WeForming

SOTA ANALYSIS, BARRIERS, REGULATORY FRAMEWORK AND END-USERS' REQUIREMENTS

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ABBREVIATIONS

ACER	European Union Agency for the Cooperation of Energy Regulators
aFRR	Automatic Frequency Restoration Reserve
AI	Artificial Intelligence
APCI	Application Protocol Control Info
APDU	Application Protocol Data Unit
API	Application Program Interfaces
ASDU	Application Service Data Unit
B2G	Building-to-Grid
B2X	Building-to-X
BACS	Building Automation and Control Systems
BAS	Building Automation System
BESS	Battery Energy Storage Systems
BIPV	Building Integrated Photovoltaics
BRP	Balancing Responsible Party
BSP	Balancing Service Provider
BUC	Business Use Case
CHP	Combined Heat and Power
CIM	Common Information Model
CIS	Component Interface Specification
CMI	Common Information Model
CO_2	Carbon dioxide
COSEM	Companion Specification for Energy Metering
CPP	Critical Peak Pricing
DC	Direct electric Current
DERs	Distributed Energy Resources
DF	Demand Flexibility
DLMS	Device Language Message Specification
DMS	Distribution Management Systems
DNP	Distributed Network Protocol
DR	Demand Response
DSO	Distribution System Operator
EC	European Commission
EE	Energy Efficiency
EED	Energy Efficiency Directive
EMCS	Energy Management Control System
EMS	Energy Management System
EPBD	Energy Performance in Buildings Directive
ESCOS	Energy Service Companies
ESS	Energy Storage Systems
ETD	Energy Taxation Directive
EU	European Union
EV	Electric Vehicle
FCR	Frequency Containment Reserve
G2V	Grid-to-Vehicle
GEB	Grid-interactive efficient buildings
GOOSE	Generic Object-Oriented System Event
GSE	Generic Substation Events
HBES	Home and Building Electronic Systems

HHU	Hand-Held Unit
HLUC	High-Level Use Case
HVAC	Heating, Ventilation, and Air Conditioning
IEC	International Electrotechnical Commission
iGFB	Intelligent Grid-Forming Buildings
IHD	In Home Displays
IoT	Internet of Things
IP	Internet Protocol
IRM	Interface Reference Model
ISO	Independent System Operator
LED	Light-Emitting Diode
MEPS	Minimum Energy Performance Standards
mFRR	Manual Frequency Restoration Reserve
ML	Machine Learning
MMS	Manufacturing Message Specification
NECPs	National Energy and Climate Plans
NZEB	Nearly Zero-Emission Building
OBIS	OBject Identification System
OLED	Organic Light-Emitting Diode
PCM	Phase Change Material
PEM	Polymer Electrolyte Membrane
PV	Photovoltaics
RDF	Resource Description Framework
RED	Renewable Energy Directive
RES	Renewable Energy Sources
RR	Replacement Reserve
RTP	Real-Time Pricing
RTU	Remote Terminal Unit
SBO	Select Before Operate
SCADA	Supervisory Control and Data Acquisition
SCL	Substation Configuration Language
SGCB	Setting Group Control Blocks
SHEMS	Smart Home Energy Management System
SMV	Sampled Measure Values
SRI	Smart Readiness Indicator
SSL	Solid-State Lighting
SV	Sampled Values
SVCB	Sampled Value Control Blocks
TAS	Thermal anisotropic systems
TCP	Transport Control Protocol
TES	Thermal Energy Storage
TNO	Transmission Network Operator
TOU	Time-of-Use
TSO	Transmission System Operator
UC	Use Case
V2G	Vehicle-to-Grid
V2V	Vehicle-to-Vehicle
VEN	Virtual End Node
VFD	Variable Frequency Drives
VPP	Virtual Power Plant
VTN	Virtual Top Nodes

ZDO	Zigbee Device Objects

Executive Summary

This document provides a comprehensive analysis of the current landscape and future potential of Intelligent Grid-Forming Buildings (iGFBs) in the European Union. It addresses the multifaceted nature of integrating iGFBs into the energy sector, covering technological, regulatory, and societal aspects. The adoption of iGFBs faces several challenges, including diverse national regulatory frameworks and the technological hurdles associated with ensuring interoperability standards between smart buildings' technologies.

The report thoroughly reviews and summarizes the interoperability and integration technologies used in iGFBs across the energy sector. It provides an in-depth analysis of both technical and economic factors, highlighting interoperability challenges and proposing viable solutions. In addition, insights from European research projects and initiatives shed light on progress and obstacles in the fields of demand-side flexibility and interoperability of energy systems and networks.

A basic overview of iGFB concepts is provided, highlighting their potential to provide services to energy System Operators through flexibility and local energy generation. It identifies key stakeholders in the iGFB value chain, presents a high-level use case methodology for describing iGFB concepts, and proposes stakeholder engagement tools.

Significantly, the report assesses the barriers and regulatory environment necessary for the development and widespread adoption of the iGFBs in Europe. The document specifically considers the context of the WeForming project, which will implement six iGFB demonstrations in different EU countries.

1. Introduction

1.1. Context and Scope

This document is an early-stage release of the Weforming project's Work Package (2) dedicated to the assessment of stakeholder requirements and system specifications, which aims to provide the basis for the Intelligent Grid Forming Buildings (iGFB) enabling framework. It consists of an analysis of the state of the art of iGFBs' fundamental concepts and operation and reviews the status quo of multi-sector interoperability and integration technologies, building solutions and system flexibility The document draws a methodology for the definition of use cases within the Weforming framework targeting the project pilot use cases based on the characterization of the potential multi-energy assets in the active building operation framework, taking into account the coupling between energy carriers, their interaction with the networks and the potential creation of services related to each particular case, while exploring the roles and diversity of the main stakeholders involved in the deployment of iGFBs. The deliverable also examines the barriers to widespread deployment of the concepts to be demonstrated in the Weforming framework, from a regulatory, technical and societal perspectives.

1.2. Content and Structure

The document begins with a broad look at the state-of-the-art of iGFB enabling technologies and devices communication standards concerning interoperability of the systems in Section 2, offering a detailed examination of energy storage technologies, decentralized energy resources, flexible loads as household appliances, other devices that can actively participate in demand-side management strategies and building construction features that can impact significantly the energy efficiency of the systems. This section also discusses capital and operational costs and sets the stage for the technological backdrop of iGFBs.

Section 3 presents an in-depth review of iGFB concepts, outlining the pivotal features such as energy efficiency, renewable energy sources and grid-interactivity, and introduces the recently introduced smart readiness indicator for buildings in the EU space. It explores the operational strategies of iGFBs and highlights load flexibility and its potential to provide services to the networks. An overview of challenges is also presented, faced in terms of technological maturity of the systems, financial constraints, grid readiness, awareness and acceptance, and the importance of market design. The discussion extends to the value chain and key stakeholders' groups involved identification in the development of iGFB projects.

In Section 4, the focus shifts to stakeholder engagement and use case development for iGFBs. It details the development of high-level use cases, maps out key energy carriers, technologies, and networks, and explores the co-creation processes and methods for engaging stakeholders effectively.

Section 5 analyzes the barriers and regulatory frameworks that impact the adoption and implementation of iGFB. It provides a comprehensive overview of the regulatory landscape across the European Union, including directives and regulations relevant to energy performance, electricity markets, and renewable energies. Additionally, this section reviews national barriers and regulatory conditions in the EU member states hosting WeForming demonstrators, offering insights into the diverse regulatory environments.

The document concludes with Section 6, which outlines the conclusions drawn from the main requirements for the iGFB deployment, and the barriers and hindrances from technical, societal, and regulatory perspectives.

1.3.Target Audience

The target audience for this deliverable in the WeForming project encompasses a diverse range of stakeholders, including:

- Partners and Advisory Group within the WeForming project
- The European Commission (EC) and European Parliament (EP)
- Members of the European Union
- Other Horizon Europe projects, particularly those related to energy and smart building initiatives (for clustering activities)
- Organizations and experts engaged in the WeForming case studies
- Other pertinent entities, both public and private, which may include associations representing stakeholders relevant to the project's scope and objectives.

2. State-of-the-art Analysis

2.1. State-of-the-art in building appliances technology

In the pursuit of a sustainable and resilient energy future, the role of end-users in building demand flexibility has emerged as a critical factor in shaping a stable and intelligent modern grid, particularly as the global energy landscape undergoes a significant transformation with heightened penetration of renewable energy sources. One of the primary challenges faced by contemporary grids when integrating these intermittent renewables, such as solar and wind, is the introduction of their volatility and unpredictability in the operation and planning of the power systems. Addressing this challenge requires a paradigm shift towards a more flexible demand-side approach.

In Europe, with its high concentration of urbanized areas, building energy consumption has a very significant impact on the overall energy balance. According to a report by the European Commission, buildings are responsible for approximately 40% of the total energy consumption in Europe [1], and a staggering 36% of the EU's greenhouse gas emissions [2]. This underscores the immense impact that buildings have on the overall energy landscape, making them pivotal players in the quest for a sustainable and resilient energy infrastructure. A large number of devices embedded in modern buildings holds great potential for demand flexibility. Many of these devices, ranging from smart appliances to heating, ventilation, and air conditioning (HVAC) systems, possess inherent flexibility potential that can be harnessed to provide valuable grid services. A significant proportion of these devices are equipped with the capability to engage in their energy consumption management, thereby contributing to the overall flexibility of the grid [3]. As defined in report [4], demand-side management strategies that can be implemented in buildings to manage load are:

1) **Efficiency:** the ongoing reduction in energy use while providing the same or improved level of building function.

2) **Load Shedding:** the ability to reduce electricity use for a short period of time and typically on short notice. Shedding is typically dispatched during peak demand periods (“peak shaving”) and during emergencies, when the risk of system-level blackouts exceeds the repercussions of shed loads.

3) **Load Shift:** the ability to change the timing of electricity use. In some situations, a shift may lead to the change in total consumed electricity. The focus of load shifting is on intentional and planned shifting, for reasons such as minimizing demand during peak periods, taking advantage of cheapest electricity prices, or reducing the need for renewable curtailment. For some technologies, there are times when a load shed can lead to some level of load shifting. Importantly, load shifting is not a measure of energy efficiency but instead of temporal reallocation of the energy consumption.

4) **Modulate:** the ability to balance power supply/demand or reactive power draw/supply autonomously (within seconds to sub seconds) in response to a signal from the grid operator during the dispatch period.

5) **Generate:** the ability to generate electricity on-site for self-consumption and even to be dispatched in response to signals from the grid. Energy storage systems are often included in the system to improve the dispatchability of such generated power.

By fine-tuning the energy consumption patterns of these devices to align with grid needs, end-users can enhance the reliability and stability of the grid. This not only facilitates a seamless integration of renewable energy sources but also unlocks the potential for buildings to actively participate in grid services without compromising user comfort or operational needs. While load shifting, load shedding, and modulating operations are viable means of providing grid services, still the most efficient approach lies in increasing the efficiency of these devices.

The active involvement of end-users holds immense potential in reshaping the power systems; however, a substantial motivational effort will be necessary to instigate a significant willingness to change their electricity consumption patterns. It is seen that active participation of end-users in demand side management, whether through demand response initiatives or efficiency improvement measures, is driven by a combination of financial incentives (lower electricity bills, incentive programs, and rebates, etc.), environmental concerns and other nonfinancial reasons such as achieving greater energy autonomy [7]. Recognizing the multifaceted benefits encourages end-users to embrace these practices, contributing to a more resilient and sustainable energy ecosystem.

Another variant of providing demand response services is through the participation of buildings as multi-energy systems. A multi-energy system is a type of system that contains different energy vectors that can cooperate and complement each other by shifting between one another or by storing energy in different forms for later use. Shifting between energy vectors is usually done as a response to outside signals, e.g. the system will switch to local electricity production during times of high electricity prices. Additionally, this type of system can provide flexibility services to the system operator, as well. Conceptually, multi-energy systems are very similar to the demand response concept as they both provide internal flexibility to the system. Unlike demand response, the multi-energy system will not have production losses since its consumption will be satisfied through different energy vectors: it readjusts the optimal combination of different energy vectors, being only affected by the efficiencies of switching between energy vectors. They can also be used simultaneously to complement each other. This type of system inherently interacts with multiple markets meaning that it needs to optimize its position on all of them.

In this chapter, we will delve into the realm of devices that can actively participate in demand-side management. This comprehensive examination aims to illuminate both the individual device-level and structural aspects (e.g. windows) contributing to effective demand-side management strategies.

2.1.1. Household appliances and other devices

According to the report [4], both devices with fixed cycle and continuous-running devices represent a moderate potential for exploitation in providing grid services. Devices with a fixed cycle are suitable for shifting consumption with a relatively small impact on the user. They operate at a constant power, allowing for limited modulation or load shedding. Instead, they primarily facilitate load shifting by delaying the start of device operation. Their consumption curve depends on when an individual turns a specific device on. On the other hand, continuous-running devices, such as refrigerators, are suitable for both modulation and load shifting (preheating or precooling). However, determining the optimal operation, while also considering the end-user comfort, can be challenging.

This chapter will scrutinize the potential for household appliances (such as refrigerators, washing machines, dishwashers, and other) and other devices (which include battery energy storage, fuel cells, etc.) to engage in demand-side management. Furthermore, it will assess how building components like walls (structures), roofs, and windows can influence alterations in end-user electricity consumption.

2.1.1.1. Refrigerator and freezer

Refrigerators play a crucial role in maintaining a set temperature within their interiors through the vapor compression process. Their consumption curve is mostly constant for households, with an exception during the late afternoon/evening hours when increased fridge door openings allow warm air to enter, making it challenging to maintain the preset temperature. Utilizing refrigerators for demand response purposes is feasible, but temperature preservation is paramount to ensure compliance with food storage regulations. In addition to household refrigerators, commercial refrigerators, including walk-in units, ice makers, and displays for items like fish or frozen foods in supermarkets, are also part of this category, with the corresponding hard constraints regarding the internal temperature as, for instance, the frozen chain should not be interrupted.

For residential refrigerators, demand response strategies can involve switching to a low-operation mode as needed, delaying the defrosting cycle, pre-cooling the freezer to a lower temperature, and then allowing airflow from the freezer to the fridge (with temperature control) during peak periods. Connected devices in the market offer these features but come at a higher cost than non-connected ones. In commercial settings, similar strategies apply. Additional controls can be integrated into existing or new products, taking advantage of the significant thermal mass and slower temperature change from the set point. However, it's essential to note that load shifting is the only feasible option; if load shedding occurs, it must be accompanied by load shifting to maintain the desired temperature.

2.1.1.2. Dish and Clothes Washer

Dish and Clothes washing machines offer control options through the definition of the start time either directly on the device, through an integrated control panel, or via a dedicated application. This functionality enables load shifting during periods of high energy consumption. When determining the optimal operation of washing machines, it is essential to consider user preferences. The models should allow users to stop the automatic control set by the device and manually specify when they want the machine to start. Smart options of these devices are available in the market, and their cost is in fact nearly indistinguishable from non-connected counterparts that lack remote control features. It's important to note that washing machines do not provide the possibility of load shedding, but rather enable load shifting to more energy-efficient periods.

2.1.1.3. Clothes Dryer

Clothes dryers offer various features that can contribute to demand response strategies. They can operate in low-power or low-temperature modes, extending the drying cycle and improving operational efficiency. Moreover, they can be turned off or paused to provide a service to the system at that moment, effectively offering a form of load shedding along with load shifting. There are different types of dryers available, such as electric resistance dryers that allow control and could potentially provide demand response through modulation, especially suitable for applications requiring quick reactions at a second-level response. Another type is the heat pump dryer, utilizing the vapor compression cycle for increased efficiency, but longer operation. On the other hand, natural gas dryers could potentially offer demand response services through power modulation. All dryers are capable of load shifting, adjusting their operation time to periods of lower energy demand. Connected dryer models, allowing integration with other devices, are available in the market but come at a higher cost compared to non-connected counterparts.

2.1.1.4. Lights

Initial control algorithms for lighting were designed to be installed on passive lights, turning them on/off based on factors like the time of the day and room occupancy. Advanced lighting technologies can now automatically and collectively respond to signals from the grid, adjusting consumption by dimming lights or switching to energy storage as a power source. Some technologies even focus on maximizing the use of daylight to reduce reliance on electric lighting in buildings.

Connected lighting comes in three main types: those with advanced sensors and controls, hybrid daylight solid-state lighting (SSL) systems, and SSL displays. The first type employs advanced algorithms to automatically manage various aspects of lighting that can impact consumption, such as light intensity and colour spectrum. Hybrid daylight SSL systems concentrate, collect, and distribute daylight throughout a building using solar collectors, optical cables, mirrors, and similar equipment. SSL displays completely replace the use of windows or any other source of daylight by utilizing LED and OLED technology to simulate light. This elimination of windows reduces heat gain in the room, decreasing the need for cooling devices, commonly found in basements. However, they might increase lighting and ventilation consumption [4].

The primary opportunity for demand response provision lies in increasing the efficiency, with potential grid services offered through occasional load shedding or rapid load modulation in the initial two options. Load shedding cannot be fully implemented when people are present in the building or when there is insufficient daylight, while light-dimming modulation can only be done to a level that will not affect end-users' activities and health (20% in spaces without daylight and up to 40% in spaces with it [4]). Lastly, load shifting might be challenging without compromising user comfort, except when energy storage is available. It is important to mention, that the change in lighting consumption is negligible at the system level, considering that a single LED bulb averages 10 W. For any significant impact, it is necessary to aggregate a larger number of lights, such as in large commercial or residential buildings grouped through aggregators.

Advanced sensors and controls are available on the market, but connected options are usually almost twice as expensive as non-connected ones. Hybrid daylight SSL systems are available, but at a high cost. SSL displays are still in their infancy, and their market development remains uncertain due to end-users' preference for having real windows in their spaces.

2.1.1.5. Electronics

Electronic devices are categorized into continuous-operation electronics for computing or data storage, such as computers, servers, and gaming consoles; battery-powered electronics exemplified by laptops and smartphones; and electronic displays that require constant power, including billboards, video walls, TV, and others. Like with the case of lighting, the most significant impact can be achieved through device efficiency improvements. For the former category, options for demand-side management include utilizing a low-power mode or automatically turning off devices during periods of inactivity. Additionally, adjusting the used power per task is viable, considering that not all tasks are equally crucial or demanding. These changes would enable load shedding. Furthermore, continuous connectivity allows for load modulation. On the other hand, battery-powered electronics contribute to load shifting by delaying charging times to off-peak hours. Lastly, electronic displays offer the potential for load shedding through brightness control, dimming, powering off, and functioning into low-power modes when these displays are not being used.

2.1.1.6. HVAC

Heating, ventilation, and air conditioning (HVAC) is a system used for controlling the temperature, whether it needs heating or cooling, and for air exchange providing air purity. HVAC is an important part of residential structures and can utilize various technologies. For heaters usual devices utilized are boiler, furnace, or heat pump. Ventilation is usually divided into forced and natural, where the forced ones use devices to force air circulation, while the natural ones do not. Cooling is usually done with air conditioning units or with heat pumps. It can participate in load-shifting demand response programs by utilizing building thermal capacity to preheat/precool the room while remaining in preset temperatures. Depending on the input to HVAC they can also be considered as multi-energy system. Heat pumps are especially important since they represent fully electrified way for heat production in households. They are also an adequate device to replace traditional gas boilers. Heat pumps and local renewable energy sources complement each other very well as heat pumps can be used to balance intermittent production of RES by utilizing either heat storage or building thermal capacity (Figure 1). The main concern when providing flexibility from HVAC the system is the user comfort which needs to be thoroughly addressed.

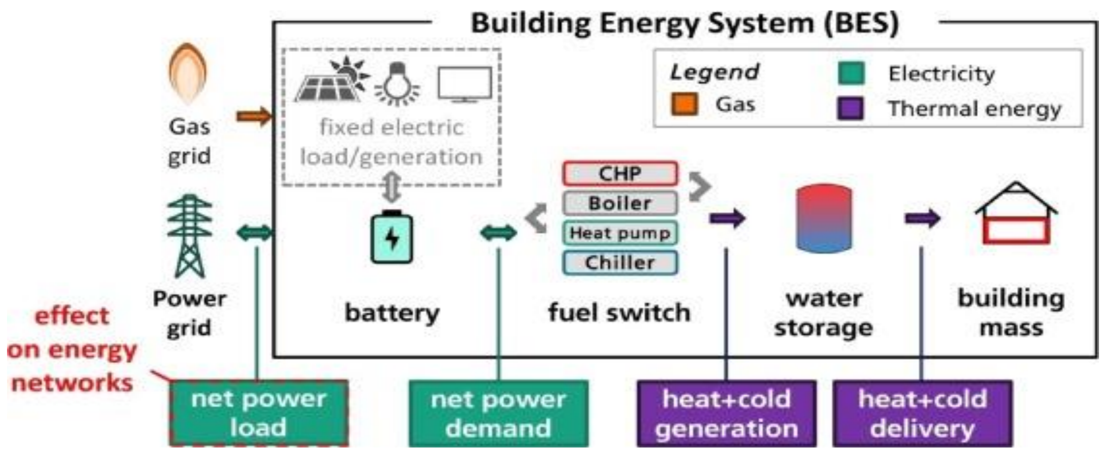

FIGURE 1 BUILDING ENERGY FLEXIBILITY WITH DIFFERENT HVAC TECHNOLOGIES [6]

Cogeneration or combined heat and power (CHP) is the use of a heat engine or power station to generate electricity and useful heat at the same time. This usually leads to more efficient usage of primary fuel because the waste heat during electricity production is further utilized. They can use various different technologies such as gas turbines or engine, steam turbines, nuclear power plants etc. Micro CHP units are usually used in households with power less than 5 kW. Micro CHP usually uses technologies like microturbines, internal combustion engines, Stirling engines, closed-cycle steam engines, and fuel cells. Outputs of the CHP can be manipulated based on the current requirements which can be used to provide different forms of flexibility.

2.1.1.8. Electrolyser

Electrolyser is a device that uses electricity to produce hydrogen through electrolysis. Electrolysis is a technique that uses direct electric current (DC) to drive an otherwise non-spontaneous chemical reaction and separate certain elements. In this case, water molecules are separated into hydrogen and oxygen. The most common electrolyser types are alkaline, polymer electrolyte membrane (PEM), and solid oxide. Electrolysers can be used to store excess electricity in the form of hydrogen for later use, thus providing different energy vector coupled with electricity.

2.1.1.9. Fuel cell

A fuel cell is an electrochemical cell that converts the chemical energy of a fuel (e.g. hydrogen) and an oxidizing agent (oxygen) into electricity through a pair of redox reactions. That process produces electricity and heat while consuming hydrogen. The most common fuel cell types are proton-exchange membrane fuel cells, phosphoric acid fuel cells, solid acid fuel cells, alkaline fuel cells, solid oxide fuel cells and molten-carbonate fuel cells. Fuel cells are similar to CHP plants in concept and as such can provide flexibility through their outputs. It also combines different energy vectors when combined, for example, with hydrogen electrolysers and hydrogen storage systems for electricity generation.

2.1.1.10. Battery Energy Storage

Battery energy storage emerges as an essential contributor to demand response strategies within buildings, specifically excelling in load shifting, shedding, and modulation. These systems empower buildings to store on-site generated energy surplus during periods of low demand, facilitating a seamless shift of loads to off-peak hours. The ability to discharge stored energy strategically allows for load shedding during peak demand periods or high electricity pricing, reducing dependency on the grid [8] emphasize the load-shifting capabilities of battery energy storage, presenting it as a key factor in optimizing energy consumption patterns within buildings. Additionally, battery energy storage offers load modulation, responding swiftly to fluctuations in demand, thus contributing to grid stability. This aligns with findings from the International Renewable Energy [9] highlighting the role of battery energy storage in providing ancillary services like frequency regulation. In essence, the load-shifting, shedding, and modulation abilities of BESS establish it as a versatile solution for enhancing energy efficiency and resilience in buildings.

2.1.1.11. Electric Vehicles

Electric vehicles play a key role in adjusting to changing energy needs. They are adept at managing loads, shifting energy use to different times, and reducing demand when necessary. Users can utilize EVs to store extra energy during low-demand periods and then use that stored energy during times when energy demand is typically high in the same way as with battery energy storage. Moreover, the bidirectional capabilities of Vehicle-to-Grid (V2G) technologies play a pivotal role. V2G allows EVs to discharge stored energy back to the grid, contributing to load modulation during peak demand or high electricity pricing, thus reducing strain on the grid. Conversely, G2V (Grid to Vehicle), the conventional unidirectional charging enables EVs to charge during periods of low electricity demand, aligning with cost-effective and sustainable energy practices. The interconnectedness of EVs goes beyond individual vehicles, as Vehicle-to-Vehicle (V2V) communication enhances the collective effectiveness of load modulation. Studies such as [10] emphasize the potential of V2G systems in supporting grid stability and providing ancillary services.

2.1.2. Building construction

2.1.2.1. Dynamic Windows

Efficient management of daylight in buildings can significantly impact heating, cooling, and lighting consumption. Smart windows, designed as dynamic glazing, offer innovative solutions. Coatings applied to glass, such as thermochromic or electrochromic materials, can change colour at specific temperatures or voltages, effectively blocking certain wavelengths and reducing building heat gain. Electrochromic windows, in particular, hold substantial potential as they allow active control aligned with system needs and user preferences. Automated building additions, such as external features (awnings, shutters) or internal elements (curtains, blinds), can also prevent sunlight penetration and subsequent room heating when closed. While they hold high potential for peak load reduction, integrating internet connectivity, light sensors, and automated control is essential to synchronize their operation with other building devices effectively. Furthermore, photovoltaic coatings on windows, whether fully or partially transparent, can absorb specific light wavelengths as a reaction to building heating up. This technology exhibits a moderate potential for achieving savings and providing system services, such as load shedding. It is particularly advantageous for buildings with extensive glass surfaces, like skyscrapers. However, their ability for load modulation depends on the inverter used.

2.1.2.2. Opaque Building Envelope

Effective building design does not directly manage electricity usage; instead, it shapes the environment by considering factors such as heat, temperature, and humidity, which, in turn, influence lighting, cooling, and heating consumption. A well-constructed building enables load shifting through precooling and preheating, and it also offers the potential for load shedding. Leveraging materials with dynamic properties, in combination with consumption and weather forecasts, can enable the creation of optimal operation models of household devices, offering system services with response times ranging from minutes to hours. Materials with variable thermal conductivity play a pivotal role, aiming to achieve cost savings in electrical energy consumption and provide system services. For instance, materials with high thermal conductivity in colder external temperatures, when cooling is needed, reduce the reliance on air conditioning. These materials are valuable for constructing thermal storage units in buildings, optimizing charging and discharging cycles. Thermal storage, utilizing Phase Change Materials (PCM), is a commercialized approach that can be integrated into building structures. PCM allows for efficient charging and discharging based on external temperatures, contributing to load-shifting strategies. Thermal Anisotropic Systems (TAS), relying on materials with layers of alternating high and low thermal conductivities, are beneficial for load shifting. Lastly, photovoltaic (PV) integration in building materials, by replacing or complementing existing opaque components like façades, offers a means of electricity generation and therefore, provision of grid services. However, their power output may be hindered by panel orientation and tilt due to their location on the building. This approach proves useful in situations where altering the external appearance or adding visible objects on a building is restricted.

2.2. Capital and Operational Costs

In this chapter, capital costs, which include the prices of devices and the costs of constructing an active and smart building, are examined. Subsequently, operational expenses will be analysed, mainly by focusing on electricity prices that will guide the operational costs of these devices.

The cost of refrigerators ranges from 800 € to over 3000 € and the refrigerators are provided by various companies, including Samsung, LG, and General Electric [11][12][13]. Smart dishwashers typically fall within the range of 1000 € to 2000 €, depending on the features included [14][15]. In addition to the companies mentioned earlier, Miele and Bosch also offer smart dishwashers [16][17]. Clothes washers and dryers are available separately, with washers priced from 500 € to 1500 € [18][19] and dryers ranging from 1000 € to 3000 €, depending on features and type (electric resistance or heat pump)[20]. Heat pump dryer versions are offered by Siemens, Miele, and Electrolux [21][22][23]. Combined washer and dryer units in a heat pump version are available at a higher price, around 2500 €, from LG or General Electric [24][25]. In most cases, even with controllable devices in higher price range, challenges are related to interoperability of these devices – most devices employ only the vendor-specific cloud-based communication option.

Lights are offered by various companies (IKEA, Philips, GE Lighting, Samsung LED, etc.), with prices varying based on the type of lighting. LED light bulbs typically range from few € to 20 €, while the price of a complete lamp can vary from 20 € to several hundred €. Additional equipment for smart lighting, such as motion detectors, may cost around 50 €, while manual controllers for switching and dimming lights can range from 5 € to 10 €. Some companies, such as MasterLed, eLEDing, and PolyBrite Solar, offer smart lights that can transition from grid electricity to PV electricity in the presence of daylight, typically used for streetlights, bike lanes, or parking lots, priced around 500-1000 € per unit. Hybrid daylight SSL and SSL displays can be found in the product range of Himawari Solar, Parans, and Lumenomics, although their prices are available only upon inquiry. In the lighting space, there is a degree of standardization and many of the lighting devices support Zigbee-based control even with other manufacturers, however interoperability in this context also leaves a lot to be desired.

Smart windows are manufactured and installed by IQ Glass, Sage Glass, View, and Smart Glass Pro. For further information, investors must contact the company directly. Similarly, various companies (CRODA Industrial Specialties, Microtek Laboratories, Inc., PCM Technology, Sunamp, etc.) offer active building envelope materials and technologies, with prices undisclosed without direct inquiry to the company. Specifically, Solar Volt, Guardian Glass, and Solar Nova offer solutions for installing integrated PVs in buildings, with prices available upon inquiry.

Smart systems based on heat pumps are available on the market from various manufacturers, such as LG, Samsung and others, but prices are only available on request. The authors in [26]state that the average price of a heat pump is €11000 for Europe. It is estimated that by replacing around 35% of total residential boilers operating on fossil fuels in EU with heat pumps would reduce total energy consumption by 36% and their CO_2 emissions by 28% [27]. According to [28], it is expected that the use of heat pumps will on average turn out to be 30% cheaper compared to gas boilers at current gas prices. Similarly, [29], also states that with the rise in electricity and gas prices, savings from switching to a heat pump are also expected to increase. In [30], it is reported that compared to a household drawing energy from the grid and using a gas boiler for heating, a household with solar panels can save up to 64% on their electricity bill, and by using a heat pump, up to 84%, based on 2022 prices.

Figure 2 shows household prices for European countries in the first half of 2023. Among all countries, the Netherlands has the highest electricity prices with more than 0.5 €/kWh, and with Ireland and Liechtenstein just behind it. Belgium and Germany have just above 0.4 €/kWh, while Croatia, Luxembourg and Portugal have around 0.3 €/kWh. Spain with less than 0.2 €/kWh is one of the EU countries with the lowest household prices. Bulgaria and Hungary have the lowest prices in EU, with just above 0.1 €/kWh. For non-household consumers, prices are lower, as given in Figure 3, and are varying between 0.10 and 0.25 €/kWh.

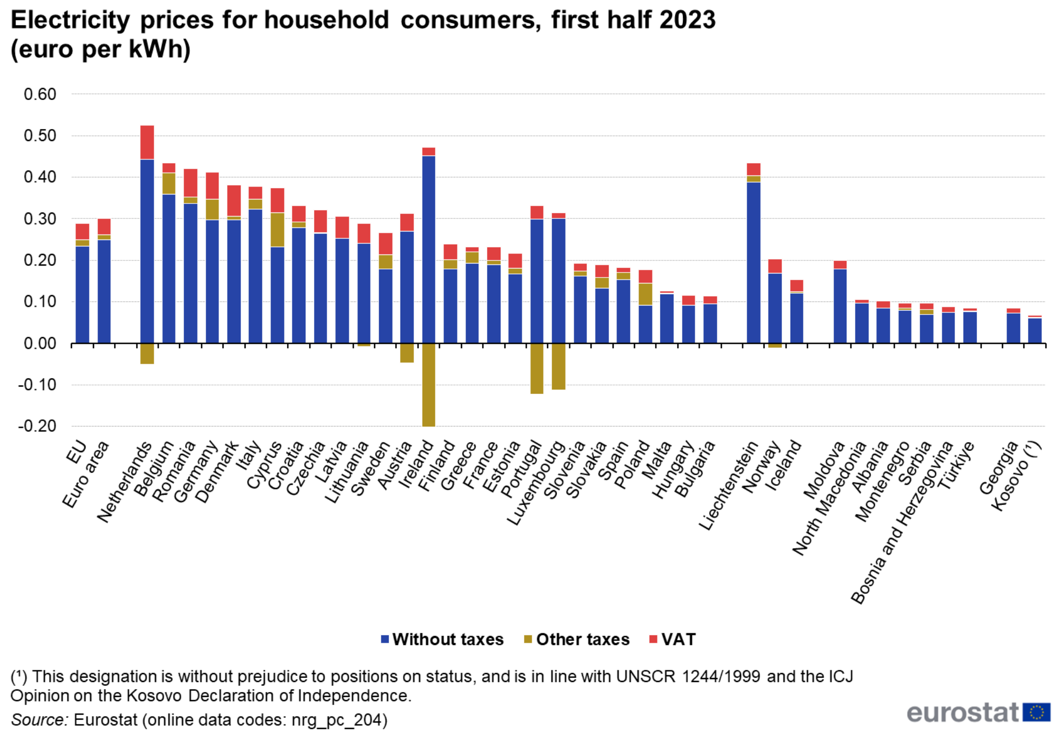

FIGURE 2 HOUSEHOLD CONSUMERS ELECTRICITY PRICES IN THE FIRST HALF OF 2023 IN EUROPE [5]

A caveat must be taken when making decisions based on these electricity prices for end-users. In many countries, there is a degree of implicit subsidies in these prices – so the current values of end-user prices do not fully reflect the economic reality, especially if investment-grade decisions are considered. Therefore, a better long-term driver for economic decisions is based on the estimate of the total cost of energy that would have to be carried by the end-user. This is ostensibly less the case in the energy prices of the non-household (i.e. commercial) end-users, as can be seen from the following figure.

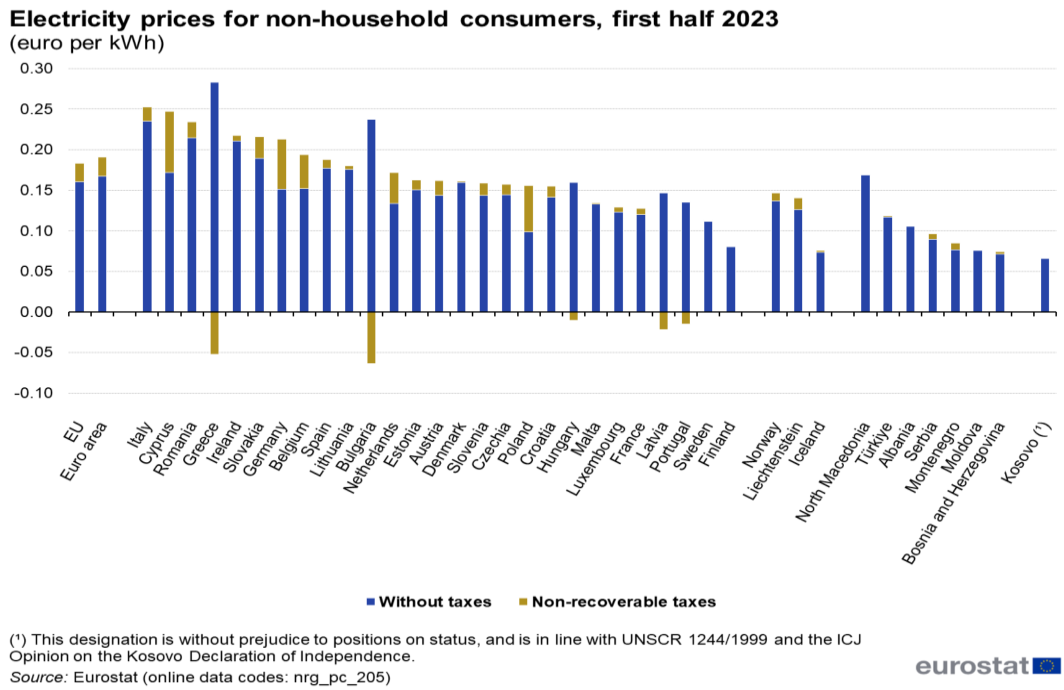

FIGURE 3 NON-HOUSEHOLD CONSUMERS ELECTRICTIY PRICES IN THE FIRST HALF OF 2023 IN EUROPE [5]

2.3.Communication standards

In this chapter we will provide a brief overview of the current communication standards that can be used for various devices in building. Protocols can be used to gather data, for communication between devices, for communication with outside entities or for device control and automation. Also, we mention methods that enable interoperability between devices with different protocols.

2.3.1. IEC 62056

IEC 62056 is a set of standards for electricity metering data exchange by the International Electrotechnical Commission (see APPENDIX A IEC 62056). The IEC 62056 standards are the international standards versions of the DLMS/COSEM specification. Device Language Message Specification (DLMS, originally Distribution Line Message Specification) is the suite of standards developed and maintained by the DLMS User Association (DLMS UA) and has been adopted by the IEC TC13 WG14 into the IEC 62056 series of standards. The DLMS User Association maintains a D Type liaison with IEC TC13 WG14 responsible for international standards for meter data exchange and establishing the IEC 62056 series. In this role, the DLMS UA provides maintenance, registration and compliance certification services for IEC 62056 DLMS/COSEM. Companion Specification for Energy Metering (COSEM) includes a set of specifications that defines the transport and application layers of the DLMS protocol. The DLMS User Association defines the protocols into a set of four specification documents namely Green Book, Yellow Book, Blue Book and White Book. The Blue Book describes the COSEM meter object model and the OBIS (object identification system), the Green Book describes the architecture and protocols, the Yellow Book treats all the questions concerning conformance testing, the White Book contains the glossary of terms. If a product passes the conformance test specified in the Yellow Book, then a certification of DLMS/COSEM compliance is issued by the DLMS UA.

2.3.2. IEC 60870

IEC 60870 is usually utilized in electrical engineering and power system automation (see Appendix A, IEC 60870). Its standards define systems used for telecontrol (supervisory control and data acquisition). Such systems are used for controlling electric power transmission grids and other geographically widespread control systems. By use of standardized protocols, equipment from many different suppliers can be made to interoperate. IEC standard 60870 has six parts, defining general information related to the standard, operating conditions, electrical interfaces, performance requirements, and data transmission protocols. IEC 60870 part 5 provides a communication profile for sending basic telecontrol messages between two systems, which uses permanent directly connected data circuits between the systems. IEC 60870 part 6 provide a communication profile for sending basic telecontrol messages between two systems which is compatible with ISO standards and ITU-T recommendations.

2.3.3. IEC 61850

IEC 61850 is an international standard defining communication protocols for intelligent electronic devices at electrical substations (see Appendix A, IEC 61850). The abstract data models defined in this standard can be mapped to a number of protocols. Current mappings in the standard are to Manufacturing Message Specification (MMS), GOOSE (Generic Object-Oriented System Event, SV (Sampled Values) or SMV (Sampled Measure Values) and to web services. These protocols can run over TCP/IP networks or substation LANs using high speed switched Ethernet to obtain the necessary response times below four milliseconds for protective relaying.

IEC 61850 features include:

- Data modelling – Primary process objects as well as protection and control functionality in the substation are modelled into different standard logical nodes which can be grouped under different logical devices. There are logical nodes for data/functions related to the logical device (LLN0) and physical device (LPHD).
- Reporting schemes – There are various reporting schemes (BRCB & URCB) for reporting data from server through a server-client relationship which can be triggered based on pre-defined trigger conditions.
- Fast transfer of events – Generic Substation Events (GSE) are defined for fast transfer of event data for a peer-to-peer communication mode. This is again subdivided into GOOSE & GSSE.
- Setting groups – The Setting Group Control Blocks (SGCB) are defined to handle the setting groups so that user can switch to any active group according to the requirement.
- Sampled data transfer – Schemes are also defined to handle transfer of sampled values using Sampled Value Control Blocks (SVCB).
- Commands – Various command types are also supported by IEC 61850 which include direct & select before operate (SBO) commands with normal and enhanced securities.
- Data storage – Substation Configuration Language (SCL) is defined for complete storage of configured data of the substation in a specific format.

2.3.4. IEC 61970

The IEC 61970 series of standards deals with the Application Program Interfaces (API) for Energy Management Systems (EMS). The series (see Appendix A, IEC 61970) provides a set of guidelines and standards to facilitate:

- The integration of applications developed by different suppliers in the control center environment;
- The exchange of information to systems external to the control center environment, including transmission, distribution and generation systems external to the control center that need to exchange real-time data with the control center;
- The provision of suitable interfaces for data exchange across legacy and new systems.

2.3.5. IEC 61968

IEC 61968 is a series of standards that define standards for information exchanges between electrical distribution systems (see Appendix A, IEC 61968). It is intended to support the inter-application integration of a utility enterprise that needs to collect data from different applications that are legacy or new and each has different interfaces and run-time environments. It defines interfaces for all the major elements of an interface architecture for distribution management systems (DMS) and is intended to be implemented with middleware services that broker messages among applications. These capabilities include monitoring and control of equipment for power delivery, management processes to ensure system reliability, voltage management, demand-side management, outage management, work management, network model management, facilities management, and metering. It establishes recommendations for standard interfaces based on an Interface Reference Model (IRM). Subsequent clauses of this document are based on each interface identified in the IRM. This set of standards is limited to the definition of interfaces.

2.3.6. IEC 62351

IEC 62351 is developed for handling the security of TC 57 series of protocols including IEC 60870-5 series, IEC 60870-6 series, IEC 61850 series, IEC 61970 series & IEC 61968 series (see Appendix A, IEC 62351). The different security objectives include authentication of data transfer through digital signatures, ensuring only authenticated access, prevention of eavesdropping, prevention of playback and spoofing, and intrusion detection. In essence, it gives detailed advice on protecting energy management systems and on the secure exchange of energy-related data. The series addresses system architecture and identifies a series of effective countermeasures that can be applied to commonly used protocols to protect the confidentiality, integrity and availability of data. It shows users how to implement a risk management process that not only identifies and assesses potential security threats and vulnerabilities but also describes countermeasures to mitigate or eliminate those risks. For example, they include clear definitions of user roles, encryption and authentication to protect against eavesdropping, spoofing and man-in-the-middle attacks, as well as intruder detection and incident response. The standard stresses the crucial importance of pervasive monitoring of the system and provides practical guidance. Systems must be subject to continuous testing during their life cycle because cyber threats are in constant evolution. Properly implemented, IEC 62351 enables the immediate detection of any power supply failure caused by a cyber-attack. It can enhance the protection of power stations and reduce the need for costly upgrades and enhancements during their operating life. It also helps to protect against malicious attacks and disruptions to the power supply, ensuring a reliable and resilient power grid. It provides guidelines for the protection of communications networks and data, as well as the management of security risks.

2.3.7. DNP3 Communication Protocol

The use of Open Standard communications for Supervisory Control and Data Acquisition (SCADA) is well established in an increasing number of utility and industry sectors across the globe. DNP3 (Distributed Network Protocol) is a group of protocols. The IEEE adopted DNP3 as IEEE Std 1815-2010 on July 23, 2010. It plays an important role in SCADA systems, where it is used between system components. The protocol was specifically developed so Remote Terminal Units (RTUs) could communicate with one another. DNP3 is typically used between central masters and remotes that are spread widely. The master links the human and the monitoring system. The remote provides the interface between the master and the actual device(s) being monitored or controlled. Properties of this protocol are, but not limited to:

- request and respond with multiple data types in single messages,
- segment messages into multiple frames to ensure excellent error detection and recovery,
- include only changed data in response messages,
- assign priorities to data items and request data items periodically based on their priority,
- respond without request (unsolicited),
- support time synchronization and a standard time format,
- allow multiple masters and peer-to-peer operations,
- and allow user definable objects including file transfer.

DNP3 uses 27 basic function codes to exchange data between Masters and Remotes. Some of those function codes enable a Master to request and receive status info from a Remote. Other function codes enable a Master to change a Remote’s settings or to control it. DNP3 uses the layered communication model:

- The application layer combines several parts. There’s an application service data unit (ASDU). Then there’s the packaged object. An application protocol control info (APCI) block is added to make an application protocol data unit (APDU).
- The transport layer breaks the APDU into segments with a max size of 16 bytes and combines them with an 8-bit transport control header and 16-bit segment CRC separators into a transport frame.
- The link layer adds a header to the control and address information. The packet is now ready for delivery.

When the packet is sent over a LAN/WAN, the three DNP3 layers are rolled up into the application layer. The assembled packet is wrapped in the TCP by the transport layer, which in turn is wrapped in the IP by the internet layer.

2.3.8. MODBUS

MODBUS is a serial communications protocol originally published by MODICON in 1979 for use with its programmable logic controllers. MODBUS protocol is simple and robust which has become a widely used standard communication protocol for connecting industrial electronic devices. During communications on a ModBus network, the protocol determines how each controller will know its device address, recognize a message addressed to it, determine the kind of action to be taken, and extract any data or other information contained in the message. If a reply is required, the controller will construct the reply message and send it using ModBus protocol.

Modicon originally developed the Modbus protocol in 1978 to exchange information between products on the factory floor. This protocol became a de facto standard for exchanging data and communication information between PLC systems. A relatively simple protocol, Modbus has been implemented by many manufacturers of instrumentation and control equipment to offer system interoperability. Equipment supporting Modbus protocol variants include PLC’s, RTU’s, VFD’s (Variable Frequency Drives), SCADA Hosts, MMI’s, Flow Computers, Power Meters, Power Line Reclosers, Valve Actuators, Intelligent Instruments, and Protocol Converters.

The MODBUS standard defines an application layer messaging protocol, positioned at level 7 of the OSI model that provides “client/server” communications between devices connected on different types of buses or networks. It also standardizes a specific protocol on serial line to exchange MODBUS request between a master and one or several slaves.

Modicon programmable controllers can communicate with each other and with other devices over a variety of networks. Supported networks include the Modicon Modbus and Modbus Plus industrial networks, and standard networks such as MAP and Ethernet.

Networks are accessed by built-in ports in the controllers or by network adapters, option modules, and gateways that are available from Modicon. For original equipment manufacturers, Modicon ModConnect partner programs are available for closely integrating networks like Modbus Plus into proprietary product designs.

Supported by a wide range of manufacturers, Modbus protocol has been the protocol of choice when a single protocol is utilized in a SCADA communications network. A majority of industrial equipment either supports Modbus directly as a native protocol or via the manufacturers or a third-party communication card.

More recently Modbus TCP developed by Modicon has been adopted as industrial Ethernet protocol transporting Modbus protocol over LAN networks.

Enhancements to Modbus include Modbus Plus and Modbus/TCP protocols, both of which allow Modbus information to be encapsulated in a network structure to support peer-to-peer communications. Modbus Plus communicates via a single twisted pair of wires and uses a token passing sequence for peer communication sequences.

Modbus/TCP is an open standard designed to facilitate Modbus message transfer using TCP/IP protocol and standard Ethernet networks.

2.3.9. CSN EN 16836-1

This European Standard gives provisions on the standardization framework of communication systems applicable to the exchange of data from metering devices to other devices within a mesh network. It includes information on the application process functions, layered protocols and metering architecture. This European Standard also specifies how to interpret Parts 2 and 3 of EN 16836 which give a list of references to the ZigBee documents. This standard is applicable to communications systems that involve messages and networking between a meter or multiple meters and other devices in a mesh network, such as in home displays (IHDs) and communications hubs. This standard allows routing between devices and also allows channel agility to avoid contention with other networks of the same type, or networks of other types operating in the same frequency bands. This standard is designed to support low power communications for devices such as gas and water meters which can make data from such devices available on the mesh network at any time through a proxy capability within a permanently powered device NOTE 1: This standard specifies a communication protocol that can embrace a multitude of smart metering architectures from a variety of countries. This standard is not designed to limit, or indeed imply a choice or preference to any one of the many possible architectures, but more over provide information on how devices can use this communications standard to publish and receive information from meters over a network.

2.3.10. KNX CENELEC EN 50090

EN 50090 is a European standard for Home and Building Electronic Systems (HBES) open communications, issued by CENELEC (see Appendix A, CENELEC EN 50090). It covers any combination of electronic devices linked via a digital transmission network to provide automated, decentralized and distributed process control for domestic and commercial and building applications; for example, the control of lighting, heating, food preparation, washing, energy management, water, fire alarms, blinds, security, etc.

2.3.11. Z-Wave

Z-Wave is a wireless communications protocol used primarily for residential and commercial building automation. It is a mesh network using low-energy radio waves to communicate from device to device, allowing for wireless control of smart home devices, such as smart lights, security systems, thermostats, sensors, smart door locks, and garage door openers. The Z-Wave brand and technology are owned by Silicon Labs. Wave system can be controlled from a smart phone, tablet, or computer, and locally through a smart speaker, wireless key fob, or wall-mounted panel with a Z-Wave gateway or central control device serving as both the hub or controller. Z-Wave provides the application layer interoperability between home control systems of different manufacturers that are a part of its alliance. Z-Wave's interoperability at the application layer ensures that devices can share information and allows all Z-Wave hardware and software to work together. Its wireless mesh networking technology enables any node to talk to adjacent nodes directly or indirectly, controlling any additional nodes. Nodes that are within range communicate directly with one another. If they are not within range, they can link with another node that is within range of both to access and exchange information.

2.3.12. IEC 62746

This protocol describes the main pillars of interoperability to assist different Technical Committees (series (see Appendix A, IEC 62746) in defining their interfaces and messages covering the whole chain between a smart grid and smart home/building/industrial area. The main topics covered by this technical report are: architecture model from a logical point of view; set of user stories describing a number of situations related to energy flexibility and demand side management; set of use cases based on the user stories and architecture; details of the communication; identified in the use cases, by describing the requirements for messages and information to be exchanged. This protocol can be leveraged to manage customer energy resources, including load, generation, and storage, via signals provided by grid and/or market operators. These resources can be identified and managed as individual resources with specific capabilities, or as virtual resources with an aggregated set of capabilities. It specifies how to implement a two-way signaling system to facilitate information exchange between electricity service providers, aggregators, and end-users. The DR signaling system is described in terms of servers (virtual top nodes or VTNs), which publish information to automated clients (virtual end nodes, or VENs), which in turn subscribe to the information. The services make no assumption of specific DR electric load control strategies that can be used within a DR resource or of any market-specific contractual or business agreements between electricity service providers and their customers.

2.3.13. SAREF

The SAREF family of standards enable interoperability between solutions from different providers and among various activity sectors on the Internet of Things (IoT) and therefore contribute to the development of the global digital market. These standards are designed to run on top of the oneM2M system, the global IoT partnership project of which ETSI is a founding partner. OneM2M provides the communication and interworking framework to share the data among applications; SAREF provides the semantic interoperability necessary to share the information carried by the data. The starting point of SAREF is the concept of Device (e.g., a switch). Devices are tangible objects designed to accomplish one or more functions in households, common public buildings or offices. The SAREF ontology offers a list of basic functions that can be eventually combined in order to have more complex functions in a single device. For example, a switch offers an actuating function of type “switching on/off”. Each function has some associated commands, which can also be picked up as building blocks from a list. For example, the “switching on/off” is associated with the commands “switch on”, “switch off” and “toggle”. Depending on the function(s) it accomplishes, a device can be found in some corresponding states that are also listed as building blocks. A Device in the SAREF ontology is also characterized by an (Energy/Power) Profile that can be used to optimize the energy efficiency in a home or office that are part of a building.

SAREF function is defined as the functionality necessary to accomplish the task for which a device is designed. For example, actuation function allows to transmit data to actuators, such as level settings (e.g. temperature) or binary switching (e.g. open/close, on/off), while sensing and metering functions allow transmit data from sensors and meters. Each SAREF function must have at least one command associated with it, like on/off/toggle command associated with on/off/toggle function. Depending on the function(s) it performs, a device can be found in a corresponding state. For example, a switch can be found in the on/off state. The state does not have to be binary, because SAREF allows to define n-ary states. SAREF service is a representation of a function to a network that makes this function discoverable, registerable and remotely controllable by other devices in the network. A service shall represent at least one function and is offered by at least one device that wants (a certain set of) its function(s) to be discoverable, registerable and remotely controllable by other devices in the network. Multiple devices can offer the same service. A service shall specify the device that is offering the service and the function(s) to be represented. A device in SAREF can be further characterized by a profile. A profile is a specification associated to a device to collect information about a certain property or commodity (e.g. energy or water) for optimizing its usage in the home/building in which the device is located. Therefore, a profile is linked to a certain property or commodity and can be calculated over a time span and can be associated to some costs.

2.3.14. EEBUS

EEBUS describes the communication interface that enables energy management relevant devices in buildings to connect and interact with each other and with grid and market operators. EEBUS empowers the digitalisation of the energy transition by creating a communication standard that ensures interoperability of all energy-relevant devices and systems across domains. EEBUS defines how the devices should behave within the energy management and how the signals from the different actors should be coordinated and implemented. EEBUS thus enables easy data exchange with the corresponding control systems on the grid and energy trading side. By using EEBUS, the building owners can benefit from lower energy costs, higher comfort and security, and reduced carbon footprint. The grid and market operators can benefit from more flexibility, reliability and efficiency in managing the energy supply and demand.

2.3.15. OpenADR

OpenADR is a communications data model designed to facilitate sending and receiving DR signals from a utility or independent system operator to electric customers. The intention of the data model is to interact with building and industrial control systems that are pre-programmed to take action based on a DR signal, enabling a demand response event to be fully automated, with no manual intervention. The OpenADR specification is a highly flexible infrastructure design to facilitate common information exchange between a utility or Independent System Operator (ISO) and their end-use participants. The concept of an open specification is intended to allow anyone to implement the signaling systems, providing the automation server or the automation clients.

During a Demand Response event, the utility or ISO/RTO provides information to the DRAS about what has changed and on what schedule, such as start and stop times. A typical change would specify one or more of the following:

- PRICE_ABSOLUTE – The price per kilowatt-hour
- PRICE_RELATIVE – A change in the price per kilowatt-hour
- PRICE_MULTIPLE – A multiple of a basic rate per kilowatt-hour
- LOAD_AMOUNT – A fixed amount of load to shed or shift
- LOAD_PERCENTAGE – The percentage of load to shed or shift

In the first three cases, it would be up to the customer to determine how best to participate in the OpenADR event. The last two cases normally shed load automatically based on an existing arrangement. If prices continue to climb higher the EMS may escalate the DR program by reducing or turning off rooftop air handlers during the same peak period. The standard also specifies considerable additional information that can be exchanged related to DR and DER events, including event name and identification, event status, operating mode, various enumerations (a fixed set of values characterizing the event), reliability and emergency signals, renewable generation status, market participation data (such as bids), test signals, and more. For example, aggregated EV charging that can offer significant potential DR value, can benefit from openADR information exchange.

2.3.16. Zigbee

Zigbee is an IEEE 802.15.4-based specification for a suite of high-level communication protocols used to create personal area networks with small, low-power digital radios, such as for home automation, medical device data collection, and other low-power low-bandwidth needs, designed for small scale projects which need wireless connection. It is a low power consumption technology limiting its transmission distance up to 10-100 meters. It is typically used in low data rate applications best suited for intermittent data transmission from a sensor or input device. Its data rate is defined up to 250 kbit/s For home automation Zigbee primarily uses a 2.4 GHz band, while for commercial utility metering and medical devices 902-928 MHz are used. Zigbee builds on the physical layer and media access control defined in IEEE standard 802.15.4. The specification also includes four additional key components: network layer, application layer, Zigbee Device Objects (ZDOs) and manufacturer-defined application objects.

Zigbee Smart Energy 2.0 is a home automation application profile that defines an Internet Protocol-based communication protocol to monitor, control, inform, and automate the delivery and use of energy and water. It can also be used for electric vehicles charging, load control and demand response.

2.3.17. Matter

Matter is an open-source interoperability standard for smart home and IoT devices. Version 1.0 of the standard was published in 2022. It is a specification for how devices should talk to each other and runs over existing protocols: thread for low-power, low-bandwidth devices such as light bulbs and sensors, and Wi-Fi or ethernet for higher bandwidth devices like streaming media players and cameras. This standard is now integrated into every major smart home platform, including Amazon Alexa, Apple Home, Google Home, and Samsung SmartThings. The standard is based on IP and works through one or several compatible border routers, avoiding the use of multiple proprietary hubs. Matter products run locally and do not rely on an internet connection, although the standard is designed to talk to the cloud easily. It is intended to enable cross-platform smart home devices, mobile apps, and cloud services, and defines a specific set of IP-based networking technologies for device certification.

2.4. Similar, ongoing and finished European projects

This chapter provides an in-depth examination of ongoing and concluded European projects, systematically catalogued in Table 1. Focused on flexibility services delivery to the smart grid, particularly within the realm of smart buildings, these projects represent a collective commitment to advancing the landscape of sustainable energy. Each project unravels a tapestry of innovative solutions and state-of-the-art technologies that have significantly influenced the evolution of smart grids across Europe. From sophisticated energy management systems to adaptive demand-response strategies, these endeavours showcase the European dedication to environmental responsibility and technological advancement. By examining these diverse projects in detail, we shed light on their achievements and contribute to a better understanding of the resilient and interconnected future of energy systems.

TABLE 1 LIST OF TOPICS COVERED IN SIMILAR ONGOING AND FINISHED EUROPEAN PROJECTS

	Project Acronym	AI/ML Tools	Distributed Ledger Technologies	Interoperability (flex services, data modeling, data sharing, markets, etc)	ICT Tools for Home Automation	Digital Twins	Hardware Components
1	BD4NRG	+		+			

2	BEYOND	+		+			
3	FleXunity	+	+				
4	MATRYCS	+				+	
5	SYNERGY	+		+			
6	i-STENTORE	+		+			
7	TWINERGY		+	+		+	
8	EPC Recast						+
9	GIFT						+
10	FLEXITRANSTORE			+			
11	INTERRFACE		+	+			
12	OneNet			+			
13	FlexiGrid		+	+			
14	FLEXIGRID	+		+			
15	frESCO			+			
16	INTERFLEX			+			
17	MAGNITUDE			+			
18	PARITY		+	+			
19	SENSEI			+			
20	iELECTRIX	+		+			
21	SYNERGIES	+		+			
22	OpenDei			+			
23	PLATOON			+			
24	REACH			+			

25	InterConnect			+			
26	SmartBuilt4EU				+		
27	FEVER		+	+			
28	BRIGHT		+	+		+	
29	Digital Building Twins (RIA)						
30	eSESH				+		
31	3Smart			+			
32	DT4FLEX			+		+	
33	SemanticLCA						+
34	NATIONTWIN					+	
35	ANIMATION	+		+	+		
36	ENERSHARE	+	+	+		+	
37	BeFlex			+			
38	ENFLATE			+			
39	CERTIFY				+		
40	SUSTAIN				+		
41	REHOUSE				+		
42	MODERATE			+			
43	DEMO-Blog			+			
44	BUILDSPACE			+		+	
45	BuildON				+	+	
46	SMARTeeSTORY	+				+	
47	THUMBS UP			+			

48	EBENTO			+			
49	EVELIXIA			+			
50	DR-RISE			+			
51	FEDECOM			+			
52	BEST-Storage			+			
53	DEDALUS			+			

2.4.1. Horizon 2020 program projects

Multiple building-oriented projects were funded under EU Horizon 2020 funding programme. The project BD4NRG defines standards for big data architectures for smart grids and regulatory frameworks for data sharing [31]. It develops a reference architecture that should enable interoperability of different big data technologies and stakeholders under smart grid standards and operational frameworks. One of the project's aims is to increase the efficiency and comfort of buildings and to optimize the operation of distributed energy resources. Similarly, a big data platform and a reference architecture for building data sharing through smart contracts are developed through BEYOND project [32]. Many other projects such as OpenDei, PLATOON, SYNERGY, SYNERGIES, and REACH deal with the topic of the creation of different reference architectures and open platforms [33][34][35][36][37]. REACH and SYNERGIES aspire to create a European Data Space to gather available data usable for future model creations and, eventually, REACH should develop the European data market. SYNERGIES, on the other hand, covers data-driven solution creation for control and flexibility provision of prosumers (smart buildings, EVs, etc.) to local energy community operators or aggregators and finally network operators, and test them on 3 demo sites. These solutions should ensure a safe and easy coupling of the building and mobility sector with the power systems sector.

Flexibility matter and interoperability of various stakeholders are covered in numerous projects like i-STENTORE, FLEXITRANSTORE, FLEXIGRID, OneNet, frESCO, INTERFLEX, MAGNITUDE, iELECTRIX, and InterConnect. In i-STENTORE, storage systems are integrated into the power systems as active grid components to provide services and contribute to grid resilience, stability, and efficiency [38]. Innovative models for planning the operation of these assets are developed for various sectors including industry, housing, and heating. Likewise, FLEXITRANSTORE develops an electricity grid with battery energy storage as a flexibility source on the distribution side that provides ancillary services to the TSO [39]. An open-source platform with different solutions for enhancing the security, reliability, and flexibility of modern power systems, like PV, demand response, or flexibility forecasts, is developed during the FLEXIGRID project [40]. This platform can be used by various stakeholders including aggregators, suppliers, and DSOs. Due to a large number of power system stakeholders that need to communicate with each other, collaborate, and share data, it is necessary to create a platform that would facilitate their interactions and make them more efficient. OneNet project creates such a platform to facilitate interoperability among different systems and actors with European system and market operators for secure and trusted data and information exchange [41]. They propose new markets, services, and products to achieve a consumer-centric approach to grid operation. Gathering local flexibility from residential buildings by ESCOS and aggregators is solved in the frESCO project [42]. With developed models, the optimized energy performance is financially rewarded both for improving energy efficiency and for providing demand response services. In addition to that, the INTERFLEX project tested how local flexibilities can help with satisfying distribution grid constraints [43]. They created multiple platforms for DSO's flexibility procurement from the aggregators. Various demand response models were tested, as well as the effect the multiple energy sources can have on satisfying distribution network constraints. Multi-energy sources were also the topic of MAGNITUDE project, where the goal was to increase the flexibility of the power system through multi sector interactions and coordination [44].

In addition to simply aggregating the local consumption and offering their flexibility to the power system, the idea of creating local energy communities, which would bring the end consumers greater autonomy and the possibility of participating in the processes of the power system through, for example, peer-to-peer trading, has been under development. This could create greater earnings for the end-users, while the provision of flexibility to the system would at least remain unchanged or even improved compared to the usual aggregation of consumption. The project iELECTRIX demonstrates the real-life development of local energy communities that enable enhanced penetration of RES [45]. In the project, the role DSOs have in the rollout of energy communities providing services for grid stability is investigated. The project addresses the optimal operation of DERs (through forecasting), explicit DR provision, and grid-forming capabilities of local energy communities. Previous projects mostly assumed that the necessary data already existed and that it is available for further use, however, in the InterConnect project, apart from trying to enable the provision of flexibility services to the DSO by households, they descend to an even lower level of the problem and develop advanced models that enable interoperability between different equipment [46]. With their solutions, devices in smart houses and buildings could be exchanged for different ones (different producers) without any difficulty and should be able to continue providing flexibility services to the system.

Certain processes such as offering flexibility, trading on the spot and balancing markets or peer-to-peer trading are modelled in some projects using distributed ledger technologies. In FleXunity, they created AI-based tools for retailers and aggregators that focus on virtual power plant cost minimization and distributed energy resources optimization in the local community [47]. Local community members are secured when sharing their assets for flexibility needs with blockchain transactions. Similarly, in the FlexiGrid, peer-to-peer transactions are based on blockchain technology, and in the project PARITY transactions on developed local flexibility market platform are secured with IoT and blockchain technology [48], [49]. Peer-to-peer trading is modelled based on distributed ledger technology in the project FEVER, as well. Within the project, it is demonstrated how energy storage (stationary batteries and EVs) and demand response (heat pumps, district heating, refrigeration) can offer flexibility to DSOs and what kind of an impact these flexibility services can have on the distribution (and even transmission) grid [50]. Load aggregation and trading solutions for local and wholesale markets are also developed. Finally, in the INTERRFACE project, models of the end-user's electricity market participation based on blockchain technology are created, together with the architecture that acts as the interface between TSO/DSO and the consumers [51].

Multiple projects also focus on creating digital twins of buildings and their flexibility provision to be able to simulate and test wanted real-world behaviour. Digital Building Twins (RIA) created a building digital twin that can, unlike building information modelling, track building and construction process data in real-time [52]. In the MATRYCS project, AI-based models for building digital twins are designed to enhance real-world energy-efficiency improvement [53]. Within the project, a data storage for building data is created. The data storage is intended for selling it to third parties that need it. TWINERGY project introduces a digital twin for energy market participation of end-users with distributed energy sources [54]. A demand response optimization model for end-users considering user comfort is created, alongside a mobile app for consumption tracking and a platform for end-user trading based on blockchain technology. A consumer and local energy community digital twin is created within the

BRIGHT project [55]. During the project was developed a framework for multi-timescale demand response provision for residential end consumers based on the optimization and operational control of individual assets providing balancing services and grid congestion services to achieve financial benefits for various participants of the power system. Also, peer-to-peer trading and energy-sharing mechanisms based on distributed ledger/blockchain/smart contracts are created and multi-energy resources utilization is assumed.

The projects described so far assumed the existence of a smart house that can provide services to the system. The SENSEI project, as well as the projects to be mentioned in the following subsections, will consider ways to increase the building's energy efficiency most effectively and how to convince users to take the necessary actions. In this project, new concepts and business models that will increase benefits from energy renovation of buildings and enhance the engagement of energy providers and third-party investors in improving energy efficiency are created [56]. Moreover, a tool for measuring energy efficiency useful for anyone interested in measuring energy savings is developed. Continuing this topic, the EPC Recast and GIFT projects also deal with hardware components [57] [58]. In EPC Recast, tools are created to enhance the use of Energy Performance Certificates that are used to assess building energy performance. With this, higher support to building owners to invest in building performance is expected to be achieved.

There exists a large number of projects dealing with the topic of providing flexibility to system operators and the topic of buildings as providers of these services. A good number of these projects even has overlapping topics, which is exactly what the SmartBuilt4EU project is dealing with [59]. The project aims to enhance and facilitate information sharing between EU-funded projects and national incentives connected to smart buildings. Another goal is to coordinate their contributions to the field not to overlap to speed up the development of the smart buildings sector based on information and communication technology and smart solutions.

2.4.2. Horizon Europe program projects

As part of the Horizon Europe funding program, which continues to Horizon 2020, many projects deal with the topic of smart buildings and their flexibility provision to the power system as well. Similarly to H2020 projects, the topics include digital twins, distributed ledger technologies, the creation of reference architectures for data sharing, etc. Project ENFLATE proposes consumer-centered flexibility markets, tools, and technologies for providing cross-sector flexibility services to TSOs and DSOs [60]. Similarly, BeFlex models cross-sectoral services and creates interoperable platforms for smart grid operation to increase the flexibility of the power system, improve TSO-DSO coordination, and facilitate the participation of all stakeholders in the operation of modern power systems [61]. Furthermore, the EU-funded ELEXIA project aims to develop new tools for planning and managing integrated energy systems [62]. The project will design a digital services platform hosting energy management and planning services.

Focusing more on the local communities and smart buildings, the project FEDECOM develops tools for easier integration of local energy systems (energy communities) to a power system with increasing penetration of renewable energy sources through sector coupling and cross-energy vectors [63]. They develop a cloud-based platform that offers analysis, modelling, and optimization services for planning and controlling such a system (containing power and gas-based units, HVAC systems, and electric and hydrogen mobility), which will lead to a higher capability of the energy system to maintain stability. An additional positive impact on the system's stability is expected to be achieved from peer-to-peer trading, demand response provision, etc. Within the DR-RISE project, the benefits of providing demand response services in the residential sector for all actors in the power system will be demonstrated [64]. The project aims to create tools for increasing energy efficiency through optimal control of household devices. The solution will be tested in various environments including smart villages, low-income households, energy communities, and urban block of flats, to achieve an all-inclusive solution. The project DEDALUS [65] tries to facilitate and scale up residential energy consumers' massive participation in demand response services and, thereby unlocking the hidden potential for service provision in this sector. The most straightforward way of providing flexibility services by smart buildings is to reduce peak load or to shift the load to reduce the operation cost. Project BEST-Storage is using short- and long-term thermal storage to store renewable energy and to achieve the mentioned cost reduction [66]. The building serving as thermal storage is also the topic of the THUMBS UP project [67]where the aim is to enable an easy integration of thermal energy storage into different types of buildings in the EU on a daily and weekly basis to increase building energy efficiency. To achieve better flexibility provision capabilities of buildings, the investigation of power-to-hydrogen options for providing services to the power system is conducted.

Building energy efficiency improvement is the key matter discussed in projects REHOUSE, BuildON and SMARTeeSTORY. Within the project REHOUSE [68], a solution is developed for accelerated, economically affordable, and efficient building renovations to improve efficiency on the level of the EU. The project proposed solutions like multi-source heat pumps, smart walls, intelligent windows, etc. In BuildON [69], they create tools for optimizing the building's performance (precisely, the operation of technologies such as storage and RES) to continuously monitor and improve energy performance that can be used for various building topologies. They develop a digital twin of the building to enable control simulation and real-time monitoring of the building's systems and devices. The project end goal is to increase the number of buildings with smart devices and digital infrastructure and to help achieve savings in the buildings that cannot be renovated. The focus on the buildings that cannot be renovated is also in the SMARTeeSTORY project [70], more specifically targeting the non-residential historic buildings. During the project, they monitor and optimize the building's energy performance (HVAC, EV charging, lights, dynamic façade, etc.) while considering the user's comfort. The project EBENTO introduces a tool that will collect data to identify energy efficiency improvements in housing [71]. The data will be gathered from device monitoring, energy savings, building information modelling, users' opinions, comfort levels, etc. With this, it is expected to accelerate building renovation processes, including deep renovations of low-income households, because the developed platform will enable easier and better coordination and management for all actors involved in the process.

DEMO-Blog and BUILDSPACE projects cover the topic of building data gathering. In DEMO-Blog, they try to gather data for better building operation, construction, design, and financing [72]. On the other hand, BUILDSPACE tries to improve the quality of the data by coupling the terrestrial data with satellite images and thermal camera drone images of the building [73]. This will be used for the creation of decision supporting tools (like digital twins) that will again improve building operation, construction, renovation, planning, energy efficiency, and other related processes. In the scope of project ENERSHARE an energy data sharing reference architecture was developed, including security solutions and data exchange architectures [74]. Through the project, a marketplace based on blockchain, and smart contracts is also developed. Similarly, MODERATE gives a formalization of a set of procedures and techniques for data sharing among all energy sector stakeholders (from building owners to service companies) according to GDPR and other regulations[75]. They create an open platform enhancing interoperability between datasets and generate synthetic data in order to keep sensitive building information private.

Projects like CERTIFY and SUSTAIN target smart devices. While CERTIFY focuses on securing the IoT devices [76], in SUSTAIN they create "conscious" and "self- and environment-aware" hardware in smart buildings based on novel distributed intelligence and improved sensing accuracy [77].

2.4.3. Other European fundings and initiatives

In the Interreg project 3Smart, building's flexibility services provision to the DSO is modelled [78]. Likewise, CPI's eSESH provides energy management and energy consumption tracking with information and communication technology tools [79]. Within the ANTIMATION project of the Croatian Science Foundation, a residential neighbourhood is providing flexibility services to the power system operator. Demand and flexibility forecasting solutions are created, together with the optimal strategies for energy and reserve market participation based on forecasted market prices [80]. The DT4FLEX project funded by Next Generation EU is introducing a digital twin of the distribution network to manage flexibility services intended for solving technical problems in the network (e.g. over-/under-voltages, overloads, etc.)[81]. Digital twins are also developed under NATIONTWIN project from INITIATE programme of Luxembourg National Research Fund (FNR) [82]. This digital twin represents physical systems and assets in Luxembourg and is used to analyze the effect of certain actions on various sectors, including the energy sector. Another project from the same funding – SemanticLCA, investigates the life cycle of building components [83].

The BRIDGE initiative, led by the European Commission, brings together projects from Horizon 2020 and Horizon Europe focused on Smart Grid, Energy Storage, Islands, and Digitalization [84]. The aim is to systematically address common challenges faced by these demonstration projects, potentially hindering innovation. Through the BRIDGE process, projects engage in ongoing knowledge exchange, enabling them to collectively draw conclusions and make recommendations on the future utilization of project outcomes. There are four working groups handling the main areas of interest:

- The Data Management Working Group focuses on addressing technical and non-technical aspects of communication infrastructure, cybersecurity, data privacy, data handling frameworks, and analytics techniques to ensure secure and interoperable data exchange for projects involving TSO and DSO.
- The Business Models Working Group seeks to establish standardized language and frameworks for describing and valuing business models, evaluate both existing and innovative models from project demonstrations, and is actively developing and testing a simulation tool for comparing the profitability of various business models applicable to smart grids and energy storage solutions.
- The Regulation Working Group is addressing regulatory aspects related to energy storage, emphasizing the need for a clear framework outlining ownership, competition, technical modalities, and financial conditions for both island and mainland cases. Additionally, the group is tackling regulatory challenges in smart grids, including incentives for demand-side response, commercial arrangements, collaboration with TSO and DSO, and the handling of smart meter data.
- The Consumer and Citizen Engagement Working Group focuses on consumer segmentation, understanding value systems, drivers for engagement, effectiveness of engagement activities, identification of behavioral change triggers (e.g., incentives), and regulatory innovation to empower consumers.

Another important initiative is the Built4People partnership, operating under Horizon Europe, which unites the entire value chain to expedite people-centric innovation for a sustainable built environment [85]. The overarching goal of this European partnership is to foster the shift towards a people-centric, climate-neutral, sustainable, and smart built environment.

3. iGFB concepts review

Grid-interactive efficient buildings (GEB) [98][99][100] are energy-efficient buildings that uses smart technologies and on-site renewable energy sources and energy storage technologies to provide demand flexibility, while co-optimizing for energy cost and building users' needs and preferences, in a continuous and integrated operability. This concept integrates various forms of energy (electrical, thermal, mechanical, and chemical energy, etc.) and high level of smartness to create buildings that are not only energy-efficient but also capable to react to the electrical grid flexibility requirements. A new concept emerging from GEBs is the Intelligent Grid Forming Building (iGFB) which elevates the dynamic interaction with the electrical grid form the standard following or supporter, to an active forming role within an interoperable and broader energy ecosystem. The iGFB concept extends beyond traditional smart buildings by incorporating advanced energy generation, storage, and management technologies that enable buildings to actively interact with the power grid and other networks to which they are connected to, such as district heating, gas, water among other possibilities. These buildings can dynamically adjust their energy consumption and production in response to grid needs, market signals, and environmental constraints while optimizing the occupants' thermal comfort and other end-use consumption requirements. The goal of iGFB is to simultaneously enhance its overall efficiency, reduce energy costs, integrate the growing share of variable renewable energy, reduce costs to replacing aging electricity system infrastructure and improve system reliability and contribute to grid resilience.

This review delves into the concept, features, and operational strategies of iGFB, highlighting its potential to accelerate the energy transition toward a zero-emission and fully decarbonized building stock by 2050 in EU [101].

In the European Union, energy use in buildings accounts for 40% of total energy consumption and one third of energy-related greenhouse gas emissions. It's important to note that around 80% of energy demand in residential buildings is for thermal comfort and hot water. The recently revised Energy Performance of Buildings Directive (EPBD) [102]and Energy Efficiency Directive [103] set the targets of reducing the average primary energy use of residential buildings by 16% by 2030 and 20-22% by 2035 and climate neutrality by 2050, in line with the EU's increased climate ambition under the European Green Deal [104]. The directives identify the digitization of energy systems for buildings and the deployment of infrastructure for better integration of energy systems for heating, cooling, ventilation, electric vehicle charging and renewable energy as key measures. While these regulatory efforts define the baseline of the iGFB approach, they are an important lever to achieve such an energy transformation of the building stock. One of the most important key steps is the proposal to establish the definition of a Smart Readiness Indicator to assess the ability of the building to adapt its operation to the needs of the occupants and the electrical grid, thereby improving its energy efficiency and overall performance.

The Smart Readiness Indicator (SRI) shall include essential features for improving energy savings, benchmarking performance levels, and enabling flexibility, enhanced functionality and capabilities resulting from more interactive equipment and energy management system and smart devices such as smart meters, building automation and control systems, self-regulating indoor air temperature devices, embedded household appliances, electric vehicle charging infrastructure and energy storage technologies. The methodology will identify detailed functionalities and interoperability standards for the implementation of these functionalities.

It is generally recognized that the benefits and advantages of iGFBs for improving the overall energy efficiency of the built environment, enhancing grid reliability, and as a vehicle for increasing the penetration of renewable energy sources are not limited to, but are particularly relevant for, urban areas. However, its adoption and widespread implementation require overcoming some barriers that still need to be addressed, namely related to countries' regulatory frameworks, some technological challenges of smart building technologies and definition of interoperability standards, the high up-front costs of implementing iGFB capabilities, current market designs which in most cases are not ready for new services provided by the building-grid interaction, and privacy and security. On the societal side challenges on privacy and data security is often risen of object of concern as the iGFB operational concepts rely on the collection and analysis of large amounts of data for the internal optimization of their energy processes, but also to interact with the grid for services provisioning and to participate in aggregation initiatives as energy communities. Finally, public awareness and engagement is an important turning point in the adoption of iGFBs, as the deployment of such a complex concept involves a wide range of stakeholders, including building owners, occupants, policy makers, utilities, market agents, system operators, among other others, who normally do not share a common understanding of the benefits and opportunities of iGFBs. Overcoming scepticism and early adoption resistance to complex and highly technical concepts such as the Intelligent Grid Forming Buildings can be achieved through the standardization of interoperable processes and platforms, which is essential for widespread adoption.

The iGFB concept represents a paradigm shift in how buildings interact with the energy grid, moving from passive consumption to active participation. By integrating energy efficiency, renewable energy sources, energy storage, and smart technologies, iGFB can significantly contribute to grid stability, efficiency, and sustainability. The operational strategies of iGFB highlight the potential for buildings not only to meet their energy needs more sustainably but also to support the grid in managing the challenges associated with renewable energy integration and demand variability. As this field evolves, further research and development will be essential in realizing the full potential of Intelligent Grid-Forming Buildings in the transition towards a more sustainable and resilient energy future.

3.1. Key features of Intelligent Grid Forming Buildings

The iGFB concept is a step beyond smart buildings that interact with the grid, nonetheless it shares the same basilar features responsible for its high energy efficiency, already stablished for NZEBs for example. There are key features that characterizes the concept:

- Energy efficiency
- Renewable energies
- Smartness
- Connectivity and interoperability
- Load flexibility and energy storage
- Grid Interactivity

The iGFB concept describes the features of a whole-building integrated approach that goes beyond individual technologies energy efficiency or particular optimal usage. As result of optimizing the balance of these attributes defines the type of iGFB in general, these buildings are able to provide efficient services and dynamic grid services through the interconnected and intelligent management of multiple flexible loads and renewable energy sources generation, with a positive impact on building operating costs.

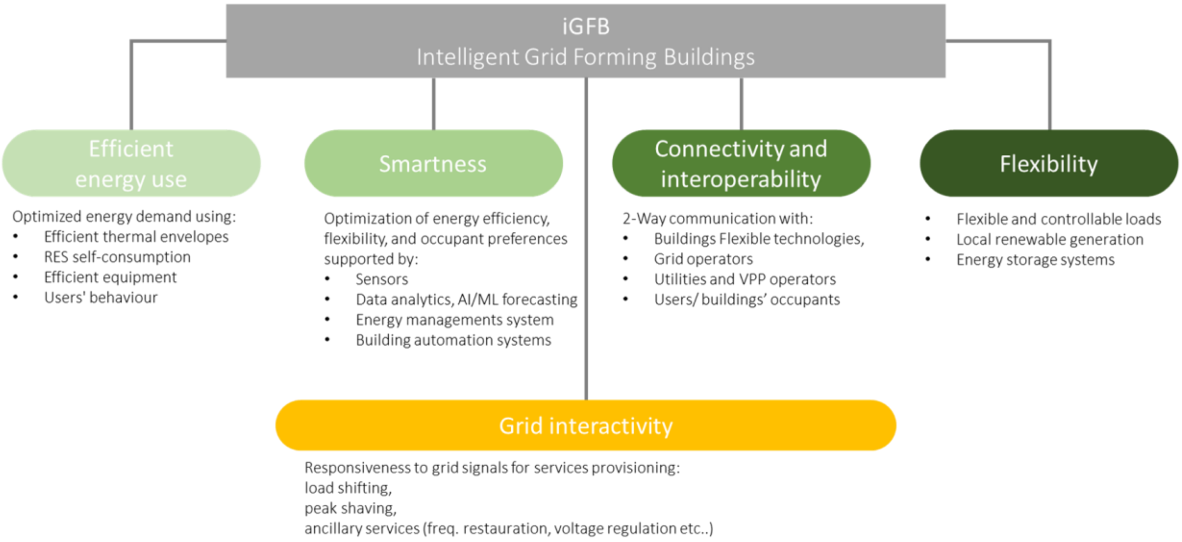

FIGURE 4 KEY ATTRIBUTES OF INTELLIGENT GRID FORMING BUILDINGS

The buildings are distinctive, each configuration, depending on its function, type of occupancy and technologies available will dictate the potential functionalities that can be offered from many possibilities, such as the most addressed flexibility-based ones:

- Adapting the scheduling of active heating loads without compromising the operational temperature in acceptable thermal comfort intervals.
- Make use of thermal storage change the heat loads profiles
- Optimize EV charging, while still ensuring that the vehicles are adequately charged according to user preferences/needs.
- Provide V2G response services, injecting power back into the grid when recruited by the System Operators or aggregators in exchange for market indexed remunerations or other contracted benefits.
- Store electricity, heat or cold to reduce the load on the respective networks.
- Sell back stored energy to the networks or neighbours' buildings when it is more valuable.
- Provide accurate predictions of the building's fluctuating loads.

Most of the technologies that support this type of building are in use today. However, connectivity and a certain level of intelligence and control are required to enhance and capacitate high-performance buildings with grid-forming capabilities.

3.1.1. Energy Efficiency

From the design and planning phase, iGFBs are intended to be operated passively or actively, with a strong emphasis on energy efficiency. Consistent low energy consumption minimizes the demand of grid resources and infrastructure. iGFBs can reduce the baseline load of a lowering overall energy use. Thermal behaviour, for example, is one of the most conventional key features toward energy efficiency improvement in builds. High-performance building envelopes are achieved using advanced construction materials, glazing and designs to minimize heat losses in winter and heat gains in summer, thereby reducing heating and cooling requirements, which are met by high-efficiency HVAC systems that minimize the power consumption associated with thermal comfort. The architectural design of the building itself can maximize natural light and ventilation, reducing the need for artificial lighting and mechanical cooling. The use of energy-efficient appliances and other electrical systems, such as LED lighting and more efficient whiteware appliances, typically more energy intensive, are further energy-efficient measures to improve the energy performance of this building.

3.1.2. Renewable Energy sources

The integration of on-site renewable energy generation is the most common feature that characterizes iGFBs, enabling these buildings to produce decarbonised energy, reduce reliance on the grid and open up the possibility of participating in aggregation schemes such as Energy Communities. Solar PV, installed on roofs and integrated into facades and even windows (e.g. screen-printed dye-sensitised PV), is the most widely used renewable energy generation technology installed in buildings, but small wind turbines and small hydro can also be used in certain locations where the renewable resources are available and justify their instalation for electricity generation. Geothermal systems combined with heat pumps have attracted more attention in recent years as they significantly reduce energy consumption by using the earth's stable temperature for heating and cooling to support air conditioning systems and domestic hot water heating, reducing the thermal step that needs to be corrected. However, the inherent intermittency and variability of RES pose some challenges for building energy management, which the iGFB approach is particularly well suited to address. Advanced energy management systems, using predictive analytics (e.g. machine learning forecasts) of both energy production and consumption, are used to control local energy storage systems to mitigate these issues.

3.1.3. Smartness: Monitoring and Control Systems

Advanced monitoring and control systems are central to the operation of iGFBs, providing real-time data and automated control over the building's energy systems. Smart technologies and energy management systems have real potential to deliver energy savings and load flexibility. Technologies like IoT (Internet of Things) applied to the most diverse interconnected sensors networks and actuators, are enablers for energy use optimization processes through data analytics and AI/ML predictive algorithms within the same ecosystem, a Smart Energy Management System. These solutions enable two-way communication between buildings and the grid, providing a link that allows utilities or other authorised entities to manage energy demand. Analytics supported by sensors and controls are then used to co-optimize efficiency and occupant preferences and flexibility to meet grid needs (voltage regulation, frequency restoration, congestion management, etc.). Predictive controls can be particularly useful for energy management and grid interactivity due to their ability to predict and optimise across multiple inputs in real time, adjusting flexible loads based on occupancy patterns, weather conditions and market prices, enabling load shaping and flexibility in the building for different timeframes of market operations, such as intra-day and day-ahead, or even for shorter-term responses when considering local markets, for example as part of Energy Communities or other aggregation platforms such as VPPs.

Typical two different layers of intelligence are distinguished:

- Energy Management Systems (EMS):

Predictive energy management software or algorithms designed to optimize multiple end-uses in the buildings and the energy resources including local renewable energy generation and storage. Optimization operations over a time window, incorporate forecasts using analytical approaches and machine learning techniques taking into account inputs as, e.g., weather, renewable energy generation, occupancy patterns, grid management requirements and day ahead markets information. Adaptive learning algorithms are continuously improving energy management strategies based on historical analytics, enhancing the building's ability to optimally managed their end-use consumption a to support grid needs. EMS is a central component to orchestrate storage and other sources of scheduling flexibility to proactively shape energy use over the different time scales, and to effectively respond to grid needs while minimizing the impact on buildings central activities, their occupants' overall energy use and comfort.

- Building Automation Systems (BAS):

Gathers all technologies for control and automation of the building's systems in response to various aspects over time to reflect changes in building assets and usage to improve comfort, efficiency and to actuate on flexible loads in response to the grid requirements for services provisioning or markets participation. BAS implementation requires, of course, certain level of local communication and end-use control, such thermostats and humidity sensors, capable of interacting with supervisory control and adjusting set points based on external signals, which is typically guaranteed under the Supervisory Communication and Control [10][11].

The integration of both EMS and BAS at the single-building scale can be cost-prohibitive. Therefore, its design and implementation should be done keeping in mind criteria of interoperability becoming more cost-effective to integrate and optimize DERs across several buildings. In this way, it is increased the effectiveness of integration of multiple grid-interactive resources using a common/interoperable control platforms capable of targeting numerous benefits on both the buildings' operators and system operators' side that would otherwise not be realized.

3.1.4. Grid interactivity

The interaction of iGFB with the grid and the other surrounding buildings and assets as EV public charging infrastructure or lightning, for example, requires two-way communication responding to time-dependent events, such as flexibility services provisioning. Any interaction of the building with the external parties through an energy carrier is denominated Building-to-X (B2X), such as the building-to-grid (B2G) interactivity in the case of electricity and capacity exchanges, and requires high level of interoperability, meaning both sides are able to communicate with each other given that from a technical point of view, devices must be capable of both physical and digital integration and basic connectivity, using syntactic and semantic standardized commons. iGFBs must be prepared to exchange information with grid operators, utilities, aggregators, and the facility manager/building operators.

There are two main aspects to ensure interoperability in-between the different technology layers of the intelligent grid forming buildings (Figure 5) but also enabling communication with grid operators and electricity markets:

- Interoperability and intelligence between buildings' energy management and automation systems
- Interoperability and building-to-grid intelligence

Intelligent grid-forming building should rely on a single, transversal intelligent system for controlling active energy-consuming systems, but that also have the potential to provide flexibility, whether through scheduling or storage capacity, such as HVAC, lighting, plug loads, thermal or electrical storage, and other major building loads. Without interoperability and intelligence between systems, buildings will not realize their full potential manage the energy demand and interact effectively with the grid in response to, for instance, price signals. Currently control systems vary widely by building functional type (residential, commercial, industrial), size, and construction age, and most building controls are not set up to coordinate across building systems. More efforts still need to be made in this sense, whether in terms of the renovation of existing buildings as for new constructions. The recent Smart readiness indicator is a significant step forward in this direction (Smart readiness indicator) [107].

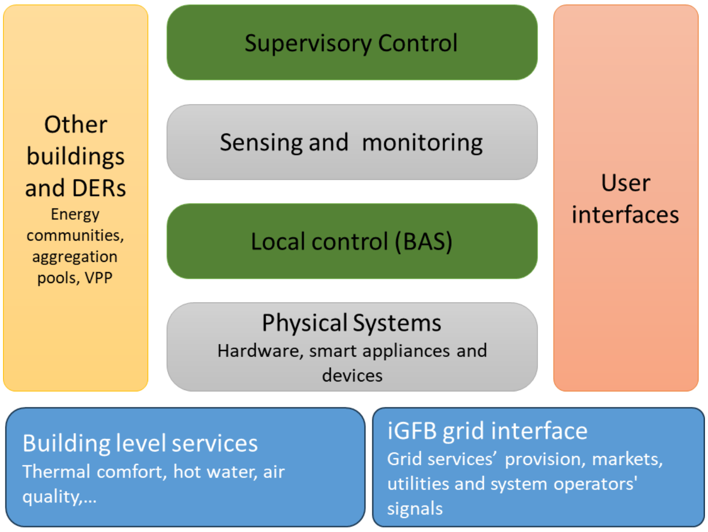

FIGURE 5 TECHNOLOGY AND INFORMATION LAYERS IN IGFBS

On the interaction side, iGFB need to be able to respond automatically to signals from the grid and receive and share the availability of flexible loads within the building to modulate and optimize its flexibility and renewable generation. The communication between building management side and system operators has been hampered by the lack of context and, more importantly, by the lack of a regulatory frameworks driving the development of interoperability criteria. Open communication protocols are important tools to guarantee interoperability and automated control. In recent years, new regulatory frameworks have come into force across the European Union's countries, in response to the EU directives REDII [108], EMD [109], promoting the creation of demand response programs, collective self-consumption and sharing groups, as the case of renewable energy communities and citizen energy communities. Interoperable digital communication is in this context the enabler for managing distributed energy resources in aggregation scenarios operated as a unified system, such as a virtual power plant, in which it can be monitored and managed electricity generation, consumption and storage across multiple sites between system and community virtual power plants.

3.1.5. Smart readiness indicator

In the European context, the smartness and ability to interact with the grid has been under discussion and define since defined in 2018 revision of the European Energy Performance of Buildings Directive (EPBD)[102], the Commission Delegated Regulation (EU) 2020/2155 [107], the Smart Readiness Indicator. It consists of a readiness indicator rating of a building dependent on its capacity to accommodate smart-ready services, refereeing to its ability to sense, interpret, communicate, and actively respond actively and efficiently in an efficient manner to the demands from building occupants, the operation of technical building systems and the external environment, namely to energy grids.

The main objective of the SRI is the promotion of new regulation and incentives towards the integration of cutting-edge smart technologies in buildings, such as building automation and electronic monitoring of building systems including heating, cooling, domestic hot water, ventilation, lighting, dynamic building envelope, electricity, electric vehicle charging, monitoring and control.

The SRI rates were designed to assess the capability of the buildings' systems to optimize energy efficiency and overall end- use performance, adapt their operation to the needs of the occupants and adapt to signals from the grid (for example energy flexibility).

The Smart Readiness Indicator has been progressively tested towards its regulation and implementation in most of EU countries, and 11 of them are currently running official test phases supported by national governments and energy agencies: Austria, Belgium, Croatia, Cyprus, Czech Republic, Denmark, Finland, France, Germany, Slovenia and Spain development. Some of the tests phases have been ran in the scope of the LIFE Clean Energy Transition sub-programme [110], but other in some of the counties already created national frameworks, consolidated methodologies, training capacities and official calculation tools developed (Table 2).

TABLE 2 SMART READINESS INDICATOR IN EU COUNTRIES [110]

Projects /Countries	SRI2MARKET [111]	easySRI [112]	tunES [113]	SRI-ENACT [115]	Smart² [113]	SmarterEPC [114]	iEPB [116]	Official test phase
Austria	✓	✓	✓	-	-	-	-	✓
Belgium	-	-	-	-	-	-	-	✓
Bulgaria	✓	-	-	-	✓	-	-	✓
Cyprus	-	-	-	✓	✓	-	-	-
Czech Republic	✓	✓	-	-	✓	✓	-	✓
Denmark	-	-	-	✓	-	-	-	✓
Finland	-	-	-	-	-	✓	-	✓
France	✓	-	-	-	-	✓	-	✓
Germany	-	-	-	-	✓	-	-	✓
Greece	✓	✓	✓	✓	✓	✓	✓	-
Hungary	-	-	✓	-	-	-	-	-
Italy	-	✓	✓	-	✓	✓	-	-
Netherlands	-	✓	-	-	-	✓	✓	-
Poland	-	-	✓	-	-	-	-	-
Portugal	✓	-	-	-	-	-	-	-
Romania	-	-	-	✓	✓	✓	-	-
Slovenia	-	-	✓	-	-	-	-	✓

Spain	✓	✓	-	✓	-	-	✓	✓

3.2.iGFB Operational Strategies

The possible operational strategies illustrate the multifaceted role iGFBs can play in the energy sector. By integrating advanced technologies and engaging in proactive energy management, iGFBs not only enhance their own sustainability and efficiency but also contribute significantly to the overall resilience, sustainability of the power grid.

Through the combination of energy efficiency measures, renewable energy generation, energy storage, and advanced control systems, iGFBs are able to pursue different operational strategies that support grid formation and stability. These strategies include real-time energy management, participation in energy markets, provision of ancillary services, and adaptive response to grid conditions.

Energy efficiency

Energy efficiency measures can lead to significant reductions in energy consumption while maintaining or improving the internal functional activities of buildings. Energy efficiency programs or strategies differ from demand response in that they are not designed and implemented in a logic of active load adjustment, but rather to manage the overall functioning of the building during its habitual use for long periods of time. These can include replacing equipment with more efficient models and technologies, improving the building's thermal envelope performance or adjusting operating temperature set points on a permanent or seasonal basis. Figure 6 shows an example of the effect of energy efficiency measures on the power demand, shifting from a higher (blue curve) to lower consumption (green curve).

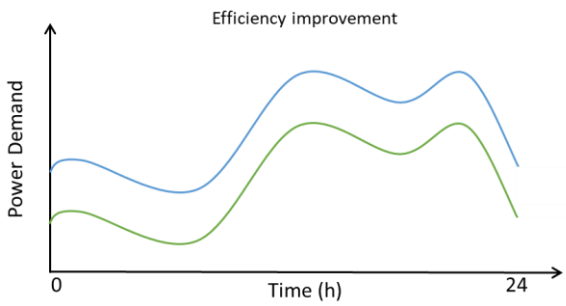

FIGURE 6 ENERGY EFFICIENCY IMPROVEMENT PROFILE EXAMPLE

Load shed

Electricity use reduction for a short time-period and typically on short notice. Shedding is typically dispatched during peak demand periods and during emergencies in response to DR programs and energy market signals. Figure 7 illustrates how load shedding reduces consumption peaks, contributing to a flatter load profile (green curve).

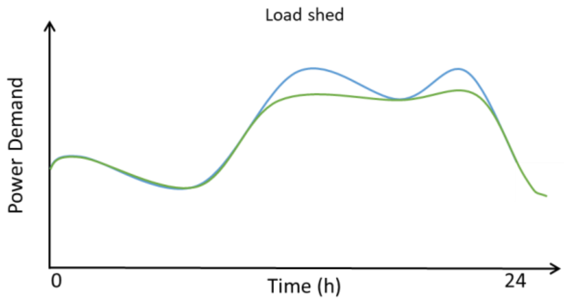

FIGURE 7 ENERGY LOAD SHED PROFILE EXAMPLE

Load shift

Load shift involves the change of the timing of energy consumption, minimizing demand during peak periods, taking advantage of lower electricity prices, or reducing the need for renewable electricity generation curtailment. Load shifting can be implemented by rescheduling certain loads or using energy storage systems. can be implemented by rescheduling certain loads or using energy storage systems that are loaded at more advantageous periods and provide energy during peak periods. An example of load shift is presented in Figure 8, where the energy consumed during the peak period in the middle of the day is shifted towards the previous valley period.

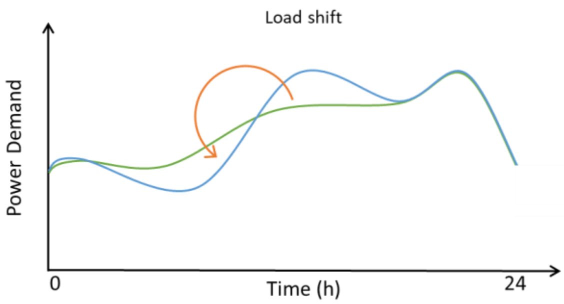

FIGURE 8 ENERGY LOAD SHIFT PROFILE EXAMPLE

Modulation

Modulation of the electrical load enables the capability to provide small-scale, distributed grid stability and balancing services by automatically increasing or decreasing a building's power or reactive power draw/production in response to external signals, usually directly from the grid operator. Figure 9 presents an example of the effect modulation on the power demand curve.

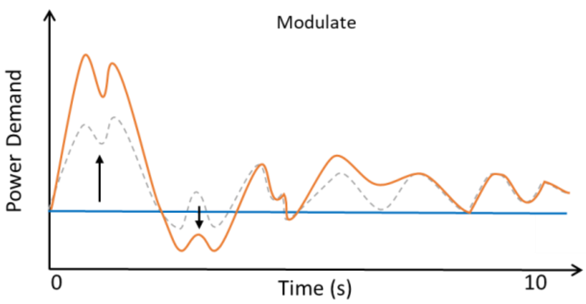

FIGURE 9 POWER DEMAND MODULATION PROFILE EXAMPLE

Generation

Intelligent grid-forming buildings have the potential to locally generate electricity and send it to the grid in response to market signals. Local generation of electricity from renewable energy sources, such as rooftop and building integrated photovoltaic (BIPV) technologies, are the most common, but other systems such as small wind turbines, small hydro, natural gas fired fuel cells and micro combined heat and power (micro-CHP) systems are also being deployed. The use of energy storage systems is typically used to provide a flexible dispatch mechanism to maximise the value of responding to wholesale spot market price levels or peak system conditions.

3.3. Load flexibility

Intelligent Grid Forming Buildings can provide ancillary services such as frequency regulation, voltage control, peak shaving, congestion mitigation and other potential flexibility derived functionalities. Flexibility is achieved through the ability to actively manage the internal load resorting to the load shedding, shifting, and modulating making use of the energy storage technologies combined with local renewable generation. While energy efficiency and self-generation, such as solar PV, can reduce and energy needs during production periods, they can also put stress the grid, depending on when the energy is locally consumed or injected into the grid. For example, solar PV can reduce energy loads during the day but may also require steep supply ramping when the sun goes down and other types of supply or storage resources are needed to meet the buildings' loads. Being able to interact with the grid iGFB systems can help smooth these peaks by shifting demand from the peak demand periods to higher peak supply times.

An important attribute to define the type of grid services that can be offered by is the reaction time of the system as response of an automated signal. In general, fast responding controls, communications and loads can provide a wider range of grid services. This feature is also determined by the existence of energy storage technologies in the buildings.

Energy Storage Systems (ESS) are a critical technological asset for the successful implementation and functionality of iGFBs flexibility by default. ESS are an efficient solution for optimizing the integration of renewable energy, allowing for the storage of electrical energy for use during peak demand periods or when renewable generation is low increasing this way the building's energy self-consumption, and reducing energy-related costs, as well as for potentially supporting the electricity grid by providing diverse flexibility base services. The reaction time of EES can range from milliseconds in the case of Li-ion Battery Energy Storage Systems (BESS) to several minutes if the case of Thermal Energy Storage (TES). TES are particularly interesting for load shifting the loads by storing cold, e.g. using ice storage or water tanks that can store chilled or heated water for later use, contributing to heating and cooling needs in an efficient manner.

The buildings automation systems should be able to track building demand, predict patterns that can help to limit peak demand, and quickly shift or reduce demand in response to grid or building events. These capabilities are defined as Demand Side Management (DSM), the capacity to modify the energy demand strategies, including energy efficiency, demand response, distributed generation, energy storage, electric vehicles, and/or time-of-use pricing structures. and are based in predictive analytics of renewable energy generation, buildings operational needs and load flexibility offered by the optimal operation of the buildings.

Load flexibility has been used in load management and demand response (DR) programs since the 1970s in US [118]. Utilities send signals to customers to take actions to reduce or shift load at certain times. In some cases, the utility can initiate such changes remotely, for example by turning off central air conditioners for short periods to reduce electricity demand. Demand response approaches are more dynamic than early load management programs and typically include some price signal from the grid operator to encourage customer action to reduce their consumption. iGFBs are particularly attractive for DR programs. Different strategies can be adopted according to the building's functional type, consuming equipment, and flexible loads, to automatically adjust their energy consumption in response to grid signals or electricity price fluctuations. DR programs can be managed through bilateral agreements between building owners or facility management companies and the local DSO, or as part of larger resource pools such as VPPs managed by Energy Service Companies (ESCOs) or aggregators responsible for participating in energy and balancing markets. Depending on the configuration and capabilities of the iGFB, demand response can be classified according to the potential dispatchability of the system, which will define the respective suitability for different demand management strategies, e.g.:

- Dynamic Load Adjustment: Temporarily reducing non-critical loads or adjusting HVAC setpoints during peak demand periods or when electricity prices are high.
- Advanced Scheduling: Precooling or preheating buildings during off-peak hours to reduce demand during peak periods.
- Participation in DR Markets: Offering controllable loads as a resource in demand response markets, providing grid operators with additional flexibility.

3.4.iGFB and Network Services

Traditional power systems were characterized by unidirectional power flows from large centers of electricity generation to final electricity consumers. Final electricity consumers were mainly passive, and their consumption was easier to predict, especially on a network or system level. Moreover, large power plants were connected to transmission networks, making the planning and operation of distribution networks not too complex. Also, the output power of conventional power plants could be regulated, which made balancing total generation and consumption, i.e. frequency regulation, easily achievable. In some cases, larger, mostly industrial consumers, could change their electricity consumption based on a system operator’s signal. Such balancing services are required for the safe and reliable operation of both transmission and distribution networks. Balancing services are not the only service requested by system operators. All such services are defined as ancillary services, services necessary for the operation of a transmission or distribution system. According to the Croatian Electricity Market Act (Official Gazette 22/13, 102/15, 68/118, 52/19) [86], ancillary services are defined as available single services necessary for the provision of power system services. Ancillary services are procured by TSO from end-users capable of provision of power system services. The rules on the provision of power system services are defined in the contracts between the TSO and service providers. The green energy transition has led to changes in power systems and the share of renewable energy sources is continuously increasing, decreasing the total generation of conventional power plants. Since renewables-based electricity generation is variable and more complex to predict, they increase the need for flexibility in power systems. Furthermore, renewable power plants cannot provide ancillary services within the same range as conventional power plants. To balance renewable energy generation variability, there is an increasing need for new flexibility providers. Even though renewable power plants are part of balancing responsible groups, in some cases their variability and uncertainty cannot be balanced with the group, and additional flexibility is required. Even though there are large renewable energy-based power plants connected to transmission networks, many of them are also connected to a distribution level, making distribution generation an important factor in total electricity generation. Distributed generation (DG) creates the same challenges as large renewable power plants, and even though DSOs are in general not responsible for regulating frequency, often uncoordinated integration of DGs creates other problems (e.g. congestion, reverse power flow) and creates the need for additional ancillary services. Distribution networks also face the integration of other distributed energy resources (DERs) such as heat pumps or electric vehicle supply equipment (EVSE), as a direct product of electrification of heating and transportation systems.

All technical problems created by RES and other low carbon (LC) technologies can be mitigated by reinforcing a network, i.e., by replacing existing transformers, lines, and cables with new ones with higher capacity, by installing new controllable generation capacities, or by battery energy storage systems. However, such approaches are expensive, especially in cases where problems occur only for a limited number of periods. Lately, the focus has been switched from capital expenditures to operating expenditures, in which problems are solved by ancillary services in which flexibility providers react to a signal sent by a responsible entity and help in mitigating the issue. One of flexibility providers are iGFBs, by increasing or decreasing their consumption and either standalone or aggregated, provide grid services to TSOs, DSO, suppliers, aggregators, etc. Such buildings are the focus of the WeForming project. In this deliverable, more general information about flexibility (ancillary) services the iGFB can provide to the power system is provided, with emphasis on the services to TSOs and DSOs.

3.4.1. Demand-side flexibility

The flexibility provided by iGFBs is part of demand-side flexibility (DSF). As per multiple sources, demand-side flexibility can be divided into load, demand-side generation, and demand-side storage. iGFBs mostly provide flexibility services by answering signals to change electricity consumption through controllable devices. However, locally installed generation units can also provide ancillary services, such as voltage control. Thanks to the thermal inertia of building spaces, buildings can serve as thermal storage, providing flexibility without disrupting the comfort of final consumers.

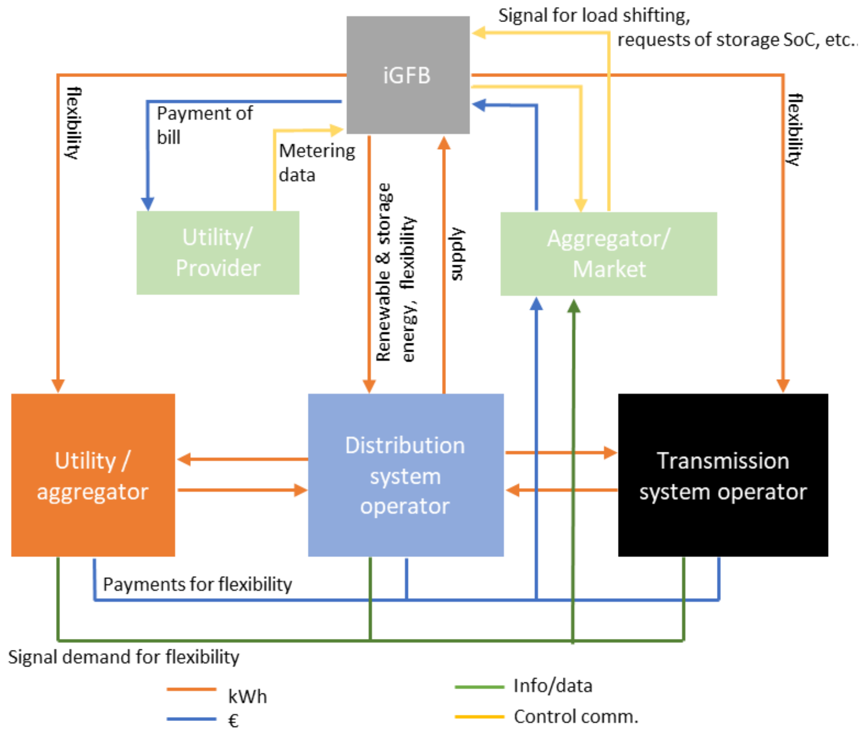

FIGURE 10 FLOWDIAGRAM OF A GENERIC EXAMPLE OF A IGFB SUPPLYING FLEXIBILITY SERVICES TO GRID

One of the biggest challenges is convincing end-users to provide flexibility services when necessary. Therefore, flexibility is becoming a market product in which consumers have financial or some other benefits. There are two market mechanisms for providing demand-side services [87]: implicit DSF, where consumers choose to be exposed to time-varying electricity prices and/or network tariffs, and explicit DSF, where consumers choose to participate in energy markets (e.g. through an aggregator) and receive payments in return for the load variation offered and accepted on the market (Figure 10).

Both in cases of implicit and explicit DSF, flexibility requests made by TSO or DSO often cannot be met by a single consumer. Therefore, most buildings are aggregated, and, through an aggregator, they provide aggregated flexibility. In this case, TSOs and DSOs define the products that smaller flexibility units can offer, and aggregators are responsible for defining a business case and technical solution for the aggregation [88]. However, building owners or occupants are in some cases motivated by environmental or other nonfinancial considerations.

Flexibility services can be differentiated by technical characteristics including the direction of a service (upward/downward), capacity and energy of service (kW vs kWh), availability and predictability, activation time and location of a flexibility provider (transmission/distribution network) [89].

Even though flexibility services provided by buildings and demand-side in general are often market-based, their main goal is to avoid problems in a given network. Therefore, they are defined as grid or network services, i.e., services that support the generation, transmission, and distribution of electricity and provide value through avoided electricity system costs [4].

All grid services benefit the grid across the three major dispatchable categories: energy, capacity, and ancillary services. Some of these grid services provide benefits to the grid by avoiding or deferring T&D upgrades and associated capital expenditures, which can prevent utility customer rate increases. There are numerous benefits that both the utility system and society can realize from utilizing demand-side management strategies, including:

- Increased system reliability and resilience
- Increased DER integration
- Improved power quality and reduced customer outages
- Increased owner/occupant satisfaction, flexibility, and choice
- Reduced generation capacity, energy, and ancillary service costs
- Reduced utility operation and maintenance costs
- Reduced T&D costs and losses
- Reduced environmental impacts, including carbon dioxide emissions
- Reduced environmental compliance costs and greater economic development [4]

Grid services refer to services that support the generation, transmission, and distribution of electricity and provide value through avoided electricity system costs (generation and/or delivery costs) [4]. European Smart Grids Task Force defines following network (grid) services and mention markets on which these services can be purchased in their report on demand-side flexibility [90]:

1) Constraint management (TSO and DSO):
    - Voltage control
    - Grid capacity management

- Congestion management
- Controlled Islanding

2) Adequacy (TSO and BRP):
   - Capacity payment
   - National capacity market
   - Strategic reserve
   - Hedging
3) Wholesale (BRP):
   - Day ahead optimization
   - Intraday optimization
   - Self/passive balancing
   - Generation optimization
4) Balancing (TSO):
   - Frequency Containment Reserve (FCR)
   - Automatic Frequency Restoration Reserve (aFRR)
   - Manual Frequency Restoration Reserve (mFRR)
   - Replacement Reserve (RR)

iGFBs can help system operators through a combination of actions that reduce or adjust electricity consumption avoid additional costs. Network services that can provide economic value can be characterized as services that:

- Reduce generation costs by offsetting generation capacity investments avoiding power plant fuel costs, avoiding operation and maintenance costs, or providing ancillary services such as frequency or voltage support as well as regulation and contingency reserves at lower costs,
- Reduce delivery costs by offsetting T&D capacity investments, increasing T&D equipment lifetime, reducing equipment maintenance, or supporting T&D ancillary services such as distribution-level voltage control at lower cost [4].

Table 3 presents the summarized information about the buildings' potential to provide different network services and the associated market size. It is important to emphasize that the table presents the current situation. With the expected increase in the share of renewables in the power grid, market sizes and offered services could significantly change.

TABLE 3 POTENTIAL GRID SERVICES PROVIDED BY DEMAND-SIDE MANAGEMENT IN BUILDINGS [1]

Grid services	Potential Avoided Cost	Potential Market Size Addressable by Demand-Side Management in Buildings

Generation Services		
Generation: Energy	Power plant fuel, operation, maintenance, and startup and shutdown costs	**Large.** The market potential for reducing generation operations is large because it is a service in every RTO/ISO. Reducing generation operations involves optimizing operation conditions and utilizing lowest-cost generation. For buildings, energy efficiency has the greatest potential to reduce generation operations. Demand response also has moderate potential, though the market size is limited by peak/off-peak price spread and hourly marginal costs, which vary by RTO/ISO (and some utilities) and change over time.
Generation: Capacity	Capital costs for new generating facilities and associated fixed operation and maintenance costs	**Large**. Deferred generation capacity investment results primarily from peak demand reduction. The size of the market varies by region based on the marginal generation costs and system load profiles. Buildings can play a large role in reducing the peak demand because they are the primary driver of peak electricity demand. Buildings can contribute to this service by both lowering the overall need for generation through energy efficiency as well as providing short-term load reduction to address system peaks. For buildings, demand response has the greatest potential to address capacity needs.
Ancillary Services		
Contingency Reserves	Power plant fuel, operation, maintenance, and associated opportunity costs	**Moderate.** The market for contingency reserves is significantly smaller than those for generation capacity or generation operations, making up less than 3% of U.S. peak demand (Ela et al. 2011; Denholm et al. 2015). Despite the small market, buildings are well positioned to provide contingency reserve products by reducing demand for short periods of time.
Frequency Regulation	Power plant fuel, operation, maintenance, and opportunity costs associated with providing frequency regulation	**Small.** Each RTO/ISO requires less than 1,000 megawatts (MW) of frequency regulation—less than 1% of total U.S. generation capacity (Denholm et al. 2015; Tacka 2016). In addition to the small market, demand-side resources must compete against cost-effective distributed supply-side resources that provide frequency regulation. In some RTO/ISOs, generators are required to provide frequency regulation, but rules are changing to allow distributed resources to participate. Multiple technologies (variable frequency drives, water heaters, batteries, solar inverters) can provide frequency regulation.
Ramping	Power plant fuel, operation, maintenance, and startup and shutdown costs	**Small.** Ramping services are an emerging market that is currently not offered in most RTO/ISOs. Ramping services include resources that offset rapid changes in generation output. It is expected to grow as more variable renewable generation is added to the grid. Buildings can provide quick response ramping services from technologies that can dispatch/store electricity (batteries) and can be cycled to offset generation shortfalls (HVAC).
Delivery Services		

Non-Wires Solutions	Capital costs for T&D equipment upgrades	**Moderate.** Opportunities to defer or avoid the need for investments in T&D infrastructure are highly location dependent. Further, the resource must be located electrically downstream from the transmission or distribution equipment to provide this service. Buildings can provide non-wires solutions in a variety of ways, including energy efficiency, demand response, distributed generation, voltage support, and energy storage.
Voltage Support	Capital costs for voltage control equipment (e.g., capacitor banks, transformers, smart inverters)	**Small.** Payments available for voltage support (or reactive power compensation) from demand-side resources vary significantly depending on the utility context and the size. Multiple building technologies can provide limited voltage support, including rooftop solar inverters and battery inverters, though they must compete against cost-effective supply-side resources, including transformers, fixed capacitor banks, and line regulators.

In many cases, a single building cannot provide a network service on its own, but demand-side flexibility must be aggregated across a large number of buildings. Also, not all buildings can provide each service, since some grid services also require certain duration and response times, load changes, and event frequencies. Furthermore, sometimes the building owners/operators are not aware of the aggregation of building's flexibility and provision of grid services. The most important inputs needed for building owners/operators to make building-level energy management decisions include how the end-use operations need to change, the duration and amount of change needed, and the compensation for that change.

Table 4 shows how changes in building operation map to the grid services in Table 4.

TABLE 4 MAPPING DEMAND-SIDE MANAGEMENT STRATEGIES TO GRID SERVICES [4]

Demand-Side Management Strategies	Grid Services	Description of Building Changes	Key Characteristics	
Efficiency	Generation: Energy Generation: Capacity T&D: Non-Wires Solutions	Persistent reduction in load. Interval data may be needed for measurement and verification purposes. This is not a dispatchable service.	Typical duration	Continuous
			Load change	Long-term decrease
			Response time	N/A
			Event frequency	Lifetime of equipment
Shed Load	Contingency Reserves	Load reduction for a short time to make up for a shortfall in generation.	Typical duration	Up to 1 hr
			Load change	Short-time decrease
			Response time	<15 min
			Event frequency	20 times per year
	Generation: Energy	Load reduction during peak periods in response to grid	Typical duration	30 min to 2 hrs

	Generation: Capacity T&D: Non-Wires Solutions	constraints or based on TOU pricing structures.	Load change	Short-term decrease
			Response time	30 min to 2 hrs
			Event frequency	< 100 hrs per yr/seasonal
Shift Load	Generation: Capacity T&D: Non-Wires Solutions	Load shifting from peak to off-peak periods in response to grid constraints or based on TOU pricing structures.	Typical duration	30 min to 4 hrs
			Load change	Short-term shift
			Response time	<1 hour
			Event frequency	<100 hrs per yr/seasonal
	Contingency Reserves	Load shift for a short time to make up for a shortfall in generation.	Typical duration	Up to 1 hr
			Load change	Short-term shift
			Response time	<15 min
			Event frequency	20 times per year
	Avoid Renewable Curtailment	Load shifting to increase energy consumption at times of excess renewable generation output. This is not a dispatchable service but can be reflected through TOU pricing.	Typical duration	2 to 4 hrs
			Load change	Short-term shift
			Response time	N/A
			Event frequency	Daily
Modulate load	Frequency Regulation	Load modulation in real time to closely follow grid signals. Advanced telemetry is required for output signal transmission to grid operator; must also be able to receive automatic control signal.	Typical duration	Seconds to minutes
			Load change	Rapid increase/decrease
			Response time	<1 min
			Event frequency	Continuous
	Voltage Support		Typical duration	Subseconds to seconds
			Load change	Rapid increase/decrease
			Response time	Subseconds to seconds
			Event frequency	Continuous

	Ramping	Load modulation to offset short-term variable renewable generation output changes.	Typical duration	Seconds to minutes
			Load change	Rapid increase/decrease
			Response time	Seconds to minutes
			Event frequency	Continuous
Generate	Ramping	Distributed generation of electricity to dispatch to the grid in response to grid signals. This requires a generator or battery and controls.	Typical duration	Seconds to minutes
			Load change	Rapid dispatch
			Response time	Seconds to minutes
			Event frequency	Daily
	Generation: Energy Generation: Capacity T&D: Non-Wires Solutions		Typical duration	30 mins to 4 hrs
			Load change	Dispatch/negative load
			Response time	<1 hour
			Event frequency	<100 hrs per yr/seasonal
	Generation: Energy Generation: Capacity T&D: Non-Wires Solutions	Distributed generation of electricity for use on-site and, when available, feeding excess electricity to the grid. This is not a dispatchable service, though metered data is needed.	Typical duration	Entire generation period
			Load change	Reduction/negative load
			Response time	N/A
			Event frequency	Daily

3.4.2. iGFB services for the Power System projects

A detailed overview of European projects related to demand-side flexibility is presented in Section 2.4. Also, that section gives information about the potential provision of grid services and entities to whom a service is provided. Therefore, this section introduces several new European projects, whose goal was calculating the potential demand-side flexibility and provision of that flexibility, mostly to an aggregation of multiple providers.

FlexCoop [91]investigates the development of ICT platforms and solutions for cooperative aggregators. In that project, the role of aggregator includes offering services to the DSO, TSO through wholesale market. The algorithm developed within the project aims to accurately forecast demand-side flexibility, monitor events and optimize microgrids and portfolios operated by aggregators. There are no proposed direct financial benefits, but the aggregated prosumers gain an increased awareness of their own consumption patterns and are provided with a framework for optimised demand response and self-consumption, and access to open IT infrastructures. Pilots on which developed solutions are tested are located in the Netherlands and Spain.

BestRES [92]concluded that aggregating smaller flexibility providers, especially through automation, is a feasible business model ready to be implemented. However, the lack of adequate market design still provides barriers to many otherwise profitable business models.

The NEBEF mechanism in France enables consumption units the remuneration on energy markets (either over-the-counter or via day-ahead and intraday power exchanges) in exchange for providing demand response service [93].

In Ireland, the Power Off & Save project [94] investigated if aggregated demand from residential consumers could contribute to mitigating congestions in the network. Residential consumers had a notification sent to their phone by their electricity supplier when network congestion occurred and in case of response, their electricity bill was reduced. The results of the project showed that 1,400 consumers contributed to a total reduction on peak demand of up to 560 kW, which indicates potential of aggregated demand.

The Norwegian Inertia 2020 pilots tested and validated that EV aggregators are capable of providing frequency balancing services from a portfolio of EVs.

The goal of the SmartNet project [95] is to provide optimized instruments and methods for improving the coordination between grid operators at the national and local level and the exchange of information for monitoring and acquiring ancillary services.

Case studies defined in the STORY project [96] aim to demonstrate the synergy of a neighborhood strategy for flexibility and grid balancing. The demonstration emphasizes potential of storage for end-consumers, distribution system operators, electricity suppliers, and potential third parties aggregating the flexibility.

3.5.Challenges

Despite the positive regulatory framework and the growing trend towards the creation of markets for flexibility services, including the general recognition and acceptance of energy prosumers, adequate national regulatory mechanisms supporting the deployment of Citizen Energy Communities, DERs aggregation and flexible demand programmes in most EU countries, the development of iGFBs may still face some barriers and challenges. In particular, on the technological side, there are still challenges related to the uneven technological maturity and adoption of the various software and hardware elements required for such complex management and operation. This fact is expressed in terms of the level of compatibility and interoperability readiness or smart readiness of buildings and building-to-grid integration to ensure: accurate access to energy consumption and end-use performance data; relatively low-cost control networks and optimisation functionality; and the ability to respond to external signals such as wholesale market prices, VPP operation, BSP or BRP, DSO and TSO requests. In addition to concerns about interoperability and cybersecurity related to sensitive data and communications, there is relatively low awareness and acceptance of the business models among end-users and other stakeholders involved in the concept adoption. Understanding the value proposition for different customer segments, adequate business models, and markets design are key to achieving meaningful aggregation of demand flexibility and distributed energy generation. In this sense, local markets design should focus customer-centric strategies for a more holistic integration of measures and technologies to improve their collective performance and penetration.

A list of potential barriers and recommendations for the implementation and adoption of the iGFB concept are listed below. A closer look at regulatory and policy frameworks related barriers and hindrances to the widespread of the iGFB concept among European Union are addressed in Chapter 5.

3.5.1. Technological maturity

Integrating different technologies such as energy management systems, renewable energy sources, storage technologies, electric vehicles, and other flexible loads, such as lighting and smart appliances, into a cohesive system that can interact seamlessly with the grid is a technical challenge. This will require significant advances in interoperability standards for smart building technologies to ensure compatibility and optimal operation. Cyber security is also critical to ensure reliable connectivity of network services at the building level and at the building-grid level, given that the technologies can communicate with system operators, aggregators, EV charging operators, etc…, over public internet channels and directly impact the operation of the power system. In addition to interoperability and communication technologies, far extended algorithms for optimizing EMS and BAS for coordinating energy flows and flexibility must be made available with as much independence as possible from the building owner, manager or occupant. In many cases these algorithms are not available or have to be developed and fine-tuned on a case-by-case basis. The current lack of interoperability and the need of specifically tailored developments can result in high-cost integration deterring potential investors and developers of the iGFB concept.

With a relevant role on the multi-technology coordinated flexibility demand response, thermal energy storage technology [119] is extremely relevant in the building energy management as the climatization and water heating loads are one of the most energy intensive processes in building. TES still requires further research and development for an efficient and affordable integration in buildings, e.g. for integration with various types and sizes of HVAC and water heating systems.

3.5.2. Costs, Financing and Investment

The upfront costs associated with retrofitting existing buildings or building new ones with iGFB capabilities are generally perceived as high and relatively risky due to the number of stakeholders involved, complex permitting processes and unclear regulations. The development of attractive business models for use cases is essential to access finance, and overcome economic barriers and encourage building owners and developers to invest in technologies. Business as usual models only consider the energy arbitrage or time-shifting benefits of energy storage and DSF, which is in fact a small part of the total value that iGFBs can provide to the grid. For example, grid-interactive water heating systems, heat-pumps, grid forming battery systems and EV charging (V2G and G2V) can be used for stability services provision over the span of seconds to minutes grid. These benefits will be missed if planning models do not consider system requirements at these granular timescales. By default, intelligent grid forming buildings have the potential to generate multiple revenue streams by offering complementary flexibility services to the grid and selling back renewable energy surpluses directly to the energy market, through aggregation, or even through new innovative local markets in communities, e.g. through P2P trading energy markets [120].

3.5.3. Grid Infrastructure and Capacity

The deployment of IGFBs, as a complex distributed energy resource, also depend on the local grid infrastructure, that in many parts of regions Europe may not be fully equipped to handle the bidirectional energy flows and capacity. In some cases, upgrading the grid to accommodate IGFBs and ensuring its resilience is crucial for they effective implementation. However, in many other cases the functional flexibility offered by the buildings, specially the one with significant energy storage capacity, using BESS and TES, are the solution to solve local grid weakness, as congestion management deferring new investments in the grid, improving its reliability and security.

3.5.4. Awareness and Acceptance

There is a need to increase awareness among stakeholders, including building owners, occupants, and policymakers, about the benefits and opportunities of iGFBs. Overcoming scepticism and resistance to new technologies is essential for widespread adoption.

The end-users or building owners are likely to adopt iGFB technologies and to provide demand flexibility with sufficient incentives. In most cases, financial incentives are the primary motivator for adoption but also the opportunity to engage with new trends for the energy transition and decarbonization of the economy contributing to a societal need for an improved grid reliability, or to become simply early adopters of new energy technologies. Although, the willingness of early adopters is not sufficient for a fast growth and widespread deployment of IGFBs if the incentives are not attractive or adequate, if the business models are not clear, or if the perception of costs and risks are too high [122].

Relying on the collection and analysis of large amounts of data to optimize energy use and orchestrate grid interaction iGFBs acceptance is directly impacted by data privacy and cyber security concerns. Robust cybersecurity of this data is a significant challenge that must be addressed to maintain user trust and comply with stringent European data protection regulations.

3.5.5. Markets Design and revenue streams opportunities

The current market structure and electricity pricing mechanisms may not be adequately developed in all countries to effectively reward the flexibility and energy efficiency provided by decentralized units such as iGFBs. However, EU's legal framework for securing clean and affordable energy supplies and contributing for a more resilient and secure energy system, set by Repower EU [121]and the EU's Clean Energy for All Europeans package [123], offers a fertile ground for leveraging demand flexibility and energy storage based services and revenues streams within frameworks as utility dynamic pricing schemes, aggregation, virtual power plants, participation in ancillary services, energy markets and energy communities.

The smart metering and grid communication technologies underpins the possibility of effective implementation of dynamic utility pricing schemes such as Time-of-Use (TOU) pricing, Critical Peak Pricing (CPP), and Real-Time Pricing (RTP). These pricing schemes can be design and implemented to iGFBs reflecting the actual cost of electricity at different times of the day, shifting the energy use to off-peak times. Nevertheless, these tariffs should be designed to engage end-users' participation and adoption, for example, allowing a demand flexibility programme to compensate participants for avoided generation capacity costs and at the same time providing a corresponding opportunity to monetise the value of load reductions that avoid distribution system costs.

EU market design initiatives have been encouraging the participation of a wide range of distributed energy resources in ancillary markets. In this context, aggregators and VPPs operators play a critical role by pooling small-scale production and flexible consumption to participate in the energy and services' markets. Also, the different configurations and regulatory implementation of renewable energy communities among EU countries offer a range of possibilities for new business models that ultimately will be defined by the markets design in each balancing control area. By becoming part of larger communities, iGFBs can co-optimize their energy use and flexibility potential, targeting services provision to grid operators and markets. Local markets energy and flexibility enabled by peer-to-peer trading platforms, e.g. supported by digital technologies like blockchain, it is also seen with potential interest for iGFBs business models design considering that the building have, by default, high-levels of digital integration, and disaggregated access to the assets energy metering and control enabling complex products designs based on exchanging and aggregating highly complex real-time energy and capacity modulation responses.

3.6. Value Chain and key stakeholders

The description of high-level use cases of iGFBs involves a clear definition of a standard value chain, and the identification of key stakeholders involved in each process enabling the creation of value. The value created at each stage of implementation and operation of the iGFB will then, ultimately, drive to the potential provision of services to the various networks while satisfying the building activities and its end-users' needs, such as the electrical network, water supply, communication networks, gas, heating, among others. Therefore, the high-level use case definition must also account for the potential interaction of the buildings with such energy carriers and the networks. This strategy must also identify the main technological assets involved, and their potential role in the case that the building can become a service provider, contributing to more sustainable, efficient, and resilient urban environment.

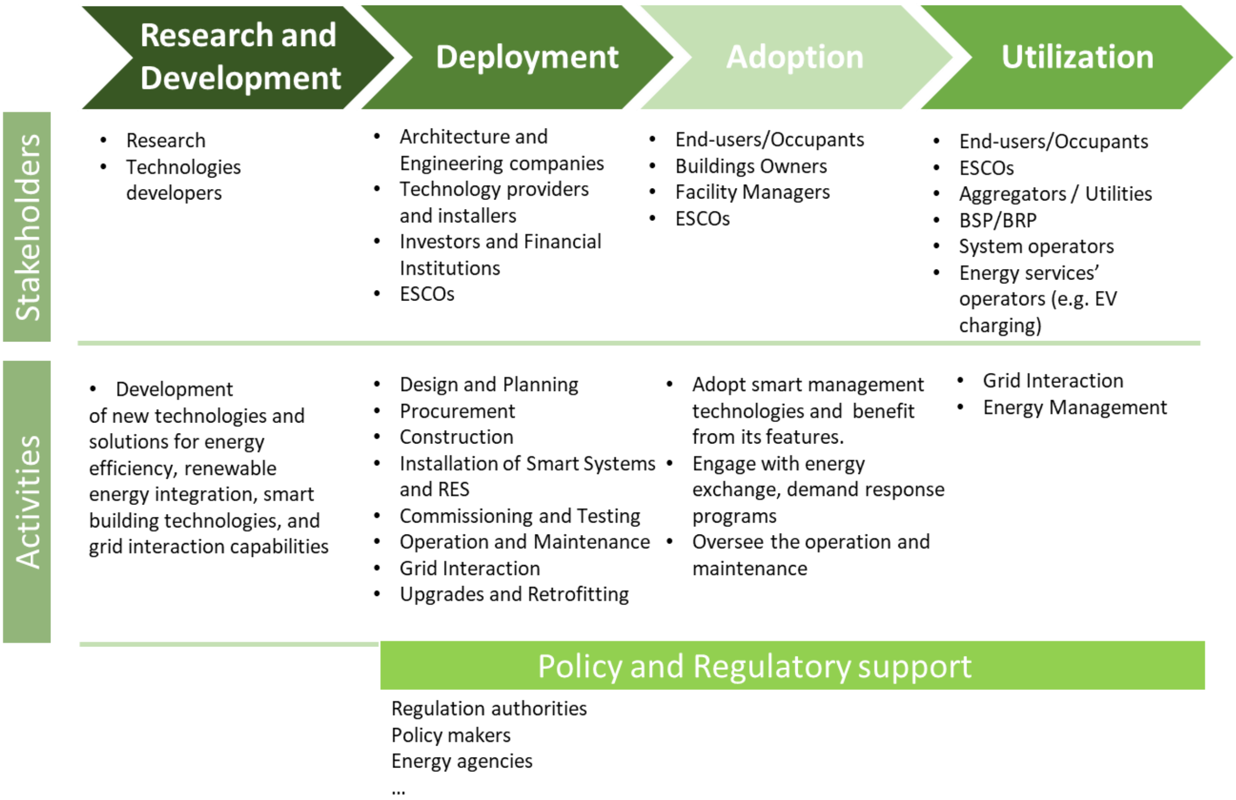

FIGURE 11: IGFB VALUE CHAIN.

The value chain for intelligent grid-efficient buildings includes the various activities that contribute to their value proposition, from the initial concept and design to its construction, operation, optimization, and integration with the energy ecosystem and the several networks to which the iGFBs are connected. Each stage of development and value creation accounts with the involvement of specific stakeholders, characterized by different levels of Interaction and Impact on the value proposition of IGFBs. Each actor plays a vital role in the ecosystem, contributing to each process of the value chain (Figure 11) with specific needs, expectations, and influence.

The iGFB value chain is complex and can involve a wide range of activities and stakeholders (Table 5). Each stage of the value chain adds a layer of value, contributing to the overall efficiency, sustainability, and effectiveness of these buildings. A high-level and generic value chain is presented, identifying the main activities and processes involved in the development of the iGFB value proposition, taking into account, however, that the diversity offered by the numerous available technologies and the impact generated by the various potential combinations of these define case by case the specific needs of each building and the possible interaction with the networks to which it is connected and consequently its interaction with the electrical grid.

Key Stakeholders Groups		
Policy Makers and Regulators Energy agencies and Certification Entities R&D and technology developers Investors and Financial Institutions Building Owners and Developers	Architects and Designers Construction Companies Technology Providers and Installers Energy Service Companies (ESCOs) Maintenance and Operational services providers	Occupants / End-Users Facility Managers Aggregators and Utilities EV changing operators. Grid Operators (DSOs)

TABLE 5 INTELLIGENT GRID-FORMING BUILDINGS' KEY GROUPS OF STAKEHOLDERS.

3.6.1. Regulatory advisory and support

The regulatory framework is a critical enabler for the development and operation of iGFBs and is transversal to the entire value chain. Adequate and supportive regulation and close cooperation with policymakers and regulators to design appropriate financial incentives are then considered essential to the deployment of iGFBs. In some EU countries, as it is the case of Netherlands, Finland, Luxembourg and Germany [124] is foreseen the possibility to request a group of regulatory exemptions with the aim to support innovative solutions by testing and demonstrating new technologies and services within a specific scope for a limited timeframe in real environments and actual targeted groups of end-users. These instruments are known as regulatory experimentation mechanisms or "regulatory sandboxes" and allow to test the fully potential of technological demonstrator, helping companies and developers to evaluate its feasibility but also to promote regulatory learning local regulatory authorities to design and adapt new regulations based on real demonstrations and impacts assessment.

As a transversal activity of the iGFB value chain, there is a vast list stakeholder that can be involved in the regulatory advisory but according to its basilar function in the value proposition is the:

- Policy Makers and Regulators
- Energy agencies
- Certification Entities
- System operators
- Building Owners and Developers
- R&D and technology developers

3.6.2. Research and Development (R&D)

As innovative concepts, Research and Development (R&D) activities occupy the basis of the iGFBs value chain, supporting the continuous development of new technologies and solutions for energy efficiency, integration of renewable energies, intelligent construction technologies, and interaction capabilities with networks. Also, innovations in building materials, energy management systems, and intelligent control devices contribute to the efficiency and effectiveness of iGFBs, such as advanced data analytics concepts for predictive maintenance, energy optimization, occupancy management, grid services provisioning, and participation in the energy market. R&D also contributes to the development of certification and labelling systems for these energy efficient buildings, such as the case of the Smart

Readiness Indicator (SRI) (Section 3.1.5) which address the potential of smart technologies in the buildings. In research and development, the key stakeholders are:

- Research Institutions and Academia
- Technology developers

3.6.3. Deployment

The iGFB projects' deployment Is a complex and extensive procedure that encompasses several stages and integrates, the larger number and type of stakeholders, starting in project financing, where investors and other financial entities play a key role the iGFB promotion driving the opportunity to validate innovative and advanced concepts that naturally present risks associated with their level of maturity.

Design and Planning

The planning phase is a multi-collaborative result of a conceptualization process in between the building owners and/or developers and teams of architecture, specialist engineers and designers, who plan and design the building with iGFB and techno-economic feasibility principles in mind, integrating energy efficiency features, renewable energy generation, energy store systems. ESCOs have at planning phase an effective role providing expertise energy use optimization, costs reduction, and ensuring the feasibility of grid interaction.

Key stakeholders:

- Building Owners
- Developers
- ESCOs
- Architecture and Engineering companies

Procurement, construction, installation of Smart Systems and Renewable Energy Sources

The deployment process follows with the procurement, actual construction, and installation of the technologies.

Sourcing materials and technologies for iGFBs construction is done by procuring high-quality, sustainable, and cost-effective materials and technologies. This includes energy-efficient materials, renewable energy systems, Building Automation Systems (BAS), for controlling and optimizing internal building operations, Energy Management Systems (EMS), for monitoring and managing energy use and production, Smart Meters, for real-time energy monitoring and communication with utility providers, and other advanced manageable systems for thermal comfort, lighting, heating, and hot water.

Specialized suppliers and installers work closely with procuring parties from the design phase through to the commissioning and testing of the acquired solutions that complete the deployment phase of buildings' projects. They are responsible for ensuring that all systems operate correctly and efficiently before the building is occupied. Proper commissioning is critical to ensure that the building operates as intended, maximizing energy efficiency and grid responsiveness.

Key stakeholders:

- Construction Companies
- Technology Providers

- Installers
- ESCOs

Operation and maintenance

The diversity and complexity of the integrated operation of in iGFBs require constant monitoring and regular maintenance of all systems to ensure and sustain the efficiency and performance of the building over time. Through preventive maintenance programs is possible to predict failures in specific equipment and communication networks of the buildings in advance avoiding prolonged disruptions and high costs associated with repairs and replacement of equipment that could have been avoided through adequate surveillance. iGFB have by default data driven operation that can be also used in predictive analytics and continuous machine learning to auto-identify anomalies.

A close attention to upgrading and retrofitting buildings with the latest energy-efficient technologies, smart systems and interoperability is also a way to continuously improving the efficiency and functionality of the building keeping it at the forefront of the new standards.

Key stakeholders:

- Facility management companies
- Maintenance and Operational
- Technology providers
- Installers

Adoption and utilization

The end-users of the iGFBs are key actors in maximising the full potential performance of building systems, whether they are households or simply occupants of commercial and industrial typologies. Their behaviour and feedback can influence energy use and system adaptations. Maintaining operational temperatures within acceptable ranges, for example, requires frequent feedback from occupants, which enables the EMS to adapt the overall system to respond optimally to the occupants' comfort requirements while ensuring the best energy performance according with the remain constraints.

The adoption of the iGFB concept involves the acceptance and engagement of end-users in active participation in the management of building resources, despite the high level of intelligence monitoring and control of systems. Building owners and facility managers can introduce incentive-based usage mechanisms to implement demand-side resource management programmes that meet the flexibility requirements of building-specific operational strategies designed according to their objectives, whether they are to improve performance, or participate in energy and services markets. ESCOs have a fundamental role to play in this task, as they are usually responsible for designing operational strategies appropriate to the existing active equipment in buildings, contributing to grid stability and generating potential revenue through energy savings and possibly revenue from stacking flexibility services considering existing market offers and programs with utilities and/or directly with system operators. In some cases, single grid-interactive buildings can be associated to a pool of buildings and other DERs operators participating in energy markets through aggregators, that can also act as Balancing Service Providers or Balancing Service Providers through bi-lateral contacts with the TSOs.

Key stakeholders:

- Occupants and End-Users
- Facility management companies
- ESCOs
- Utilities companies
- DSOs and TSOs
- Aggregators
- Facility management companies
- BSP/BRP

4. Stakeholder Engagement and Use Case Development

4.1. Development of high-level use cases (HLUC) for iGFBs

The high-level use cases should describe the innovative and uniqueness of each implementation plan and purpose of the Intelligent grid forming buildings as result of complex combination of the interaction of the active elements with the energy carriers and networks. In such a complex diversity of solutions, stakeholder and roles involved, the use of standards as the use case methodology IEC 62559 [125] can provide common cooperation platform, standardizing terminology, and collaboration workflows, which facilitates the cooperation among stakeholders from several different domains, as the iGFB concepts require. Here is proposed a methodology inspired in a top-down approach proposed in the aforementioned methodology, with the objective to describe the use cases in an abstract and high-level manner, without in depth technical implementation details that are specific of the particular use case.

4.1.1. Scope and Objective

The definition of the use case goals requires the identification of the functional purpose of the use case. The objectives of each high-level use case are of course related to the main concepts of the iGFB, and can be focused on a specific functionality or may follow a more holistic approach seeking for the improvement of the buildings' activities enhancing their energy efficiency and at the same time contributing to the resilience and security of the power system by providing services supported by flexibility, energy supply and grid-forming abilities, for example:

- Improve building performance and energy efficiency.
- Increase of occupant's thermal comfort.
- Reduce peak demand and associated costs.
- Optimize energy related costs through Energy arbitrage.
- Increasing self-consumption of RES.
- Supporting RES generation.
- Deferring grid connection investments.
- Participate in ancillary services (TSO frequency regulation, congestion mitigation, etc..) and energy markets.
- Participation in local flexibility markets.
- Participate in a community Virtual Power plant through capacity and or energy aggregation.

The scope outline description should clearly identify the types of building regarding its primary function as residential, commercial, or industrial; identify the nature of potential single or multiple services capable of providing according to the identified interaction with networks and different energy carriers, highlighting the specific technological assets to be integrated, for examples:

- Investment deferral of a commercial building for EV charging capacity increase - Photovoltaic systems, Li-ion Batteries and electric vehicles charging points.
- Participation in the local Energy Market of a multifamily residential building - Photovoltaic, flexible loads (lighting, programable HVAC and whiteware appliances)

- Participation in the balancing market of Frequency restoration reserve of an Industrial building - Flexibility provided by high-capacity thermal storage using hot furnaces.

4.1.2. Mapping the key Energy carriers, Technologies and Networks

As key elements of smart grids, Intelligent Grid-Forming Buildings often consume energy in various forms, but also contribute to its generation through local production from renewable sources. The energy exchange between the different energy sources is closely linked to the type of technologies that characterise each iGFB. Therefore, the characterisation of the use cases includes the classification of the different energy carriers, the identification of the technologies involved in their operation and how these can potentially interact with the connected networks. As multi-energy use platforms, buildings can benefit from the different carriers as part of a smart grid - electricity, heat, gases, liquid and solid fuels, radiation, etc... as defined and identified in the Smart Energy Grid Architecture Model (SGAM) [126]. Figure 12 and Figure 13 show how the building's equipment and active assets interact with each energy carrier.

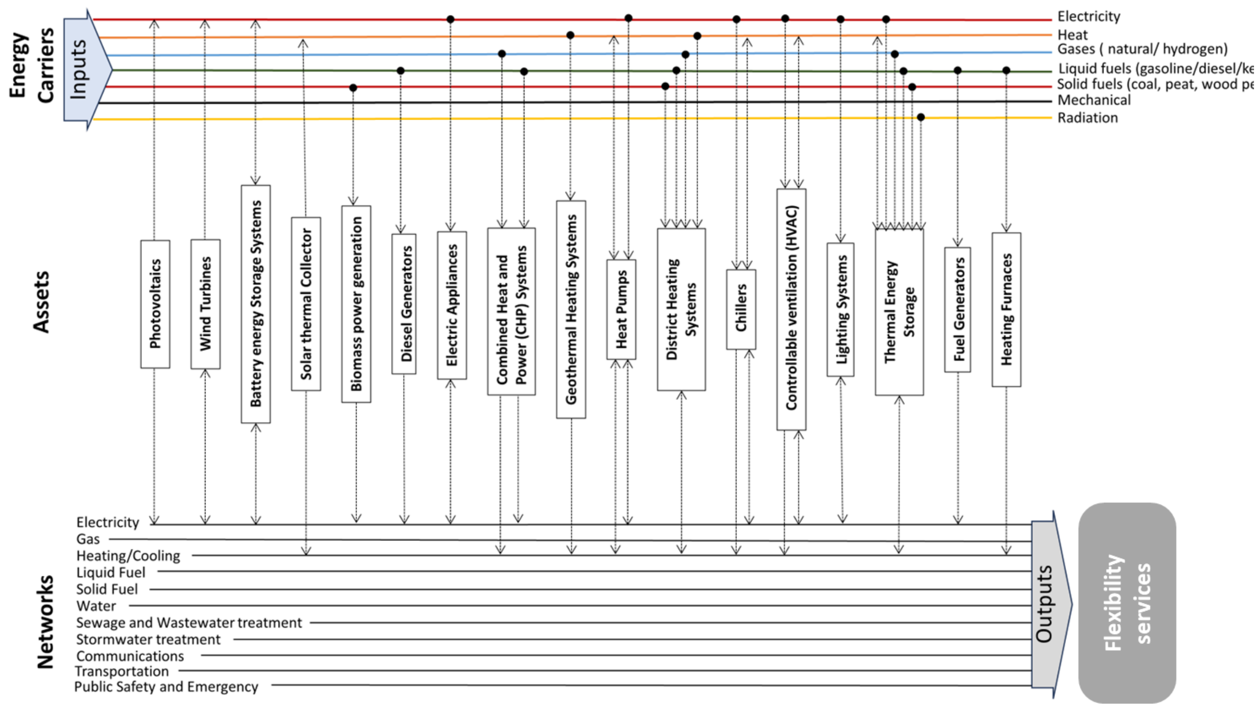

FIGURE 12: IGFB KEY TECHNOLOGY ASSETS INTERATION WITH ENERGY CARRIERS AND THE NETWORKS (PART 1).

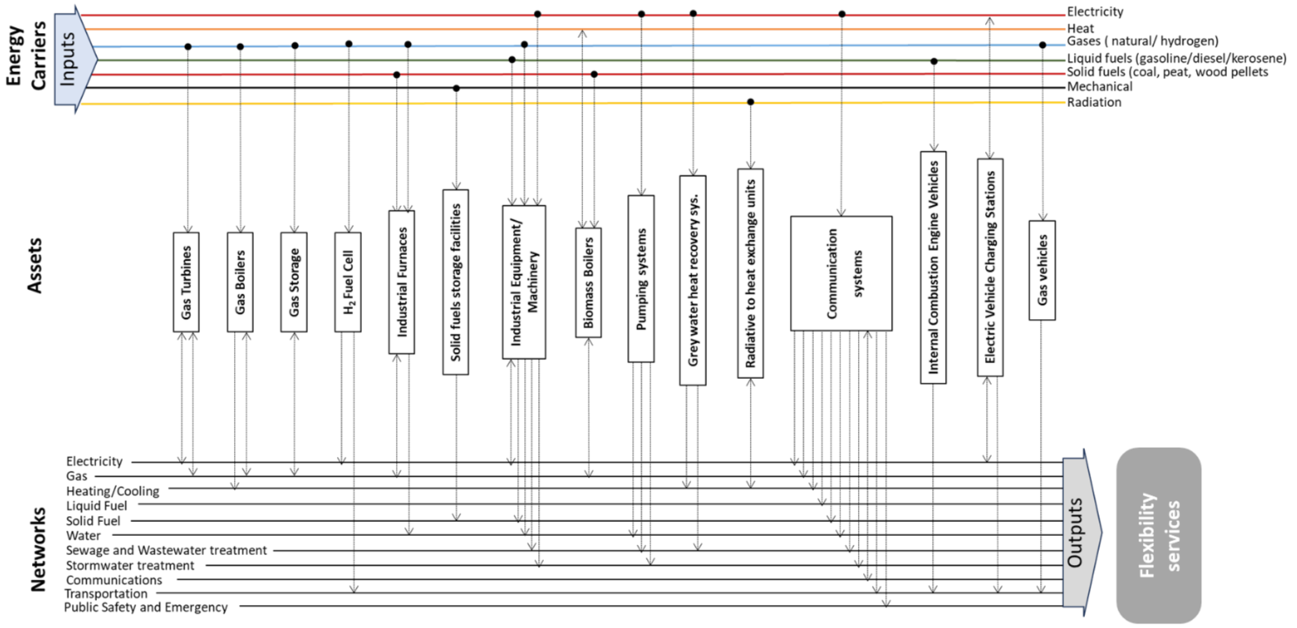

FIGURE 13: IGFB KEY TECHNOLOGY ASSETS INTERATION WITH ENERGY CARRIERS AND THE NETWORKS (PART 2).

The orchestrated operation of the different technologies (Section 2.1, Figure 12 and Figure 13) can be strategically optimized to offer different degrees of flexibility, contributing different types of impact on the networks to which buildings are connected. These latest can be classified according to the infrastructure they belong to, the energy carriers or other commodities they provide. Below follows a non-exhaustive description of some of the networks and how buildings benefit the respective interaction:

Electricity grid

Distributes electrical power, providing electricity as final energy for lighting, heating, cooling, suppling the most diverse appliances, industrial machinery, and other electrical machines. It's the backbone of modern buildings and urban infrastructure, normally connected to the national grid and often Integrating local RES generation. Intelligent Grid-forming buildings can use energy storage systems to supply the grid injecting surpluses and providing ancillary and other flexibility services, as demand response e.g. reducing or shifting their electricity usage during peak periods, contributing for enhancing the grid resilience and sustainability.

Gas Network

Supplies natural gas, a primary energy carrier, mostly used for heating, food preparation, and in some cases, power generation. In industrial settings, it can also fuel certain manufacturing processes. It is unusual for buildings to supply gas to the network, although those producing biogas could do so if they meet quality and safety standards.

Heating/Cooling Network

Provides centralized heating and/or cooling to buildings. District heating systems, e.g., may use steam or hot water from cogeneration plants, while cooling networks often use local or more centralized water-cooling systems, such as chillers and cold storage systems. Buildings can efficiently manage heating resources, potentially supplying excess heat back to district heating networks, e.g. through the optimal use of advanced heating, ventilation, and air conditioning (HVAC) systems.

Liquid Fuel Supply

Involves the distribution of liquid fuels like hydrogen, diesel, kerosene, ethanol, gasoline, and others… primarily for transportation and backup generators but also in some cases for residential heating systems and industrial applications. This network is still crucial in contexts where electric or gas networks can't meet all energy needs and when the existing transport relies mainly in thermal vehicles.

Solid Fuel Supply

Includes the storage and provision of solid fuels such as coal, wood chips, or pellets, mainly used in industrial processes or in areas where the access to other energy sources are limited.

Water Supply Network

Ensures the distribution of potable water for residential, commercial, and industrial use. It's essential for daily living, hygiene, and various industrial processes. Smart water management systems can optimize water use for heating and cooling, reducing overall consumption and pressure on water systems. The proper management of this network can generate potential savings associated with pumping and heating energy consumption Impacting the co-related networks provisioning.

Communications Network

Comprises internet, telephone, and other data services. This network is vital for modern communication, business operations, and the integration of smart grid technologies in energy management. Buildings can serve as nodes in a broader communication network, hosting infrastructure broadband services. They can also use these networks for Interconnected IoT devices and systems management.

Transportation Network

Traditionally it includes roads, public transport systems and other infrastructure to support the movement of people and goods. Within iGFB concept, transport plays a relevant role in covering the EV charging infrastructure, opening innovative opportunities for electricity demand management, offering potential flexibility services based on the optimization of the transportation needs and the vehicles charging periods and power. The Injection of energy back to the grid through V2B (vehicle-to-build) mechanism it is also a possibility where it is deployed. Local renewable generated energy can be stored In EV batteries and be sold to the grid whenever is necessary or more profitable, supporting the RES balancing. The vehicles storage capacity can be also used for flexibility services provisioning.

Waste Management and Recycling Network

Responsible for the collection and processing of waste and recyclables. In some applications, can include waste-to-energy processes and composting facilities contributing to waste management.

Sewage and Wastewater Treatment Network

Concerns the collection and treatment of sewage and wastewater. Modern systems often focus on recovering resources and minimizing environmental impact. Heat recovery from wastewater, e.g., can generate potential high value in the energy management of buildings.

Stormwater Management Network

Buildings with rainwater collection and treatment systems can supply non-potable water applications inside the building and also sustainable urban development, often through green infrastructure like rain gardens and permeable pavements. Buildings with advanced grey or black water treatment systems can treat and reuse water on site or supply it to local networks, such as municipal irrigation systems, local water management facilities for agricultural purposes, etc…

Public Safety and Emergency Network

Encompasses any public and emergency services, e.g. fire, police, and medical services, which require response systems such as public alert systems and emergency warning systems. Buildings can collaborate and provide services to local, regional, and even national emergency networks, by participating as nodes or even hubs of these critical networks. The provision of these kind of services requires an uninterrupted supply of electrical energy and advanced, robust and high-security communication systems.

The interaction of technological assets with networks results in potential services that improve the performance of iGFBs and the networks in which they operate, resulting from the optimization of the buildings' internal processes with the ultimate objective of maximizing energy efficiency and the comfort of occupants. The services contracted or provided by different types of buildings, whether residential, commercial, or industrial, determine where a building can become a service provider to such a network.

4.1.3. Implementation overview

Stakeholders and roles

Identification of the groups of stakeholders involved or affected by the iGFB implementation and operation must be identified in the HLUC. A short and generic description of their roles, interaction with system components and other actors. A general assessment of each stakeholder's requirements to perform their role must be also identified and addressed. The involvement of stakeholders and roles can be supported by the mean of standardized high-level diagrams and terminology as the proposed by *The Harmonised Electricity Role Model* (HRM) [127] developed by ENTSO-e, in collaboration with the European Federation of Energy Traders and ebIX®, in particular when identifying and describing energy market participants and related objects. However, due to the comprehensive participation of diverse types of actors the diagrams should be adapted to the reality of the use case.

Control Strategies

Brief descriptions explaining how the building's systems are orchestrated towards their functionalities and services provisioning, how they respond to grid signals (e.g., demand response events, time-of-use pricing) to optimize energy use and support grid stability. Algorithms or decision-making processes for balancing energy savings, occupant comfort, and grid needs, etc., should be named in this section, and along them the identification and description of the type of data required, its origin and how it is exchanged between the building, the grid, and other entities. For example,

- Weather and radiation forecasting information obtained by certified forecasting services providers for day ahead estimation of photovoltaic systems generation.
- Locally metered consumption data for real-time EMS operation.
- Power metered data shared via cloud platforms for Virtual Power Plant management by Aggregators.
- Energy market prices via a cloud platform service every 15 min for the EMS for intraday market participation.
- Capacity reverse signals received by direct communication from the DSO.

Regulatory and Policy Framework

Identification of the main regulatory requirements, existing incentives and barriers affecting the implementation and operation of iGFBs in the specific countries of deployment. These include, for example, energy efficiency standards, building codes and grid participation rules. In the HLUC description, an initial and high-level assessment of the regulatory and policy framework provides critical information on the feasibility and implementability of the type of iGFB described by the HLUC, and also relevant information for the business model design of specific projects and applications.

4.1.4. From HLUC to concrete use cases

As stated before, high-level use cases must be abstractions of the application potential of certain iGFB projects, considering the type of technological assets and respective networks interaction, objectives and scope, stakeholders' identification, and integration overview. Those descriptions must avoid in depth detailing that will be further refined during the description of particular use cases development. For instance, in addition to the refinement of the topics covered in the high-level descriptions, business case should be addressed considering the economic and financial ecosystem where the iGFB is inserted, along with a detailed planning of the implementation, performance monitoring, risk assessment and mitigation which are essential points in defining particular use cases. Figure 14 suggests a development workflow for the UC definition of iGFBs, which comprehends the previous steps described for the HLUCs.

Analysing the economic benefits and costs associated with the use case is fundamental to assess the techno economic feasibility of the use case, including energy savings, potential revenues from grid services provisioning, considering the initial investment in technology, the construction costs as well as the operational and maintenance costs. European and national incentives or programs that support the adoption iGFB or components of the system should be also identified in the phase of the UC description and prior to an actual implementation.

The implementation plan outlines the steps for deploying the technologies and systems involved in the use case, including timelines, milestones, and all responsible parties involved in the process. Use case demonstration projects or phased implementation strategies should be considered to test and assess the reliability of the applications in the local realities that may face some unexpected constraints of regulatory or technical nature. In this respect, setting up a use case specific performance monitoring plan by defining appropriated metrics and KPIs (Key Performance Indicators) for evaluating the success of the use case. Energy savings due the optimization of the networks use and energy efficiency enhancement, energy volumes exchanged with the grid, revenues obtain from grid support provided in markets, and occupant satisfaction are example of KPIs that may be considered.

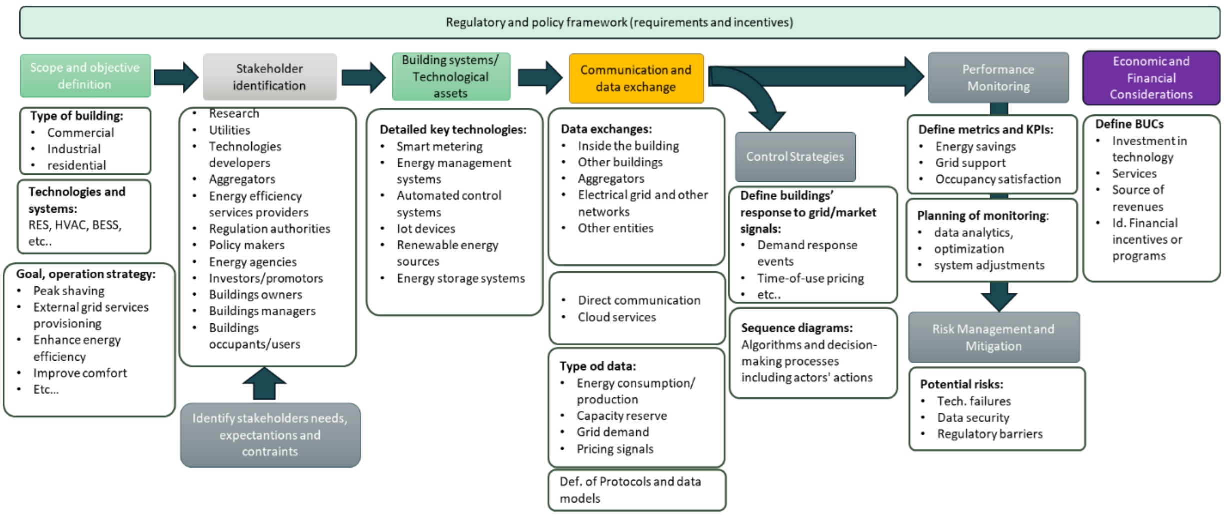

FIGURE 14. FLOWCHART OF THE USE CASE DESCRIPTION OF IGFBS.

According to the technical systems considered in a use case a plan for ongoing monitoring, data analysis, must be design adequately in order to anticipate and required system adjustments for optimal optimize performance. Performance indicators portfolio design and monitoring planning should naturally be taken in consideration while identifying potential risks and challenges associated with the use case, such as technology failures, data security concerns, and regulatory changes, for which preventive and mitigating strategies are defined to reduce the risk of concurrency and impact.

4.2.Co-creation processes and stakeholder engagement methods

Similar to the challenge of interoperability to integrate the energy management, control and automation systems required by iGFBs for effective orchestration of energy generation systems and the various elements interacting with the various energy carriers and networks, with the aim of enhancing energy efficiency and sustainability, while providing flexibility to the grid, a common level of knowledge needs to be leveraged between the various stakeholders involved, taking into account their roles, requirements and expectations. The involvement of stakeholders in co-creation and engagement processes is critical to the success of the implementation and exploration of smart grid buildings.

From the ideation stage of each iGFB, the project development must rely on multidisciplinary teams including representatives of all key stakeholder groups involved in the concept development, such as: architects, engineers, technology providers and developers, energy experts, building owners and facility manager, and end-users' representatives. The diversity of participants ensures a holistic approach to the overall building design and operation.

Organizing participatory design sessions, engaging stakeholders in the design process ensures that the solutions developed meet their requirements and are more likely to be adopted. This can include workshops and focus groups where many stakeholders can contribute ideas, express needs, and preferences, and provide knowledge on and feedback on the challenges and opportunities of the proposed designs and technology integration, and objectives. For example, user-centric design workshops focusing user-friendly interfaces for the energy management systems is a co-creating process that can impact significantly future end-users' behaviours and participation level in demand participation on demand-side response programs. The success of implementing flexibility-based response programs are highly dependent on end-users' interaction with the EMS, while meeting their specific requirements, e.g. in the scope of climatization preferences adjustment for thermal comfort, preferential scheduling for high demand appliances, EV charging routine, etc... Many Living Lab initiatives have been implemented in Europe in recent years [128] demonstrating the usefulness of this type of user-centred action for end-user engagement in complex, multi-nodal use cases aiming at the deployment of Citizen Energy Communities, as in the case of the SMILE project in Portugal, which demonstrated the impact of end-user engagement in the design of digital energy management solutions and the overall implementation in a multi-building application. Workshops on the value proposition of the projects, focusing on the expectations of building owners and developers, as they are the linchpin for implementation, are also recognised as a valuable tool to identify the key drivers for their involvement and to analyse potential financial barriers [131]. These initiatives should involve local DSOs, utilities, ESCOS, aggregators and regulators, as they are all essential in the business modelling process of each use case. A common understanding of the concepts and solutions to be integrated, as well as a clear alignment of user needs and preferences with the objectives and business models, must be ensured to increase the likelihood of successful uptake and deployment.

In co-creation planning strategies, surveys and interviews are valuable tools to gather detailed insights into the requirements, preferences, and behaviours of stakeholders regarding the interaction with buildings. Collecting data from technology providers, installers, services operators is also necessary for a successful and seamless implementation an integrated energy management system. Survey can be used to assess interoperability requirements among the different systems providers with the aim of fine-tune integration compatibility among the metering, sensing and control systems during the building features identification phase and energy programs design. Tailor questions to extract actionable insights that can inform the design and operation of intelligent systems.

An opportunity of the highly digitalized environments of iGFB for the stakeholders' engagement is the possibility of implementing mechanisms for continuous feedback allowing them to actively interact and contribute for improvement and maintenance programs, for example fostering the sense of involvement in the operation and management of the building. This can be facilitated through digital platforms, which should at the same time inform continuously the overall performance of the iGFB operation and the benefits for each type of participant. For example, the use of holistic digital platforms with tailored end-users' dashboards and interactive functionalities can be used to implement incentive programs based in rewards resulting from demand response programs, or revenue streams from markets participation to motivate stakeholders, in particular end-users, to participate actively in energy-use behaviours and grid-interactive programs leading to better performance of the building. Incentive programs rewards can be designed to be financial, recognition-based, or provide other benefits, depending on the stakeholder role and the iGFB implementation specific objectives and business models.

As part of the activities foreseen in WeForming project WP2, a number of surveys have been defined and are under development, addressing the specific thematic objectives of each and covering a wide range of different stakeholder groups. These surveys will be launched in the following project timeline and the results will be published in the next deliverables:

- on the existent devices' characterization on each demonstrator, concerning nature of the data needed or resulting from their operation or need for control, its ownership among stakeholders, and potential privacy constraints of its usage. (a draft version can be found in APPENDIX B)
- on the use case definition and requirements assessment. (under development)
- identification of potential novel business cases identification for the different single-core and multiple-core case implementation among the demonstrators. (under development)
- assessment the buildings' end-users, and occupants' engagement and awareness. (a draft of the survey can be found in APPENDIX B)

Based on the findings of these surveys a set of workshops will be organized with building users to further assess their needs and expectations on the iGFBs demonstrator they belong to. These workshops will be used to clarify the value proposition of iGFBs for the occupants, identifying their priorities and interactions with their local context. Participants will then help co-design the local digital platforms and other important aspects of each demonstrator using transdisciplinary methods such as Design Thinking and Emancipatory Boundary Critique.

5. Analysis of Barriers and Regulatory Framework

The transition towards a more sustainable and efficient energy system is a cornerstone of modern environmental and economic policy. In this context, intelligent grid-forming buildings (iGFBs) are emerging and represent a significant shift in how energy is produced, consumed, and managed. iGFBs, with their ability to actively participate in the energy system, could help provide a future where buildings are not only energy consumers but key players in energy management, contributing to network stability, energy efficiency, and overall sustainability. However, the path to implementing iGFBs is hindered by a complex array of barriers that span across regulatory, technical, and social domains. This document analyses these barriers, providing a foundation for understanding of the challenges inhibiting the widespread adoption of iGFBs.

According to the International Energy Agency, not enough demand response is available to reach net-zero emissions on a global scale. As of 2020, only 23 GW of demand response in buildings was available worldwide compared to 259 GW needed by 2030 to be on track for net-zero, as depicted in Figure 15 [132]. This underlines the urgent need to implement iGFBs as rapidly as possible to help increase by 10-fold the amount of available demand response in buildings [133].

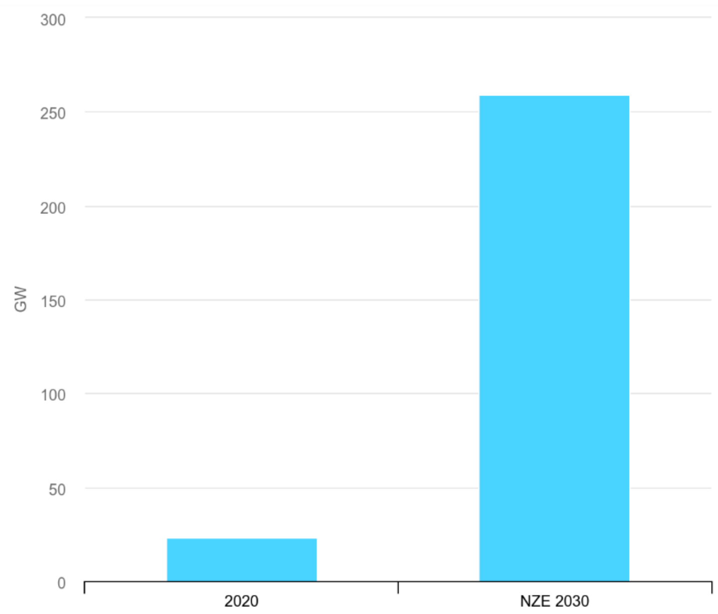

FIGURE 15: DEMAND RESPONSE AVAILABILITY IN BUILDINGS, 2020 AND 2030 IN IEA'S NET-ZERO SCENARIO.

SOURCE: IEA [133]

The European Union presents a diverse landscape regarding the adoption and implementation of iGFBs. Each Member State has its unique set of circumstances, with varying degrees of regulatory maturity, technical readiness, and social acceptance. This diversity offers both challenges and opportunities for the development and deployment of iGFBs. A 2023 study by ACER also showed that flexibility in the European power system will need to double by 2030 and called on Member States to assess their flexibility needs and use their National Energy and Climate Plans (NECPs) to create common flexibility initiatives, such as implementing iGFBs [134].

In some countries, regulatory frameworks are well-developed and supportive of iGFBs, facilitating their integration into the energy system. In these environments, iGFBs are more likely to find a conducive market, technical support, and public acceptance. Conversely, in countries where the regulatory framework is still evolving, iGFBs face greater challenges. These may include lack of clarity in policies, insufficient incentives, and a general lack of awareness or understanding of the benefits of iGFBs.

Technical readiness varies widely as well. Some countries have advanced significantly in developing the necessary infrastructure and technology for iGFBs, such as widespread deployment of smart meters and the availability of renewable energy sources. Others, however, are still in the early stages of this journey, facing hurdles such as outdated grid infrastructure, lack of technical expertise, and limited access to renewable energy technologies.

Social preparedness also differs across the European Union. In some countries, there is a high level of public awareness and acceptance of renewable energy and energy-efficient technologies, which bodes well for the adoption of iGFBs. In others, however, public awareness is limited, and there may be significant resistance to change, particularly if the benefits of iGFBs are not well understood or communicated.

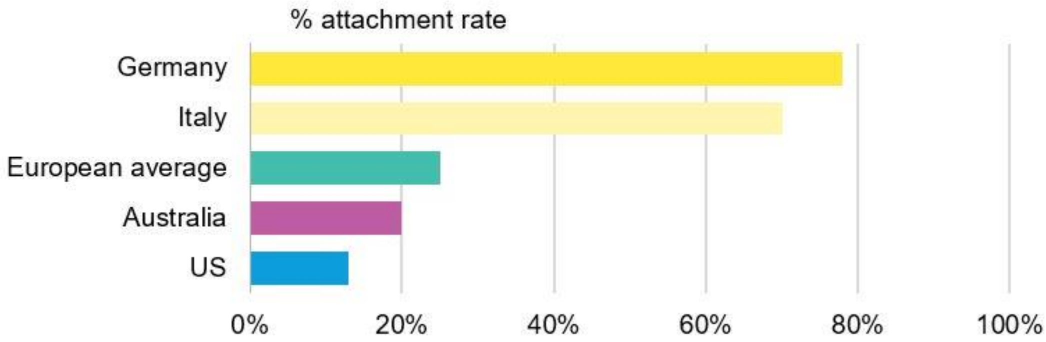

FIGURE 16 SHARE OF RESIDENTIAL SOLAR INSTALLATIONS WITH BATTERY STORAGE IN 2023.

SOURCE: BLOOMBERG NEW ENERGY FINANCE [135]

The share of residential solar installations with battery storage is rising quickly. In Germany, more than 3 out of every 4 residential solar PV installations was equipped with a battery storage system. In Italy, the levels were similar, and far above the European average of around 22%, as illustrated in Figure 16 [135]. However, the regulatory environment can restrict the ability for buildings to act as energy producers as well as consumers, highlighting the need to remove regulatory barriers to enable the efficient use of this type of battery storage.

This document dives into these challenges starting with a general overview of the barriers followed by a review of EU legislation and a review of national barriers.

5.1.General Overview of Barriers

Key barriers to the widespread uptake of intelligent grid-forming buildings can be categorized into regulatory, technical, and social challenges.

iGFBs face certain **regulatory hurdles**, including the inadequacy of current energy prices and electricity tariffs in incentivizing electrification and flexibility. For instance, the disproportionate allocation of energy transition costs to electricity creates misleading incentives, particularly as the power system becomes lower carbon [136]. The regulatory regime often views demand-side flexibility merely as an individual consumer right, rather than a systemic resource, failing to establish coherent objectives and incentives for customer flexibility at scale [137]. Additionally, there is a lack of clear legislation regarding the future of non-electric heating technologies, such as fossil fuel boilers, and an absence of ancillary markets for demand-side flexibility [136]. Many European countries have markets that are either inactive commercially or have high entry barriers, like large minimum bid sizes [138]. Furthermore, there's an absence of a comprehensive framework for demand response aggregation, and the development of time-differentiated network tariffs is limited. Another significant issue is the lack of legislation enabling citizen and energy communities and the absence of a standardized methodology to assign value to demand-side flexibility [137]. Finally, progress on smart meter rollouts is uneven across Europe, and there's a lack of clear business models for deploying public charging and ensuring interoperability among charging services [138].

Recommendations for improvements in distribution tariff structures and network tariff design also are important, as current methods lack a dynamic link to daily grid congestion [139]. The implementation of more responsive approaches, such as event-based tariff designs for early stages of smart meter rollouts, and eventually, hourly dynamic and energy-based tariffs, is recommended [139]. However, the wholesale market design often fails to reflect the true system value or cost of user actions, with non-cost-reflective network charges and incentives, and other policy subsidies distorting the real value that should incentivize customer actions [137].

These barriers are compounded by the complexity of price interventions and technology subsidies, which, if not carefully designed, can inadvertently strengthen obstacles to demand response and slow the market adoption of new technologies like iGFBs. The lack of a solid legal foundation in multiple EU Member States hinders the unlocking of the full potential of distributed energy resources, crucial for iGFBs. The prevalence of regulated tariffs that do not encourage active demand response further constrains the flexibility capabilities of iGFBs. However, there has been progress in recent years, with clearer regulatory frameworks emerging in certain Member States and more inclusive capacity mechanisms, indicating a gradual shift towards a more favourable environment for intelligent grid-forming buildings [140].

In terms of **technical barriers**, the main challenges include the need for improvements in building efficiency to make smart electrification cost-effective and a lack of smart and electric devices, especially smart meters. The need to manage electricity demand is increasingly critical, especially in scenarios where the electricity supply is scarce or at risk. The changing power system in the EU offers a unique opportunity for these buildings to actively participate in the energy transition through demand response. However, this requires not only technological advancements but also the right mix of financial incentives and access to reliable consumer information, as well as access to building energy data to assess the flexibility potential of buildings and the volume activated, which can be then procured by system operators to help them balance and optimise their grids. These elements are essential to facilitate the adaptation of energy demand in iGFBs, allowing them to respond effectively to market conditions [140]. There is also a fragmented landscape of flexibility services across various markets, each with different procedures and requirements, leading to administrative burdens and inefficiencies [141][137].

Social barriers, though appearing minor in isolation, can aggregate to form significant impediments to iGFBs [137]. These include issues such as the lack of consumer awareness, as well as ability and willingness to operate flexibly under current conditions. Many households are not motivated or able to access flexible products and services, which include access to appropriate retail offers and the adoption of flexible assets [137]. Lower income and vulnerable residents often live in homes less capable of flexible energy use due to factors like poor insulation and older appliances. Furthermore, the distributional effects of time-varying electricity tariffs suggest that households' energy demand patterns are influenced by factors outside of income, such as age, location, culture, working hours, and family composition [137]. Energy bill support schemes often focus more on protecting at-risk groups from price signals rather than empowering them to participate in emerging marketplaces for flexibility [137].

Additionally, insufficient retail regulation, limited consumer access to redress, and lack of transparency over flexibility value hamper engagement in market propositions, with innovative offers often targeting affluent groups. Digital literacy, trust in energy service providers, shortage of skills, cultural preferences, and the ability to absorb price risk have also been identified as significant barriers [137][142].

Some Member States have taken actions to increase consumer awareness through efforts such as targeted and social media campaigns, mobile applications, government programmes, and more, as shown below [140].

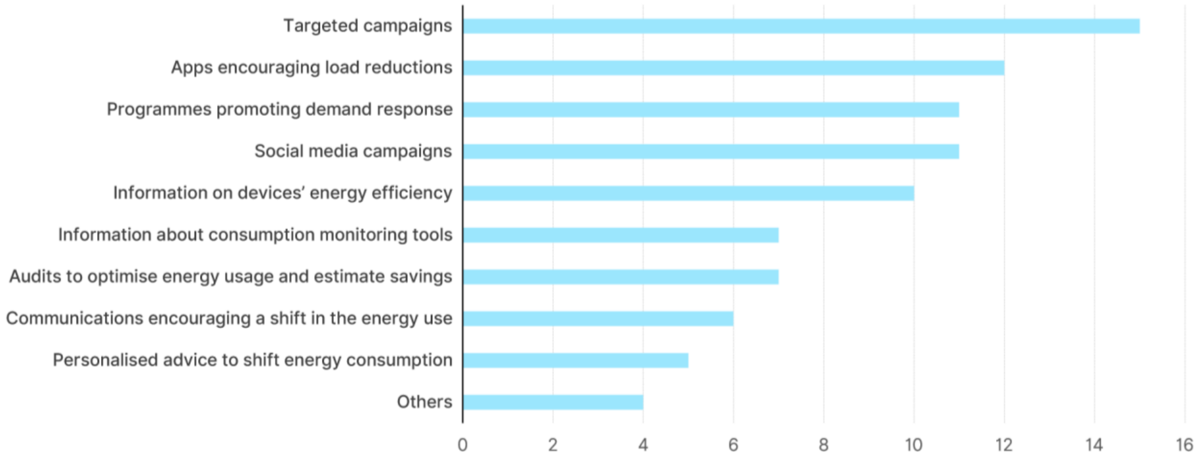

FIGURE 17 MEMBER STATES IMPLEMENTING MEASURES TO IMPROVE CONSUMER AWARENESS ON DEMAND RESPONSE

SOURCE: ACER [140]

The EU-funded project SmartBuilt4EU [59] also dove into some of these barriers and described them in an overview as shown below [143].

Technical	Weak adaptability of buildings to different end-users' profiles and to their different life phases in the building (e.g., moving in, getting used to the equipment...)
Economic	Economic concerns for end-user, occupant, private investor and owner: affordability/short- term, compared to benefits (medium to long-term)
Social	Fears related to lack of data privacy and lack of control over smart solutions Unknown, different perceptions of comfort for different end-users with respect to smart building use
Value Chain	Lock-in effects: How the smart solution will evolve in the future, requirements for updates and upgrades

TABLE 6 OVERVIEW OF MAIN BARRIERS TO SMART BUILDINGS FROM SMARTBUILT4EU PROJECT

SOURCE: SMARTBUILT4EU [143]

Further, the same project outlined more specific requirements for smart buildings, as shown in Table 7 [143]

Regulation and legal framework	Define legal requirements for data collectors/providers to **ensure data security** and allow for **transparent access** to authorized stakeholders. Set up **"Open Source" regulations** requiring any software that will not be maintained to release publicly its source code to allow updates.
Certification and Standardization	**Further standardize the user interfaces** to allow multiple solutions and services to be visualised in a user-specific interface. **Standardize user interfaces for users with specific needs** (age, disability, etc.) **Address the gap in calibration means and accuracy of sensing devices** in view of data sharing amongst smart building service providers (lack of clean standards)
Scaling up and industrialisation	**Explore potential market disruptions** in relation to **very large players from the IT sector** (Google, Apple, Facebook, Amazon, etc.) potentially entering the buildings market Explore how smart buildings can qualify with regard to the **EU Taxonomy for Sustainable Investments** as a driver for smart building investments Ensure that smart building concepts are taken up by the **New Bauhaus Initiative** as viable green, sustainable investments.

TABLE 7 SUGGESTED REQUIREMENTS FOR SMART BUILDINGS FROM SMARTBUILT4EU

SOURCE: SMARTBUILT4EU [143]

The slow progress and lack of proper legal frameworks at the national level mean that much of the demand-side flexibility potential will remain untapped, and the market will stay fragmented. This is crucial to the future viability of iGFBs. Some of these barriers can be addressed by European and national legislation. The following sections discuss opportunities and challenges in existing European legislation, such as the Energy Performance of Buildings Directive (EPBD) [102] and more, before diving into a review of national barriers for eight Member States.

5.2.Review of European Union Regulation

This section explores the current EU directives and regulations, with a focus on the Energy Performance in Buildings Directive (EPBD) [102], Electricity Directive and Regulation, Electricity Network Codes, Renewable Energy Directive (RED) [108], Energy Efficiency Directive (EED) [103], and Energy Taxation Directive (ETD). Each regulatory framework plays a distinctive role in shaping the landscape for iGFBs, offering both opportunities and challenges.

5.2.1. Energy Performance in Buildings Directive

The current Energy Performance in Buildings Directive (EPBD) [102] negotiations mean details may change. The revised EPBD presents opportunities for iGFBs, mainly in two areas:

- **Deployment of efficient infrastructure.** This includes a new requirement for smart-charging-capable EV charging points in new and certain renovated buildings. It also introduces a standard for Zero Energy Buildings, defined nationally as highly efficient buildings with zero on-site fossil fuel use. Additionally, there are minimum energy performance standards aimed at encouraging the use of fabric efficiency, efficient systems and appliances, and connection to district heating networks.
- **Building systems and data requirements.** The revised EPBD mandates a 'smart readiness indicator', which is yet to be defined through a European Commission delegated act. This indicator is designed to evaluate a building's ability to adjust its operations according to occupant needs, particularly in terms of environmental quality and grid interaction, and to enhance overall performance. Another potential development is the introduction of Building Renovation passports. If these focus on the smartness of buildings, they could be instrumental in promoting iGFBs.

Despite these opportunities, the EPBD poses challenges and unfulfilled prospects for iGFBs. Notably, it seems unlikely to establish minimum energy performance standards (MEPS) for the worst-performing homes, a significant oversight given the importance of efficiency in integrating electrified heat and the fact that residential electrified heat is the greatest source of flexibility potential [102]. Also, the focus of the smart readiness indicator on large non-residential buildings means that key areas like electrified heating and EV charging in residential buildings, crucial for future energy flexibility, are not adequately addressed. In general, the EPBD's revised focus leans more towards the operation of standalone buildings rather than integrating them as part of a smart, efficient energy demand and supply system.

5.2.2. Electricity Market Directive and Regulation

The Electricity Market Directive (EMD) [109] and its accompanying Regulation created a comprehensive regulatory framework for integrating demand-side resources that help enable iGFBs, including energy storage and other demand-response technologies. The Directive safeguards the rights of active consumers with storage facilities, including grid connection, exemption from double charging, and the ability to offer system services (Article 15(5)). Additionally, it prohibits double taxation, similar to the 2023 Storage Recommendation, and sets a regulatory framework for Distribution System Operators (DSOs) to use storage and other flexibility services (Articles 32(1) and 32(3)).

In parallel, the Regulation targets the integration of DSF including energy storage into power markets. It mandates market rules to encourage investment in and efficient dispatch of generation, DSF, including storage, fostering competitiveness of these solutions (Article 3). It ensures non-discriminatory access to balancing markets (Article 6), day-ahead and intraday markets with a minimum bid size requirement of 500kW or less (Article 8) and addresses redispatch (Article 13). The Regulation also aims to create network tariffs that do not discriminate against energy storage and aggregation. It facilitates DSF and self-generation by removing regulatory obstacles (Article 18) and requires that any capacity mechanism be accessible to DSF including storage (Article 22). Article 19 also requires Member States to deploy smart meters that assist customers in actively participating in the electricity market [138]. This approach seeks to optimize the integration of DSF including storage, promoting a more efficient and flexible power market system.

While a wide variety of topics relevant to iGFBs have been addressed by the Directive and Regulation, implementation in Member States has been inconsistent. Several Member States have not yet established clear roles and responsibilities for active customers, aggregators (including independent aggregators), and citizen energy communities, as required by the Electricity Directive [140]. Some countries have advanced on some issues but not others, and certain countries have been stagnating. As of early 2023, more than 20 articles relevant to demand-side flexibility and iGFBs were delayed in implementation. Only a handful of countries had moved forward with regulatory measures, with inaction in some key countries such as Italy and Spain.

The revised EMD introduces a requirement for national flexibility assessment that accounts for demand-side flexibility resources (including from buildings) and includes rules on energy sharing that would open the possibility for buildings to contribute to the optimisation of the grid and their integration in the energy system, through an energy sharing organiser. A proposed revision of Article 6 would mandate that balancing markets provide products sufficiently small (minimum bid size of 100 kW), which are important for third-party aggregators building their portfolios from scratch. Additional changes to the common rules for the internal market include Recital 9b) and Recital 10. The former states that "meeting decarbonisation goals at least cost requires the full Implementation of the Energy Efficiency First Principle", underlining the rapid adoption of electrification technologies and their smart use in energy systems. The latter is revised to state that demand-side flexibility is "not only a consumer right, but also an essential system resource which must be delivered at scale".

With regards to energy communities, it is recommended also to include a formal definition of energy sharing. Otherwise, the concept of its implementation will be the sole responsibility of Member States, which can lead to different levels of consumer access across the EU and leaves potential for barriers and restrictions.

5.2.3. Electricity Network Codes

The European Union's grid code ensures that all generators connected across EU Member States meet a minimum set of technical standards, essential for maintaining system stability and guaranteeing a secure supply of electricity. The Network Code on Requirements for Grid Connection of Generators [144] establishes a harmonised set of technical requirements that generators must comply with to connect to the grid. These requirements are designed to ensure that generators can safely and reliably operate within the power system.

ENTSO-E and the EU DSO Entity are currently developing a new network code that focuses on demand response, which is expected to help facilitate iGFBs. This code is expected to be presented to ACER in February 2024. It will include the outcomes of the current revamp of the EU electricity market design, which will be integrated into the updates of the 2019 Electricity Directive and Regulation. The main goal of this network code is to harmonise market access and ease the entry of demand response services into the market, including aspects like load management, storage, and distributed generation. Furthermore, it seeks to simplify how services are procured in a market-driven manner by both distribution and transmission system operators. The implementation of this code will be applied across all EU Member States.

5.2.4. Renewable Energy Directive

The Renewable Energy Directive (RED) [108] represents a cornerstone in the Union's commitment to a sustainable and efficient energy future, setting ambitious targets for the integration of renewable energy across various sectors. Notably, several articles highlight provisions or regulations which have the potential to benefit iGFBs.

Article 15a focuses on integrating renewable energy into the buildings sector. It mandates Member States to set an indicative national target for renewable energy production on-site or near the grid, aiming for a minimum of 49% renewable energy share in building sector energy consumption by 2030. These targets should be included in the integrated NECPs. Member States are allowed to count waste heat and cold towards this target, improving the overall integration of the energy system. Member States also are required to implement measures such as promoting renewable energy self-consumption, energy communities, local energy storage, smart and bi-directional recharging, demand response, and combining these with energy efficiency improvements in cogeneration and major renovations to increase the prevalence of nearly zero energy buildings.

Article 20a emphasizes the integration of renewable electricity into the grid, focusing on system integration and data transparency. It mandates Member States to require operators to provide data on renewable electricity shares and greenhouse gas emissions, aiming for hourly updates. This data availability, including demand response potential and renewable energy generation by self-consumers and communities, is essential for integrating grid-forming buildings, as it enables effective monitoring and management of energy flows. The article also stresses digital interoperability of this data for various stakeholders, including building energy management systems. Furthermore, it includes provisions for real-time access to battery and electric vehicle data, essential for smart grid integration.

Additionally, the RED streamlines the integration of renewable energy projects into grid-forming buildings by simplifying permitting processes, coordinating spatial planning, and identifying dedicated areas for accelerated renewable energy development. It also seeks to bolster public support for renewable energy through enhanced citizen participation. The directive further advocates for expedited installation of technologies like heat pumps in buildings by recommending simplified permit procedures for smaller units, thus potentially accelerating the evolution of iGFBs.

However, the final version of the directive does not include a European Parliament suggestion that would have required Member States to establish indicative national targets for demand-side flexibility and energy storage, both key elements in supporting iGFBs. Moreover, the RED's approach to calculating renewable heating and cooling contributions potentially underrepresents the value of electrification technologies, such as heat pumps, in their contribution to renewable energy [145].

5.2.5. Energy Efficiency Directive

The EU's Energy Efficiency Directive (EED) offers opportunities for the increased use of intelligent grid-forming buildings. Articles 3 and 27 emphasize the importance of investing in energy efficiency (EE) and flexibility assets by system operators, linking these investments to broader electricity regulations. The EED not only sets efficiency targets for Member States but also imposes an energy savings obligation to encourage the adoption of policy measures that promote energy efficiency, especially in the public sector. The shift towards energy-efficient technologies is further reinforced by Article 8, which, starting from 2024, progressively restricts the use of fossil fuel combustion technologies, prioritising more efficient alternatives such as heat pumps and solar thermal systems. These measures align with the concept of grid-forming buildings, which integrate electrification and efficient technologies.

Additionally, the directive mandates large companies to conduct energy audits or establish energy management systems (Article 11), fostering an environment conducive to the adoption of intelligent, efficient building technologies. Articles 13 to 20 on billing and Article 26 on heating and cooling supply also contribute to this goal by providing financial incentives and efficiency standards for renewable energy integration in buildings. Moreover, Articles 28 and 29, focusing on accreditation, qualifications, and market development for energy services, help overcome barriers to the adoption of new technologies and skills necessary for the development of grid-forming buildings.

5.2.6. Energy Taxation Directive

The Energy Taxation Directive (ETD) sets minimum tax rates for energy products in the European Union, with a planned revision aiming to align these rates with the EU's climate goals. The current ETD has low minimum tax rates for fossil fuels and allows Member States to tax electricity at much higher rates than polluting fuels. This places a heavier burden on electrification technologies, worsening their financial case and providing economic incentives that run in opposition to environmental goals. Derogations have been granted to allow exemptions in certain cases, such as for Finland [146]. The proposed revision of the ETD would contain higher minimum tax rates for fossil fuels and biomass, while requiring electricity to be the least-taxed fuel [147].

5.3.Review of National Barriers

The countries chosen for the review of national barriers are those from the partners of the WeForming project (Belgium, Croatia, Germany, Greece, Ireland, Luxembourg, Portugal and Spain). They exhibit many shared points, however, differ greatly in other measure of progress, such as smart-meter roll-out. A table from the recently published ACER report on barriers to demand response and distributed energy resources can help shine light on some of these challenges [140].

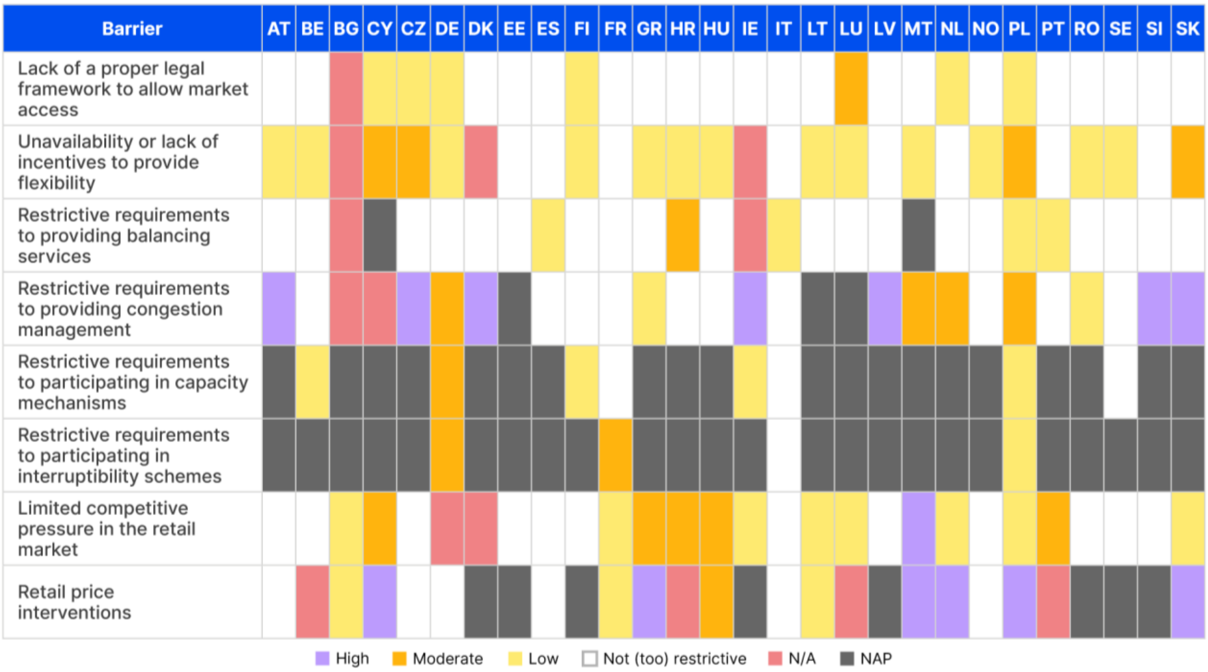

TABLE 8 OVERVIEW OF BARRIERS TO DISTRIBUTED ENERGY RESOURCES AND OTHER NEW ENTRANTS AND SMALL ACTORS PER MEMBER STATE

SOURCE: ACER [140]

5.3.1. Belgium

Belgium has three regions (Flanders, Wallonia, Brussels), each with its own energy regime at the distribution level and regional regulator, which is an obstacle to the efficient implementation of operating models for iGFBs. The national TSO, Elia, is a strong proponent of demand-side flexibility [148], but the country ranks as one of the lowest on a European ranking of distribution system flexibility [141]. The three regions also have different enablers for consumers to become active consumers: only the Flanders region has 6 suppliers providing dynamic energy contracts, both for offtake as well as injection, Wallonia just one for offtake, and Brussels region has none [149].

In the past three years, the Flemish region has reduced support for home solar panels and ended support for home batteries for self-consumption optimisation [150], changed the rules on grid tariffs to a capacity-based model (where the smart meter records the monthly highest 15-minute value, regardless of direction) and simultaneously ended net metering.

Wallonia has also changed its treatment of residential solar installations, moving from an initially publicly funded 'prosumer fee', an additional contribution to cover grid costs - in addition to net metering of the electricity fed into the grid - to a system where prosumers pay proportionally [151]. A different mechanism is used for newer installations as of 2024. Prosumers can either sell their surplus to a supplier or participate in energy sharing (peer-to-peer or within an energy community) [152]. The peer-to-peer trading is also possible in Flanders, the energy community concept has been made possible in all three regions (including Brussels).

Belgium offers a tax credit for home charging stations that can communicate with a home energy management system [153]. If the station is capable of bi-directional charging, the tax credit is significantly higher, however expected uptake is still limited.

The December 2023 report by the European Union Agency for the Cooperation of Energy Regulators (ACER) recommended that Belgium should establish a legal framework for new energy market entrants, accelerate the rollout of smart meters – which is likely to apply to a different extent in the three regions, and address restrictive requirements in capacity mechanisms. The report also suggested facilitating competitive retail markets and conducting studies or pilot projects to determine the need for differentiated network charges for active customers. Moreover, Belgium is advised to monitor retail electricity contract types and manage taxes and levies to not distort cost signals [140].

5.3.2. Croatia

Croatia’s Energy Development Strategy anticipates a large increase in distributed production installed at the consumer’s side. They are expecting that by 2030, the share of renewable generation will be more than 35%. By 2030, end-user energy consumption is expected to increase by 7%, while it is expected that it will decrease slowly by 2050 [154]. To accompany all this, they also emphasize improvements in the transmission and distribution grid that needs to be made to ensure the security of supply for consumers. They also underline the need for improvement in smart grid implementation with smart metering, bi-directional flow of electricity, better digitalisation, and better flexibility procurement from active end-users.

In Croatia, emphasis is placed on integrating distributed renewable energy sources at the end-user side. However, these energy sources are almost entirely installed in single-family households. If residents in a multi-unit building wish to incorporate renewable energy sources or offer flexibility, they need to form some type of collective active consumer (energy community). The Croatian electricity market regulation and regulation on renewable energy sources and highly efficient cogeneration recognize four types of end-users [155]: active consumer, collective active consumer, citizen energy community and renewable energy community.

In Croatia, there are distinct categories related to the integration of renewable energy sources and active consumer participation. An "active consumer" refers to an end-user or a group of end-users who consume, store, or sell electricity produced within their defined boundaries. They can also engage in flexibility provision or energy efficiency programs if these activities aren't their primary business focus. A "collective active customer" represents a group of end-users acting together as active consumers, without the need for formal legal entities like energy communities.

A "citizen energy community" is a legal entity formed with the involvement of natural persons, local government units, or small businesses. It operates under the actual control of the members and aims to provide environmental, economic, or social benefits to its members, local areas, or shareholders, rather than generating financial profit. It can engage in various energy-related activities, including renewable energy production, energy storage, energy efficiency services, and electric vehicle charging. "Renewable energy communities" are legal entities that comply with national laws and are characterized by open and voluntary participation. They are under the effective control of their shareholders or members, who must be located near renewable energy projects owned by the community. Like citizen energy communities, their primary goal is to benefit the community, its members, or local areas environmentally, economically, or socially, without a focus on financial gain.

Although they are defined in laws, as of the end of 2023, none of these groups of end-users exist in Croatia despite ongoing attempts to establish them. One reason for their absence is that most of the consumers are not incentivized to enter end-user groups. They may not see enough benefits with respect to investment costs and the process of establishing the groups can be lengthy with administrative barriers.

New changes in electricity market law reduced some barriers by removing locational restrictions for collective active customers and citizen energy communities. Some barriers remain, such as the need to employ full-time professional workers in energy communities. They also require 1000 € to establish an energy community and always require at least 2656 € of liquid funds in the energy community’s banking account.

Furthermore, there currently is no flexibility market for end-users connected to the distribution network. Only those connected to the transmission network can offer flexibility services.

The government of Croatia is also known to cap the prices of electricity and other energy sources which can negatively impact production from renewable energy generation and disincentivize their installation.

From a technical standpoint, the implementation of smart grid and smart metering systems is not widespread in Croatia, and the grid infrastructure is not fully equipped to handle distributed energy production. While this may not be a significant issue for small-scale renewable energy installations, it could become a challenge if there is a substantial increase in renewable energy generation. Another technical barrier lies in the electrification of heating, particularly in large cities like Zagreb and Osijek, which already have efficient cogeneration plants for electricity and heat supply, meeting the heating needs of most residents. Consequently, there may be limited motivation for people to invest in alternative heating methods as the existing options are the cheapest. In coastal regions of Croatia, the demand for heating primarily revolves around hot water, creating opportunities for smaller-scale heating solutions in buildings. Additionally, these areas have substantial cooling energy requirements during the summer, making energy-efficient cooling units or centralized cooling and heating systems beneficial options.

Installing renewable energy systems at the end-user level in Croatia doesn't pose significant technical challenges, with many households and industries successfully implementing such projects. The primary obstacle lies in regulatory barriers and the time-consuming process of obtaining the necessary permits. To connect renewable generation to the low voltage network, the Croatian distribution system operator has outlined several steps, including that the installed power doesn't exceed the agreed connection power, obtaining an electricity approval (EES), securing a main project certificate, paying the connection fee, finalizing a network usage contract, installing the connection, and obtaining certificates for both trial and permanent operation. While technical obstacles for end-user groups are limited, the complex regulatory framework and permit procedures can hinder the broader adoption of renewable energy sources.

The Ministry of Physical Planning, Construction, and State Assets in Croatia has issued guidelines for the implementation of nearly zero-energy buildings. However, there are several significant barriers to their adoption, including restrictions on innovation in the public sector due to public procurement laws, the absence of a clear energy source strategy for buildings (especially in the public sector), no accountability for failing to implement energy efficiency measures, a lack of tax and local incentives, extended return on investment periods for renovations, limited successful financial models, inadequate knowledge among construction stakeholders, resistance within the construction sector to change, insufficient information about the benefits for users, and a tendency to prioritize short-term gains over long-term benefits. These challenges pose obstacles to the widespread adoption of nearly zero-energy building practices in Croatia and parallels can be made to iGFBs.

A case study exists showing the potential for iGFBs in Croatia. In the EU-funded project FLEXIGRID [40], demo area 3, they innovatively addressed distribution network flexibility and virtual energy storage for urban buildings. This involved modelling distribution networks, exploring third-party flexibility providers, and testing protection functions, logic, and schemes based on operating points. Additionally, they developed and tested control algorithms for virtual energy storage in buildings across various feeders in the distribution network while establishing a robust database and communication structure.

Messer Croatia Plin d.o.o. is an industrial end-user that has provided a flexibility service to the Croatian TSO, alongside the cement plant operator Cemex and aggregators KOER and Nano Energies. A complete list can be found online[1]. As far as the authors are aware, no other end-users, industrial or household, have provided this service.

The ACER report from December 2023 advised Croatia to develop a comprehensive national legal framework for new market participants, enhance smart meter deployment, and ease capacity mechanism restrictions. Croatia is also encouraged to stimulate retail market competition and ensure fair network charges for active customers. Monitoring retail electricity contracts and general management of taxes and levies for active customers are also highlighted in the report [140].

5.3.3. Germany

Germany has not been at the forefront of enabling iGFBs, largely due to the lack of smart meter rollout and associated tariff models. However, two important steps in the legislative and regulatory framework have started a change in the country's approach towards iGFBs in 2023.

First, a law has been passed to accelerate the rollout of (residential) smart meters [156], which should be fully deployed by 2032, with priority given to prosumers. Second, after a lengthy consultation process, the national energy regulator has finalised the details of the Energy Act's section on flexible loads [157]. These new rules came into force in January 2024. These 'Paragraph 14a' details define the mandatory participation of flexible loads, specifically EV charging points, batteries, air conditioners, and heat pumps (with an installed power more than 4.2 kilowatts), in emergency curtailment schemes of the local DSO, which in turn must not delay the application for permission to install such devices (which is mandatory for heavier loads).

During such DSO-controlled periods of demand reduction, connected appliances such as heat pumps and EV charging points can be obliged to reduce their power to 4.2 kW each, leaving the rest of the

[1]https://www.hops.hr/page-file/yJ5qjoIToQHKojY0057cm7/postupak-nabave-mfrr-rezerve-snage-iili-energije-uravnotezenja-za-sigurnost-sustava-javnim-nadmetanjem/Registar pru%C5%BEatelja usluga uravnote%C5%BEenja.pdf

household consumption unaffected. On-site generation (rooftop solar) or storage (home battery, V2G-enabled vehicle) can be used to increase behind-the-meter capacity. When using a Home Energy Management System (HEMS), the per-device power limitation can be combined and used in other constellations, which is expected to open a market for grid-interactive HEMS.

With households (and other small electricity users) installing a 'flexible load' such as a heat pump or EV charger on the priority list for smart meters, household access to other types of flexibility marketing, such as dynamic energy contracts, is rapidly improving. From 2025, all electricity suppliers in the country will be required to offer a dynamic energy contract (a result of the implementation of the 2019 European Electricity Market Directive) [158].

In the pipeline, but not yet finalised, are new rules for (small-scale) energy storage and bi-directional charging, which will allow car batteries to be used via vehicle-to-grid (V2G) technology to buffer electricity from the grid. Home batteries are seeing a very strong rise, with installed capacity doubled in 2023, now reaching over 1 million installed battery energy storage system (BESS) [159]. Of newly installed residential solar installations in 2023, approximately 70% came with a BESS [160]. This is mainly driven by solar feed-in tariffs, which have previously incentivised the supply of electricity to the grid (feed-in), but now provide a higher remuneration for solar electricity used for self-consumption. However, restrictive requirements for BESS currently prevent their wider use, for example to provide ancillary services to the grid. Simplified requirements for so-called 'balcony solar' allow residential customers, including those living in rental properties, to easily install up to 800 Wp of solar panels.

In Germany, there is a strong customer appetite (for local energy systems). Nevertheless, the regulations are lagging, hindering the development of energy communities [141]. However, at building level, 'Mieterstrom' allows energy sharing amongst residents of the same building (or group of buildings) [161]. The concept of energy sharing as introduced in European legislation is also being discussed for introduction in Germany [162].

The December 2023 ACER report recommends that Germany establishes a proper legal framework for new entrants, expedites smart meter penetration, and modifies capacity mechanism requirements. The report also emphasizes improving retail market competition and differentiating network charges for active customers. Furthermore, Germany should monitor retail electricity contract penetration and manage taxes and levies effectively [140].

5.3.4. Greece

Greece has several significant barriers that slow the uptake of iGFBs. For one, less than 5% of households currently have smart meters, with about 170,000 units installed. The Hellenic Electricity Distribution Network Operator has outlined a plan to replace analogue meters with smart meters over an eight-year timeframe, aiming for completion by 2030 with an estimated total of 7.5 million smart meters [163].

Households have opportunities to engage smart buildings in Greece through the integration of photovoltaic (PV) systems and smart metering. They can tailor PV systems to their specific needs, ensuring optimal energy production and consumption patterns. Upon connecting these systems to the grid, managed by HEDNO S.A., buildings are equipped with smart meters that enhance energy management. The Net-Metering and Direct Grid Injection schemes provide incentives for energy production. Net-metering allows households to reduce electricity bills by compensating for excess energy fed into the grid, while direct grid injection offers fixed payments for the energy produced.

However, as of end-2023, Greece still lacked an active market for energy flexibility. Nonetheless, in July 2022, Greece completely opened its markets for Frequency Containment Reserve, as well as Automatic and Manual Frequency Restoration Reserve. These markets permitted both Demand Side Flexibility (DSF) and aggregation, with a minimum bidding size set at 1 MW [141].

As per the ACER report of December 2023, Greece is recommended to establish a comprehensive legal framework for new market participants, enhance smart meter deployment, and address capacity mechanism restrictions. Stimulating retail market competition, ensuring fair network charges for active customers, and managing retail price interventions effectively are also advised. Additionally, Greece should focus on monitoring retail electricity contracts and general management of taxes and levies for active customers [140].

5.3.5. Ireland

Ireland's progress is notable in energy management and integration due to its strategy to implement smart meters and dynamic electricity pricing [141]. However, Ireland currently lacks a national framework for demand response, meaning that markets conditions and products are lacking to support building participation in demand response, important to the effective use of iGFBs [138].

The roll-out of smart meters, underway since 2019 and led by the transmission system operator ESB Networks, is a key component of this progress. The National Smart Metering Programme aims to install 2.4 million smart meters in homes and businesses by the end of 2024 [164]. As of April 2023, over 1.2 million smart electricity meters had already been installed [168]. These devices are an essential part of modernizing Ireland's electricity meters, enabling functionalities like remote reading, near real-time consumption information, and more efficient power system management [169]. They also empower consumers with instant access to electricity use information and facilitate smart services. These offerings are important to the advancement of iGFBs, however there still exists regulatory gaps with regard to energy sharing and peer-to-peer trading.

In terms of pricing, customers with smart meters have the option to opt for a time-of-use tariff through their electricity supplier [138]. Suppliers are mandated to offer such tariffs to customers with smart meters and are prohibited from discriminating against customers who have contracts with aggregators [138].

Ireland's lack of national demand response framework may pose issues for iGFBs. The National Energy Demand Strategy was out for consultation at the time of writing. The National Regulatory Authority (NRA) has engaged in consultations (CRU/21028) on energy communities and active customers, aiming to establish workstreams involving multiple stakeholders to advance this area [138]. Despite these efforts, Ireland's capacity market arrangements, operational since 2018, have technical requirements and testing procedures that have effectively excluded demand response from these arrangements.

Technical barriers include lacking communication protocols that should define how the grid signals and provides an actionable communication to a building to allow a response.

Social barriers include a widespread lack of awareness related to iGFBs and opportunities such as demand response. The Sustainable Energy Authority of Ireland plans to create an online portal to provide education and awareness to businesses looking to participate in flexibility markets. An Irish research project identified both technological and social barriers to the integration of "smart technology" in Ireland. Technological barriers include poor connectivity due to geographical factors, outdated building systems, the risk of obsolete devices, and concerns about e-waste generation. Social barriers encompass a lack of awareness about smart technology, absence of responsibility, privacy concerns, inability to address concerns about smart services, and dependency on services outside the user's control [170].

An assessment of perceived barriers to Nearly-Zero Energy Buildings in Ireland may also shed light on common barriers to iGFBs [142]. This survey of housing professionals' perceptions identifies barriers such as higher costs, lenient building regulations, and risks associated with innovation. The study notes that these perceptions often diverge from actual obstacles highlight a gap between policy development and local practice. Better information dissemination and assimilation is listed as key to transition towards Nearly Zero-Energy Buildings (NZEBs) in Ireland and it can be assumed that iGFB perceptions would be similar. Likewise, a different survey noted that information on heating system alternatives was critical for adoption of such technologies among homeowners [171].

Ireland's approach to energy management and smart meter integration reflects significant regulatory progress and holds great potential for iGFBs. However, the lack of a demand response framework and potentially negative perceptions on iGFBs may hold the sector back from rapid expansion. In addition, there is a great potential for public sector buildings, which could be mandated to act in this area.

According to the ACER December 2023 report [140], Ireland should focus on allowing all energy resources in electricity markets, accelerating smart meter implementation, and addressing capacity mechanism requirements. Enhancing retail market competition and differentiating network charges for active and non-active customers are also recommended. Additionally, Ireland is encouraged to focus on the general handling of taxes and levies for active customers [140].

5.3.6. Luxembourg

Contrary to the previously discussed countries of Germany and Greece, more than 90% of households in Luxembourg are equipped with smart meters. What's more, Luxembourg has taken recent steps that could enable the use of iGFBs.

In a move to modernize its electricity market regulations, Luxembourg enacted a new law in 2020. This update harmonizes Luxembourg's policies on individual and collective self-consumption, as well as renewable energy communities, with EU directives [172]. Individual renewable energy producers can store and sell their excess electricity, but their primary business activity cannot be electricity trading. Both individual and collective self-consumption must be limited to the same building or apartment complex. Renewable energy producers must also connect to the public grid at a single point of entry. They can sell or store their surplus electricity through electricity suppliers or renewable power purchase agreements. Additionally, they have the right to organize the sharing of their electricity independently. Third parties can own and manage collective self-consumption installations, but these entities must follow the instructions of the self-consumers.

Collective self-consumers must enter into a contract with the DSO that outlines a six-step process, encompassing at least the following details: a) Identification and contact information of the renewable energy self-consumers, b) Specifications of the renewable energy installations involved and c) Established mechanism for distributing the generated electricity. The DSO will calculate how much electricity each renewable energy self-consumer has produced and consumed, as well as how much electricity they have received from the public grid. This information will be calculated based on a pre-defined distribution key and will be provided to the self-consumers and their suppliers at least once a month. The State had introduced a new subsidy geared towards self-consumption. It allows individuals to receive a subsidy of almost 50% of the installation cost, up to a maximum of 1250 €/kW [173] .

The DSO plans to use a similar approach to track the generation and consumption of renewable energy communities (RECs). RECs are legal entities composed of individuals, small and medium-sized enterprises, or local authorities, including municipalities. In Luxembourg, RECs must be based within the same geographical area and situated downstream from high or medium voltage to low voltage transformer stations. If RECs do not directly allocate the generated electricity to their members, the distribution system operator (DSO) will handle the distribution using a "static and simple" method. The specific distribution model will be developed by the regulator in collaboration with the DSOs. RECs have the flexibility to define their own distribution model if they manage the sharing themselves, but the required data exchange with the DSO must be clearly outlined. RECs must enter into an agreement with the DSO, like the one for collective self-consumers. RECs can sell surplus renewable electricity injected into the grid through the individual suppliers of their members or shareholders, or through a common supplier if specified in their statutes. Alternatively, RECs can sell their excess electricity through renewable power purchase agreements, provided they operate as a balance responsible party.

Luxembourg's primary electricity providers include Enovos and Electris. Creos is the entity responsible for overseeing the electricity network. Regardless of the chosen electricity supplier, all electricity is delivered through Creos. The Grand-Ducal regulation governs the electricity tariff, which is guaranteed for a period of 15 years from the initial export of electricity to the grid. For installations with a capacity of up to 10 kW_p and a first export in 2022, the tariff is set at 0.15 €/kWh.

It should be noted that frequently situations occur where the electricity produced by photovoltaic (PV) installations cannot be fed into the grid. This is often due to insufficient transformer capacity or inadequate connection possibilities. While the DSO is obligated to connect and feed-in renewable energy installations, project developers are responsible for contributing to grid reinforcement costs if insufficient capacity exists. Consequently, these costs can render renewable energy projects financially unsustainable. In addition to this grid capacity issue, there is significant public resistance to grid expansion, particularly at the Transmission Network Operator (TNO) level [174].

The ACER report from December 2023 [140] suggests that Luxembourg should focus on legal frameworks for new entrants, smart meter rollout, capacity mechanism requirements and retail market competition. Differentiating network charges for active customers and general management of taxes and levies for active customers are also recommended.

5.3.7. Portugal

As the energy landscape in Portugal undergoes significant transformations, the integration of iGFBs represents a pivotal step towards a more sustainable and resilient future. In the Portuguese context, the nature of these barriers underscores the need for a collaborative approach involving regulatory authorities, technology developers, and the construction industry.

Grid interconnection policies for Portuguese iGFBs are evolving with recent regulatory changes. Standards and protocols for connecting iGFBs to the grid have been refined, aligning with the provisions of the 2019 Decree-Law (DL 162/2019). The new regulation facilitates direct exchange between iGFB prosumers, fostering the development of micro-grids and collective self-consumption models. However, challenges persist in regulatory approval processes for grid integration. While administrative procedures have been streamlined, the communication requirement is now extended to 30 kW, and installations exceeding 100 kW require approval from the grid operator, potentially leading to prolonged administrative processes.

Tariff structures have undergone significant changes, moving from the previous regime's Feed-In-Tariffs (FITs) to the DL 162/2019, which emphasizes a remuneration model reflecting the market value of surplus energy. The shift is aligned with the principles of collective self-consumption, offering prosumers the opportunity to commercialize surplus energy through independent aggregators or utility companies. The impact of Time-of-Use (ToU) tariffs on iGFBs remains key, and while the regulatory framework allows for flexibility, the actual implications on iGFB adoption and operation need specific assessments depending on the application. Portugal is one of Europe's leading countries in demand-side flexibility [141].

Grid code compliance is crucial for iGFBs aiming to provide services to the grid. The regulatory landscape ensures that iGFBs must adhere to established grid codes, aiming to maintain stability and reliability. However, the absence of strict spatial limits for prosumer proximity, as outlined in DL 162/2019, introduces complexities that require careful consideration. The National Directorate for Energy and Geology's (DGEG) mandatory assessments are essential for monitoring the development of Renewable Energy Communities (RECs), ensuring accessibility, and driving potential legal amendments.

Persistent barriers in the regulatory landscape for Portuguese iGFBs are underscored by historical gaps in legal provisions for collective prosumers, hindering the formation of RECs and impeding collective prosumer initiatives. The recent shift in regulatory frameworks, while demonstrating adaptability, leaves challenges in the specific legal frameworks for RECs. The reduction or removal of FITs has added complexity to the sector, necessitating ongoing adjustments. The International Energy Agency (IEA) recommends fostering more competitive markets, incentivizing flexibility in supply and demand for iGFBs. A comprehensive review of network development plans is undergoing to align with 2030 targets and support smart grid integration. The IEA places a strong emphasis on the development of the MIBEL wholesale market (Iberian Electricity Market), collaborating with Spain on electricity interconnection, and enhancing retail market competition.

In terms of social barriers, the complex nature of iGFBs, involving interconnected loads, distributed energy resources and advanced control systems, requires effective communication to enhance public understanding. The benefits, such as improved energy efficiency, grid stability, and environmental sustainability, need to be clearly communicated to dispel potential misconceptions.

Misconceptions and concerns may arise due to the innovative nature of iGFBs. Regulatory efforts should focus on addressing these concerns through targeted educational campaigns. Providing transparent information about the technology, its safety features, and the positive impact on the local environment can contribute to a more accurate public perception. Regulatory agencies play a key role in facilitating dialogues to address concerns and promote an accurate understanding of iGFBs [175].

Social acceptance is a critical factor influencing the fate of iGFB projects, which is determined by how the transition in the workforce skill set is carried out. Regulatory initiatives should focus on implementing comprehensive training programs to equip the existing workforce with the skills required for iGFB maintenance, operation, and optimization. Workforce transition should be viewed not only as a challenge but also as an opportunity for job creation. Emphasizing the potential for new employment opportunities within the iGFB sector contributes to a positive perception of the technology.

The impediments to adoption of iGFBs extend to a lack of trust in innovative technologies and a resistance to change inherent in renovation processes. This short-term vision can be held by both inhabitants and technical professionals. This resistance is compounded by limited awareness and trust in modern technologies and public procurement processes. Additionally, managing a real renovation project becomes intricate due to the lack of commitment from building owners/developers, insufficient communication, and an absence of a long-term vision for building performance post-renovation. Client scepticism towards innovations and the postponement of blueprints for new production processes underscore the challenges in revolutionizing a market resistant to change [176] [177].

For technical barriers, iGFBs in the Portuguese context need integration with smart building systems. This involves harmonizing the innovative aspects of iGFBs with existing smart technologies to create a cohesive and efficient ecosystem. The challenge lies in ensuring that the incorporation of iGFBs enhances overall building intelligence, enabling functionalities such as optimized energy consumption, real-time monitoring, and responsive automation. In this sense, the compatibility with the existing infrastructure is a critical consideration. This requires a deep understanding of the building architectures present in Portugal and adapting iGFBs to coexist with various technologies.

In addition, the integration of iGFBs introduces new concerns regarding cybersecurity. Protecting these intelligent systems from cyber threats is of paramount importance, especially considering the sensitive data they collect and manage to provide services to the grid. This must be achieved while ensuring the adequate treatment of confidential data and information collected by iGFBs. Adhering to stringent privacy regulations, ensuring secure and robust data storage, and providing transparent information to building occupants regarding data usage are crucial. Addressing privacy concerns is not only a legal requirement but also a key factor in gaining public trust and fostering widespread acceptance of iGFBs.

The reliability of the operation of iGFBs under various conditions is a technical challenge that requires thorough testing and validation. Portuguese iGFBs must demonstrate consistent performance, meeting the demands of diverse environments and usage scenarios. Ensuring that these systems operate reliably contributes to their overall acceptance and effectiveness in enhancing building performance.

Assessing the resilience of iGFBs to natural disasters is a critical aspect in the Portuguese context, considering the region's susceptibility to certain seismic events. Incorporating design features that enhance structural and operational resilience, such as backup power systems (as battery energy storage systems), is vital. Remaining challenges include adapting iGFBs to the diverse architectural landscape, addressing the intricacies of existing building infrastructure, and navigating through regulatory frameworks. Moreover, considerations for seismic risk, energy transition needs, and the integration of innovative technologies highlight the multifaceted nature of these technical barriers. Additionally, the cost breakdown, with a significant portion allocated to prefabricated envelope and building services, raises financial concerns and requires strategic planning to make iGFBs economically competitive [177] [178].

According to the December 2023 ACER report [140], Portugal is advised to allow all energy resources in electricity markets, address capacity mechanism requirements, enhance retail market competition, and manage retail price interventions. Portugal should also focus on monitoring retail electricity contract types and handling taxes and levies for active customers.

5.3.8. Spain

Spain has undergone significant reforms in its energy policy, aligning with EU objectives for a clean energy transition. The country's strategic framework aims for national climate neutrality by 2050, with a 100% renewable electricity mix and 97% renewable total energy mix. Key policies include massive renewable energy development, energy efficiency, electrification, and renewable hydrogen production [179].

However, Spain's decentralized governance grants regional authorities significant sway over energy policy, necessitating effective coordination for policy implementation. Spain's challenges include ensuring energy security in a system increasingly reliant on renewable generation, requiring backup solutions beyond fossil fuels. In addition, Spanish buildings have complicated ownership structures, such that any buildings law, such as like the "horizontal property law" (49/1960 Law), requires high degrees of approval to pass the necessary internal procedures [180].

Spain's recovery plan post-COVID-19, bolstered by EU funds, emphasizes energy transition investments in sustainable mobility, renewable energies, and green hydrogen. The National Energy and Climate Plan (NECP) outlines actions to reduce greenhouse gas emissions, increase renewables usage, and improve energy efficiency. The Climate Change and Energy Transition Bill underlines the imperative of transitioning to renewable energy and efficiency. Moreover, Spain's Just Transition Strategy ensures that communities dependent on traditional energy sectors are supported through the transition.

Spain has become a leading country for energy communities. Individuals and groups can engage in collective self-consumption (CSC) through the public network without needing to create a legal entity.

This approach reduces initial expenses and opens doors for various participants. Consequently, numerous CSC models have emerged, encompassing energy cooperatives, local communities, municipal bodies, and energy utility companies [141].

The implications for the iGFB industry in Spain are profound. As the country moves towards a more integrated, renewable-based energy system, iGFBs can play a critical role in balancing the grid, optimizing energy use, and participating in the emerging energy market. However, the successful integration of iGFBs will depend on navigating the regulatory environment effectively, particularly at the regional level where energy policies can diverge. Engagement by local actors such as urban and rural energy communities can help alleviate these barriers, development of which is increasing rapidly [181].

In Spain, the technical challenges facing iGFBs span production, technology, infrastructure, and logistics. Challenges in production and technology include integrating renewable energy sources and managing decentralized energy production. To meet the government's ambitious 2030 targets, there's a need for sophisticated monitoring and control systems within smart grids. The focus on infrastructure and logistics is primarily on upgrading substations for efficient grid management. With smart meter implementation almost complete, the next step is the modernization of substations, crucial for telemetry and smart grid operations. The growing presence of renewable electricity generation demands substantial investment in the distribution system to ensure its adaptation, maintaining both the quality and the continuity of the electricity supply.

Spain, like many countries, is confronting obstacles in integrating renewable energies and managing distributed generation. The government's legislation on climate change and energy transition sets ambitious goals for 2030, which include a reduction in CO_2 output and a significant increase in renewable energy consumption, with smart grids being essential to meet these goals. However, the deployment of smart grids and the necessary modernization processes involve substantial investments and technological advancements, particularly in monitoring and control systems in substations.

The integration of renewable energy production sites and the management of distributed generation units into the grid require precise control systems and modifications to the regulatory framework to ensure proper integration. This includes improving corrective and predictive maintenance and integrating new types of decentralized generation and consumption, which are critical for Spain's future energy distribution system.

Spain has nearly finished installing smart meters nationwide and is now turning its attention to upgrading monitoring and control systems in substations, with 30-40% already modernized. This upgrade is essential for enabling telemetry and facilitating smart grid management. The introduction of new renewable energy generation facilities marks a significant shift in the distribution system, transforming power lines into both suppliers and producers of electricity. To meet these evolving demands and maintain supply quality and continuity, Distribution System Operators (DSOs) are required to invest in enhancing the network's intelligence for swift adaptation [182].

A notable success story has been Spain’s move towards smart grid technology through the initiative undertaken by Iberdrola Distribución. The company has installed over 10 million digital meters and adapted infrastructure to support smart grids, modernizing 95% of its meters in Spain. This project, known as the STAR project (Grid Remote Management and Automation System), included the adaptation of around 67,000 transformer centres across Spain with remote management, supervision, and automation capabilities [183].

The modernization has enabled Iberdrola to offer customers detailed data on electricity consumption, improve the quality of service, and integrate renewable energy more efficiently. This initiative demonstrates the potential for other DSOs in Spain to modernize their systems.

ACER also advises Spain to develop a comprehensive legal framework for new market participants, address capacity mechanism requirements, and stimulate retail market competition. The report also recommends managing retail price interventions and ensuring fair network charges for active customers. Spain is further encouraged to monitor retail electricity contracts and manage taxes and levies for active customers [140].

6. Conclusions

The concept of iGFBs as multi-energy systems introduces an innovative model for distributed response to electricity grid needs by providing services base in highly diversified demand flexibility response and energy storage, contributing for enhancing the grid resilience and energy supply security. These systems, capable of optimally manage different energy sources and optimizing energy use across different energy carriers by managing multiple-networks resources, embody a sophisticated capacity to increase distributed flexibility in the power system while enhancing the internal processes efficiency, meeting the functional activities and end-users’ requirements. By exploring and combining different demand-side management strategies: efficiency improvement, load shedding, load shifting, modulation, and local renewable energy generation, iGFBs have the potential to strengthen grid reliability while contributing as a platform for increasing the penetration of distributed renewable energy sources in the energy system. However, unlocking this potential requires a convergence of the commitment of the many stakeholders involved in such complex development and implementation projects, as well as adequate technological innovation that overcomes barriers to end-user participation and enables energy demand flexibility. A combination of financial incentives and the pursuit of energy autonomy have been identified as key drivers to engage end-users to adopt energy flexibility concepts. In addition, the complexity of the multi-system approach of iGFBs requires high standards of interoperability between the technological components within the buildings and also with the network operators, enabling the provision of services and participation in the balancing and energy markets. A comprehensive analysis of the state-of-the-art of controllable and energy devices, monitoring equipment, and other systems with a high potential impact on demand response showed a wide range of technologies available for households, commercial, and industrial buildings. In that perspective, an extensive set of standards for data exchange and communication protocols was presented, highlighting the challenges of integrating interoperable, secure, and integrated energy management and orchestration of iGFB processes.

The analysis of the iGFBs value chain revealed a high number of stakeholders in each step of value creation, from research and development, ideation, and planning phase to the exploration of the potential of iGFBs by utilities, system operators, or the users themselves by participating in community initiatives through aggregation models such as community Virtual Power Plants or balancing pools. It is therefore important to establish channels of communication between the various stakeholders, promoting their interaction and common understanding in order to align their objectives and expectations regarding their role in the development and operation of each specific iGFB and main goals, which will ultimately define the groundset for the development of new business models.

The exploration of regulatory, social, and technical barriers to iGFBs reveals a complex ecosystem where many factors combine to shape the future of smart buildings. The evolving regulatory landscape needs to be more cohesive and supportive of the iGFB approach. It is essential to establish clear, supportive policies and frameworks that encourage innovation, ensure fair pricing, and facilitate the integration of renewable energy sources.

On the technical front, advancements in building efficiency, energy management systems, and grid compatibility are critical for the seamless integration of iGFBs. The need for robust cybersecurity measures and reliable operation under diverse conditions is essential. Furthermore, addressing the infrastructural challenges in existing buildings is vital for the widespread adoption of iGFBs.

Social acceptance and awareness are pivotal for the success of iGFBs. Regulatory efforts should concentrate on educational campaigns, transparency in technology deployment, and the creation of favourable market conditions that encourage consumer participation. Addressing the concerns and needs of various social groups, especially low-income households, is crucial for an inclusive energy transition.

As a result, the following checklist is proposed to assist governments in providing a comprehensive framework to assess and strengthen policies in support of iGFBs, while addressing the key barriers identified in this chapter.

- **Provide regulatory clarity concerning iGFBs**, including clear definitions, rights, and responsibilities for all stakeholders involved. Establish supportive policies for demand-side flexibility, including incentives for iGFBs to participate in energy markets and the provision of local grid flexibility. Encourage the integration of iGFBs with all types of energy infrastructure.
- **Mandate the adoption of technical standards** for iGFB compatibility with the grid, including communication protocols and electrical standards. Promote the development of the necessary infrastructure for iGFBs, such as smart meters and advanced grid capabilities.
- **Provide financial incentives for the development and integration of iGFBs**, such as subsidies, tax credits, or grants. Support innovative business models that facilitate the operation and benefits of iGFBs, including energy-sharing schemes and aggregation services.
- **Ensure consumer protection and participation in the context of iGFBs**, ensuring transparency, privacy, and the ability to participate in energy markets. Educate and engage consumers about the benefits of iGFBs and how they can participate in and benefit from such systems.
- **Encourage the formation of energy communities and social equity involving iGFBs**. Ensure policies promote social equity, providing access to the benefits of iGFBs across different socio-economic groups.

The path to a sustainable and efficient energy future through iGFBs is loaded with challenges, but also full of opportunities. A collaborative approach involving policymakers, industry stakeholders, and consumers is essential to overcome the barriers discussed in this document. Embracing innovation, fostering a conducive regulatory environment, and ensuring social inclusivity are key to unlocking the full potential of intelligent grid-forming buildings.

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APPENDIX A

Appendix A extends the overview of current communication standards presented in Section 2.3, by listing sets of standards and parts of each protocol when relevant to the scope of the WeForming project.

IEC 62056

IEC 62056 consists of following standards:

- IEC 62056-1-0:2014: Smart metering standardization framework.
- IEC 62056-3-1:2013: Use of local area networks on twisted pair with carrier signalling.
- IEC 62056-4-7:2014: DLMS/COSEM transport layer for IP networks.
- IEC 62056-5-3:2017: DLMS/COSEM application layer.
- IEC 62056-6-1:2017: Object Identification System (OBIS).
- IEC 62056-6-2:2017: COSEM interface classes.
- IEC 62056-6-9:2016: Mapping between the Common Information Model message profiles (IEC 61968-9) and DLMS/COSEM (IEC 62056) data models and protocols.
- IEC 62056-7-3:2017: Wired and wireless M-Bus communication profiles for local and neighborhood networks.
- IEC 62056-7-5:2016 Local data transmission profiles for Local Networks (LN).
- IEC 62056-7-6:2013: The three-layer, connection-oriented HDLC based communication profile.
- IEC 62056-8-3:2013: Communication profile for PLC S-FSK neighborhood networks.
- IEC 62056-8-5:2017: Narrow-band OFDM G3-PLC communication profile for neighbourhood networks.
- IEC 62056-8-6:2017: High speed PLC ISO/IEC 12139-1 profile for neighbourhood networks.
- IEC TS 62056-8-20:2016: Mesh communication profile for neighbourhood networks.
- IEC TS 62056-9-1:2016: Communication profile using web-services to access a DLMS/COSEM server via a COSEM Access Service (CAS).
- IEC 62056-9-7:2013: Communication profile for TCP-UDP/IP networks.
- Other IEC 62056: parts deal with electricity metering - Data exchange for meter reading, tariff and load control.
- IEC 62056-21:2002: Direct local data exchange.
- IEC TS 62056-41:1998: Data exchange using wide area networks: Public switched telephone network (PSTN) with LINK+ protocol.
- IEC 62056-42:2002: Physical layer services and procedures for connection-oriented asynchronous data exchange.
- IEC 62056-46:2002+AMD1:2006: Data link layer using HDLC protocol.
- IEC 62056-47:2006: COSEM transport layers for IPv4 networks.

- IEC TS 62056-51:1998: Application layer protocols.
- IEC TS 62056-52:1998: Communication protocols management distribution line message specification (DLMS) server.
- IEC 62056-61:2002: Object identification system (OBIS).

- IEC 62056-21 is restricted to local data exchange, whereas remote data exchange is covered by other standards of the IEC 62056 series. It describes hardware and protocol specifications for local meter data exchange. In such systems, a hand-held unit (HHU) or a unit with equivalent functions is connected to a tariff device or a group of devices. The connection can be permanent or disconnectable using an optical or electrical coupling. An electrical interface is proposed for use with a permanent connection, or when more than one tariff device needs to be read at one site. The optical coupler should be easily disconnectable to enable data collection via an HHU. The protocol permits reading and programming of tariff devices. It is designed to be particularly suitable for the environment of electricity metering, especially with regards to electrical isolation and data security. While the protocol is well-defined, its use and application are left to the user. This standard is based on the reference model for communication in open systems. It is enhanced by further elements such as an optical interface, protocol-controlled baud rate switchover, data transmission without acknowledgement of receipt. The protocol offers several modes for implementation in the tariff device. The HHU or equivalent unit acts as a master while the tariff device acts as a slave in protocol modes A to D. In protocol mode E, the HHU acts as a client and the tariff device acts as a server. As several systems are in practical use already, particular care was taken to maintain compatibility with existing systems and/or system components and their relevant protocols.

IEC 60870

IEC 60870 consists of following standards:

- IEC TR 60870-1-1:1988: General considerations. Section One: General principles.
- IEC 60870-1-2:1989: General considerations. Section Two: Guide for specifications.
- IEC TR 60870-1-3:1997: General considerations - Section 3: Glossary.
- IEC TR 60870-1-4:1994: General considerations - Section 4: Basic aspects of telecontrol data transmission and organization of standards IEC 870-5 and IEC 870-6.
- IEC TR 60870-1-5:2000: General considerations - Section 5: Influence of modem transmission procedures with scramblers on the data integrity of transmission systems using the protocol IEC 60870-5.
- IEC 60870-2-1:1995: Operating conditions - Section 1: Power supply and electromagnetic compatibility.
- IEC 60870-2-2:1996: Operating conditions - Section 2: Environmental conditions (climatic, mechanical, and other non-electrical influences).
- IEC 60870-3:1989: Interfaces (electrical characteristics).
- IEC 60870-4:1990: Performance requirements.
- IEC 60870-5-1: Transmission Frame Formats.
- IEC 60870-5-2: Data Link Transmission Services.

- IEC 60870-5-3: General Structure of Application Data.
- IEC 60870-5-4: Definition and Coding of Information Elements.
- IEC 60870-5-5: Basic Application Functions.
- IEC 60870-5-6: Guidelines for conformance testing for the IEC 60870-5 companion standards.
- IEC TS 60870-5-7: Security extensions to IEC 60870-5-101 and IEC 60870-5-104 protocols (applying IEC 62351).
- IEC 60870-5-101: Transmission Protocols - companion standards especially for basic telecontrol tasks.
- IEC 60870-5-102: Transmission Protocols - Companion standard for the transmission of integrated totals in electric power systems (this standard is not widely used).
- IEC 60870-5-103: Transmission Protocols - Companion standard for the informative interface of protection equipment.
- IEC 60870-5-104: Transmission Protocols - Network access for IEC 60870-5-101 using standard transport profiles.
- IEC TS 60870-5-601: Transmission protocols - Conformance test cases for the IEC 60870-5-101 companion standard.
- IEC TS 60870-5-604: Conformance test cases for the IEC 60870-5-104 companion standard.
- IEC 60870-6-1: Application context and organization of standards.
- IEC 60870-6-2: Use of basic standards (OSI layers 1–4).
- IEC 60870-6-501: TASE.1 Service definitions.
- IEC 60870-6-502: TASE.1 Protocol definitions.
- IEC 60870-6-503: TASE.2 Services and protocol.
- IEC 60870-6-504: TASE.1 User conventions.
- IEC TR 60870-6-505: TASE.2 User guide.
- IEC 60870-6-601: Functional profile for providing the connection-oriented transport service in an end system connected via permanent access to a packet switched data network.
- IEC 60870-6-602: TASE transport profiles.
- IEC 60870-6-701: Functional profile for providing the TASE.1 application service in end systems.
- IEC 60870-6-702: Functional profile for providing the TASE.2 application service in end systems.
- IEC 60870-6-802: TASE.2 Object models.

IEC 61970

IEC 61970 consists of the following parts:

- Part 1: Guidelines and general requirements.
- Part 2: Glossary.
- Part 301: Common Information Model (CIM) base.
- Part 302: Common information model (CIM) financial, energy scheduling and reservations.

- Part 401: Component interface specification (CIS) framework.
- Part 402: Component interface specification (CIS) – Common services.
- Part 403: Component Interface Specification (CIS) – Generic data access.
- Part 404: Component Interface Specification (CIS) – High speed data access.
- Part 405: Component Interface Specification (CIS) – Generic eventing and subscription.
- Part 407: Component Interface Specification (CIS) – Time series data access.
- Part 453: Exchange of Graphics Schematics Definitions (Common Graphics Exchange).
- Part 501: Common Information Model Resource Description Framework (CIM RDF) schema.

IEC 61850

IEC 61850 consists of the following parts:

- IEC TR 61850-1:2013: Introduction and overview.
- IEC TS 61850-2:2003: Glossary.
- IEC 61850-3:2013: General requirements.
- IEC 61850-4:2011: System and project management.
- IEC 61850-5:2013: Communication requirements for functions and device models.
- IEC 61850-6:2009: Configuration language for communication in electrical substations related to IEDs.
- IEC 61850-7-1:2011: Basic communication structure – Principles and models.
- IEC 61850-7-2:2010: Basic communication structure – Abstract communication service interface (ACSI).
- IEC 61850-7-3:2010: Basic communication structure – Common Data Classes.
- IEC 61850-7-4:2010: Basic communication structure – Compatible logical node classes and data classes.
- IEC 61850-7-410:2012: Basic communication structure – Hydroelectric power plants – Communication for monitoring and control.
- IEC 61850-7-420:2009: Basic communication structure – Distributed energy resources logical nodes.
- IEC TR 61850-7-510:2012: Basic communication structure – Hydroelectric power plants – Modelling concepts and guidelines.
- IEC 61850-8-1:2011: Specific communication service mapping (SCSM) – Mappings to MMS (ISO 9506-1 and ISO 9506-2) and to ISO/IEC 8802-3.
- IEC 61850-9-2:2011: Specific communication service mapping (SCSM) – Sampled values over ISO/IEC 8802-3.
- IEC/IEEE 61850-9-3:2016: Precision Time Protocol profile for power utility automation.
- IEC 61850-10:2012: Conformance testing.

- IEC TS 61850-80-1:2016: Guideline to exchanging information from a CDC-based data model using IEC 60870-5-101 or IEC 60870-5-104.
- IEC TR 61850-80-3:2015: Mapping to web protocols – Requirements and technical choices.
- IEC TS 61850-80-4:2016: Translation from the COSEM object model (IEC 62056) to the IEC 61850 data model.
- IEC TR 61850-90-1:2010: Use of IEC 61850 for the communication between substations.
- IEC TR 61850-90-2:2016: Using IEC 61850 for communication between substations and control centres.
- IEC TR 61850-90-3:2016: Using IEC 61850 for condition monitoring diagnosis and analysis.
- IEC TR 61850-90-4:2013: Network engineering guidelines.
- IEC TR 61850-90-5:2012: Use of IEC 61850 to transmit synchrophasor information according to IEEE C37.118.
- IEC TR 61850-90-7:2013: Object models for power converters in distributed energy resources (DER) systems.
- IEC TR 61850-90-8:2016: Object model for E-mobility.
- IEC TR 61850-90-12:2015: Wide area network engineering guidelines.

IEC 61968

IEC 61968 consists of the following parts:

- IEC 61968-1: Interface architecture and general requirements.
- IEC 61968-2: Glossary.
- IEC 61968-3: Interface for Network Operations.
- IEC 61968-4: Interfaces for Records and Asset management.
- IEC 61968-5: Interfaces for Distributed Energy Optimization
- IEC 61968-6: Interfaces for Maintenance & Construction.
- IEC 61968-7: Interfaces for Network Extension Planning.
- IEC 61968-8: Interfaces for Customer Support.
- IEC 61968-9: Interface Standard for Meter Reading & Control.
- IEC 61968-10: Interfaces for Business functions external to distribution management. This includes Energy management & trading [EMS], Retail [RET], Supply Chain & Logistics [SC], Customer Account Management [ACT], Financial [FIN], Premises [PRM] & Human Resources [HR].
- IEC 61968-11: Common Information Model (CIM) Extensions for Distribution.
- IEC 61968-12: Common Information Model (CIM) Use Cases for 61968.
- IEC 61968-13: Common Information Model (CIM) RDF Model exchange format for distribution.
- IEC 61968-14-1-3 to 14-1-10: Proposed IEC Standards to Map IEC 61968 and MultiSpeak Standards.

- IEC 61968-14-2-3 to 14-2-10: Proposed IEC Standards to Create a CIM Profile to Implement MultiSpeak Functionality.
- IEC 61968-100: Application Integration.

IEC 62351

IEC 62351 consists of the following parts:

- IEC 62351-1: Introduction to the standard.
- IEC 62351-2: Glossary of terms.
- IEC 62351-3: Security for any profiles including TCP/IP:
  - TLS Encryption.
  - Node Authentication by means of X.509 certificates.
  - Message Authentication.
- IEC 62351-4: Security for any profiles including MMS (e.g., ICCP-based IEC 60870-6, IEC 61850, etc.):
  - Authentication for MMS.
  - TLS (RFC 2246) is inserted between RFC 1006 & RFC 793 to provide transport layer security.
- IEC 62351-5: Security for any profiles including IEC 60870-5 (e.g., DNP3 derivative):
  - TLS for TCP/IP profiles and encryption for serial profiles.
- IEC 62351-6: Security for IEC 61850 profiles.
  - VLAN use is made as mandatory for GOOSE.
  - RFC 2030 to be used for SNTP.
- IEC 62351-7: Security through network and system management:
  - Defines Management Information Base (MIBs) that are specific for the power industry, to handle network and system management through SNMP based methods.
- IEC 62351-8: Role-based access control:
  - Covers the access control of users and automated agents to data objects in power systems by means of role-based access control (RBAC)
- IEC 62351-9: Key Management:
  - Describes the correct and safe usage of safety-critical parameters, e.g. passwords, encryption keys.
  - Covers the whole life cycle of cryptographic information (enrollment, creation, distribution, installation, usage, storage and removal).
  - Methods for algorithms using asymmetric cryptography.
  - Handling of digital certificates (public / private key).
  - Setup of the PKI environment with X.509 certificates.
  - Certificate enrollment by means of SCEP / CMP / EST.
  - Certificate revocation by means of CRL / OCSP.

- A secure distribution mechanism based on GDOI and the IKEv2 protocol is presented for the usage of symmetric keys, e.g. session keys.

- IEC 62351-10: Security Architecture.
  - Explanation of security architectures for the entire IT infrastructure.
  - Identifying critical points of the communication architecture, e.g. substation control center, substation automation.
  - Appropriate mechanisms security requirements, e.g. data encryption, user authentication.
  - Applicability of well-proven standards from the IT domain, e.g. VPN tunnel, secure FTP, HTTPS.
- IEC 62351-11: Security for XML Files:
  - Embedding of the original XML content into an XML container.
  - Date of issue and access control for XML data.
  - X.509 signature for authenticity of XML data.
  - Optional data encryption.

IEC 62746

IEC 62746 consists of the following parts:

- IEC TR 62746-2:2015: Use cases and requirements.
- IEC TS 62746-3:2015: Architecture.
- IEC 62746-10-1:2018: Open automated demand response.
- IEC 62746-10-3:2018: Open automated demand response - Adapting smart grid user interfaces to the IEC common information model.

CENELEC EN 50090

CENELEC EN 50090 consists of the following parts:

- EN 50090-2-1:1996: Architecture - withdrawn and replaced by EN 50090-1:2011.
- EN 50090-2-2:1996 & A2:2007: General technical requirements (concerns cabling and topology, electrical and functional safety, environmental conditions and behavior in case of failures as well as specific installation rules) - partially replaced by EN IEC 63044-3:2018 Home and Building Electronic Systems (HBES) and Building Automation and Control Systems (BACS). Electrical safety requirements, EN 50491-5-2:2010 Environmental conditions, EN 50491-5-3:2010 and EN 50491-5-1:2010 EMC requirements.
- EN 50090-2-3:2005: General functional safety requirements - withdrawn and replaced by EN 50491-4-1:2012.
- EN 50090-3-1:1994: Introduction to the application structure.
- EN 50090-3-2:2004: User process for HBES Class 1, twisted pair (asynchronous character-oriented data transfer in a half-duplex bi-directional communication mode, using a specifically

unbalanced/unsymmetrical (Type 0) or balanced/symmetrical (Type 1) baseband signal coding with collision avoidance under SELV conditions).

- EN 50090-3-3:2009: Interworking model and common data types (so that different manufacturers' products send and receive datagrams and are able to properly understand and react on them without the need for translators or gateways as well as common configuration tools, training, etc.).
- EN 50090-3-4:2017: Secure application layer, secure service, secure configuration and security resources (based on ISO/IEC 24767-2 Home Network Secure Communication Protocol for Middleware - important for anti-intrusion security).
- EN 50090-4-1:2004: Application layer for HBES Class 1 (specifies services that can be used for both management and run-time communication).
- EN 50090-4-2:2004: Transport layer, network layer and general parts of data link layer for HBES Class 1 (provides the communication stack for the data link layer, the network layer and the transport layer).
- EN 50090-4-3:2015: Communication over IP.
- EN 50090-5-1:2005: Power line for HBES Class 1 (defines the medium-specific physical and data link layer of power line Class 1 in two variations, PL110 and PL132).
- EN 50090-5-2:2004: Network based on HBES Class1 (defines the medium-specific physical and data link layer for twisted pair in its two variations, TP0 and TP1).
- EN 50090-5-3 2006: Radio frequency (defines requirements for the RF physical and data link layer).
- EN 50090-6-1:2017: Webservice interface (defines a standardized web service-based interface with other IT systems via a gateway device).
- EN 50090-7-1:2004: Management procedures (capturing the dynamics of managing distributed resources on the network in terms of a sequence of telegrams, exchanged between two partners: the management client and the management server).
- EN 50090-8:2000: Conformity assessment of products.

EN 50090-9-1:2004: Generic cabling for HBES Class 1 (provides cabling planning and installation rules taking into account the layout of the cable support, cables and connectors, and commissioning).

APPENDIX B

Survey on the existent devices' characterization on each iGFB demonstrator (draft version)

(developed in the scope of task 2.1)

Asset Information	**Asset ID**	*Unique identifier of the asset - we will use this as the unique ID when referencing the asset*
	Asset	*Name of the asset*
	Description	*A brief description of the asset data*
	Asset possession	*Ensured possession of the asset (Y: asset already in possession/ N: asset planned to be acquired)*
	Date of last update	*Date of the last update of the data on the asset - update the date when updating the data asset information*
Data Ownership and Availability	**Data Owner**	*The name of the data asset owner (other: if available from a third party)*
	Data Provider	*The name of the data provider to WeForming project - **this entity needs to resolve the data access with the original owner***
	Acessibility Method	*The way to access the data (through an exposed API, downloadable file, from a database, other)*
	Frequency of Updates	*Frequency of new data samples added to the dataset (hourly, daily, monthly, yearly)*
	Update Strategy	*The way new data samples will become available (add new samples to existing file, create new file for each update, other)*
	Historical data handling	*How is the historical data handling solved: Can be queried on request, or should the WeForming side orchestrate the storage*
	Data Availability	*Ensuring constant access to data (Y/N): Will the data provider ensure this data is updated continuously?*
	Documentation	*Documentation availability (Y/N, if Y please provide its location)*
Data Features	**Volume**	*The size of data (X GB per hour or day or year or in total)*
	Type	*Data type (audio, image, number, text, video, other)*
	Format	*Data format (csv, json, xml, other)*
	New Data Availibility	*Frequency of new available data (real-time, near real-time, batch)*
	Temporal Resolution	*Temporal granularity of data (minute, 15-minute, hour, day)*
	Spatial Resolution	*Spatial granularity of data (room/zone, building, district/area, other)*
	Historical Data Availability	*Historical data is stored (Y/N)*
	Temporal Availability	*Time interval of available data (From --- to ---)*
	Spatial Availability	*Location of measurements (city, country, other)*
	Data Originality	*Whether the data was edited (raw, preprocessed; if preprocessed how: hourly/daily aggregation, filled NaN values, preprocessed outliers, other)*
	Relevant Standards	*List of international standards to which the data complies*
	Connection to Other Sources	*Whether the data is dependent on or connected to other asset/source (Y/N, if Y please state which)*
Data Privacy	**Privacy**	*Confidentiality of data (confidential : complete inability to share/ demo : sharing possible with other demo partners with appropriate licensing/ project : sharing possible among project partners with appropriate licensing/ public : available to all)*
	License	*License currently applied to data*
	Sharing Mode	*Mode in which data is available to others (unencrypted, encrypted, other)*
	Need for Anonymization	*Sensitivity of data (Y/N: Y if personal or sensitive data)*
	Pricing	*Payment to access data (per transaction, subscription,other)*
	Tracking	*The need for tracking of data sharing between different data users (Y/N)*

Survey on the assessment the buildings' end-users, and occupants' engagement and awareness. (draft version)

(developed in the scope of task 2.4)

Introduction

As an introduction to the survey, we propose two definitions so the participants will understand the topic.

This survey is part of an EU funded project and it has a purpose to measure your views on smart buildings. To avoid wrong interpretations, this is a short dictionary of definitions used in the survey.

Building design, construction and use evolve according to the needs of society and adapt to new technologies. Additionally, the need to respond to the climate crisis is more evident than ever, requiring a rapid and large-scale increase in the use of renewable energy sources in buildings and a reduction of their energy consumption.

Intelligent Grid-Forming Buildings (iGFBs) integrate smart technologies that transform buildings from passive consumers of energy into active nodes of the energy network. IGFBs integrate various forms of energy, manage electricity loads, and optimize energy use within individual structures or across premises, increasing the flexibility of electricity grids, district heating, and other networks.

A smart grid is a network that intelligently integrates new digital information technologies that enable two-way communication between energy consumers, utilities, and energy producers. Moreover, it enables interaction between the building's energy systems and the wider electricity grid. Finally, through advanced metering infrastructure, a smart grid can increase energy efficiency and improve the control of users over their energy consumption.

More information about the project: https://weforming.eu/

Demographics

- **Age**
18-24
25-34
35-44
45-54
55-64
65+

Gender
Female
Male
Non-binary
Rather not to say

-**Education**

High School
Bachelor's degree
Master's degree
PhD
Post PhD
-**Occupation**
Administrator
Engineer
Researcher
Private employee
State employee
Student
Unemployed

We're currently implementing real-life demonstrations of WeForming in six cities, and we're interested in gathering feedback from end-users regarding its benefits and potential improvements. Are you located or employed near any of these cities?
Rout Lens, Luxembourg
Viseau, Portugal
Krk, Croatia
Martelange, Belgium
Fornes-Granada, Spain
Karlsruhe, Germany Other

Smart Grids

Where have you heard from about smart grids?

1. Social media
2. European union media outlets
3. State/Community media outlets
4. Workplace
5. Family or friends
6. From this survey
7. Other (...)

Are you aware of the concept intelligent Grid-Forming Buildings (IGFBs), which use advanced technologies to optimize energy use and interact with the electricity grid?

1. Yes
2. To some extent
3. No

Please explain what the concept of intelligent Grid-Forming Buildings (IGFBs) is or what it should be:

(Open-ended question)

Select to what extent you agree or disagree with the following statements about the properties of smart grids:

(5-Point scale: Strongly agree to Strongly disagree)

Statements

- Intelligent Grid-Forming Buildings (IGFBs) can contribute to energy efficiency, cost savings, and sustainability compared to traditional buildings

-Smart grids differ from conventional grids in terms of self-healing capacity, resilience to natural disasters and improved power quality

-Conventional grids cannot distribute energy from multiple renewable energy sources

-Smart grids allow consumers to monitor and control their energy usage in real-time

-Smart grids facilitate two-way communication between utility companies and end-users for efficient energy management

-Smart grids utilize sensors and communication technologies to monitor and manage electricity flow in real-time

Select to what extent you agree or disagree with the following statements:

(5-Point scale: Strongly agree to Strongly disagree)

Statements

-The use of smart meters in grids provide more accurate measurement and billing of electricity consumption

-Smart grids are vulnerable to cyber attacks, making them less secure than conventional energy systems

-Smart grids are only relevant for those who use renewable energy sources

-Through smart grids the carbon will be lower since renewable energy resources can be used efficiently

- Smart grids contribute to a more resilient power system, reducing the impact of natural disasters, power outages and improving overall community safety

-The implementation of smart grids supports the integration of a higher percentage of renewable energy sources, leading to a greener and more sustainable energy future

-Smart grids help reduce carbon emissions and mitigate the effects of climate change by optimizing energy use and promoting energy efficiency

- Smart grids let you monitor in real-time the electricity rises so you have the opportunity to reduce the energy bills by choosing the volume and price of consumption that best suits you

Monitoring Energy Use

Which of the following methods would help you get more involved in monitoring your energy use?

1. **Education** on methods to reduce energy consumption
2. **App** where you can monitor how much energy you consume any time
3. **Reduction of the energy bill** when you use smart ways to reduce your energy consumption

Statements

Select to what extent you agree or not with the following statements

(5-Point scale: Strongly agree to Strongly disagree)

Statements

-I am aware of the electricity that I consume

-I would reduce my electricity consumption if i knew **how much i consume**

-The idea of having **control** over my energy usage through smart grid technologies is appealing to me

-I would adopt new technologies, such as smart meters, to improve **energy efficiency** in my home OR workplace

-I believe that power grids can enhance the **reliability** of my electricity supply

-I am concerned about the **environmental impact** of energy consumption and I believe smart grids can address it

-**Financial incentives**, such as reduced electricity bills, would influence my decision to adopt smart grid technologies

-I would participate in demand response programs if there were **financial incentives** or rewards offered for reducing my electricity usage during peak hours

-Adopting smart grid technologies would contribute to achieving greater **energy independence**

Would you be interested in having features of Intelligent Grid-Interactive Efficient Buildings, such as automated energy management and demand response capabilities in your municipality that promote more environmentally friendly practices?

1. Yes
2. To some extent
3. No

Which of the following would drive you to engage in smart grid management programs?

1. Reduced energy bills
2. Independence to control your energy usage
3. Lower environmental impact
4. None of the above
5. Other (...)

Barriers

What would you see as potential barriers to the adoption of smart grids in buildings?

1. Lack of Information
2. Implementation costs
3. Privacy and cyber security
4. Legislation barriers
5. All of the above
6. Other (...)

Which of the following would concern you the most in the use of a smart grid? (Rank them according to your priority, from 1 to 5)

- ❑ Security and Privacy
- ❑ Quality of Electricity
- ❑ Reliability of energy system
- ❑ Change of routine
- ❑ Other (...)

Is this concern due to (Rank them according to your priority, from 1 to 3):

- ❑ Not enough information available to me
- ❑ Not enough understanding about how smart grids work
- ❑ Concerning articles about the inefficiencies of smart grids

Select to what extent you agree or disagree with the following statements about potential barriers of smart grids:

(5-Point scale: Strongly agree to Strongly disagree)

Statements

-I would **trust** an external party to control my electrical appliances (e.g. washing machine, fridge) for more efficient electricity usage and for giving me the ability to monitor at any time my energy consumption

-I would be concerned about my **privacy** when using smart grid technologies and sharing information about my energy usage habits

-It is challenging to understand the **technical aspects** of smart grid technologies and how they impact my energy consumption

-There is a **lack of information (or education)** about smart grid technologies, making it challenging for me to understand how they work and adapt to them