures being implemented at the national level. Some countries have gone relatively far with implementing the policies and legal framework necessary for promoting flexible energy use, such as dynamic electricity retail prices etc., while other countries have only implemented limited measures. The review indicates that the development of commercial and residential energy flexibility (demand response) has gotten farthest in countries with the most ambitious policies, which shows the importance of policy-making and regulation for the realization of the energy flexibility potential connected with DERs. This was also pointed out in the previous IEA EBC Annex 67 (Mlecnik et al., 2020).

Aggregators are often highlighted as key for making it feasible for small consumers, like households, to become active participants in the flexible energy markets. However, the actual realization of aggregators for small consumers still appears minimal across countries, which indicates that existing policies have been far from sufficient to create a fertile framework for aggregators to establish as commercial activities. This points to the need for more proactive and ambitious policies on this. One example of a policy change, which could support the penetration of aggregator services targeted at smaller consumers, is the trend of lowering the threshold of marketable volume for EU market operators. A trend is also seen in other countries. In EU, the threshold was typically 1 MW, but in many countries (e.g., countries under Nord Pool), bids as low as 250 kW are now allowed. This reduces the barrier to utilizing building flexibility for day-ahead and intraday arbitrage.

However, energy communities appear to have gained some foothold in several countries, which is worth noticing as these can, to some extent, be seen as aggregators of multiple DERs and their related flexibility capacity. Many of these energy communities are citizen driven, which points to the effectiveness of strategies targeted at citizens and local communities, and that such strategies might in some cases be more viable than strategies aimed at more classical commercial and market-driven aggregator concepts. In this way, the review might contest the dominant market-based approaches to the energy transition. This said it is important to observe that in countries with many energy communities (like Austria and Italy), there has also been implemented significant economic benefits for these communities (e.g. substantial governmental subsidies for capital investments of smaller energy communities in Italy or reduced grid tariffs in Austria).

A further example of energy flexibility policies not primarily based on market-based mechanisms is the Chinese regulation that stipulates a minimum peak-to-valley price ratio in areas with a maximum peak-to-valley difference in energy consumption exceeding a certain threshold. This illustrates the high diversity in policy measures and approaches between the surveyed countries.

Another insight from the review is that implicit demand response appears to be most prevalent in countries with a high share of small consumers having ToU and dynamic pricing already. The soaring energy prices during the recent energy crisis promoted time-shifting of consumption among small consumers in these countries. This shows that the participation of individual (non-aggregated) consumers in energy flexibility actions, and implicit demand response, should not be ignored in policy-making and as a measure to create more flexible electricity consumption.

In countries with high fixed fees and taxes on electricity, the effect of dynamic electricity pricing is often overshadowed by these (e.g., distribution and other fees). This can be a barrier to customers' participation in energy flexibility, as also observed by Madsen et al. (2024), who furthermore suggest policy-makers consider implementing dynamic tax and fee structures instead of today's fixed structures.

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3 Price incentive structures influencing stakeholder engagement in energy flexibility

Some countries have implemented variable price structures that support the utilization of energy flexibility by the end-users. This is especially the case for electricity prices. However, also gas and district heating price structures have been investigated.

To be able to apply energy demand flexibility there is a need for general roll-out of smart meters and set up a billing system that operates at the same frequency as the varying prices in the supply grid. In the European Union, mandatory roll-out of smart meters are required in all member states (Directives 2009/72/EC and 2009/73/EC) concerning the electricity and gas markets. In other countries it is often up to the end-user to implement smart meters to be able to participate in an energy flexibility programme.

To analyse this potential, example cases have been collected and are reported in the following. A questionnaire was developed to collect information on pricing structures in different countries for collective energy supply (electricity, gas, and district heating). The questionnaire covers not only the raw energy price, but also the different net tariffs and taxes i.e., the breakdown of the energy prices. The questionnaire focussed on residential customers.

We received answers to the questionnaire from Australia (Queensland and Victoria), France, USA (California), Canada (Quebec), Czech Republic, Switzerland, Austria, Ireland, and Denmark. Figure 2 shows the countries evaluated concerning flexibility incentives through pricing of electricity, gas, and district heating.

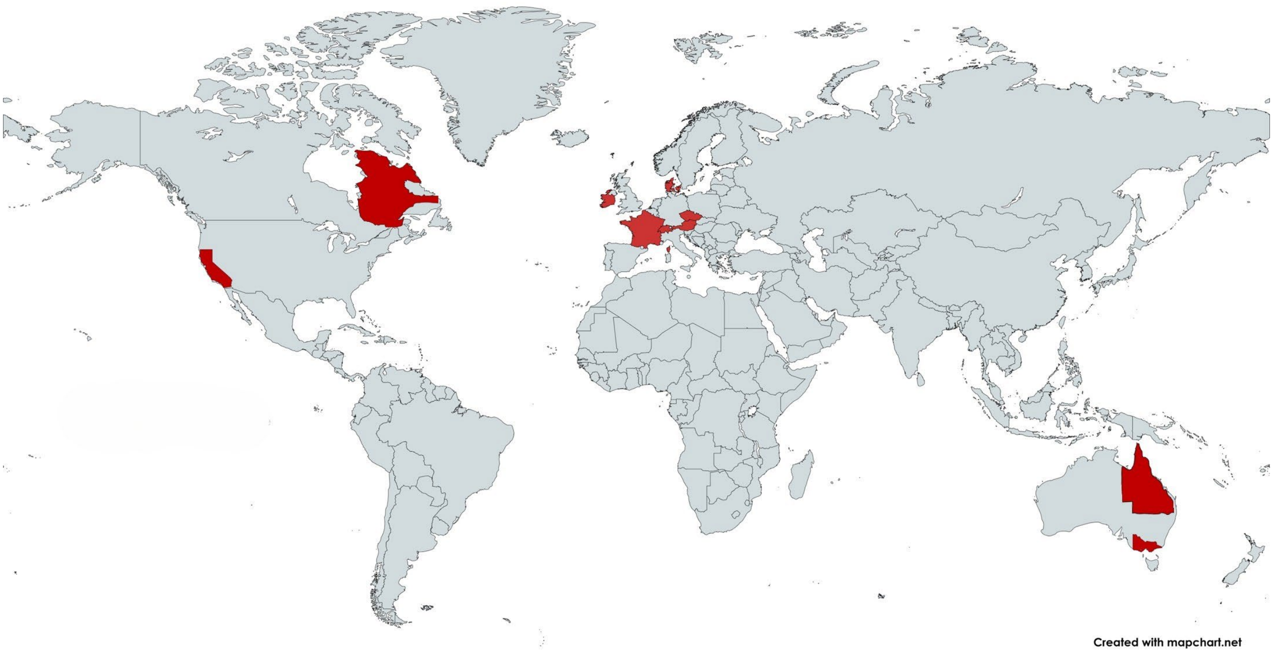

Figure 2: Countries and jurisdictions evaluated in the pricing questionnaire.

3.1 Pricing incentive examples

A comparison of the different countries can be found on page 49. The following gives a more detailed overview of pricing incentives for flexibility in Austria (page 46) and Denmark (page 47). These two countries were specifically selected due to availability of dynamic pricing for electricity.

Austria

In Austria, as in all EU countries, household customers are free to switch their energy suppliers, enabling them to choose from a variety of electricity pricing models. One of the more innovative options available is hourly electricity tariffs, which are based on real-time spot prices from the energy exchange. These tariffs are designed to incentivize households to optimize their energy consumption by using electricity when prices are lower (see, e.g., Chapter 5.5). To fully benefit from such dynamic pricing models, the installation of smart meters is essential, as they provide the necessary real-time data on energy usage. Figure 3 depicts spot prices for a specific day that are the base for the hourly electricity tariff from the energy supplier aWATTar. The actual electricity tariff offered by this supplier is based on the spot price and includes additional pricing components, such as a margin for the energy provider. Other suppliers offer similar tariffs with varying price structures, though all are built upon the foundation of spot market prices.

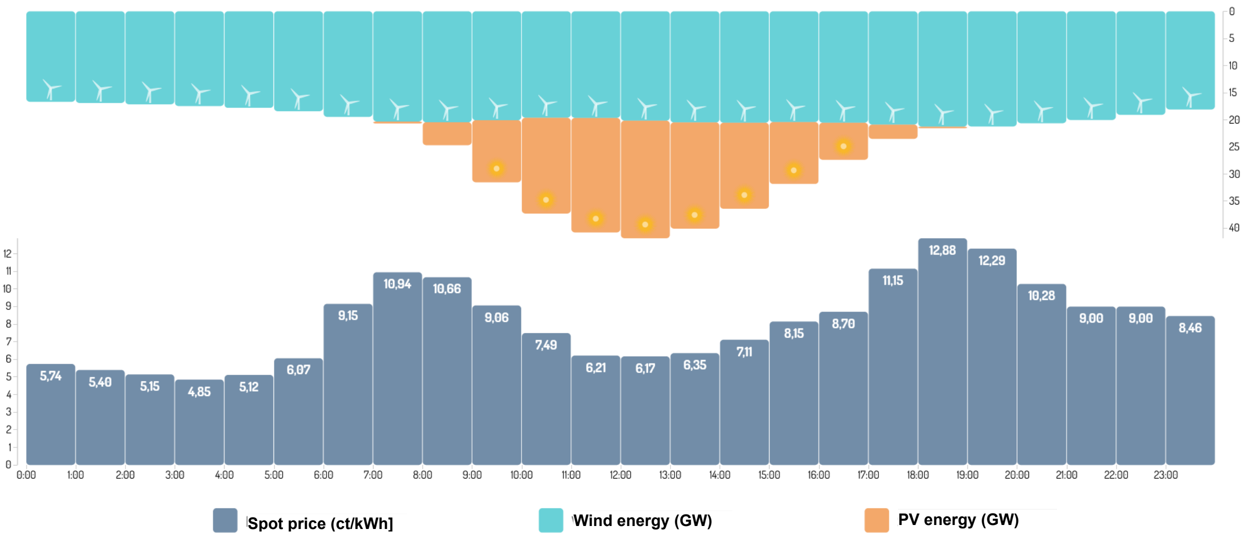

Figure 3: Hourly spot prices for one exemplary day (24th September 2024) provided by electricity supplier aWATTar (aWATTar, 2024).

As of 2024, Austria has made significant progress in the nationwide roll-out of smart meters for electricity at the household level (network level 7). By the end of 2024, Austria is aiming for at least 95% of households to be equipped with smart meters (RIS, 2022). The introduction of smart meters in Austria is anticipated to provide households with more accurate consumption data, enabling more efficient energy use and facilitating the transition towards a more sustainable energy system. According to the Austrian Smart Meter Regulation, the network operator is required, regardless of the project plan for the phased introduction of smart meters, to equip end consumers with a smart meter upon request. Unless otherwise specified, the installation must take place as soon as possible, but no later than within two months (RIS, 2022).

In Austria, grid charges for households consist mainly of an annual flat fee and consumption-based tariffs (measured in kWh), as defined by the Grid Tariff Ordinance 2024 (RIS, 2024). On higher network levels, in addition to the consumption-based charges, a capacity-based pricing component replaces the flat fee. The current price components of the grid tariff are depicted in Figure 4. As can be seen in Figure 4, the grid tariffs in Austria consist of one-time charges at the time of connection (grid access tariff and grid availability tariff, whereas the grid availability tariff needs to be paid only by consumers and not generators) and ongoing charges. As ongoing charges, the greatest share of grid costs for consumers arise from the grid use tariff, which has a demand component (€/kWh) and a capacity-based component (€/kW), but the capacity-component is not applicable to households (they pay an annual flat fee). Further grid tariff components are the grid losses tariff (for both consumers and generators), the system service tariff (only for generators above 5 MW), the metering charge and charges for other services (both for consumers and generators).

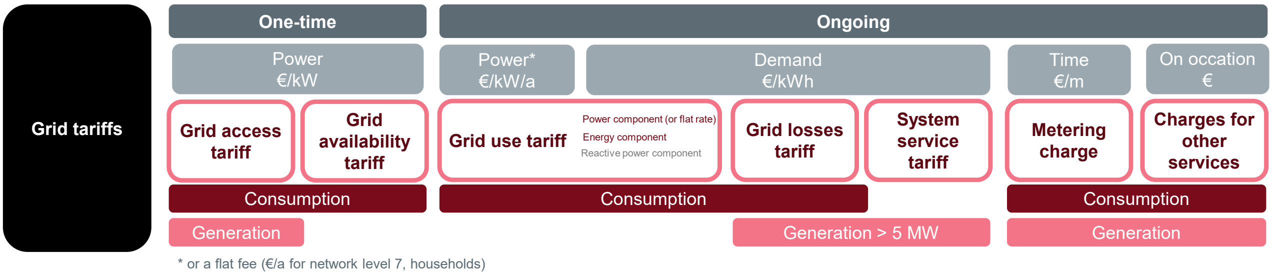

Figure 4: Price components of the grid tariff in Austria (own illustration © AIT Austrian Institute of Technology GmbH)

The regulatory authority, E-Control, has proposed in its "Tarife 2.1" position paper to apply capacity-based charges to household customers (network level 7) as well, instead of the current flat fee (E-Control, 2020). In the draft of the new Electricity Act (ElWG), the regulatory authority is expected to be given more flexibility in determining the structure of grid tariffs, potentially allowing for further reforms in the pricing model for households. The ElWG would also enable the establishment of specific grid tariffs for system-supportive components. (Parlament Österreich, 2024).

Denmark

All Danish buildings are equipped with a smart power billing meter from which the utilities download consumption data. All Danish customers have the possibility to have dynamic prices – i.e. to be billed according to the price of electricity for the time they use electricity. Several apps are available telling the electricity price hour by hour of the day, and at 13:00 also for the following day. It is thus possible to choose to use electricity when it is cheapest. The raw electricity price fluctuates much due to the amount of RES power input from wind turbines and PVs – see Figure 5. The raw electricity price can sometimes even be negative. On top of that, net tariffs vary over the day and over the year.

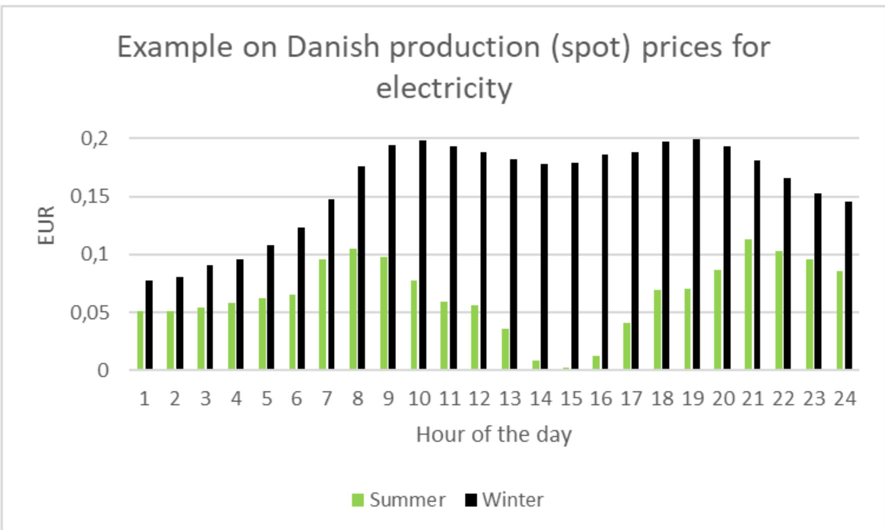

Figure 5 The summer example is a situation where there is a lot of solar energy during the day. The winter example is a situation with little wind energy during the period 8:00-23:00 (Byggeri og Energi, 2023).

From January 1st, 2023, the Danish DSOs were further allowed ToU tariffs better reflecting the cost of transporting the electricity hour by hour – see examples in Figure 6. The highest transport tariff occurs during the hours between 17:00 and 21:00, which in Denmark is called the cooking peak where the highest demand for electricity occurs in Denmark. It is called so, as it is when many Danes come home from work in the afternoon and start domestic appliances, including cooking – see Figure 6.

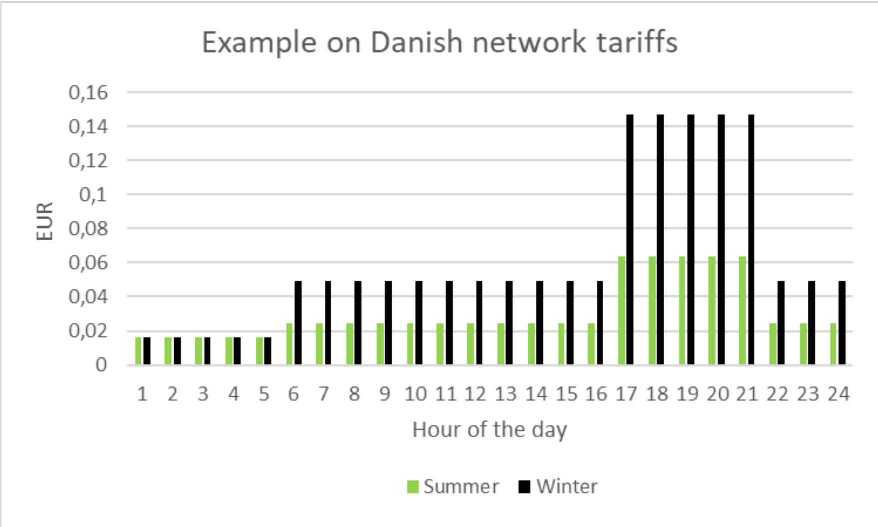

Figure 6 The network (or transportation) tariffs are based on the cost of transportation of the electricity increasing with higher amount of transported electricity. The transport tariffs are therefore higher during the winter than during the summer. The network tariffs are highest during the evening peak, while lowest during the night (Byggeri og Energi, 2023).

Many Danes have shifted electricity use away from this cooking peak as can be seen in Figure 7. People postponed the use of dishwashers, washing machines, and tumble dryers but also programmed postponed charging EVs. The extra use of electricity during the night is primarily believed to be programmed postponed charging of EVs. Figure 7 shows a reduction of the peak values of 10% at 18:00 between 2020 and 2023, while the figure shows an increase in demand during the night between 1:00 and 3:00 of 25%. So, dynamic prices have influenced the use pattern of electricity over the day – shifting consumption from the cooking peak to the night.

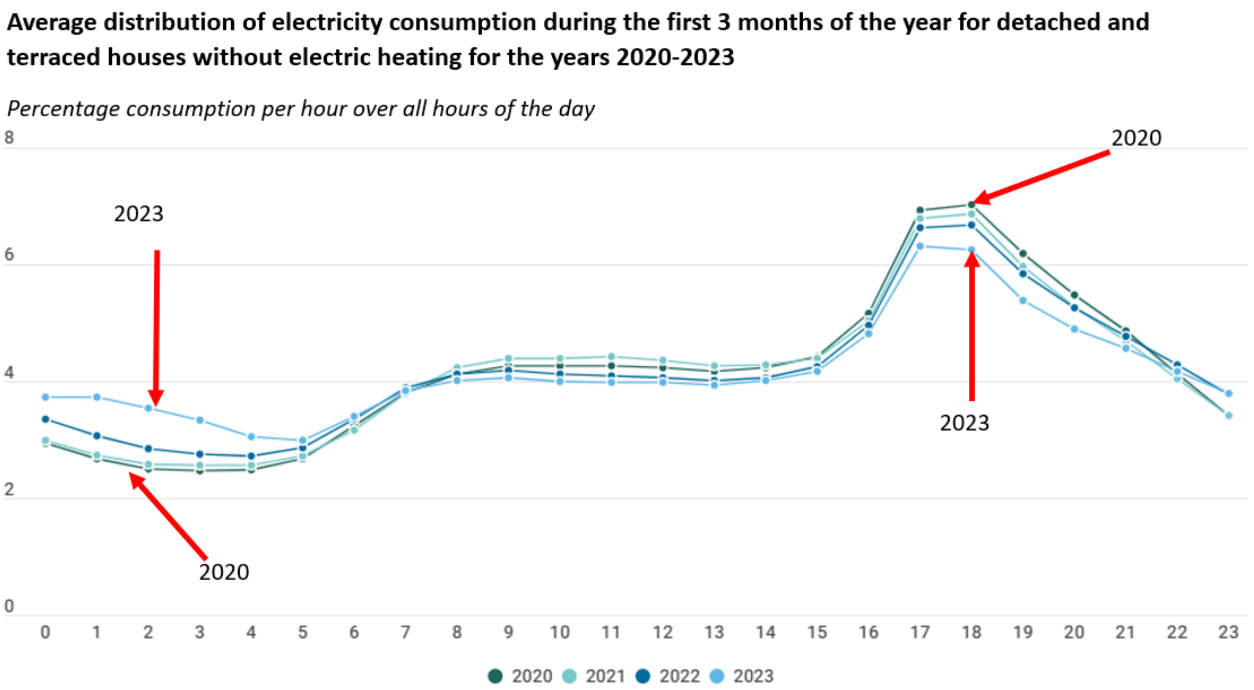

Figure 7 Distribution of domestic electricity consumption (percentage consumption per hour over all hours of the day) for the years 2020-2023 (Green Power Denmark, (Faruqui, 2023)). Hour 0 is the timeslot 0:00-1:00, and so on.

The transport tariff is higher during winter than summer making it a better business case to control a heat pump to mainly run during low price hours. In addition, most Danish buildings have high internal mass due to building tradition, which can be utilised for thermal storage.

3.2 Country comparison

In all evaluated countries, some sort of fluctuating electricity price (often as time of use, ToU price) is available to all customers. Most of the countries offer the option of real-time pricing (RTP), which is hourly pricing (Australia, USA (California), Czech Republic (not for households), Austria, Denmark, and soon Ireland). When it comes to network tariffs, some countries, i.e., Czech Republic, Ireland, Canada (Quebec) and with exceptions Austria, still apply fixed tariffs (especially on the household level). A higher network tariff for higher consumption is available in France, USA (California), and Czech Republic. A higher network tariff for higher consumption means that once a certain consumption threshold is reached or exceeded, the network tariff increases and becomes more expensive. Additionally, peak power consumption is rarely priced for households (only in Switzerland and Canada (Quebec)). The number of available electricity suppliers and (distribution) network operators varies significantly by country. Furthermore, the change of the electricity supplier is easy in all evaluated EU countries and Australia. However, retail competition is not possible in all US states and Canadian provinces and a change of electricity supplier is not possible in Switzerland.

Various flexibility solutions, both on the retailer and network operator side, are available. Pricing is a common flexibility option, as well as energy management systems and remote-controlled devices. Specifics on batteries as flexibility options and pricing schemes in energy communities can be found in the following tables.

Concerning feed-in tariffs for renewables (for households), most countries apply a fixed tariff or market premium. However, Australia (Victoria and Queensland), the Czech Republic, Switzerland (rarely), and Denmark offer time-varying feed-in tariffs. A reduced energy tariff for energy communities can be found in France, USA (California), Switzerland and Austria.

In only two countries, Austria and Denmark, costumers are offed varying gas prices for the end costumer and the variations are monthly. The gas price for the following month is announced at the end of the actual month.

Prices for district heating are, in all cases, offered on an annular basis.

Table 1, Table 2 and Table 3 show a country comparison of received answers to the questionnaire concerning electricity pricing.

Table 1: Comparison of responses to the questionnaire on pricing for encouraging energy flexibility regarding electricity (Part 1/3). The figure uses green to indicate that the question was answered with "yes", red to indicate a "no", and diagonal lines to signify that the question was not applicable to this part of the tariff.

	Questionnaire answers concerning electricity by countries					
	AU		F		USA	
	Electricity tariff	Network tariff	Electricity tariff	Network tariff	Electricity tariff	Network tariff
Fluctuating pricing available	Y (e.g. ToU, RTP)	Y (some offer zero tariff for middle of day)	Y (e.g. ToU)	Y (hourly, daily, seasonal)	Y (hourly, seasonal)	Y (hourly, seasonal, usually fixed schedule)
Change of electricity supplier	Easy		Easy		Small number of US states allow retail competition	
Number available suppliers	114	21	~40	1	~3000	
Flexibility solutions	RTP	PeakSmart for air conditioning; economic tariff 33 (interruptable tariff)	ToU + direct control for DHW; Voltalis direct control of radiators; Tempo pricing for commercial customers		Most common are either customer-controlled devices (e.g., programmable thermostats), utility-controlled devices (e.g., air conditioner load switch), or pricing	
Higher network tariff for higher consumption		N (often lower tariff with more consumption), but demand tariffs may be applicable		Y		Y (inclining block rates that charge a higher price as consumption levels increase)
Peak power consumption is priced for households		N (only for demand tariffs, most residential tariffs have energy-based charges)		N (fixed cost based on contracting power)		Peak-driven costs recovered via volumetric energy rates (residential) and via demand charges (commercial/ industrial)
Direct/incentive payments for network flexibility		Y (e.g. PeakSmart for air conditioners)		Y (depending on peak power, ToU style)		Y (monthly bull payments or other reservation/participation-based incentive)
Price reduction for controlled components	Y (with end-user's consent)	Y (with end-user's consent)	N	N	N (few, if any)	N (few, if any)
Feed-in tariff system	fixed or time-varying		fixed (set by government, depending on type)		net energy metering; some examples of net billing	
Batteries as feed-in devices	Y		N		Y	
Specific requirements/pricing for grid-connected batteries	N		N		Y (net billing program: compensates net export based on marginal supply cost in that hour)	
Reduced tariff for shared electricity in energy communities	N (under discussion)		Y (based on rules established internally; taxes and grid cost must be paid)		Y (community solar)	

Table 2: Comparison of responses to the questionnaire on pricing for encouraging energy flexibility regarding electricity (Part 2/3). The figure uses green to indicate that the question was answered with "yes", red to indicate a "no", and diagonal lines to signify that the question was not applicable to this part of the tariff.

	Questionnaire answers concerning electricity by countries					
	CZ		CH		AT	
	Electricity tariff	Network tariff	Electricity tariff	Network tariff	Electricity tariff	Network tariff
Fluctuating pricing available	Y (hourly for commercial/prosumers, ToU for households+SE)	Y (DSO manage via load ripple control, LO/HI fee with expected schedule week-ahead; high voltage: maximal load contract)	Y (two-tiered day/night tariff)	N	Y (e.g. hourly, monthly)	N (not for households, only for measured power in some grid areas day/night tariff)
Change of electricity supplier	Easy		Not possible		Easy	
Number available suppliers	~150	4	~630 (unbundled concerning information and accounting)		~150	136
Flexibility solutions	energy management systems, but for households hourly prices not available - also due to missing smart meters	ripple control; smart meters in pilot phase	Remote controlled devices that the utility company can shut off	aggregated HPs offering ancillary services	energy management systems of customers or utilities (device/cloud); pricing (e.g. hourly)...	interruptible tariff; special tariff for balancing energy
Higher network tariff for higher consumption		Y (different tariffs available from residential/small-enterprises (LV) and commercial (HV))		N		N (often lower tariff with higher connection capacity due to higher network level)
Peak power consumption is priced for households		N (only for commercial customers)		Y		N (for household: flat tariff for connected power. For commercial customers: peak is measured monthly)
Direct/incentive payments for network flexibility		N		N		N
Price reduction for controlled components	N	N	N		N (maybe for bigger installations, not on household level)	Y (interruptible tariff)
Feed-in tariff system	fixed and spot feed-in available (<50kWp). >50kWp can enter wholesale market as part of VPP		depending on supplier of area (must purchase PV electricity): fixed prices (standard) or, rarely, spot market prices		fixed or other scheme (by electricity supplier) or market premium on top of market price (subsidy)	
Batteries as feed-in devices	Y (but not common)				Y	
Specific requirements/pricing for grid-connected batteries	N (not for prosumers)				N (only if they provide balancing services there is a lower grid tariff for consumption)	
Reduced tariff for shared electricity in energy communities	N (not yet, set out to change in 2024)		Y (energy communities behind the meter possible, can charge only 80% of energy costs that would occur if not part of the EC)		Y (Electricity tariff for shared electricity can be agreed upon within the energy community; there are reduced grid tariffs for RECs)	

Table 3: Comparison of responses to the questionnaire on pricing for encouraging energy flexibility regarding electricity (Part 3/3). The figure uses green to indicate that the question was answered with "yes", red to indicate a "no", and diagonal lines to signify that the question was not applicable to this part of the tariff.

Questionnaire answers concerning electricity by countries						
	IRE		DK		CAN	
	Electricity tariff	Network tariff	Electricity tariff	Network tariff	Electricity tariff	Network tariff
Fluctuating pricing available	Y (ToU, RTP to be expected soon)	N	Y (different periods of time)	Y (off-peak, peak and in-between periods over day and seasonal variation)	Y (flexible dynamic rate for peak demand shifting that is seasonal (Flex D) . Tariff goes on top of base rate (Rate D))	N (Rate D covers energy and network component, volumetric and fixed charge)
Change of electricity supplier	Easy		Easy		Not possible (for Quebec)	
Number available suppliers	11	1	47	39	Quebec: 1	Quebec: 11 (Hydor-Quebec and municipal/cooperative networks)
Flexibility solutions	demand side services only available to aggregators and large energy users		for private costumers currently none, but can be negotiated for commercial customers		Hilo (virtual power plant with smart home service including app-controllable devices, energy consumption guidance, rewards)	
Higher network tariff for higher consumption		N		Y (there is a subscription fee depending on the installed max capacity)		N
Peak power consumption is priced for households		N				Y
Direct/incentive payments for network flexibility		N				Y (Flex D tariff mostly lower than standard rate, only higher for exceptional peak demand events)
Price reduction for controlled components	Y (only for large commercial/industrial energy users via an aggregator)	N			Y	N
Feed-in tariff system	available		Feed in tariff equals the production price in the actual hour, which is marginal compared to the total electricity price		net-metering applied (grid as virtual storage)	
Batteries as feed-in devices	N		Y (normally better economy in buying cheap electricity and use it when prices are high)		Y	
Specific requirements/pricing for grid-connected batteries	N				Y (residential battery backup systems for power-outages and to feed-in during peak demands are tested and remuneration granted)	
Reduced tariff for shared electricity in energy communities	N		N		N	

The questionnaire results concerning gas can be found in Table 4. Since the usage of flexibility in the gas sector is not widespread, the questions were limited to whether fluctuating pricing for gas exists in the respective country. The results show that only Austria and Denmark offer fluctuating pricing schemes on a monthly basis.

Table 4: Comparison of responses to the questionnaire on pricing for encouraging energy flexibility regarding gas.

Questionnaire answers concerning gas by countries						
	AU		F		USA	
	Gas tariff	Network tariff	Gas tariff	Network tariff	Gas tariff	Network tariff
Fluctuating pricing available	N (households have flat tariffs, more sophisticated for	N	N	N	N (at least not typically)	N (at least not typically)

Questionnaire answers concerning gas by countries						
	CZ		CH		AT	
	Gas tariff	Network tariff	Gas tariff	Network tariff	Gas tariff	Network tariff
Fluctuating pricing available	N (not for retail)	N (not for retail)	N		Y (monthly)	N

Questionnaire answers concerning gas by countries				
	IRE		DK	
	Gas tariff	Network tariff	Gas tariff	Network tariff
Fluctuating pricing available	N		Y (monthly)	N

Concerning district heating, the results (see Table 5) show that fluctuating prices are unavailable (or unknown) in the investigated countries. However, the first discussions on this topic have started in Denmark.

Table 5: Comparison of responses to the questionnaire on pricing for encouraging energy flexibility regarding district heating.

Questionnaire answers concerning district heating by countries				
	AU	F	USA	CZ
Fluctuating pricing available	N (DH is rare in VIC)	N	Unsure	N

Questionnaire answers concerning district heating by countries				
	CH	AT	IRE	DK
Fluctuating pricing available	N	N (or few: a lot of small district heating grids in Austria with different pricing structure)	N (district heating not prevalent in Ireland, only a few pilot schemes in operation)	N (but biggest utilities discuss about possible seasonal price changes)

It was also asked who pays for a possible smart meter (electricity, gas, and district heating). The results, which vary from the grid customers to all taxpayers or the operator/supplier, can be found in Table 6.

Table 6: Comparison of responses to the questionnaire on pricing for encouraging energy flexibility regarding smart meters.

Questionnaire answers concerning electricity by countries									
	AU			F			USA		
	Electricity	Gas	DH	Electricity	Gas	DH	Electricity	Gas	DH
Who pays for smart meters needed to participate in flexibility program	Housholds/ commercial customers (some states have piblic resources)	Housholds/ commercial customers	Housholds/commercial customers	Taxpayers	Taxpayers		Taxpayers	(few smart gas meters installed)	

Questionnaire answers concerning electricity by countries									
	CZ			CH			AT		
	Electricity	Gas	DH	Electricity	Gas	DH	Electricity	Gas	DH
Who pays for smart meters needed to participate in flexibility program	DSO	network operator?	network operator	DSO	network operator?	network operator	Taxpayers	Taxpayers (but not widely applied)	

Questionnaire answers concerning electricity by countries						
	IRE			DK		
	Electricity	Gas	DH	Electricity	Gas	DH
Who pays for smart meters needed to participate in flexibility program	DSO			Electricity company (but part of subscription fee)	no smart meters (phase out)	district heating company (but part of subscription fee)

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4 Factors influencing stakeholder engagement in energy flexibility

Without acceptance from the energy end-users, energy flexibility will not become a success. In this section different approaches for engaging the end-users and to improve their acceptance of taking part in demand-side management and demand response programmes are summarized.

First, the key findings from a comprehensive literature review performed with focus on existing research on key factors influencing the enrolment and participation of electricity consumers in building demand management processes are presented. Second, the insights from an international, comparative questionnaire study on demand response in residential, but also some educational and commercial buildings, are given. Finally, the chapter concludes by addressing questions related to how to ensure a just and socially equal implementation of building flexibility.

4.1 Key factors of customer enrolment and participation in building demand management programs

So far, only few comprehensive review studies on demand-side management (DSM) have been carried out. With the systematic literature review on studies on factors influencing customer enrolment and participation in building demand management programs, which was carried out in Annex 82 (see Langevin et al., 2024), we aim to contribute to a better understanding of the key drivers behind DSM in buildings.

To date, studies have established that a wide range of factors impact the level of enrolment and/or participation of customers in utility demand-side management (DSM) programs, but systematic evidence is lacking on the strength of understanding about each factor and the relative impact each factor may have on DSM outcomes in relation to other possible factors. Using a structured, multi-stage framework for retrieving, screening, and scoring relevant studies, we have aggregated evidence about the impacts of several potential DSM factors on enrolment and participation outcomes. We have also highlighted the contexts in which relationships between the DSM factors and outcomes are most studied and uncovered gaps in understanding that could hinder the broader adoption and use of DSM by utilities to meet power system decarbonization targets.

Our review comes at an important juncture for DSM program design and implementation: DSM is often cited as a promising resource for power system decarbonization, but the collective understanding of how to scale DSM programs and their impacts to fulfill energy system decarbonization targets remains limited. This goes in particular for the understanding of customer behavioural constraints. Our study provides a comprehensive snapshot of the current state of knowledge about factors that may drive DSM program enrolment and participation, as well as key knowledge gaps that must be filled. Its findings will be of strong interest to stakeholders ranging from utilities and grid planners to policy-makers and energy system researchers.

Design of literature review

The literature review is based on the Context-Intervention-Mechanism-Outcome (CIMO) framework developed by Buchanen & Bryman (2009) and later applied to energy-related studies by Pênasco et al. (2021). We have framed the research question and focus of our review according to the four key elements of CIMO as follows: What is known in the scientific and industry literature about the changes in DSM customer enrolment and/or level of participation (O) that arise from various market, policy, or other contextual factors (I) that may activate demand-side management resources (M) to facilitate electric grid decarbonization (C)?

The literature database was developed on the basis of a five-stage review, screening and scoring process. First, an initial screening of academic databases (Scopus and ScienceDirect) was performed by use of relevant keywords. Second, we performed a title and abstract screening and category tagging, mainly to exclude papers not relevant to this review. Third, a parallel search for relevant reports and key authors were made in order to ensure the inclusion of DSM program research conducted outside the academic context by grid planners, utilities, governments, etc. Fourth, a detailed review and scoring of screened papers was done, which resulted in a final database of papers, including the addition of metadata across categories of interest and a scoring of the paper's reported effects of DSM factor(s) on DSM outcomes. Fifth, a supplemental scoring was carried out, which added additional information on the nature of customer's control over their participation in DSM programs.

With regard to outcomes, our main focus was on results related to how different factors influence customers' enrolment and participation in DSM programs. We define *enrolment* as the total number of customers enrolled, rate of enrolment in buildings and similar. We define *participation* as levels of load flexibility and/or energy efficiency impacts achieved by the participating customers. The changes in enrolment and participation reported in the reviewed studies represent the Outcome element in the CIMO framework.

The reviewed studies covered a wide span of different market, policy, and other contextual factors, that can be applied by utilities or other relevant stakeholders to increase enrolment and/or participation in DSM programs. These factors represent the Intervention element in the CIMO framework. All reviewed papers were categorized according to six types of interventions (also named "DSM factors"):

- **Incentives**: Providing economic rewards for adjusting consumption temporarily or permanently (e.g. customer equipment rebates and time-varying electricity rates)
- **Structural barriers**: Removing barriers to enrolling and/or participating in DSM programs (e.g. expanding program availability)
- **Third-party services**: Partnering with other entities to enrol customer participation and/or guide participation in DSM programs (e.g. aggregators and ESCOs)
- **Customer engagement**: Educating customers about DSM programs and provide feedback (e.g. about their consumption)
- **Customer segmentation**: Binning customers by common characteristics (e.g. load adjustment preferences or socio-demographic profiles) to tailor engagement in DSM programs
- **Regulatory**: Enacting rules to compel customer enrolment and participation in DSM programs (e.g. default time-of-use rates)

The review study focused only on papers published in English and after 2000. Also, it was set as an inclusion criterion that the reported studies should include a focus on building electric loads and that the studies made an assessment of individual DSM factors' impact on individual DSM outcomes.

In total, 746 papers were initially retrieved and screened. Of these, 80 papers were ultimately scored and made the basis for the final review.

A detailed presentation of the methods behind our literature review, including limitations, can be found in Langevin et al. (2024).

Key findings and recommendations

Interestingly, most of the papers (80%) were published after 2015, which likely reflects that the interest in studying DSM enrolment and participation took off by the mid-2010s with the ramping up of policies and initiatives concerning the decarbonization of electricity systems.

Based on the literature review, we identify the following common themes of relevance to utilities, grid planners, and other decision-makers seeking to increase DSM program deployment and efficacy.

First, we find the focus on economic incentives and DSM participation to be dominating and often explored through simulation methods rather than through experimental trials or full-scale rollouts (see Figure 8). While there might be methodological reasons why participation studies prevail (changes in enrolment might be more difficult to measure/model compared to changes in loads related to participation), it seems recommendable to reduce the dependence on simulations and to a higher extent prioritizing studies based on measured data within DSM research and development. The dominance of economic incentives studies likely reflects the emphasis in much policy-making and smart energy R&D on financial and market-based DSM strategies. This ties in with the predominant belief in stakeholders (e.g. households) being rational agents reacting primarily to economic incentives (Strengers, 2013). However, this emphasis on the rational character of stakeholders' decision-making has also been criticized by social science researchers for underestimating the importance of other factors such as structural conditions or how DSM solutions fit in with existing household and business practices (Christensen et al., 2020; Shove & Walker, 2014).

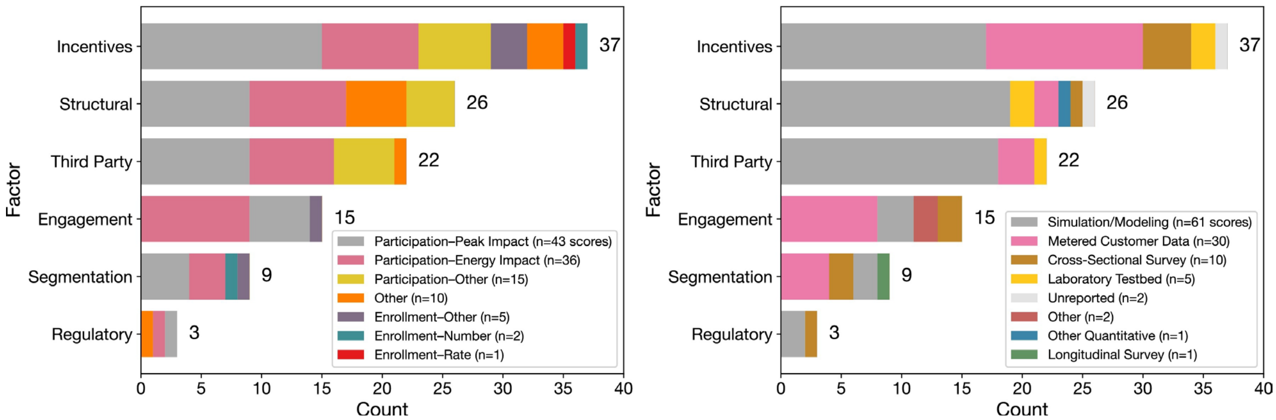


Figure 8: DSM enrolment or participation outcome assessed by studies (left). Primary study methodology applied (right). Both charts show the distribution of studies by DSM factor type. Original source: Langevin et al. (2024).

Second, we find a muted hierarchy in DSM impacts across influencing factors and other relevant dimensions. The analysis of the papers indicates that interventions within third party services, customer engagement and removal of structural barriers have the highest overall scores with regard to their impact on DSM participation. However, the review shows generally high variation around the scored impacts of DSM factors, and it is, therefore, difficult to make certain conclusions about their internal hierarchy when it comes to their effectiveness. In addition to many papers being based on simulated results, a reason for this variation can be related to the vast diversity in contexts across studies. There seems to be a need for more research that compares the relative impacts of interventions under similar conditions and with similar evaluation metrics.

Third, we find that automated technologies play a clear role across studies. The application of controls seems important to removing structural barriers to DSM participation and is also an enabling condition for other factors (in particular, remote third-party load aggregation and time-varying price signals for demand response). In addition, the automation of such controls seems to result in larger positive impacts on participation outcomes compared to active or manual control schemes. However, and interestingly, highest impacts are found if automation and manual control are combined, e.g. by providing customers the possibility for overriding automated and/or remote control.

Fourth, we identify some important gaps in the existing literature. One of these relates to the lack of studies on regulatory interventions, which seems to be problematic as regulatory factors are expected to play an important role in promoting DSM solutions for buildings. Another gap in the literature relates to studies on the intersection of building load electrification (seen as pivotal for the energy system decarbonisation) and DSM enrolment or participation. It seems recommendable to focus more on these gaps in the existing knowledge in future studies.

4.2 Results from occupant questionnaires and interviews

In many countries, studies have been carried out on users' involvement in DR events. In connection with Annex 82, three national survey studies were carried out, exploring the potential of diverse households, as well as partly offices and educational buildings, in demand response initiatives. These studies and their results are presented in this section.

Study Design

The studies consider the range of indoor activities that can contribute to demand response as well as different types of demand response programs that may be implemented. The surveys were conducted in the United States (U.S.), Belgium, and Austria. The surveys include the following components: demographics, occupancy schedules, occupant activities (e.g., cooking, dishwashing) and willingness to adjust these activities, occupant preferences on temperature setpoints and willingness to adjust these setpoints, and DSM (Demand Side Management)/DR (Demand Response) perceptions. The survey was originally developed by researchers at the Michigan State University's Department of Civil and Environmental Engineering, where the work was led by associate professor Kristen Cetin.

In the U.S., the survey was designed in Qualtrics, a web-based survey tool that allows the development of survey research and other types of data collection (Qualtrics, 2020). The online survey was completed during the summer of 2023 for enrolled participants at the Pecan Street Research Institute (Pecan Street, 2023). This is an organization that collects data on consumer energy consumption of residential buildings in the U.S. A total of 240 participants responded to the survey.

The Belgian survey focused on social housing tenants. This group warrants particular attention because they are among the most vulnerable to the energy transition (see also section 4.3). Social housing tenants often have limited financial resources, making them more susceptible to rising energy costs and less able to invest in energy-efficient and -flexible technologies or renewable energy solutions. To prevent widening the energy poverty gap, ensuring their inclusion in energy transition initiatives, such as demand response programs, is crucial.

To this end, the survey was distributed within the 'oPEN Lab' living lab in Genk, Belgium. In this H2020 project the scope is to investigate how social housing neighbourhoods can become positive energy neighbourhoods. All 25 households involved in the living lab participated in the survey. At that moment, their dwelling was still in its pre-renovation phase. An overview of their dwelling and household characteristics is provided in Table 7.

The distributed survey was based on the one developed by Michigan State University's Department of Civil and Environmental Engineering and was supplemented with questions from the survey conducted by Lambie (2021) and the survey from the Center for the Built Environment (Peretti & Schiavon, 2019), which covered aspects of building systems and comfort. Administering the survey orally improved question comprehension, particularly given the participants' limited familiarity with demand response.

In Austria, the survey was designed as a LimeSurvey and completed in July 2024. The Austrian survey focused on occupants of 3 different building types, namely office, university and residential buildings. In detail, it focused on the flexibility given to some appliances and energy-consuming activities by these users. Out of more than 80 respondents of this online-survey, only 29 delivered social data together with the completed questionnaire. Additionally, 17 delivered the questionnaire without filling in social data, but still gave comprehensive answers on demand response questions, so all together 46 completed questionnaires have been analysed. It showed evidence about the flexibility users would give to specific energy consuming activities or appliances. The survey was distributed among more than 500 persons working or living in different buildings in Vienna, Lower Austria and Styria, all of them Austrian regions.

Country-specific survey results

A characteristic of the U.S. survey results is that most of participants were highly educated (97% had college or above) and belonged to a high-income group (43% had more than $150,000 annual income). They tend to own their house (97%) with the type of detached single-family home (93%) being dominant. As well as considerable numbers of respondents had high occupancy rates, which can be inferred from significant percentage of retirement (33%) in Table 7**.** These characteristics may lead to a high level of interest in residential DSM/DR, and the survey results showed their familiarity with DSM to be relatively high (Figure 16). However, the actual participation in DSM/DR was found to be low (Figure 17 (a)), and the most common reason they are not participating in DSM/DR programs is that these are not available in their area. Nevertheless, a considerable share of respondents had positive opinions on and recognized benefits about DSM/DR (Figure 9).

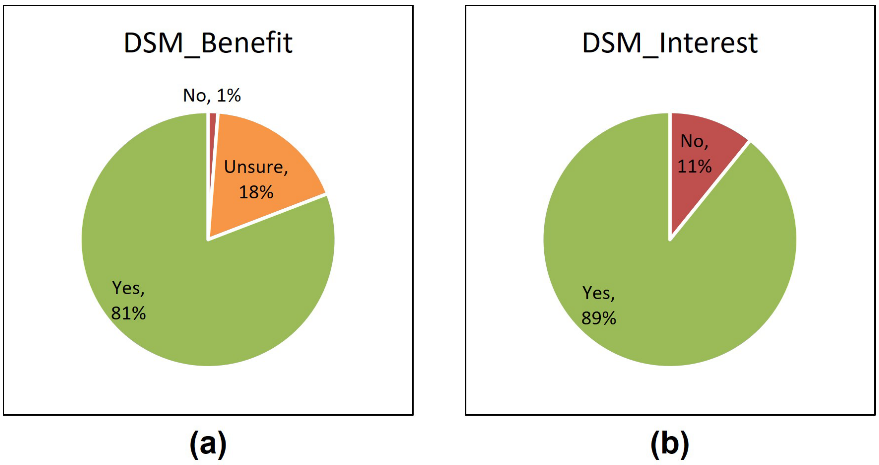


Figure 9 Participants' opinion on if there are benefits to participating in DSM, and (b) if they are interested in participating in DSM in the future.

The Belgian survey analysis indicated that respondents' willingness to adapt their thermostat set point temperatures varies between the day during weekdays as highest (36-44%) to lowest on Sundays (16-32%). Willingness seems highest when the household or most of its members are not at home during the day. It is households with a member who is unemployed or retired, as well as households where someone is almost always home, that never want to adjust their thermostat (Figure 10). Furthermore, within this specific sample, households with a lower net income are less flexible in adjusting the thermostat setpoint, while no specific age groups are more flexible than others.

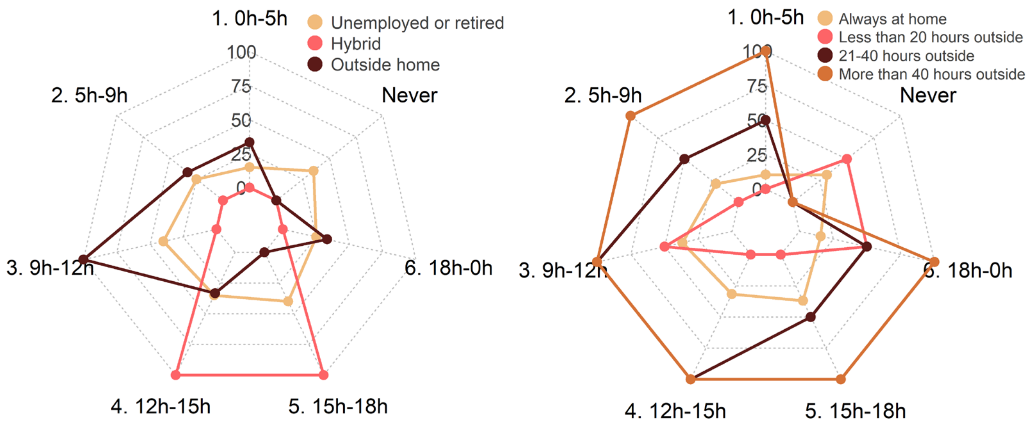


Figure 10 Differences in willingness to adjust thermostat setpoints based on employment type (left) and time spent outside the home during a typical week (right).

With respect to the preferred tariff structure, the respondents could choose in the survey between incentive-based and price-based demand response programs. Among the respondents that are willing to shift household activities, an equal number of respondents prefer incentive-based demand response programs as price-based ones (40% versus 40%). There is a trend that incentive-based demand response programs are preferred by households within this specific sample with an average net income and those with 1 or 2 members (Figure 11). Furthermore, automatization for participating in demand response is slightly preferred over self-control (40% versus 36%). Self-control seems to be primarily preferred by households with lower net incomes, those who spend less time outside the home, and those without working members.

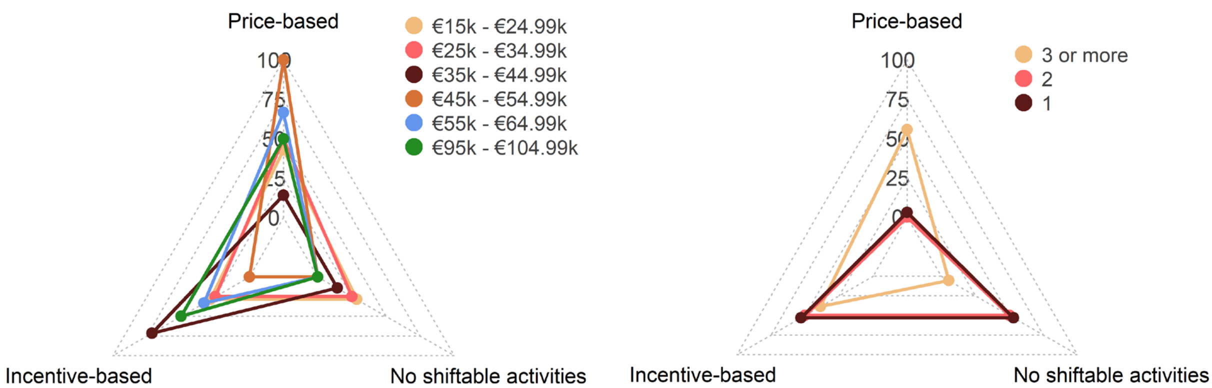


Figure 11 Differences in preferred tariff structure based on net income (left) and household size (right).

The Austrian survey found an overrepresentation of respondents in the age group of 25 to 34 years old respondents (41%), which is to be expected when it comes to dormitory, research office and university buildings' use. So, most of the respondents answered from an office buildings' perspective. And of course, some of the dormitory or university buildings are always occupied (4), whereas most of them are partly but more than 40 hours in use (24).

The survey analysis indicated that respondents' willingness to adapt the different uses of appliances relates very much to what would be expected. For example, the willingness to shift the washing machine and the dishwasher usage to any other time than the one specified is the highest (Figure 12: 56% and 58% at weekdays) in comparison to other appliances or activities. The willingness to change the time of energy consuming activities is generally, but only slightly, higher at the weekends compared to weekdays.

A remarkable result is that even TV is by some seen as a service that could be carried out at other times, although the specified time of usage would be preferred (e.g. 22% at weekdays - see Figure 12).

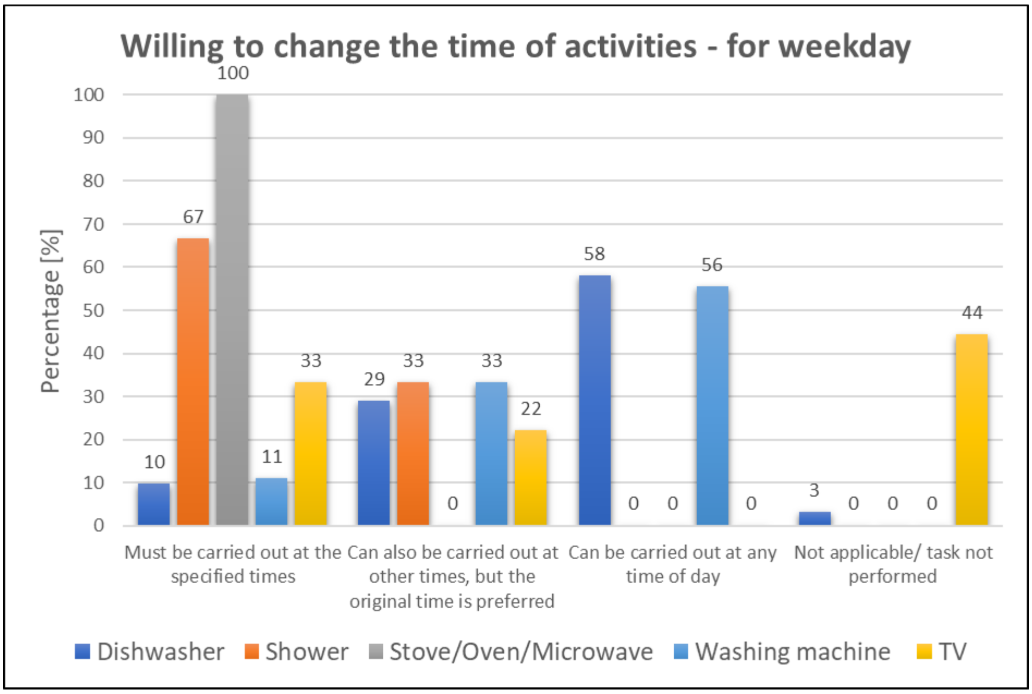


Figure 12 shows the results of the questions asking about the willingness to change the usage times of 4 different appliances and domestic hot water use for shower at weekdays

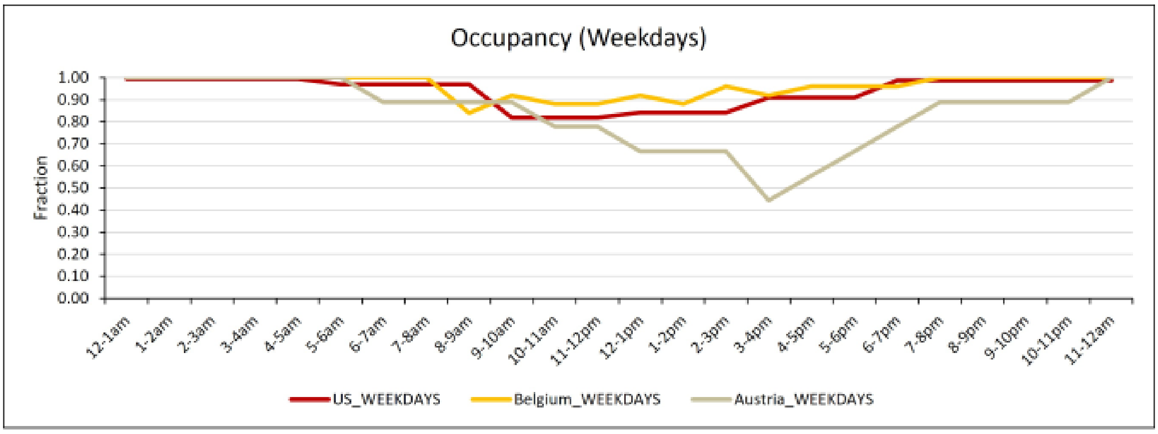
Country comparison

Demographics: Table 7 shows the overall demographic comparison among 3 countries. In Austria, 9 residential buildings out of a total of 29 were included for this comparison. For gender, the U.S. survey included 30% female and 69% male, Belgium had 64% female and 36% male, and Austria had 67% female and 33% male. For age group, the most common group in Austria was 25-34, whereas Belgium and U.S. were 45-54. Regarding employment status, 59% of the U.S. participants were employed full-time, followed by retired (33%). In case of Belgium, 68% of participants were unemployed. Austria did not ask questions about employment status. For housing type, 93% of the U.S. participants lived in detached single-family homes, and 85% of Belgium were attached single-family homes. The Austrian survey did not ask for the specific housing type, but answers were spread among three different building types. Most of the U.S. residents owned their homes, whereas all the Belgium residents who participated were renting. Austria, for residential sector respondents, shows a mix with 56% indicating that they own their home and 44% that they are renting it. In terms of household size, the most frequent responses were 2 people (49%) in the U.S., 4 people (32%) in Belgium, and 2 people (44%) per household in Austria. The most common type of utility bills were electricity and natural gas for both US and Belgium, and Austria had equally high responses for electricity and natural gas, and electricity only.

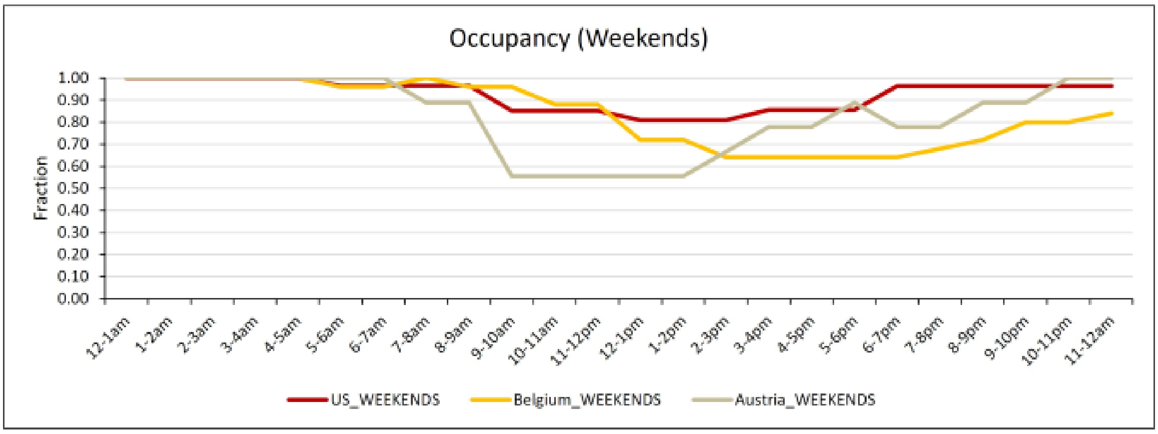
Table 7 Demographic information of respondents in the surveys of the 3 countries

Category	Data Field	U.S. (n=240)	Belgium (n=25)	Austria (n=9)
Gender	Female	30.4%	64.0%	66.7%
	Male	68.8%	36.0%	33.3%
Age	18 – 24 years	-	-	-
	25 – 34 years	2.9%	4.0%	44.4%
	35 – 44 years	14.6%	20.0%	11.1%
	45 – 54 years	26.7%	32.0%	33.3%
	55 – 64 years	18.8%	28.0%	11.1%
	65 – 74 years	23.3%	8.0%	-
	Over 75 years	12.9%	8.0%	-
Employment status	Full-time	58.5%	4.0%	
	Part-time	7.6%	12.0%	
	Retired	32.6%	16.0%	
	Unemployed	1.3%	68.0%	
Highest education	High school or below	2.9%	-	11.1%
	College or above	97.1%	-	88.9%
Housing type	Apartment (2-4 unit)	1.3%	7.5%	-
	Attached single family	5.4%	85.0%	-
	Detached single family	92.9%	7.5%	-
Housing tenure	Own	96.7%	-	55.6%
	Rent	3.3%	100.0%	44.4%
Household size	1	14.6%	16.0%	22.2%
	2	48.8%	8.0%	44.4%
	3	15.4%	16.0%	22.2%
	4	16.7%	32.0%	-
	5 or 5+	4.6%	28.0%	11.1%
Utility bills	Electricity only	10.0%	-	33.3%
	Electricity, Natural gas	83.3%	96.0%	33.3%
	Electricity, Oil	0.4%	-	-
	Electricity, Propane	5.8%	-	-
	Electricity, Propane, Oil	0.4%	-	-
	Electricity, Natural gas, Pellets	-	4.0%	-
	Electricity, Biomass	-	-	11.1%
	Electricity, District heating	-	-	22.2%

Occupancy: The surveys asked participants to identify typical unoccupied/occupied times in their homes for each day of the week. The U.S. survey asked about typical unoccupied time blocks from 3 to 6 hours. The Belgium survey asked about typically occupied times by hourly timesteps. The survey of Austria asked about typically unoccupied times by hourly timesteps. Responses are used to create averaged weekdays and weekends occupancy profiles at an hourly timestep, as shown in Figure 13, across all three country samples, including (a) for the weekdays, and (b) for the weekends. Based on this data, the average daily occupancy rate of the U.S. was 0.94 (94%), Belgium was 0.96 (96%), and Austria was 0.84 (84%). Austria had the lowest occupancy rate among 3 countries – the reason is that the Austrian sample includes a wider range of occupancy types, not only residents. For all 3 countries, weekends average occupancy rates are lower than weekdays, with differences from 1% to 12%. For hours of the day with the least occupancy, these hours occur later weekends than weekdays for the U.S. and Belgium.



(a)

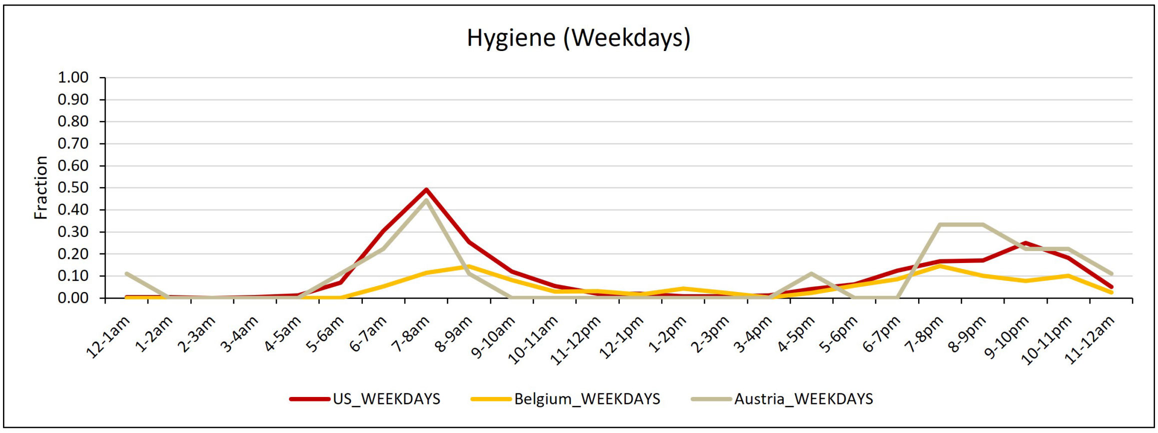


(b)

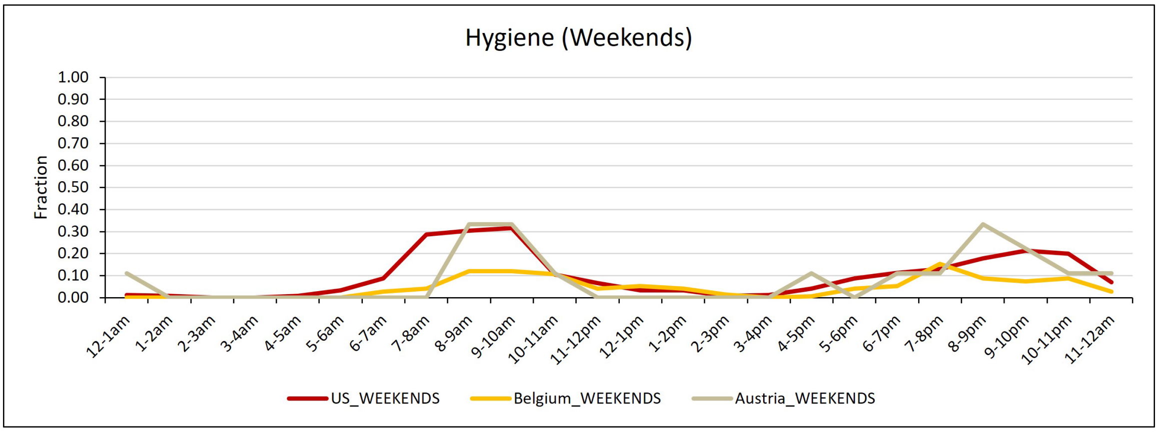
Figure 13 Occupancy fraction on (a) weekdays and (b) weekends for the U.S., Belgium, and Austria.

Occupant activities: The surveys asked for typical activity hours for several household activities including sleeping, hygiene, cooking, dishwashing, washer and dryer use, watching TV, and using a computer. An example of these questions is the following: “During what hours of the typical weekday do the individuals in your household spend sleeping?”. This was collected for both weekdays and weekends. For the interpretation of the results shown in Figure 14, hygiene is taken as example to be described in the following.

For hygiene activities (Figure 14), the average fraction of time spent on weekdays was 0.10 (10%) for the U.S., 0.05 (5%) for Belgium, and 0.10 (10%) for Austria. For weekdays the times where the highest percentage of people were doing hygiene were 7-8am (49%) for the U.S., 7-8pm (15%) for Belgium, and 7-8am (44%) for Austria. The average fraction of time spent on weekends was 0.10 (10%) for the U.S., 0.05 (5%) for Belgium, and 0.08 (8%) for Austria. The time on weekends where the highest percentage of people were doing hygiene were 9-10am (32%) for the U.S., 7-8pm (15%) for Belgium, and 8-10am and 8pm-9pm (33%) for Austria.



(a)

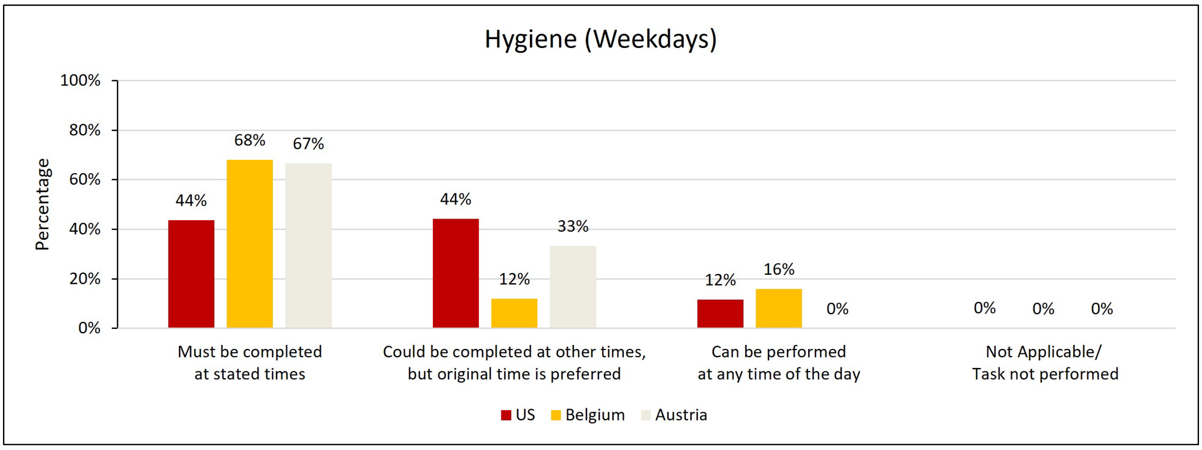


(b)

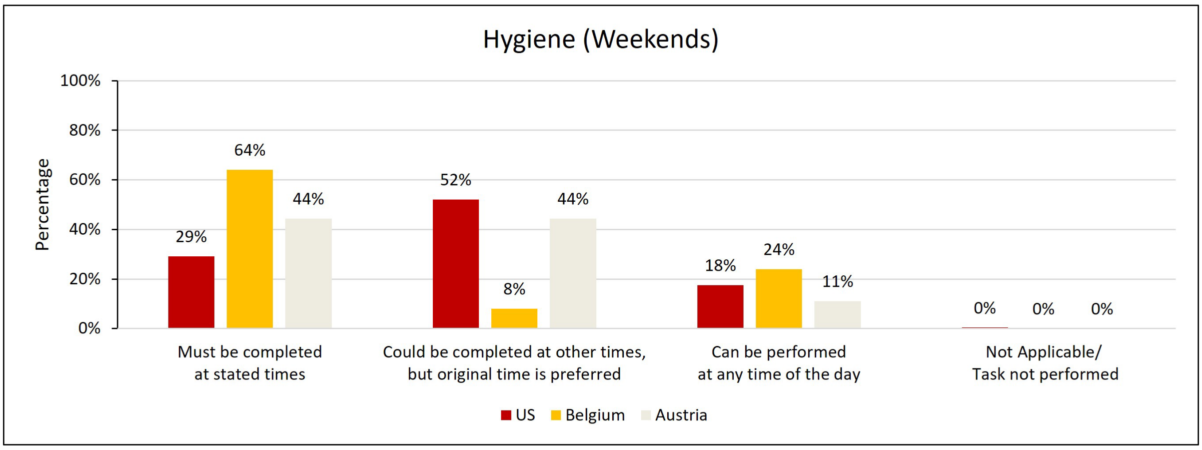
Figure 14 Fraction of time spent on hygiene on (a) weekdays and (b) weekends for the U.S., Belgium, and Austria

The surveys also asked about the willingness to adjust each activity (except for sleeping), using the question "How open would you be to changing the time of day that these tasks are performed during the weekdays?" The participants were able to choose between 4 options: "must be completed at stated times (not adjustable)", "could be completed at other times, but the original time is preferred (somewhat adjustable)", "can be performed at any time of the day (adjustable)", and "not applicable/task not performed". The results are shown in Figure 15, and again one example activity, hygiene, is taken in the following to describe the results.

For hygiene on weekdays (Figure 15 (a)), the U.S. showed both not adjustable and somewhat adjustable as highest responses of 44%. Belgium and Austria responded not adjustable as highest answer at 68% and 67%, respectively. For hygiene on weekends (Figure 15 (b)), the most frequent answer of the U.S. was somewhat adjustable at 52% unlike weekdays – it shows more flexibility on weekend hygiene activities. Belgium still indicated not adjustable at 64%. Austria also showed some flexibility, including both not adjustable and somewhat adjustable at the same frequency of response (44%).



(a)



(b)

Figure 15 Participants' willingness to adjust hygiene on (a) weekdays and (b) weekends for the U.S., Belgium, and Austria

Demand Side Management perceptions: The survey also asked several questions on DSM/DR perceptions, such as familiarity with DSM, DSM participation, concerns about DSM, issues impacting interest in DSM, factors helping address concerns, benefits encouraging participation, benefits of DSM, and interest in participating in DSM in the future. Only the U.S. and Austrian survey asked those questions as the Belgian households were not familiar with DSM/DR. The comparisons are therefore conducted for the U.S. and Austria only.

Regarding familiarity with DSM, the questions asked was "How familiar are you with the Demand-Side Management (DSM)/Demand Response (DR) programs?" on a scale of 1 (not familiar) to 10 (most familiar). Figure 16 shows the distribution of the results. For the U.S., the average value was 6.29, and the median was 7, which is a relatively positive response. The average value for Austria was 3.67, and the median 2, which is a lower position than the U.S.

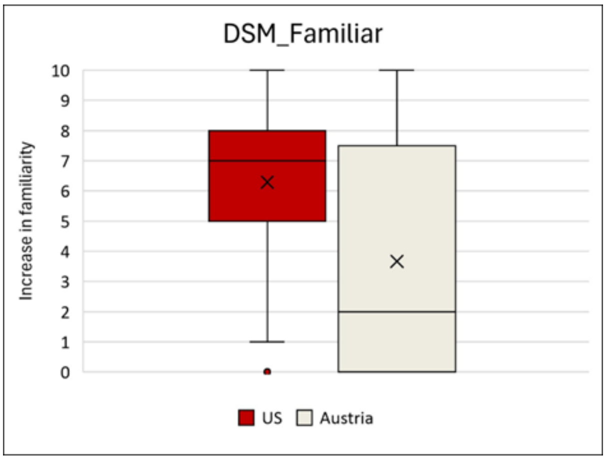


Figure 16 Familiarity with Demand Side Management

The survey also asked about DSM participation and concerns about DSM (Figure 17). For the question about current DSM participation (Figure 17 (a)), an example of the question was “Are you currently participating in any DSM/DR program?” For the U.S., 58% of participants were not participating in DSM/DR programs, whereas 31% were participating. 12% of participants were unsure about whether they are participating or not. For Austria, all participants were not participating in any DSM/DR program. Regarding concerns about DSM (Figure 17 (b)), the question asked, “Do you have any concerns about DSM/DR programs?”, 54% of the U.S. participants answered they do not have concerns about DSM/DR program, and 23% answered they have. 23% of participants were unsure about concerns. For Austria, 67% of participants answered they do not have concerns, and 33% were unsure. Remarkably, none of respondents in the Austrian sample indicated concerns about DSM/DR.

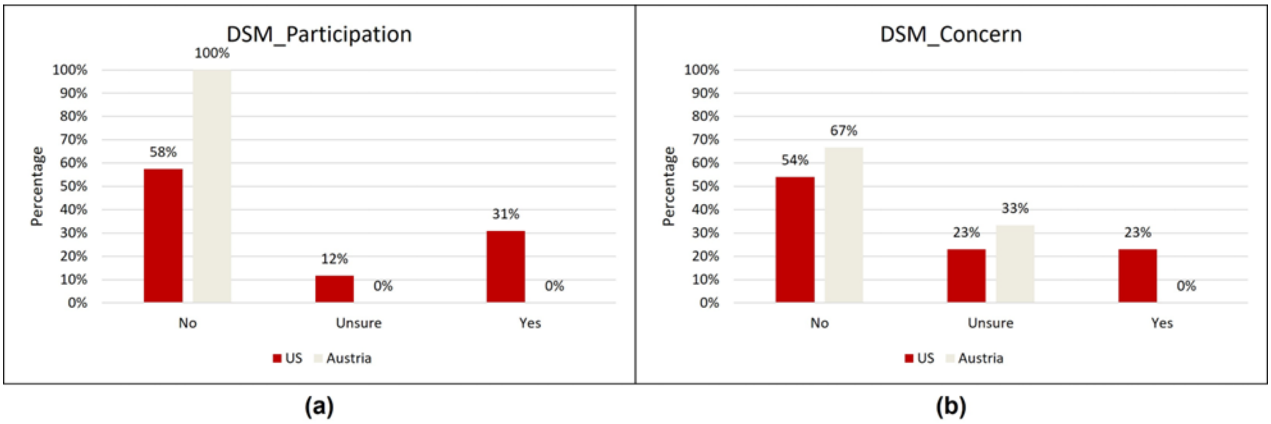


Figure 17 (a) Current DSM participation, (b) Concerns about DSM

For the question about benefits encouraging participation, the original question was “What benefits would encourage you to participate in DSM/DR programs?” Participants were able to select multiple among these options: “Reducing electricity bills”, “Receiving system upgrades (smart home devices)”, “Making my home more energy efficient”, “Saving energy”, “Helping the environment”, “Improving network reliability (less risk of power outages)”, “Increasing comfort of home”, and “Other”. The responses are shown in Figure 18. Regarding the U.S., the most encouraging option for participating in the DSM/DR was helping the environment (86%); followed by reducing electricity bills (82%), making my home more energy efficient and saving energy (74% for both), improving network reliability (68%), receiving system upgrades (58%), and increasing comfort of home (46%). For Austria, the most frequent answer was saving energy (89%); followed by reducing electricity bills (78%), helping the environment and increasing comfort of home (67% respectively), making my home more energy efficient and improving network reliability (56% respectively), and receiving system upgrades (33%).

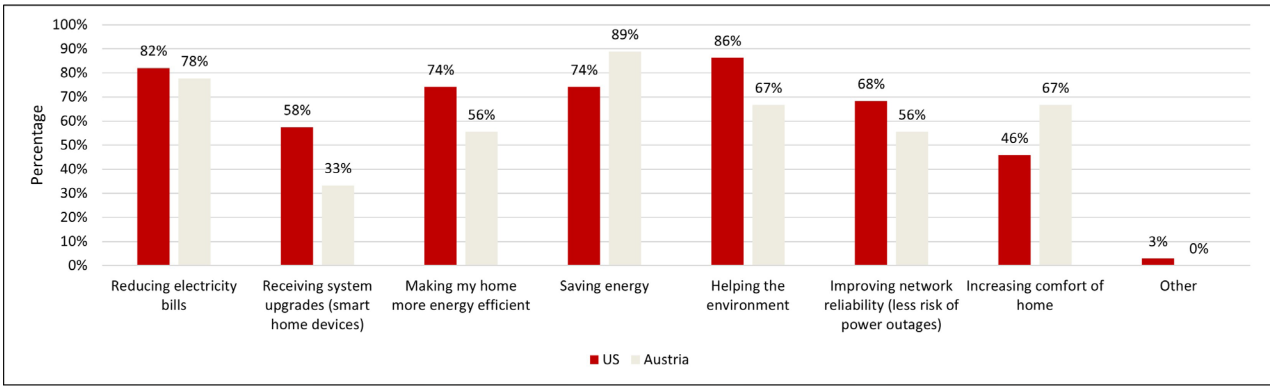


Figure 18 benefits of DSM that would encourage participation.

Conclusion

The surveys, conducted in the U.S., Belgium and Austria, show that the willingness to adjust the timing of household activities varies across countries and between weekdays and weekends. Additionally, various incentives, rate structures, preferred times of day for shifting, and perceptions of DSM influence participants' willingness to change the timing of their activities. Overall, the U.S. participants demonstrated more flexibility in adjusting the timing of their activities. Belgium and Austria showed a stronger preference for maintaining fixed schedules. This may be due to U.S. participants being more familiar with DSM/DR programs and related tariff systems. Across the countries, more flexibility is provided during less occupied and sleeping periods. Monetary and environmental incentives were generally effective across all countries, while reliability and other incentives had more varied responses. Additionally, price-based incentives and self-initiated participation were preferred in the U.S. and Austria, while Belgium showed a slight preference for automated participation.

4.3 Energy flexibility and the question of inequality

When it comes to realising flexibility potentials within buildings and clusters of buildings, it is important to recognize how this happens within a society where stakeholders from the outset have different capabilities to take part in and benefit from energy flexibility programs. One way to think of this is how different stakeholders have different sets of resources that they can utilize. The most obvious and recognized of these resources is of course financial resources. Financial resources can be invested in new smart energy solutions, and therefore, stakeholders with higher levels of financial resources have better opportunities for taking part in energy flexibility programs than others.

However, stakeholders also possess other forms of resources (often also termed capitals) than just the financial. These can be, for instance, the level of education (which can be a resource for understanding and navigating within energy flexibility schemes) or factors limiting the flexibility of the stakeholder's energy consumption (e.g., households with dual-earner parents will typically have lower flexibility than retired or unemployed and people living alone).

When making policies and designing for energy flexibility, it is important to be aware of these differences in capitals and capital compositions among stakeholders, and how capital is unequally distributed, for two main reasons: First of all, if not taken into account in policy plans and design of flexibility solutions, there will be a risk of making strategies and schemes that will fail a broader uptake because only those with higher levels of capital are capable of taking part in the energy flexibility rollout. Second, and in compliance with the ethic position of equality and fairness, it would be problematic to develop strategies and designs that one-sidedly benefit stakeholders with higher levels of capital. This could lead to increasing social inequality. For instance, if the design of dynamic pricing, as a price scheme to incentivize participation in demand response, unintentionally ends up primarily rewarding high-capital stakeholders, while low-capital stakeholders without the same capacity of investing in energy flexibility solutions are systematically punished by higher energy costs.

The concept of *flexibility capital* can help to better understand the nature and role of uneven distributions of capital among stakeholders for the transition to energy flexible demands.

Flexibility capital

The concept of flexibility capital was originally developed by Powells and Fell in a paper from 2019 titled *Flexibility capital and flexibility justice in smart energy systems* (Powells & Fell, 2019). They define energy flexibility as "having the ability to shift energy use in time and space, or through changes in intensity or vector, such as switching from gas to electricity, for example" (ibid.: 56). The focus of Powells and Fell is mainly on households, and their examples of what determines the ability to shift energy use for individual actors therefore reflects this. They mention factors such as working patterns, household composition, culture, wealth, life stage and the size of energy loads. An important observation by Powells and Fell is that under certain circumstances, non-monetary capitals might be "economized" in the sense that they can be translated into money on a flexibility market. For instance, single-person households might experience greater flexibility in their everyday life, which represents a higher level of flexibility capital compared to family households, and which can potentially be monetarized on a market with dynamic pricing. In the words of Powells and Fell (2019: 57):
"In our view, smart energy systems create the conditions for flexibility to be valued and, as a result, the flexibility of energy users is effectively 'capitalised'. We define flexibility capital as the capacity to responsively change patterns of interaction with a system to support the operation of that system."

In their paper, Powells and Fell develop a graphical model showing the connections between affluence (financial resources) and flexibility capital, which are all other non-financial capitals combined. The model basically has two dimensions (see Figure 19): Level of financial resources (vertical axis) and level of flexibility capital (horizontal axis). Individual stakeholders are positioned within this framework according to their unique composition of financial resources and flexibility capital. Thus, people with little flexibility capital belongs to the left-hand side, while people with high flexibility capital are placed on the right-hand side. Similarly, affluent people (or stakeholders) belong to the two upper quadrants, while less affluent people are placed in the lower quadrants.

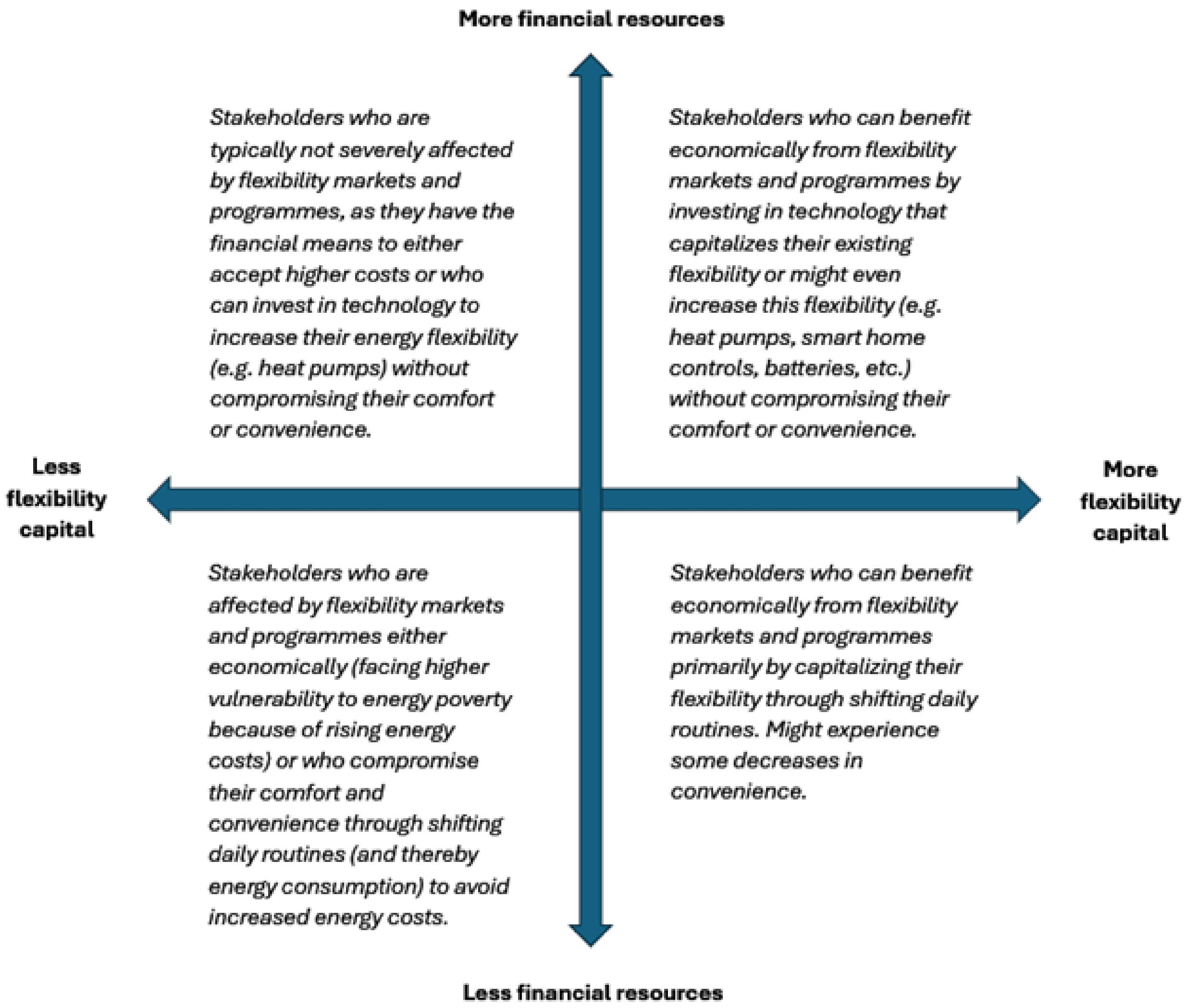


Figure 19 Energy flexibility programmes and markets impact stakeholders differently depending on their individual compositions of flexibility capital and financial resources. Figure developed on basis of Powells and Fell (2019).

Stakeholders' ability to react to, and potentially benefit from, energy flexibility programmes and policy measures differs in systematic ways according to their different composition of capitals (see also the text in the four quadrants in Figure 19). Thus, stakeholders with less flexibility capital, the left-hand side of Figure 19, are typically more exposed to additional costs or cannot benefit from flexibility systems. Conversely, stakeholders with more flexibility capital, the right-hand side, are capable of adopting new, energy flexibility patterns and are therefore more able to benefit from flexibility systems. Furthermore, how stakeholders are affected by their (in)ability to adapt to energy flexibility is unevenly distributed, as stakeholders with higher financial resources are either less hardly affected by being inflexible than those with less financial resources (upper-left quadrant compared to lower-left quadrant) or are better capable of leveraging their flexibility capital (i.e. economizing from it) compared to those stakeholders with lower levels of financial resources (upper-right quadrant compared to lower-right quadrant).

If not designed carefully, flexibility programmes and markets might be systematically advantageous to groups with high levels of financial and flexibility capital, whereas groups with low levels of these capitals might disadvantage consistently through higher living costs and/or the need to compromise comfort and convenience. According to Powells and Fell, such possible inequality biases of the smart energy transition call for a discussion of "flexibility justice". As they write (ibid.: 57):
"(…) in the context of the fixed capacity of energy systems, flexibility provided by some (through the acceptance of different and, most likely, more constrained energy services) directly 'makes way' for others to

enjoy an uncompromised level of service. This amounts to a zero-sum game – capped by the system capacity – in which the ability of some to enjoy the benefits of energy services may come directly at service quality cost for others. The effect of this can be compounded if the flexibility capital held by those making way is, as we suggest is more likely, socially derived."

The concept of flexibility capital has spurred a wave of studies of the social implications of energy flexibility and smart energy transitions within recent years. Some of these studies have also contributed to a further development of the concept. Among these are Libertson (2022), who added a more comprehensive understanding of how the social-temporal organization of everyday practices of households plays a role in determining the flexibility capacity of households. Libertson has also showed how energy actors' understanding of energy flexibility, and its role in the energy transition, affects the development within the field and the design of new smart energy solutions (Libertson, 2024).

Other studies have through empirical studies explored how energy flexibility programs can enhance social inequalities. For instance, a Californian survey study focusing on air-conditioning and electric vehicle control found that energy-related inequalities and the energy burden of vulnerable populations can be exacerbated by their lack of energy flexibility and resources needed to shift consumption effectively (Chen et al., 2024). Similarly, Calver & Simcock (2021) find that groups with little flexibility capital are also often the most vulnerable to energy poverty.

So far, the focus on households has been paramount within the literature on flexibility capital and flexibility justice. However, as already Powells and Fell suggested, the concept is similarly relevant to other societal domains than just the residential sector, for instance business. Here, like with households, individual companies and entire business sectors might differ from each other in terms of their capabilities to adopt to energy flexibility and how they might be affected by energy flexibility. The flexibility capital of companies could depend on many different factors, for instance the size of companies (and thereby their capacities in economic and competence terms to adopt new practices or invest in new technologies) or the framework conditions for the markets they operate on. As an example of the latter, national companies operating on highly internationalized markets with fierce competition might find it difficult to adapt to national energy flexibility schemes, e.g. dynamic pricing, given their limited capacity for additional capital investments.

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5 Business models case studies

5.1 Introduction

The growing demand for building energy flexibility requires not only technological innovation but also the development of sustainable and scalable business models that offer incentives to a wide range of stakeholders (Liu et al., 2024). Key stakeholders include grid operators (utilities), aggregators, building operators/users, as well as product and software providers and enablers across the entire value chain, such as:

- **Grid side**: Utility Distributed Energy Resources Management System (DERMS) enablers, Greenhouse gases (GHGs) data providers, and Clean energy/tariff providers.
- **Aggregator side**: Distributed Energy Resources (DER)-specific Virtual Power Plant (VPP) providers, Residential-specific VPP providers and enablers, and Cross-sector VPP providers and enablers.
- **Building side**: Smart controller providers, Building-to-Grid (B2G) Energy Management Information Systems (EMIS) providers, (Vehicle-to-Grid) V2G charging station providers, DERs providers (with and without embedded flexibility control) and DERs interface providers.

By "enablers", we refer to companies that develop software platforms and applications that support others in delivering flexibility services. In contrast, "providers" are companies that either supply the physical products (such as DERs and smart controllers) required for flexibility services or use their own or third-party platforms to provide these services. These stakeholders were identified through survey questionnaires on business models conducted as part of Annex 82, as well as through research on partners or members of well-established organisations and associations in the field, including the California Load Flexibility Research and Development Hub (CalFlexHub)[1], Demand Response for Europe (DR4EU) coalition[2], OpenADR Alliance[3], BRIDGE Initiative[4], SmartEn Association[5] and FlexiblePower Alliance Network (FAN)[6].

Some stakeholders may take on multiple roles, while others hold distinct, specialised roles. Their interactions and the relationships between their business models shape different B2G integration architectures, which Paul et al. (2024) describe as “coordinated control architectures”. Their study examines a range of architectures shaped by unique stakeholder use cases, market conditions, and the types of integrated buildings and energy resources within the DOE Connected Communities program, which includes 10 projects across the United States. Building on their findings, we broadened our analysis, including roughly 80 use cases worldwide (detailed in the next section). This wider perspective lets us outline four main types of generalised architectures, ranging from direct (centralised) to indirect (decentralised) control approaches.

Figure 20 shows a generalised version of a centralised B2G integration architecture without aggregators. In this setup, grid operators, particularly Distribution System Operators (DSOs), typically act as the primary interface for enabling load flexibility services (Brooks et al., 2021). They can interact with building operators/users through notification alerts to influence demand behaviour, or they connect directly with DERs using smart controllers (such as thermostats, plugs, chargers, and inverters), B2G EMIS or V2G platforms, in line with contractual agreements (Eid et al., 2016). The control signals they employ vary depending on the type of DER (Murphy et al., 2024). For instance, a grid signal might adjust the setpoint of a smart thermostat to lower HVAC demand or switch the system on and off at regular intervals. With batteries, grid signals

[1] https://calflexhub.lbl.gov/
[2] https://dr4eu.org/
[3] https://www.openadr.org/
[4] https://bridge-smart-grid-storage-systems-digital-projects.ec.europa.eu/
[5] https://smarten.eu/
[6] https://flexible-energy.eu/

can be sent to discharge stored electricity to meet a building's demand during peak times. For other appliances, such as clothes dryers and heat pumps, they can issue direct load control signals to shut off their cycles or reduce their load.

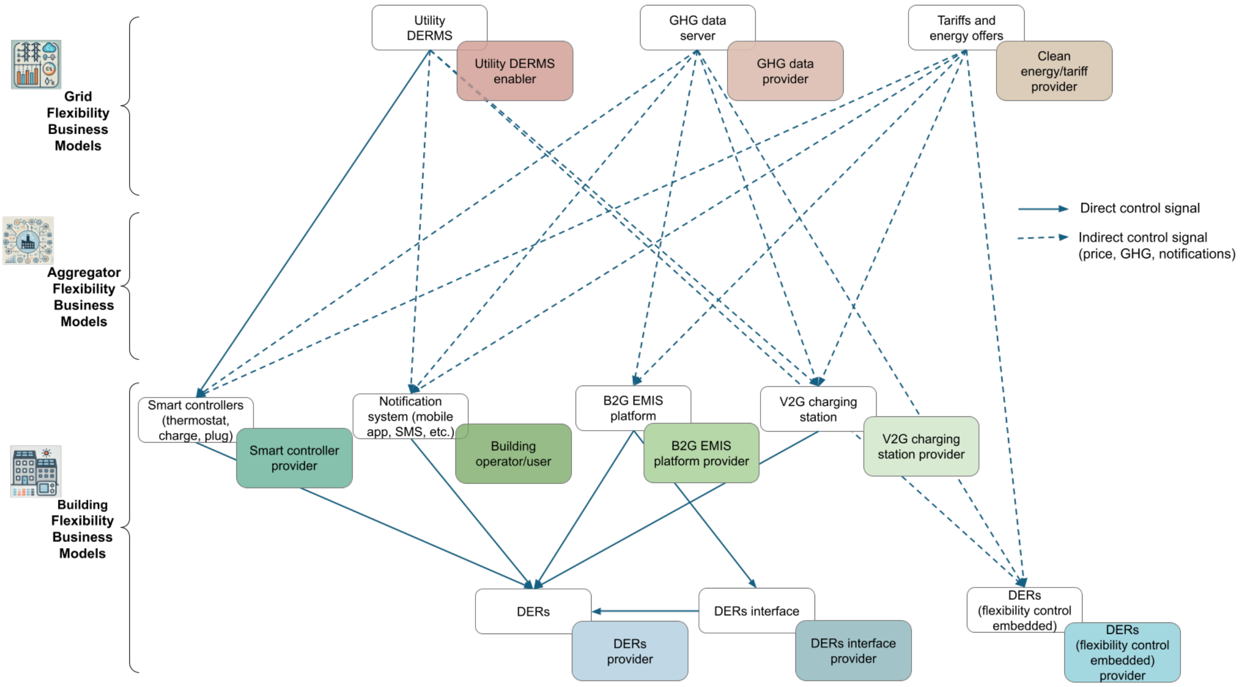


Figure 20 A generalised version of a centralised B2G integration architecture without aggregators.

Business models based on this approach often encourage customers by providing direct compensation. They offer upfront incentives to encourage adoption, such as helping acquire the necessary technologies for program participation, as seen in the Energy Queensland "**SmartPeak**" program[7] and the now-concluded Ausgrid "**Coolsaver**" program in Australia. There are also enrolment and retention rewards to encourage ongoing participation and performance incentives to promote demand reductions, such as those in the "**Beat the Peak**" initiative[8] by ESB Networks in Ireland. These incentives can also vary by the DER technology involved, as highlighted in a study of 148 U.S. demand flexibility programs (Murphy et al., 2024). For example, smart thermostat programs typically provide upfront incentives (around $100 per device) and annual retention rewards (around $30), but few include performance incentives, suggesting a greater emphasis on enrolment rather than savings. In contrast, battery programs generally offer fewer retention incentives, mostly providing upfront or performance incentives instead.

In addition to grid and building operators, several other stakeholders play a key role in this architectural approach. On the grid side, DERMS providers offer software solutions with pre-defined applications to help grid operators manage various flexibility programs and markets. GHG data and clean energy/tariff providers supply real-time data through APIs and dashboards, which can influence load demand or automate the control of DERs. On the building side, there are providers for smart controllers, B2G EMIS, and V2G charging platforms, which can be directly integrated with DERs or indirectly connected via specialised interfaces such as CTA 2045. These DERs (including solar PV, battery energy storage, EVs, water heating, HVAC, lighting, combined heat and power plants and plug loads), as well as these interfaces, often have their own dedicated providers.

[7] https://www.energex.com.au/manage-your-energy/cashback-rewards-program/peaksmart-air-conditioning
[8] https://www.esbnetworks.ie/who-we-are/beat-the-peak/beat-the-peak-business

In this approach, the flexibility control logic can be implemented in various locations: at the grid's DERMS, within the B2G EMIS, and/or on V2G charging platforms that effectively manage DERs. Alternatively, this logic can also be integrated directly into the DERs themselves, allowing them to respond dynamically to signals as a built-in feature of their products. Li et al. (2024) have explored the latter in the context of emerging business models, particularly in smart-grid-ready heat pump systems.

Utilities around the world have increasingly adopted this centralised approach. However, as the connections to DERs grow, managing these systems becomes more complex and less scalable. This is where aggregators play a vital role. They bring together buildings to connect with the grid, manage bundled services and operational processes, and coordinate the activation of multiple DERs (Reis et al., 2021). This approach can help reduce capital costs and create additional revenue streams through wholesale markets (Olgyay et al., 2020). Aggregators can also provide hedging services to help customers navigate fluctuations in electricity prices (Lu et al., 2020). Given their emerging importance, many projects around the world are exploring how third-party aggregators can facilitate services for both wholesale and retail markets. One such example is the Australian **Symphony** pilot project[9], which designs, procures, develops, implements, and tests software-based ‘platforms’ capable of registering, aggregating and orchestrating DERs to create a VPP for future energy markets. As a result of this and other initiatives, different aggregators' business models are evolving, resulting in distinct decentralised architectures, as illustrated in the following figures.

Figure 21 illustrates a generalised architecture for decentralised B2G integration, which includes DER-specific aggregators. In this model, VPPs are created to aggregate specific types of DERs, typically battery energy storage systems. This aggregation is often supported by battery manufacturers that enable their batteries to be integrated, or by manufacturer-agnostic aggregators that offer their own interfaces to facilitate the integration of various battery energy storage systems. As part of an aggregator business model, once enrolled, these DERs can provide grid services during scheduled events. Participants usually receive a monthly credit on their electricity bills, earning compensation for each kilowatt-hour (kWh) supplied and each kilowatt (kW) capacity. In contrast, aggregators often receive a portion of this compensation and earn rewards for new signups. Building operators/users also have the option to opt out of these events, allowing their DERs to return to regular operation.

[9] https://aemo.com.au/initiatives/major-programs/wa-der-program/project-symphony

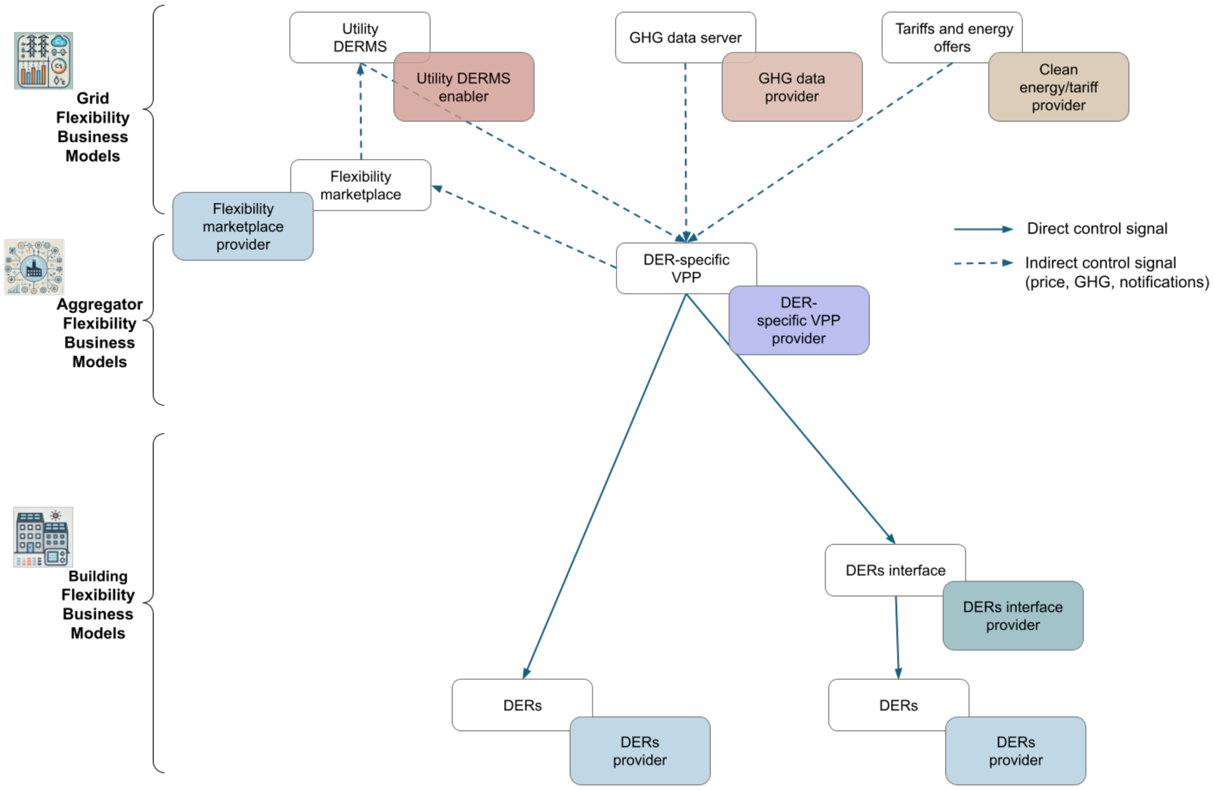


Figure 21 A generalised version of a decentralised B2G integration architecture featuring DER-specific aggregators.

Flexibility marketplace providers are also key stakeholders in this approach. They aim to facilitate and maximise participation among aggregators in various utility markets and support DSOs in coordinating multiple flexibility markets more effectively. To achieve this, these providers typically offer a single trading platform that connects multiple aggregators with various utilities while providing performance verification, invoicing and settlement, data analytics and reporting, onboarding for new bids, and network data-feeding services. As the number of aggregators and flexibility market programs increases globally, the role of flexibility market providers is becoming more significant. This trend is reflected in various pilot projects aiming to demonstrate ways to facilitate participation in DER marketplaces. One example is Australia's Project **EDGE** (Energy Demand and Generation Exchange)[10], a pilot initiative designed to test an off-market, proof-of-concept DER marketplace. The project seeks to assist aggregators in managing DERs to provide both wholesale and local network services.

Figure 22 and Figure 23 illustrate a generalised version of a decentralised B2G integration architecture featuring residential-specific aggregators and cross-sector aggregators, respectively. Residential-specific aggregators manage multiple home DERs, either directly by sending control commands to smart controllers, or indirectly by notifying grid events to building operators/users so they can manually modify their demands or by sending grid signals to V2G, 'smart home' B2G EMIS platforms or DERs (with embedded control capabilities). Cross-sector aggregators have a similar architecture, with the difference that they often communicate with a building EMIS platform instead of sending notifications to users. The platform can then host a building-specific control logic to coordinate its DERs. In both architectures, it is common to find VPP providers acting as aggregators with their own platform solutions, as well as enablers that offer third-party software solutions to support these aggregators.

[10] https://aemo.com.au/en/initiatives/major-programs/nem-distributed-energy-resources-der-program/der-demonstrations/project-edge

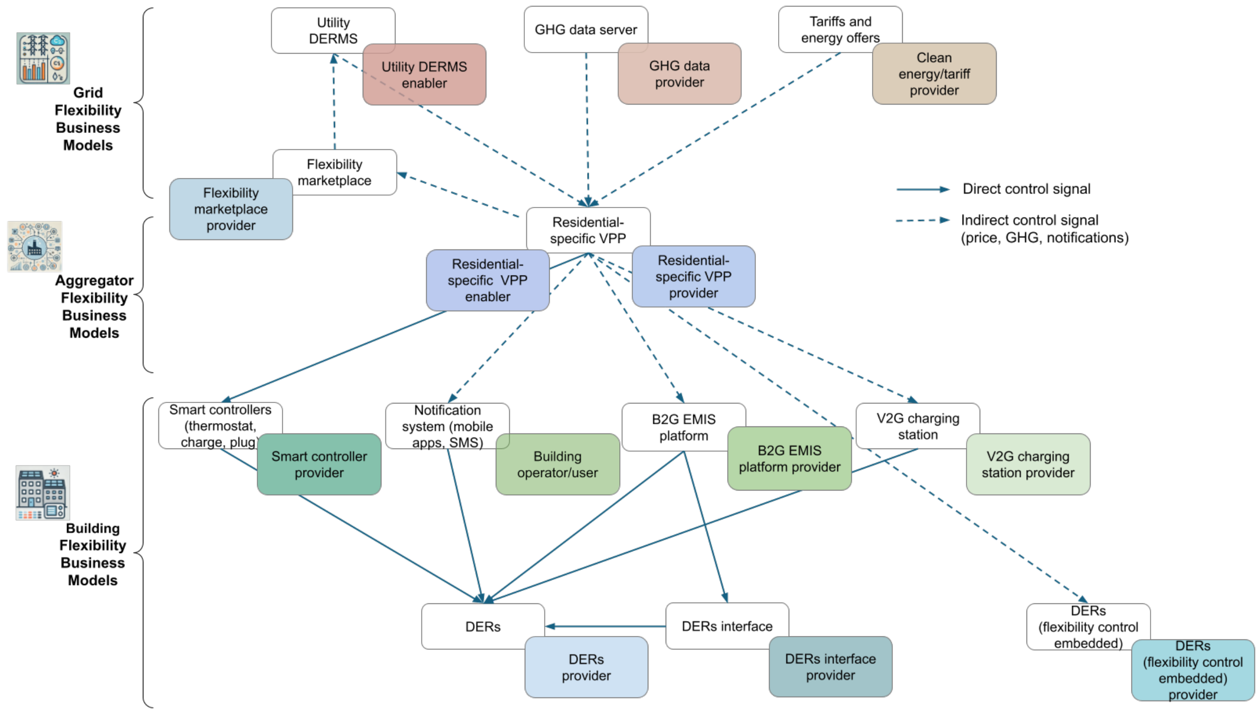


Figure 22 A generalised version of a decentralised B2G integration architecture featuring residential-specific aggregators.

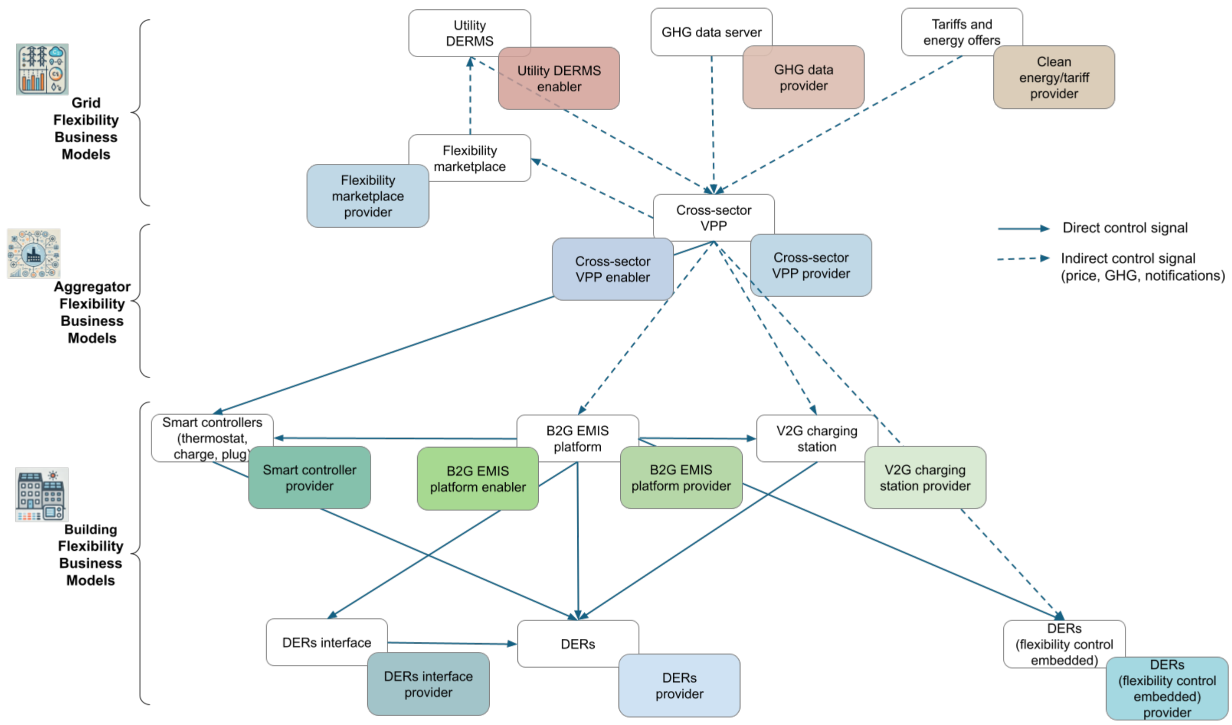


Figure 23 A generalised version of a decentralised B2G integration architecture featuring cross-sector aggregators.

As shown by the variety of stakeholders and alternative architectures we have presented, several new business models are emerging. While many of these models are in early development, they are expected to evolve as the market adapts to initial commercial offerings and upcoming regulations supporting energy flexibility. The following section summarises the case studies that emerged from our survey and research.

5.2 Example Cases Overview

Our survey and research on business models supporting energy flexibility in buildings resulted in 79 diverse case studies from 21 countries across Europe, North America, Asia, and Oceania. The countries represented are shown in Figure 24, and a brief summary of each case study is provided in Table 8.

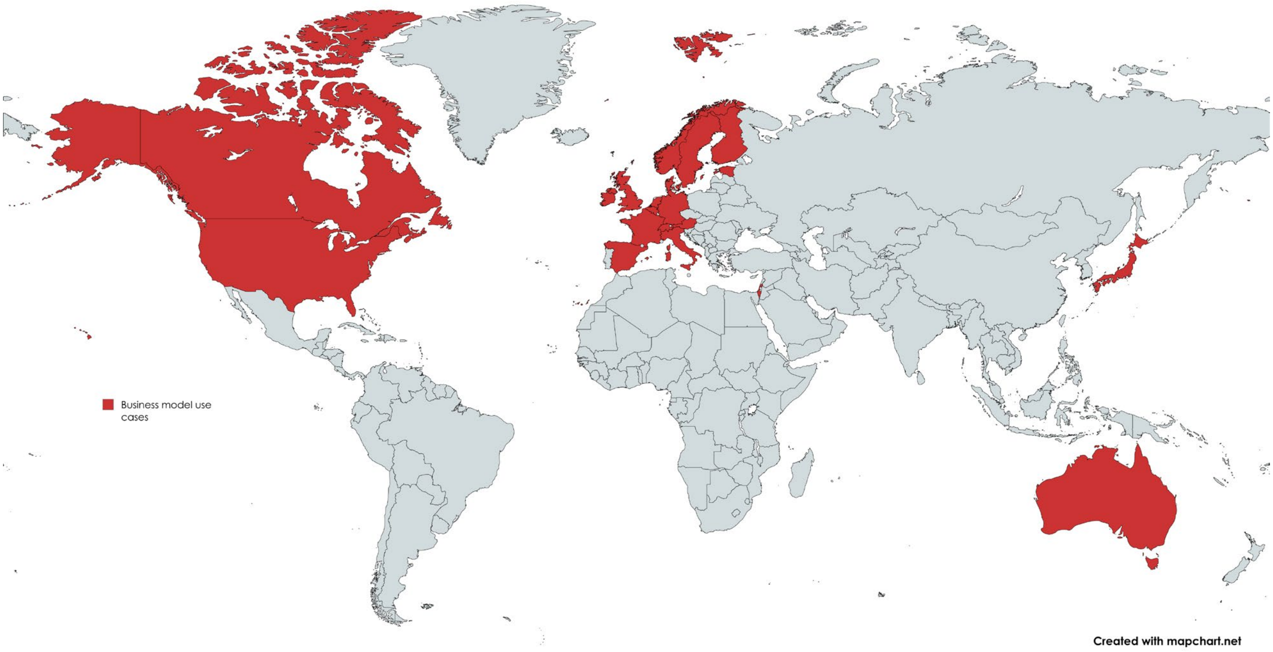


Figure 24 Countries evaluated in the Business Models and Case Studies survey and research.

Table 8 Summary of Business Models Case Studies evaluated in the survey[11]

Country	Case study	Stakeholder	Short description	Reference
Australia	AGL	Residential-specific VPP	AGL offers one of Australia's largest Virtual Power Plants (VPPs), linking home batteries, generators, solar, and EV chargers to stabilize the grid and reduce electricity costs in South Australia. Through AGL's "Bring Your Own Battery" program, customers who join the VPP receive a $100 sign-up credit, $70 quarterly bill credits, and access to the Solar Savers plan, which pays 20c/kWh for excess solar sent back to the grid. To qualify, customers need a compatible battery, such as Tesla, LG, or SolarEdge, and a smart meter.	https://www.agl.com.au/business/sustainability/optimise-solar-and-energy-storage/virtual-power-plant
Australia	PeakSmart	Smart controller provider	The PeakSmart, an Energy Queensland Broad-Based program, incentivises customers for flexible energy demand, specifically targeting residential and small business users. It supports the acquisition of a controller which leverages air conditioner demand response capabilities, adhering to the Australian Standard AS/NZS 4755.3.1, allowing utilities to directly control air conditioning units.	https://www.energex.com.au/manage-your-energy/cashback-rewards-program/peaksmart-air-conditioning
Austria	aWATTar	Clean energy/tariff provider	aWATTar is a green electricity provider that focuses on variable tariffs and hourly trading to promote Renewable Energy Sources (RES). The company encourages energy consumption during cost-effective and environmentally friendly hours and works with manufacturers to optimise appliances such as heat pumps and electric vehicles.	https://www.awattar.at/
Austria	cyberGrid	Cross-sector VPP provider, Cross-sector VPP enabler	cyberGrid offers innovative software solutions for managing electric flexibility through its Flexibility Management Platform, cyberNOC. This platform connects flexible energy assets, such as commercial & industrial loads, renewable generation, and battery storage, to key electricity markets. Through Flexibility as a Service (FaaS), cyberGrid provides end-to-end support for flexibility needs, integrating resources into energy markets and linking them with energy market players. With AWS-based Software as a Service (SaaS), users can independently manage and monetise flexibility at any scale. cyberGrid operates in 24 countries, managing over 200 MW of flexibility assets.	https://www.cybergrid.at/
Belgium	BeeBop	Residential-specific VPP provider	Beebop's Power Grid Orchestration Software unlocks grid flexibility within consumer devices and turns it into a tradable asset. Its solution uses AI to integrate consumer devices into the power system.	https://www.beebop.ai/

[11] Each case is classified and described based on our own analysis of publicly available information.

Canada	BrainBox AI	B2G EMIS platform provider	BrainBox provides AI-driven solutions that can connect directly to existing HVAC systems or through cloud-based, AI-enabled thermostats. Once connected, BrainBox maps and standardises system data using Haystack tagging. It then applies algorithms to optimise HVAC systems. BrainBox also offers multi-site EMS, allowing easy control over individual or portfolio-wide HVAC schedules. It also aims to link BrainBox AI-enabled buildings via the cloud, creating a virtual power plant (VPP).	http://www.brainboxai.com/
Canada	Dcbel	Residential-specific VPP provider	Dcbel empowers residential energy management with advanced hardware and software solutions. Their Home Energy Station integrates solar power, bidirectional EV charging, and home battery storage, all managed through a cloud-based platform that optimises energy use and coordinates with energy markets. This platform facilitates real-time control with flexibility service providers and grid balancing entities.	https://www.dcbel.energy/
Canada	Ecobee	Smart controller provider	Smart thermostat that responds to grid signals to shave or shift HVAC loads. Also provides smart home security and automation systems.	https://www.ecobee.com/en-us/
Canada	Hilo	Cross-sector VPP provider, Smart controller provider	Hilo, a Hydro-Québec subsidiary, offers a smart home service with app-controlled devices that optimise energy use and reward customers for flexibility. It is available for residential and commercial users.	https://news.hydroquebec.com/en/press-releases/2083/hilo-fully-integrated-into-hydro-quebec/
Denmark	Electricity Maps	GHG data provider	Electricity Maps is an API platform that provides real-time and predictive electricity signals (with their CO_2 emissions), helping devices minimise costs and emissions by indicating the best times to use electricity. It offers extensive data on electricity usage across over 230 regions in more than 100 countries.	https://www.electricitymaps.com/
Denmark	FlexShape	Residential- specific VPP enabler	FlexShape Aggregator-as-a-Service (AaaS) is a robust platform for integrating energy systems and applications. It offers prosumers, aggregators, and energy community operators access to a wide range of smart energy apps. These apps, designed for energy communities, enable members to monitor, manage, and optimise various physical systems for flexibility trading, self-consumption, renewable energy use, and reducing costs and CO_2 emissions. AaaS connects seamlessly with popular IoT platforms (e.g., Azure IoT Hub, OpenHub, TP-Link Cloud), data sources such as Nord-Pool, FlexShape tools (e.g., Solar Predictor, Battery Controller), and an AI library for energy forecasting and optimisation.	https://www.flexshape.dk/solutions/aaas

Estonia	Fusebox Energy	Cross-sector VPP enabler, Utility DERMS enabler	Fusebox specialises in energy and demand response, offering a virtual power plant (VPP) as a service solution that enables clients to trade in electrical flexibility. Their platforms, which manages technology, trading, reporting, and payments, are suitable for power utilities and aggregators. Fusebox's pricing tiers range from a low-cost, basic package to a full VPP solution with advanced features such as central monitoring and market access. Pricing increases with feature complexity (from €0–1,000/month to €10,000+/month), with onboarding fees applied only to advanced plans.	http://www.fusebox.energy/
Finland	Caverion	B2G EMIS platform provider	Caverion provides a building management system with demand flexibility capabilities, including weather forecasts and analytical models that are regularly reviewed to optimise energy usage.	https://www.caverion.com/catalog/services/grid-flexibility-and-demand-response/
France	Digital4Grids	Cross-sector VPP enabler	Digital4Grids provides consulting, architecture support, and platform implementation services to develop digital operational technology platforms. They leverage open-source components to accelerate DER integration and design energy flexibility solutions.	https://www.digital4grids.com/
France	Energy Pool	Cross-sector VPP provider, Utility DERMS enabler	Energy Pool is an energy management company that optimises energy flexibilities and complex systems, including end-user equipment, storage units, and onsite generation assets. Managing a global portfolio of 6 GW of flexible load and distributed generation across France, Japan, Turkey, Saudi Arabia, and other European countries, Energy Pool uses its innovative software platform to connect, aggregate, and optimise assets for balancing and ancillary services. For utilities and systems operators, Energy Pool also offers a unique software solution (DERMS) in a SaaS mode to connect, operate and monetise your flexible assets.	https://www.energypool.eu/
France	Tilt	Cross-sector VPP provider	Tilt provides a VPP platform that uses machine learning to optimise energy consumption and automate participation in demand response markets for commercial properties, residential buildings & electric vehicles. The platform includes consumption forecasts, connection to distributed energy resources, energy analytics and flexibility control.	http://tilt-energy.com/
France	Voltalis	Smart controller provider, Cross-sector VPP provider	Voltalis provides free, connected, eco-friendly thermostats for electrically heated homes, optimising radiator and heat pump control. Their technology can temporarily reduce the energy consumption of thousands of devices during peak demand to relieve the network and avoid the need for polluting energy sources.	https://www.voltalis.com/
France	Wattpark	V2G charging station platform provider	Wattpark is a provider of EV charging station that allows owners to sell their energy through their station.	http://wattpark.eu/

Germany	EON	B2G EMIS platform provider, Cross-sector VPP provider	EON provides a smart building and energy management system that manages several assets, including lighting and HVAC. They've also developed a virtual power plant system for in-house demand-side response, helping businesses identify energy flexibility, reduce peak demand, and even sell excess energy back to the grid. Their app and customer portal make it easy to track and manage energy use in real time.	https://www.eon.com/en.html
Germany	Equigy	Flexibility marketplace provider	Equigy offers streamlined access to TSO markets across Europe, allowing flexibility service providers to maximize revenue through easy participation. It also provides a reliable data exchange platform for aggregators to effortlessly integrate smaller flexibility devices into electricity balancing markets.	https://equigy.com/
Germany	GridX	Cross-sector VPP enabler, B2G EMIS platform enabler	GridX integrates distributed energy resources from more than 50 different manufacturers with IoT-Platform XENON, which works as an abstraction layer for DERs allowing developers to easily develop and deploy new solutions using the constantly updated API of their platform.	https://www.gridx.ai/?r=0
Germany	Sonnen	Equipment-specific VPP provider, DERs provider	SonnenVPP (Virtual Power Plant) connects thousands of residential batteries globally, allowing members to share clean energy. Active in six countries across three continents, it helps replace fossil fuel power plants. Sonnen also provides batteries and assists customers in finding incentives, such as Australia's Schemes & Rebates, which offer subsidies or interest-free loans for installing solar batteries.	https://sonnen.com.au/
Greece	domx	Smart controller provider	domX aims to build cost-effective and universal monitoring and control systems that integrate seamlessly with legacy building equipment. It does so by developing end-to-end hardware and software solutions for domestic and commercial energy management that enable centralised monitoring and control of connected appliances for both the electricity and natural gas energy vectors.	https://mydomx.eu/
Ireland	GridBeyond	Cross-sector VPP provider	The company's advanced AI-driven DERMS & VPP platform elevates asset management at the grid edge, optimising real-time energy usage, enhancing efficiency, and ensuring grid stability. Team of 160+ employees. Load portfolio over 2.6 GW.	https://gridbeyond.com/
Ireland	VIOTAS	Cross-sector VPP provider	VIOTAS offers technologies that allow commercial and industrial organisations to earn revenue by participating actively in the power system through smart electricity management and demand response services. They also support utilities in market interactions and asset dispatch.	https://viotas.com/

Israel	mPrest	Utility DERMS enabler	mPrest provides orchestration and optimisation software. Its intelligent grid management solution, mDERMS, optimises DERs by balancing energy loads, directing power to high-demand areas, and alleviating the stress on the grid to improve efficiency and reliability. mDERMS also integrates with third-party DR, VPP, and microgrid management systems, as well as SCADA, DMS, and ADMS systems.	https://mprest.com/mprest-products/mderms/
Israel	Solar Edge	Cross-sector VPP enabler, DERs provider, Residential- specific VPP enabler, Smart controller provider	SolarEdge is a global leader in smart energy, offering solutions for residential, commercial, and large-scale PV, battery storage, EV charging, home energy management, grid services, and UPS. Dedicated to energy flexibility services for electricity suppliers, aggregators, and distributors dealing with dynamic tariffs, SolarEdge provides an API platform for Virtual Power Plant (VPP) development. The platform includes cloud applications for seamless integration, enabling fleet-level management of controllable sites in frequency and voltage response markets. Users can set dispatch programs based on price plans and predictive algorithms to optimise costs and maximise efficiency.	https://www.solaredge.com/en
Italy	Enel X (EnerNOC)	Cross-sector VPP provider	EnerNOC rebranded into Enel X and is now a global leader in Demand Response, with a 9.0 GW capacity managed offered. Uses Energy-as-a-Service (EaaS) approach. Enables customers to enroll in multiple demand response programmes. It also provides emission tracking services and consulting for distributed generation solutions.	https://corporate.enelx.com/en/our-offer/business-solutions/flexibility#our-solutions
Japan	Shizen Connect	DER-specific VPP provider, DERs interface provider, Smart controller provider	Shizen Connect provides a comprehensive energy management system (EMS) that brings together multiple resources. It enables individual control of storage batteries and EV chargers, manages microgrids connecting multiple buildings via private transmission lines, and oversees VPPs for large-scale energy assets. The system is compatible with equipment from any supplier, offering the flexibility to choose energy resources independently of specific manufacturers.	https://www.se-digital.net/
Netherlands	Sympower	Cross-sector VPP provider	Sympower offers an independent energy load aggregation platform that helps commercial and industrial facilities monetise their energy assets, such as HVAC, batteries, generators, and pumps, through grid services. Beyond its software solution, Sympower's sales engineers work directly with asset owners and partners to maximise flexibility. Being independent of any energy company, Sympower can collaborate with customers across industries, grid operators, and utility players, enabling fast, unrestricted scaling across sectors and countries. Sympower operates in the Netherlands, Estonia, Finland, Sweden, Greece, and Israel.	https://sympower.net/

Norway	Enode	Cross-sector VPP enabler	Enode's APIs enable energy providers to instantly connect users' energy devices, including EVs, solar inverters, home batteries and thermostats, to the energy providers apps. It also allows providers to use algorithms for automated smart charging and energy device insights as suggestions to customers.	https://enode.com/
Norway	Nodes	Flexibility marketplace provider	Nodes offers a market platform that provides a route to market for flexibility service providers looking to sell services to system operators.	https://nodesmarket.com/
Spain	Bamboo energy	Cross-sector VPP enabler	Bamboo energy offers a platform for retailers and aggregators to efficiently manage distributed flexibility resources. Solution to manage the entire value chain of flexibility for retailers and aggregators, including forecasting and optimization of flexibility, day-ahead trading, and flexibility operation in real-time.	https://bambooenergy.tech/en/
Sweden	Flower	DERs interface provider, Equipment-specific VPP provider	Flower integrates existing residential batteries into the grid, allowing consumers to get money back by selling energy to utilities in times of stress.	https://www.flower.se/hub/
Switzerland	Tiko	Smart controller provider, Residential-specific VPP provider	Tiko offers an equipment-brand agnostic VPP solution and home energy management system. Its advanced tools support full end-to-end control, from installation to market operation. Tiko also offers 100% free connected thermostats for electric radiators, allowing their remote control.	https://tiko.energy/
United Kingdom	Centrica	Cross-sector VPP provider, Flexibility marketplace provider	Centrica local energy market enables national grid utilities to procure flexibility from the same platform. Centrica has also acquired REstore, Europe's leading demand response aggregator, and now also offers a VPP solution that can aggregate different types of energy assets from hundreds of sites. Centrica manages 1GW of flexible energy assets.	https://www.centrica.com/
United Kingdom	Electron	Flexibility marketplace provider	ElectronConnect is a SaaS platform for flexibility markets, enabling seamless coordination across multiple markets, time frames, and products. From onboarding to settlement, the platform connects system and network operators with distributed energy resources (DERs) and provides a full trading solution, along with services such as baselining and performance insights. Used across the UK, Europe, and North America, the platform helps utilities scale local flexibility markets, expand partnerships, and develop a broad ecosystem of providers.	https://electron.net/

United Kingdom	Elyos Energy	B2G EMIS platform provider	Elyos Energy offers an all-in-one energy management platform for buildings, handling visualisation, optimisation, energy flexibility, and demand response. The Elyos Gateway links to the Building Management System, accessing real-time data and using machine learning to identify savings opportunities. It also remotely adjusts BMS settings to optimise schedules, AHU parameters, and set points. Elyos Energy can also connect to smart thermostats, EVs, HVAC systems, solar panels, and batteries in large commercial properties to streamline energy use and automate demand response participation.	https://www.elyosenergy.com/
United Kingdom	Equiwatt	Residential-specific VPP provider	Equiwatt offers three products to facilitate residential demand flexibility programmes: flex trading service, virtual power plant, and virtual energy management. With the free app (powerDOWN) and a smart meter that sends half-hourly readings, Equiwatt lets users easily join the energy market and earn rewards.	https://www.equiwatt.com/
United Kingdom	Flexitricity	Cross-sector VPP provider	Flexitricity offers a 24/7 control room to manage and optimise the energy consumption of assets in battery energy storage and gas peaking plants, industrial and commercial businesses, enabling load adjustments that enhance performance using AI and advanced optimisation algorithms.	https://www.flexitricity.com/
United Kingdom	Kaluza	B2G EMIS platform provider	Kaluza Flex is an energy software company that provides a cutting-edge distributed energy resource (DER) management solution. It enables the rapid design, launch, and scaling of demand response programs, as well as the management of charging programs, virtual power plants, and home energy solutions. Kaluza’s cloud platform streamlines operations, lowers costs, and enhances customer engagement, empowering major energy suppliers to serve millions of customers more efficiently via services such as smart EV charging and billing.	https://www.kaluza.com/
United Kingdom	Kiwi Power (ENGIE)	Cross-sector VPP provider	ENGIE acquired Kiwi Power, which offers Kiwi Core, an automated Energy-as-a-Service platform. Kiwi Core easily integrates with power generation, storage assets, and high-demand buildings, connecting them to energy markets and enabling distributed energy resources to participate effectively.	https://kiwi-power.flywheelsites.com/
United Kingdom	Mixergy	DERs (flexibility control embedded) provider	Mixergy offers smart, tariff-ready equipment, including smart water tanks, a solar diverter that turns the tank into a hot water battery, and an integrated indoor heat pump. The Mixergy app integrates with smart tariffs, using machine learning to optimise heating schedules based on tariff rates—heating water during off-peak times for efficient, on-demand use.	http://www.mixergy.co.uk/
United Kingdom	Octopus Energy Agile	Residential-specific VPP provider	Octopus Energy offers a smart tariff that provides clean energy with half-hourly pricing tied to wholesale rates and updated daily. Through its plunge pricing tariff, Octopus also pays customers to use electricity when there's an oversupply. Through partnerships, such as with Tesla, Octopus has proposed a pilot demonstration allowing households to join the VPPs.	https://octopus.energy/smart/agile/

United Kingdom	Piclo	Flexibility marketplace provider	Piclo offers two products. PicloMax gives flexibility service providers access to different electricity markets from one platform. It simplifies cross-market participation and maximises the value of assets portfolio. PicloFlex provides system operators with a marketplace that is commercially proven, end-to-end solution, for flex buyers (system operators) worldwide.	https://www.piclo.energy/
United Kingdom	Powervault	DERs (flexibility control embedded) provider	Powervault offers a smart solar battery and energy management software with predictive algorithms. It has been used in many recent pilot projects to enable remote control and provide intelligent aggregation capabilities.	http://www.powervault.co.uk/
United Kingdom	Smarter Grid Solutions	Utility DERMS enabler	Smarter Grid Solutions offers a DERMS platform with focus on flexible control strategies. It provides the specialised distributed energy asset monitoring and control methods building up from real-time data to advanced look ahead DER management and optimisation.	https://www.smartergridsolutions.com/
United Kingdom	Temix	Cross-sector VPP provider	The TeMix RATES™ Platform provides a solution to improve the adoption of dynamic pricing structures for both energy providers and consumers. It orchestrates both operational and investment decisions across the entire energy network.	https://temix.com/
United Kingdom	Tepeo	DERs (flexibility control embedded) provider	Tepeo offers a smart boiler that heats up and stores energy when electricity rates are lowest.	https://www.tepeo.com/
United States	AutoGrid (FlexSaver) Schneider Electric (AutoGrid and Uplight)	Residential-specific VPP provider	AutoGrid's FlexSaver program partners with utilities to offer cash rewards to household users who reduce energy use during peak times, helping prevent outages and lower reliance on natural gas. Users can register devices such as smart thermostats or EV chargers, earning signup incentives and rewards. Enrolled devices automatically adjust their consumption, such as changing EV charging speeds or adjusting temperature set points, including pre-cooling.	https://www.autogridflexsaver.net/
United States	Cpower Energy	Cross-sector VPP provider	CPower is a provider of Distributed Energy Resources (DERs) monetisation and Virtual Power Plant (VPP) solutions. With approximately 7 GW of capacity across over 27,000 sites in the U.S., CPower helps commercial buildings and DER owners maximise asset value. Its VPP platform integrates with various systems to automate asset dispatch, mitigating risk and maximising opportunity. CPower helps DER owners and operators expand their portfolios by enabling end-use customers to optimise DER investments and enhance grid services revenue.	https://cpowerenergy.com/
United States	EDO energy	Cross-sector VPP provider, B2G EMIS platform provider	Edo offers innovative energy efficiency and demand flexibility solutions, aggregating commercial buildings into virtual power plants (VPPs). Its platform integrates with existing building systems, connecting with onsite Distributed Energy Resources (DERs). Edo uses advanced optimisation and machine learning to enhance load forecasting and management.	https://edoenergy.com/

United States	Emporia	Equipment-specific VPP provider, Residential-specific VPP, DERs provider	Emporia is a Colorado-based company focused on smart home energy solutions that offer demand response services. Emporia's Home Energy Management Platform integrates a variety of devices such as the Vue Home Energy Monitor, Level 2 EV Charger, Smart Plugs, Home Battery, and third-party appliances such as thermostats. The platform offers real-time energy monitoring, automated scheduling, and consumption optimisation, all controlled through an intuitive mobile app. By enrolling in Emporia's demand response program, customers can reduce energy costs while earning cashback or credits for participating in energy-saving events, all while maintaining full control over their home's energy use through the app.	https://www.emporiaenergy.com/
United States	EnergyHub	Cross-sector VPP enabler	EnergyHub is a software technology company that empowers consumers to transform their smart thermostats, electric vehicles, EV charging equipment, energy storage systems, solar inverters, water heaters into virtual power plants. With its self-service platform, EnergyHub enables utility demand management teams to analyse virtual power plant (VPP) data, delivering real-time insights within moments of initiating a demand flexibility event.	https://www.energyhub.com/
United States	Enersponse	Cross-sector VPP provider	Enersponse is a leading provider of Distributed Energy Resource (DER) management services, facilitating participation in Demand Response (DR) and Auto-DR programs to reduce CO2 emissions and pricing volatility. The Enersponse platform connects seamlessly with most building management systems, allowing for easy integration and automation with existing controls. Currently, it connects 2.89 GW of load across commercial buildings, schools, and other sectors.	http://www.enersponse.com/
United States	Fermata Energy	V2G charging station platform provider	Fermata Energy specialises in Vehicle-to-Everything (V2X) technology, providing bidirectional charging solutions that enable electric vehicles (EVs) to supply energy back to commercial buildings or the grid. Their platform offers cost parity with fast one-way chargers, allowing users to earn revenue and lower EV ownership costs. From site assessment to installation, Fermata Energy transforms EV chargers into profit centres, maximising value for businesses and customers alike.	https://fermataenergy.com/
United States	Flexmarket	Flexibility marketplace provider	FLEXmarket is a user-friendly platform that simplifies the payment process and maximizes the revenue of aggregators for the virtual power plants they contribute to the grid. Instead of relying on traditional methods, FLEXmarket focuses on measuring actual outcomes at the meter level. It uses open-source, transparent M&V (Measurement & Verification) to ensure fairness and accuracy in payments, allowing aggregators to earn more for the valuable work they're already doing.	https://www.demandflexmarket.com/
United States	Flip energy	Residential- specific VPP enabler	Flip Energy provides an API platform that supports Virtual Power Plants (VPPs). Their technology simplifies the process for developers to integrate new features that enable energy companies and their customers to generate revenue. By allowing smart devices to participate in VPPs, Flip Energy helps optimise energy usage and create new income opportunities within the energy sector.	https://flip.energy/

United States	GridPoint Inc.	B2G EMIS platform provider	GridPoint Inc. provides a unified energy management platform for commercial buildings, offering equipment-level submetering, building management systems, and software analytics. The platform also connects building assets with the grid, enabling a decentralised network of grid-interactive buildings that supports dynamic load flexibility and automated demand response.	https://www.gridpoint.com/
United States	Harvest Thermal	DERs (flexibility control embedded) provider	Harvest Thermal provides thermal energy storage systems that optimise home heating and hot water based on price signals. Its cloud-based smart Harvest Pod integrates software, sensors, and controls, allowing homeowners to benefit from future performance-based rebate programs. In trials, Harvest Thermal demonstrated responsiveness to dynamic grid price signals, paving the way for commercialised services that support homeowners while enhancing grid modernisation.	https://www.harvest-thermal.com/
United States	IPKeys Power Partners	Utility DERMS enabler	IPKeys Power Partners offers demand response solutions for utilities with flexible Software as Services (SaaS) platforms and proven APIs, enhancing grid reliability and lowering deployment costs. Its OpenADR-based Utility Enterprise Data Management platform efficiently manages diverse loads such as batteries, generators, solar, thermostats, and EV chargers across customer segments. In addition, its FLEXmarket platform supports demand flexibility, compensating aggregators for virtual power plant contributions to the grid, based on measurement and verification (M&V) techniques.	http://ipkeyspowerpartners.com/, https://www.demandflexmarket.com/#!directory
United States	Leap	Flexibility marketplace provider, Cross-sector VPP provider	Leap provides a software platform that enables fast, automated access to energy markets for distributed energy resources. It provides a single interface that can seamlessly connect building devices to multiple programs across multiple markets. With over 1.5 GW of load under management, Leap simplifies participation by integrating with existing systems and requires no specialised hardware.	https://leap.energy/
United States	Nantum OS	B2G EMIS platform provider	Nantum OS, an AI-driven platform, offers demand-side management and automated demand response for commercial real estate. By integrating with grid signals via openADR, Nantum OS enables direct automation and increases incentive revenue, bypassing aggregator fees. Real estate managers gain real-time insights into HVAC, metering systems, people counting systems, IoT devices (air quality, lighting, shade, smart glass), distributed energy systems (battery storage, fuel cells, on-site generation equipment, solar), and third-party datasets in real time.	https://www.nantum.ai/
United States	NEST	Smart controller provider	NEST is a company that provides a smart thermostat designed to support energy flexibility services. Their product offers features, such as participation in programs like "Rush Hour Rewards," where users can receive rebates from energy providers to reduce their usage during peak demand times. NEST also supports a "Seasonal Savings" program that automatically makes slight temperature adjustments to optimise savings based on seasonal needs.	https://nest.com/energy-solutions/

United States	NRG Curtailment Solutions	Residential-specific VPP provider	NRG Curtailment Solutions provides tailored demand response programs to help organisations reduce electricity load and maximise market benefits. Since 2003, it has supported various clients with over 2GW of capacity. Participants receive compensation for their registered programs and access to a real-time tracking dashboard. NRG collaborates with diverse customers, focusing on those with significant electricity loads and the capacity to curtail usage when needed.	http://demandresponse.nrg.com/
United States	OhmConnect	Smart controller provider, Residential-specific VPP provider	OhmConnect is a no-cost, no-risk VPP solutions for home use that offers financial rewards for residential users to reduce energy consumption during peak periods. Users can be notified of electricitty price spikes and manually reduce consumption or can connect smart devices such as smart thermostats and plugs (from OhmConnect or other vendors) to the OhmConnect app for automatic participation in energy-saving events. OhmConnect earns money by trading energy in markets, bidding to reduce community energy consumption, and then distributing the rewards to its members as cash payments and prizes.	https://www.ohmconnect.com/
United States	Olivine Inc.	Cross-sector VPP provider	Olivine Inc. provides technology-agnostic infrastructure and services to aggregate resources such as smart thermostats, EVs, and solar. Its offerings include program design, marketing, enrollment, Software as a Service, value stream optimisation, and operational support for residential and commercial buildings (and other sectors). Olivine's platform offers a strategic edge, bridging Distributed Energy Resource (DER) owners with utility programs and markets to enhance operational flexibility and demand response. Over 2.5 GW of flexible loads managed.	https://olivineinc.com/
United States	Optiwatt	V2G charging station platform provider	Optiwatt provides a smart EV scheduling solution, enabling users to create customizable, advanced charging schedules. By syncing in real time with home electricity rates and gas prices, Optiwatt ensures cost-effective and energy-efficient charging. Users can securely log in through their EV’s app, automatically retrieve their electric utility costs using their home address, and gain insights into their EV’s impact on their electricity bill.	https://getoptiwatt.com/
United States	Rheem	DERs provider	Rheem offers demand response-ready Smart Electric Water Heaters that connect to the grid. These water heaters help homeowners save on energy costs, support grid stability, and access utility incentives. With permission, a third-party communication module is installed in the water heater’s EcoPort (CTA-2045 port). This allows the electricity usage to be adjusted during peak periods.	https://www.rheem.com/

United States	Schneider	Utility DERMS enabler	Schneider's EcoStruxure Distributed Energy Resource Management System (DERMS) is a cutting-edge, grid-aware solution designed to help utilities efficiently monitor, forecast, and control distributed energy resources (DERs). By providing real-time insights and management capabilities, it enables utilities to analyze hosting capacity, manage grid constraints, and optimise DER flexibility, enhancing grid planning and operations while ensuring a seamless integration of renewables and electric vehicles.	https://www.se.com/us/en/product-range/89571422-ecostruxure-derms/#overview
United States	SkyCentrics	DERs interface provider, B2G EMIS platform provider	SkyCentrics provides a universal platform for building management and uses AI/ML to enhance comfort, cost-efficiency, and carbon reduction. SkyCentrics also collaborates with equipment manufacturers (including Mitsubishi Mini-splits, Siemens EV Charger, Nyle Water Heaters) to manage energy use based on grid conditions. Its solutions enable demand flexibility in response to grid incentives through open standard connectivity (CTA-2045), which can be facilitated via its EcoPort module and SkyBox.	https://www.skycentrics.com/
United States	Sunverge Energy	B2G EMIS platform provider, Equipment-specific VPP provider, DERs provider	Sunverge Energy is a California company that provides a solution to combine distributed generation, energy storage, and software services for energy flexibility. Through its storage appliances, Sunverge provides localised energy services while simultaneously pooling reserve energy from each unit into the cloud. This virtual energy pool allows utilities and third parties to both reserve and access energy on-demand, ensuring more reliable and balanced grid management.	https://www.sunverge.com/
United States	Swell Energy	Cross-sector VPP provider	Swell Energy offers an energy Virtual Power Plant (VPP) platform, Compass, to residential and commercial buildings. It integrates with connected energy devices, allowing real-time monitoring, energy optimisation and strategic monetisation in connection with local utility programs. Swell has recently acquired Renu and now offers full-service in-house solar and energy storage turnkey solutions.	https://www.swellenergy.com/
United States	Synop	Equipment-specific VPP provider, DERs interface provider	Synop offers an enterprise platform for EV fleets, connecting vehicles, chargers, and the grid with software that optimises charging and energy management. Using AI, telematics, and real-time monitoring, Synop provides a vendor-agnostic solution for charging, energy (VPP/V2G), vehicle, and payment management. It maximises uptime, reduces charging costs, and enables revenue from smart grid participation.	https://www.synop.ai/

United States	Tesla (VPP initiatives)	Equipment-specific VPP provider, DERs provider	Tesla's Virtual Power Plant (VPP) initiative leverages its Powerwall battery systems installed in households to aggregate and manage energy from distributed sources. When enrolled, Powerwall batteries provide emergency grid support by dispatching excess stored energy during scheduled events. Participants earn a monthly credit on their electricity bill, receiving for every kWh supplied and per kW capacity. Users can opt out of events, allowing the Powerwall to resume normal operation.	https://www.tesla.com/support/energy/powerwall/virtual-power-plant
United States	THG Energy Solutions	Cross-sector VPP provider	THG's Automated Demand Response (ADR) solution combines hardware, software, and services to enable energy adjustment strategies for demand response programs and market opportunities. Certified with OpenADR 2.0b, it serves commercial and industrial facilities and is backed by energy and engineering experts. The solution leverages existing building controls, provides real-time usage reporting, and automates electricity adjustments, ensuring performance tracking for market program settlements and payments.	https://www.thgenergy.com/
United States	Virtual Peaker	Cross-sector VPP provider, Utility DERMS enabler	Virtual Peaker offers cloud-based platforms and solutions that empower utilities to optimise distributed energy resources (DERs). Their key solutions include Topline Demand Control, which dispatches and controls DERs during virtual power plant (VPP) events to maintain steady power output, and EV Managed Charging, which balances grid demand and enhances EV driver experience, as well as a Shift Grid-Edge DERMS suite allows utilities to manage residential energy demand, reducing costs and peak load while maintaining a smooth customer experience.	https://virtual-peaker.com/
United States	Voltus	Cross-sector VPP provider	Voltus offers a platform that enables organisations in the U.S. and Canada to earn money by conserving energy through demand response. As a leading Virtual Power Plant (VPP) operator, Voltus compensates users for reducing or shifting electricity consumption during grid stress, high prices, or elevated emissions. The company provides a no-cost, no-risk agreement, allowing thousands of commercial, industrial, and residential users to access real-time tracking of earnings and performance through cash-generating programs.	https://www.voltus.co/
United States	WattTime	GHG data provider	WattTime is an environmental tech nonprofit offering real-time emissions data via an API for devices such as EV chargers and smart thermostats to reduce emissions. Its data enables automated demand response, helping optimise energy use for lower environmental impact. Over 500 million devices, through partnerships with device manufactures and software providers, currently leverage WattTime's data to automatically reduce emissions.	https://wattime.org/

The use cases cover a variety of business models worldwide, from established corporations to growing companies and startups. They provide insights on product and software solutions from stakeholders across the grid, aggregator, and building sectors. In total, 16 unique stakeholders are represented. Figure 25 shows the number of use cases associated with each stakeholder. Most cases come from cross-sector VPP providers, followed by B2G EMIS platform providers, and those VPPs focus on residential solutions. Figure 26 highlights the geographic distribution of these use cases: around 51% are based in various European countries and 37% are in the United States.

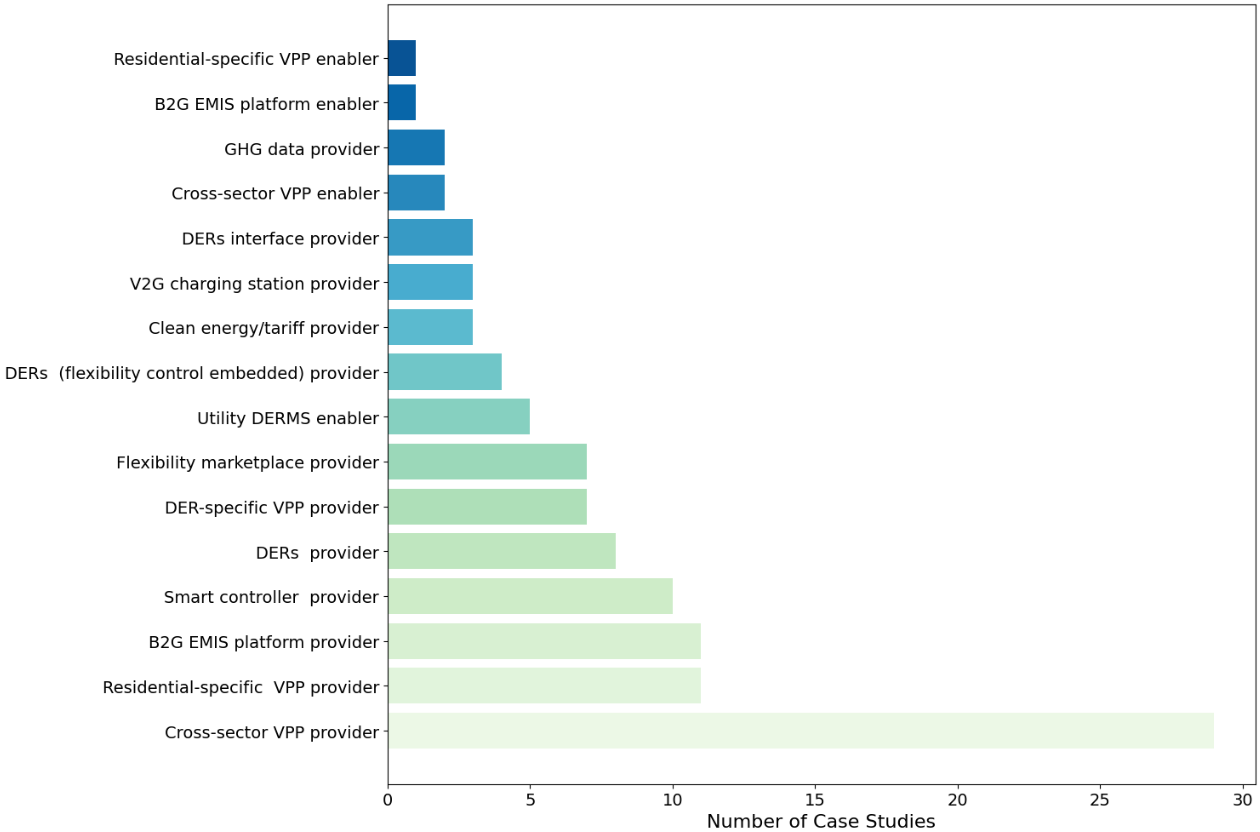


Figure 25 Number of use cases per stakeholder type

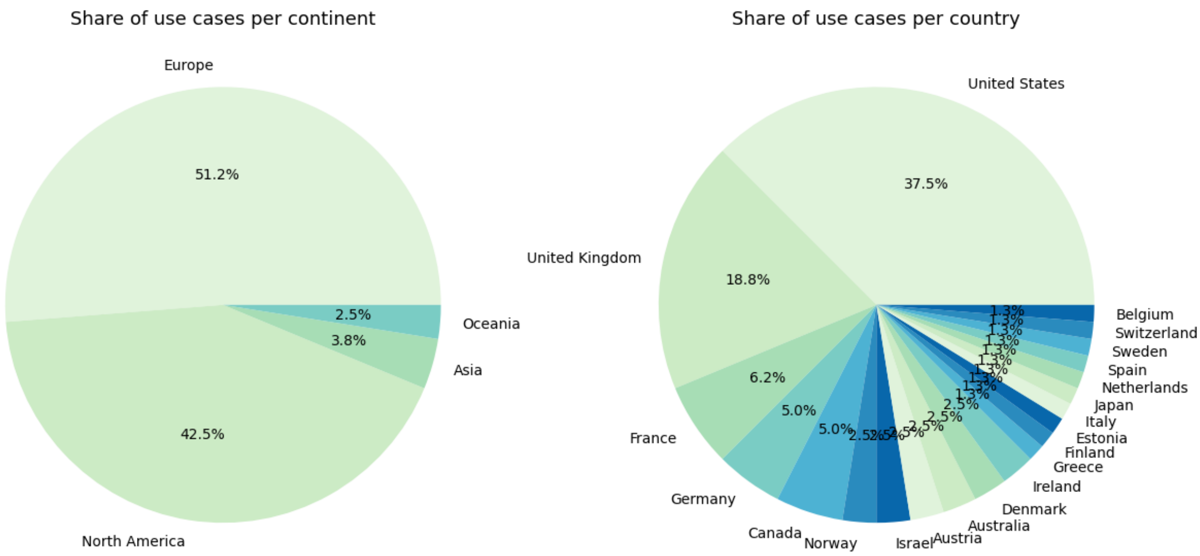


Figure 26 Distribution of the use cases per continent and country

5.3 Example Cases Analysis

Energy flexibility business models are generally structured around three fundamental components: value proposition, value creation and delivery, and value capture (Hamwi et al., 2021 and Le Dréau et al., 2023). The **value proposition** outlines the benefits provided to customers, including financial and operational benefits such as customer bill savings, enhanced grid resilience, or avoiding penalties in wholesale markets. **Value creation and delivery** involve the processes and resources required to deliver the value. This may include aggregating energy loads from smaller consumers to offer flexibility to grid operators, as well as using smart technologies such as advanced metering and communication systems to facilitate real-time energy load management. **Value capture** describes how a business model can be financially sustained, involving revenue models, customer remuneration, cost structures, and asset ownership (Brinker et al., 2021). For instance, customer revenues may be generated directly through reduced energy costs or by participating in flexibility markets, benefiting from shared financial incentives utilities provide via aggregators.

To analyse the three main aspects (value proposition, value creation and delivery, and value capture) across the case studies in this report, we used different methods depending on how we sourced each case. For cases collected through our survey, we gathered direct insights into these aspects. For cases identified through independent research on companies in the field, we interpreted these aspects based on available online documentation. It is important to note that this approach may introduce limitations, as some interpretations rely on our own analysis of publicly available information.

Value Proposition

Figure 27 illustrates the various combinations of stakeholders and value propositions within the energy flexibility ecosystem, highlighting the percentage of each occurrence. These combinations are driven either by the specific goals of each use case or by the mutual benefits that come from their integration. Essentially, the figure analyses how frequently each unique value proposition is represented across different stakeholders. This reveals that financial incentives, such as those for enrolling and participating in energy markets, energy bill savings and improved reliability, are major drivers throughout the energy flexibility value chain. The data also highlights a strong focus on societal contributions, CO_2 reduction, and sustainability branding, indicating that many stakeholders prioritise sustainability and community impact alongside cost savings. Each stakeholder group has its own focus: for example, building owners prioritise energy savings and comfort, grid operators emphasise service reliability, grid efficiency, and operating cost reduction, while data providers, VPP providers and platform enablers concentrate on empowering people and companies to drive decarbonisation, solution scalability, lower overheads, and sustainability branding. This shared interest in both financial and environmental benefits shows the potential of energy flexibility solutions to drive cross-sector impact. As the industry matures, it is also possible to see that the focus is shifting from purely financial benefits to a more balanced emphasis on community impact, environmental responsibility, and long-term stewardship.

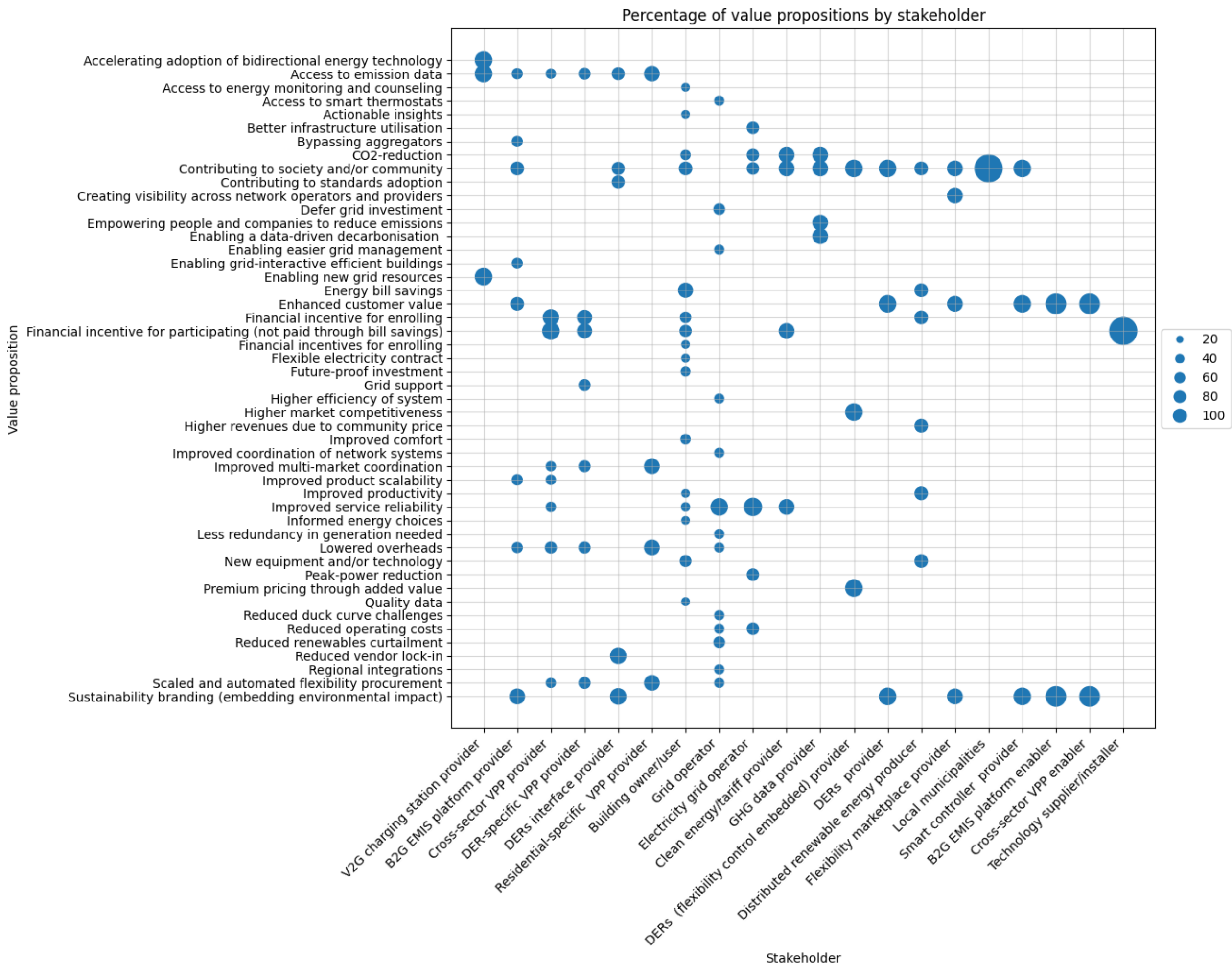


Figure 27 Stakeholder-value proposition combinations indicating the percentage of occurrence.

Value Creation and Delivery

Figure 28 shows the distribution of energy flexibility-enabled equipment among various stakeholders. The most common types of equipment found across different use cases include HVAC systems, which are often paired with smart thermostat controls, batteries (both electric vehicle batteries and stationary batteries, such as those used in homes and commercial buildings), solar PV panels, and thermal storage systems enabled in heat pump water heaters systems.

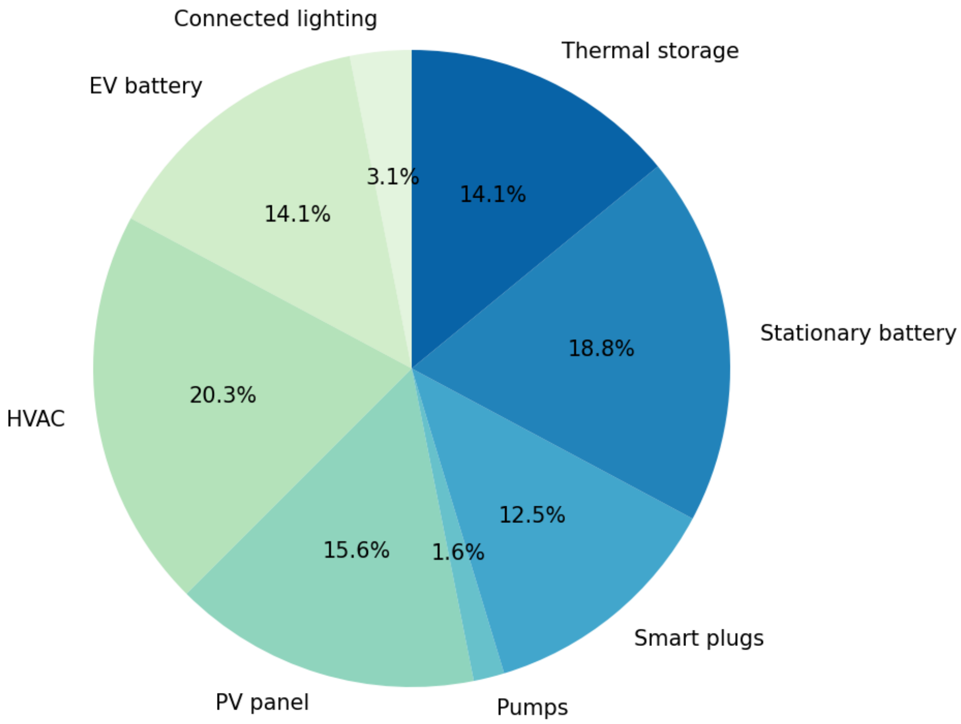
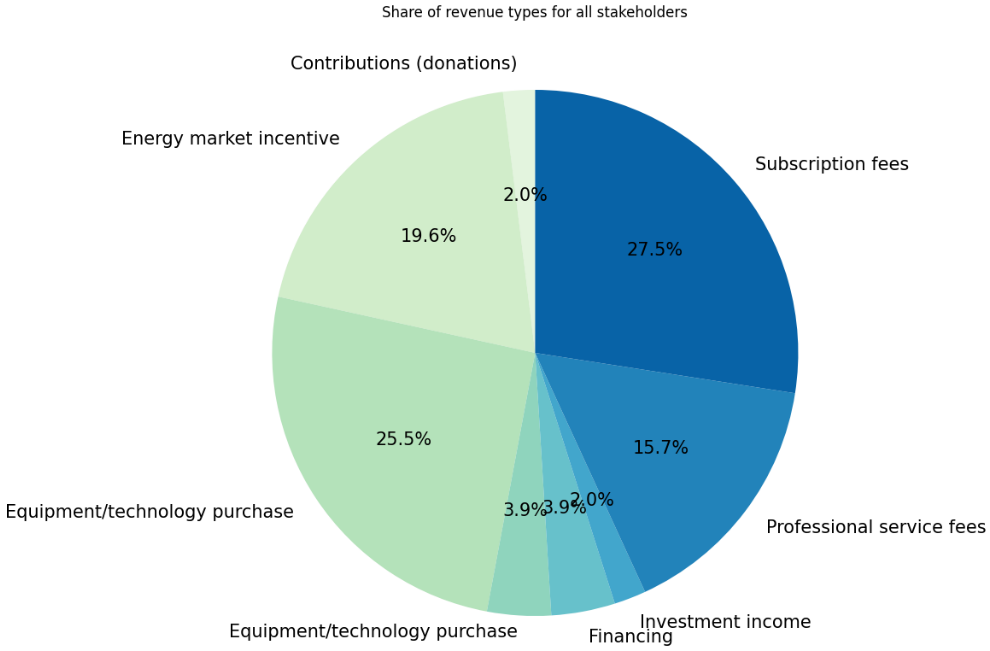


Figure 28 Share of energy flexibility-enabled equipment for all stakeholders.

Value Capture

Figure 29 shows the distribution of revenue sources (top) and cost types (bottom) among all stakeholders. The most prevalent revenue sources are subscription fees, equipment and technology purchases, and energy market incentives, including upfront enrolment payments and performance-based participation payments. Meanwhile, the most common cost types are labour, software, and capital costs for equipment. In both cases, stakeholders typically have multiple revenue sources and cost types.



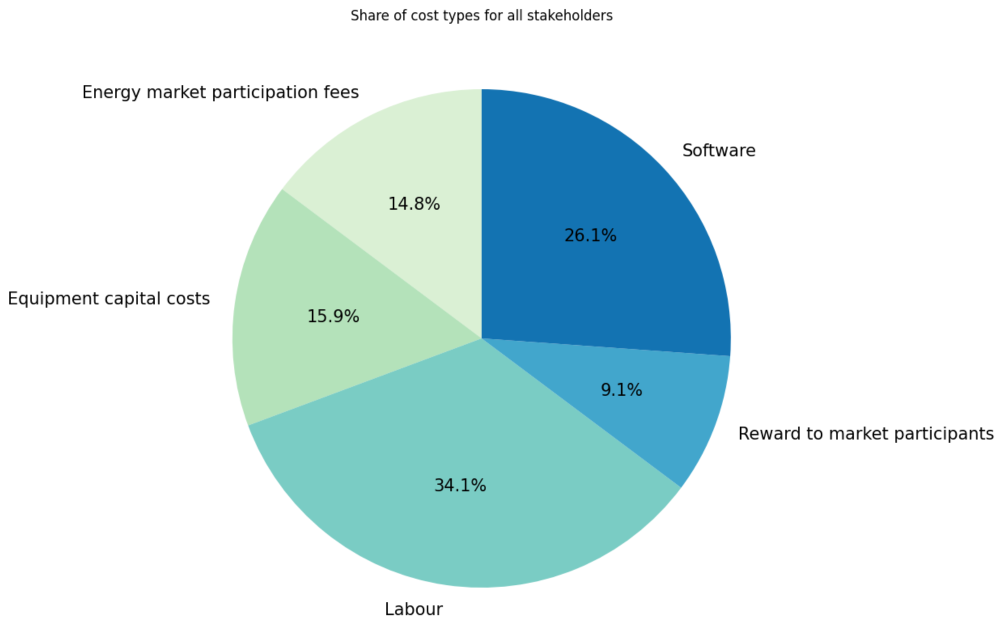


Figure 29 Top: Share of revenue sources for all stakeholders. Bottom: Share of cost types for all stakeholders.

To gain deeper insights into how example case studies operate, the benefits they offer, and the challenges they face, the following subsections analyse two of them. The first case study is the PeakSmart (Energy Queensland Broad-Based Program) from Australia, providing an electricity grid operator's perspective from Energex. This case focuses on residential and commercial buildings and stands out as one of the longest-running examples, having been active since 2012. The second case study examines aWATTar GmbH, an Austrian enterprise operating in the electricity provider sector leveraging variable tariff systems and hourly-based electricity trading. Established in 2014, aWATTar stands as one of the pioneering companies in this domain, accumulating substantial experience and customer base in both residential and commercial buildings.

5.4 Case 1: PeakSmart - Energy Queensland Broad-Based Program

The Energy Queensland Broad-Based program rewards customers for their flexibility in energy demand, aiming to establish a Demand Management portfolio to tackle peak demand and support the local Energex network. The initiative is a key part of the organisation's "Our Future Grid Roadmap" and primarily targets residential and small business customers leveraging air conditioner demand response switching capability, as per the Australian Standard AS/NZS 4755.3.1. To date, the program has over 130,000 connected air conditioners, which contribute to reducing peak demand by approximately 0.7 kW to 1.55 kW per unit when operating at 50% demand reduction mode. The aggregated portfolio yields about 150 MW of controllable load.

The Energex Broad-Based program offers the utility direct control over PeakSmart air conditioners, which are activated during periods of extreme demand or emergency response. Through cashback rewards[12], this program encourages building owners and users to receive a one-time payment for installing PeakSmart air conditioners or upgrading existing ones with a control device (Demand Response Enabled Device or DRED). Additionally, air conditioner suppliers and installers receive incentives for providing and installing units with the control device.

During dispatch events (peak demand periods), when the network service provider activates resources to alleviate stress on the grid, there are no additional payments involved. This is because the communication technology (audio frequency load control) is one-way, meaning it cannot confirm whether an air conditioner has responded to a request. This limitation prevents payment for confirmed activation. To evaluate the program's overall performance, a specific portfolio of buildings is equipped with meters and sensors.

The value proposition can be listed as shown in Table 9.

Table 9 Value proposition of PeakSmart, Queensland, Australia.

Stakeholder #1: Building owner/user	Stakeholder #2: Network service provider	Stakeholder #3: Technology supplier/installer
→ Financial incentive for enrolling → New equipment (DRED) → Contributing to society and/or community	→ Improved service reliability → Defer augmentation of the grid	→ Financial incentive for participating (not paid through bill savings)

The value creation and delivery can be summarised as:
The building loads are controlled by the grid operator to deliver:

- Load shed (short-term power demand reduction during peak hours or emergency events). This is obtained at AU$249/kVA (around 20% of the cost of large-scale electric batteries), not including costs for program management and pre-existing control functionality. For comparison (though not directly comparable), the regulatory asset base of Energex's entire network per unit of peak demand experienced by the entire network is >AU$2,400/kVA.

[12] https://www.energex.com.au/manage-your-energy/cashback-rewards-program

The flexibility resources and enabling initiative is based on the following flexibility resources and enabling technologies:

- 'PeakSmart' air conditioner: air conditioners that must contain a control device (as per Australian Standard AS/NZS 4755.3.1) to control the compressor (while the fan remains on). Several major brands offer PeakSmart air conditioners, with over 800 compliant models available[13].
- AS/NZS 4755.3.1 DRED: control device in the air conditioner that can receive audio frequency load control signal and activate the demand response mode. The device has control modes DRM 1—Do not consume power, DRM 2—Do not consume at more than 50% of rated power, and DRM 3—Do not consume at more than 75% of rated power. The DRM 2 is the most common mode.
- Audio frequency load control (AFLC) technology: communication technology used to manage the operation of a group of air conditioners. It works by sending control signals across five channels to gradually bring the air conditioners back into service. This communication is one-way, broadcasting a demand response request without receiving confirmation from the consumer regarding whether the air conditioner has complied with the request.

The control implementation relies on the following strategy:

- When needed, Energex sends the AFLC signal to activate registered air conditioners into demand response mode (off, 50%, or 75%). When the event is over, the air conditioners return to full service.

Building owners/users access payment for participating in the program through their air-conditioning product supplier/installer, facilitated by Energex. The technology supplier/installer receives the payment from Energex.

Value capture can be summarised as shown in Table 10.

Table 10 Value capture for PeakSmart, Queensland, Australia.

Revenue source	Business cost
→ Regulated return for the network service provider (cost claimed as part of the necessary cost of providing network services in the network area)	→ Equipment capital costs (DRED device provided free of charge by Energex. The audio frequency control is not included in this case study because it is already paid for as part of the traditional hot water control program) → Program management (not included in this case study because it is already paid for as part of the traditional hot water control program) → Incentives for building owners/users of AU$100 for air conditioners < 4 kW, AU$200 for air conditioners between 4 kW and 10 kW and AU$400 for air conditioners >10 kW → Incentives for HVAC suppliers/installers of AU$50 per air conditioner

Pricing structure and impacts

PeakSmart is not reliant on electricity pricing since there is no incentive tied to electricity consumption.

Direct load control/Emergency control (customers receive incentive payments for allowing the utility a degree of control over certain equipment).

[13] https://www.energex.com.au/manage-your-energy/cashback-rewards-program/peaksmart-air-conditioning/peaksmart-air-conditioner-models

The network service provider has aggregated ~150 MW of controllable air conditioner load at around 20% of the cost of batteries.

Although it is possible, to date, only a few homeowners have experienced service loss or deactivated the device.

The program relies on standard compliance rather than specific regulations. It adheres to the Australian Standard AS/NZS 4755, which sets up a framework enabling various appliances and manufacturers to connect and respond to remote signals.

Barriers, lessons and/or future plans

Building owners/users cannot bypass the control unless they remove the devices. However, to date, only a few homeowners have encountered service disruptions or deactivated the device. In general, the complaint rate remains low.

Events are scheduled in advance with specified start and end times, and their occurrence rate is relatively low. In 2023, there were a total of eight events, each lasting an average of two hours[14]. The majority were classified as DRM 2, with only two instances of DRM 1 activated during extreme weather conditions. The activation of DRM 1 was crucial for meeting operational requirements, as it enabled effective management of overloads and helped mitigate outages.

The program initially faced issues with its devices in the early years, but these were gradually resolved through updates over time. Looking ahead, their future involves updating the control devices to adhere to internet-based protocols.

5.5 Case 2: aWATTar

aWATTar, a dynamic and innovative small enterprise based in Austria, actuates as an electricity provider operating with variable tariff systems and hourly-based electricity trading. They prioritise Renewable Energy Source (RES) and offer a distinct tariff plan for RES producers. This strategy encourages residential and commercial users to shift their electricity consumption to greener and more cost-effective hours, thus increasing demand for renewables and reducing the need for curtailing excess energy. To further support flexibility services based on tariffs, aWATTar facilitates interfaces and collaborations with manufacturers. This allows appliances such as heat pumps and electric vehicles to consume energy during optimal time frames.

aWATTar offers an interface that daily provides building owners/users with hourly electricity prices. The tariff advocates greener hours, even including negative prices during surplus periods. A distinct tariff plan is in place for RES producers, who are promised to be situated only in Austria. Customers can also ensure a price guarantee ceiling linked to their annual consumption by opting for exclusive pricing structures. This involves a maximum price cap, and a yearly adjustment cap. Customers can also benefit from a SYNC bonus by shifting their consumption to more environmentally friendly time slots. aWATTar requires connection to remotely readable smart meters and collaborates with manufacturers to facilitate seamless shifts in consumption to more favourable hours.

The value proposition can be summarised as shown in Table 11.

[14] https://www.energex.com.au/manage-your-energy/cashback-rewards-program/peaksmart-air-conditioning/peaksmart-events

Table 11 Value proposition for aWATTar, Austria.

Stakeholder #1: Building owner/user	Stakeholder #2: RES producer
→ Energy bill savings → Improved service reliability → New equipment and/or technology → Gaining experience in green electricity market → CO_2 reduction	→ Financial incentive for enrolling → Improved productivity and efficiency → New equipment and/or technology → Contributing to society and/or community

The value creation and delivery can be summarised as:

The building loads can be incentivized by the green tariffs to deliver:

- Load shift (Energy use timing change to reduce the power demand during peak demand hours or exploit renewable generation)
- Load shed (Short-term power demand reduction during peak demand hours or emergency events)
- Modulation (Power demand adjustment on a sub-minute timescale)

The aWATTar data interface (API) and its partners' applications can automatically activate several flexibility resources. The aWATTar API informs the prices for the next day at 2pm. The data is sent in a machine-readable form that can be processed by connected devices, including:

- EV charges (via go-e Charger or Fronius Wattpilot), which can be charged cost-effectively based on aWattar's hourly electricity tariffs and/or PV available generation.
- Heat pumps (via IDM or KNV heat pumps), which can adjust the consumption based on the aWattar's hourly electricity tariffs.
- Air conditioners (via tado° Balance AC), which can adjust the consumption based on the aWattar's hourly electricity tariffs.
- Home automation and energy management systems (via Nymea, Loxone, ASKI—energy management) can incorporate aWattar's hourly electricity tariffs to control loads accordingly.

The control strategies are implemented through the partners' applications.

The customers access the services offered by this provider through:

- Free online registration via the company website. The company also facilitates the electricity provider's transition, including cancelling the previous service.

Value capture can be summarised as shown in Table 12.

Table 12 Value capture for aWATTar, Austria.

Revenue source	Business cost
→ Subscription fees → Equipment/technology purchase	→ Software → Taxes and other fees → Energy market participation fees

Pricing structure and impacts

aWATTar uses real-time pricing (RTP).

Capacity market programs (customers receive incentive payments for providing load reductions as substitutes for system capacity).

Using aWATTar interfaces and tariff-optimized charging applications, building owners/users can save up to 32% on electricity expenses for electric cars.

In Austria's electricity market, the lack of other relevant tariff systems employing hourly rates or variable rates throughout the day highlights a legislative and policy framework that lags behind the innovative opportunities. Despite the presence of companies such as aWATTar, introducing progressive approaches, regulatory constraints hinder their potential for expansion.

Barriers, lessons and/or future plans

aWATTar's business model relies heavily on its infrastructure and service quality to adapt to market transitions. Government support should be increased for companies providing such services to encourage their growth.

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6 Conclusions

On basis of international reviews and comparisons, this deliverable has made a number of key findings related to policy and regulation, price-incentive structures, business models and key factors influencing customers' willingness and possibilities for taking part in energy demand flexibility. These findings will, together with Annex 82 deliverable D1, inform the recommendations to policy-makers and others reported in deliverable D3 of the annex.

Our review of policy and regulation (Chapter 2) shows great variety between countries in terms of the extent and type of policy measures implemented. We find a tendency that countries with the most advanced policies are also those who are most advanced in deploying energy flexibility, which indicates that "policies matter" and that in most countries more policies will be needed to support the development of new markets for energy demand flexibility. Similarly, we find a tendency that countries with a widespread availability of price incentives to smaller customers (Chapter 3) are also those countries having the highest penetration of active energy flexibility on the demand side. However, flexible pricing schemes mainly exist within the electricity sector and are very limited within gas markets and non-existing within district heating.

Our review of the broader set of social, economic and institutional factors influencing energy flexibility (Chapter 4), and the existing knowledge from experiments and trials, shows – among other things – that simulation-based studies are still the main source of knowledge on the effect of energy flexibility. Thus, much of our existing knowledge seems still based on more theoretical and "idealistic" studies, whereas findings from "real-world" experiments are still limited. Also, previous studies have had a dominant focus on economic and price incentives, which might have the risk of ignoring the importance of also other types of motivations for smaller customers to take part energy flexibility programs (e.g. environmental concerns or the interest in contributing to local resilience, as in the case of energy communities). This is partly confirmed by the survey targeted smaller customers (mainly residential sector) carried out as part of this annex. On a more general level, our study emphasises the importance of developing an awareness and sensitivity towards the social inclusiveness and "social fairness" of developed energy flexibility solutions and programs (including policies), as this is key to ensure a social just energy transition as well as the general public support of such solutions and programmes.

Finally, our review of existing business models within demand-side energy flexibility (Chapter 5) illustrates that DSOs play a particular key role as they serve as the primary interface for facilitating energy flexibility through their direct (physical) connection to customers. Another key stakeholder in developing business models is the aggregators. In terms of value proposition, our review showed that energy bill savings, new equipment/technology acquisition and financial incentives were among the most important types of value proposition, but also broader societal gains, e.g. CO_2 reductions and sustainability branding for companies, appeared to be important. The main technological focus of the reviewed business models was heat pumps and air conditioners, PV panels and batteries. The reviewed business models primarily focus on load shedding and load shifting. In terms of revenue sources, 30% of the cases involved a combination of subscription fees, equipment purchases, research funds and professional service fees. This shows that revenues often depend on a multiplicity of sources.