

PNNL-32572

# **Digitalisation for the Energy Efficiency of Buildings Operations: Lessons Learned from the EE Hub Digitalisation Working Group**

September 2022

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*operated by*  
BATTELLE  
*for the*  
UNITED STATES DEPARTMENT OF ENERGY  
*under Contract DE-AC05-76RL01830*

Printed in the United States of America

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Prepared for  
the U.S. Department of Energy  
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*The Energy Efficiency Hub (EE Hub) is a platform for global collaboration on energy efficiency, pursuing solutions through Task Groups focused on topics of common interest to Hub Members. The EE Hub was established as a Special Activity of the International Energy Agency. The Hub has sixteen founding Members, which comprise eight of the ten largest economies in the world and represent a third of the world's population. This report was developed under the Digitalisation Working Group (DWG), an EE Hub Task Group led by the United States.*

## Acknowledgments

We would like to thank the U.S. Department of Energy for sponsoring this effort under project number 78850 and contract number DEAC0576RL01830. We are very grateful to all the members of the Energy Efficiency Hub Digitalisation Working Group who contributed valuable case studies, presentations, resources, and edits during the development of this report. We would like to express a special thanks to the following agencies and individuals who provided additional inputs to this report: our Australian collaborators Steven Beletich (Beletich Associates) and Lesley Dowling (Department of Climate Change, Energy, the Environment and Water); our Canadian collaborators from Natural Resources Canada for their contributions and input in DWG meetings; from France, the Ministry of Ecology, Sustainable Development and Energy for their contributions; from the European Commission, the Directorate-General for Energy; from the International Energy Agency, Clara Camarasa and Vida Rozite; and from the United States, Ben Polly (National Renewable Energy Laboratory), Meredydd Evans (Pacific Northwest National Laboratory), and Andrea Mott (Pacific Northwest National Laboratory). Finally, we would like to express many thanks to the Energy Efficiency Hub Secretariat for their inputs and support of the DWG activities. Specifically, we would like to thank Jonathan Sinton, Kristina Klimovich, Laura Garcia, Sarah Zaft, and Anne Kost.

## Executive Summary

In an increasingly interconnected world, digital technologies represent significant potential to improve the efficiency of human systems, particularly in the energy sector. A primary concern underlying energy systems is the need for decarbonization, which is currently a primary focus for several governments around the world. In this context, digitalisation is creating new opportunities to optimize energy systems and decrease greenhouse gas emissions across key industries such as power grids, buildings, transportation, manufacturing, oil and gas, and agriculture. Among these, buildings are perceived as a critical sector since they constitute around 40% of energy consumption and 25–30% of direct carbon dioxide emissions. In particular, building operations are responsible for a significant portion of worldwide electricity consumption and energy-related carbon dioxide emissions.

To fully realize the potential for energy efficiency improvement through digital tools, technological advancements must be coupled with robust policy. The Digitalisation Working Group (DWG) within the Energy Efficiency (EE) Hub platform of the International Energy Agency represents the efforts of several countries to build upon one another's experiences in leveraging digitalisation for the advancement of energy efficiency solutions in building operations. Each country has provided unique insight on best practices, case studies, and policy practices. For this report, we draw from this breadth of knowledge in combination with existing, publicly available literature.

This report builds on a literature review published in March 2022 to characterize technologies and tools that are expected to play a prominent role in improving the energy efficiency of building operations, including smart devices and computational models and platforms (Otte et al., 2022). The report also incorporates findings from interviews, case studies, and presentations from DWG representatives to define and characterize the main barriers faced by member countries in relation to building digitalisation. Interoperability, data concerns, privacy, cybersecurity, and device energy consumption and decentralization constitute major barriers. The report provides an assessment of the challenges, opportunities, successes, and lessons learned from policies and technological advancements designed to augment the dissemination of digitalisation in building operations. This analysis is presented through case studies representing member countries' contributions to accelerating digitalisation. A selected list of these case studies is presented in Table ES.1 below.

To analyze the impact of the policies embedded in the case studies, the team focused on the conditions surrounding their implementation across each DWG member country. These countries offer diverse experiences with digitalisation, each possessing unique infrastructure, socioeconomic conditions, and opportunities for digital transformation. Thus, the sections dedicated to each country and their individual policy and technology case studies help exemplify the unique conditions impacting their progress implementing digitalisation for building operations.

The case study findings reveal that a combination of measures is needed to address the identified barriers. Both Australia and Denmark have established digitalisation-focused hubs to accelerate learning in this area which have allowed them to coordinate efforts more easily. The case studies, particularly those from Japan, demonstrate the importance of engaging industry partners, as well as providing voluntary schemes and pilot studies to test the market. Standards such as those on data security and protection under Germany's phased rollout of Smart Meter Gateways are also key to enabling interoperability while ensuring that privacy, cybersecurity, and data integrity concerns are met. Publicly available information, such as the data made available via the United States' Green Button Initiative, can have large impacts in terms of equipping policymakers and consumers with relevant information and can help inform future improvements in programs. As a next step, the EE Hub Digitalisation Working Group will use the country experiences and findings contained in this report to help inform an EE Hub DWG roadmap on

digitalisation technologies and for program and policy acceleration pathways that can advance energy efficiency through digitalisation.

Table ES1. Selected Case Study Examples

Barrier	Practice Description	Impact	Lessons Learned
Data availability and analysis	Database for energy performance certificates (EPCs) (Denmark): The Danish Energy Agency maintains a central database and public website that provides access to and displays energy performance certification data. These certification ratings are valid for 10 years and apply to both residential and nonresidential buildings.	The detailed data on buildings, collected over several years, have helped inform the development of subsidy schemes.  The database has been the basis for implementing risk-based control of the issued EPCs and enabled a geographical display of data on maps.	A great deal of information technology knowledge is needed to bring data into applications in new ways and adjust the information technology infrastructure.
	Green Button Initiative (United States): Industry-led effort to provide utility customers with easy and secure access to their energy usage information in a consumer-friendly, digitized format.	Over 60 million homes and businesses can securely access their own energy information in a standard online format.  Over 50 utilities and electricity suppliers are participating in the initiative and over 35 companies have developed applications that take advantage of Green Button data.	The initiative was possible by leveraging successful policy models and existing standards.
Interoperability	Innovation Hub for Affordable Heating and Cooling (i-Hub) (Australia): An initiative led by the Australian Institute of Refrigeration, Air Conditioning, and Heating, in conjunction with multiple partners, that investigated various innovations that could make digitalisation more scalable. This effort included developing a real-time data management platform to address interoperability barriers and better understand the digital infrastructure that might be required to underpin future institutional arrangements for data management.	Over 60 buildings and nine software applications are utilizing the data management platform.  A self-service International Performance Measurement and Verification Protocol app has been developed to streamline settlement processes for various policy initiatives.  Has resulted in significant interview and focus group research on barriers to adoption.	Establishing digital connectivity in existing buildings is very expensive if done in isolation for the sole purpose of implementing energy productivity applications, but costs can be significantly lower if done as part of normal equipment lifecycle investments.  This case study highlights the importance of coordinating first with existing property industry processes.
	EchoNet Lite Standard (Japan): The Japan Smart Community Alliance (Global Standard Working Group), whose members consist of manufacturers and the Ministry of Economy, Trade, and Industry, developed a Universal Home Network Connection Standard.	Before EchoNet Lite, Smart Home management systems were provided with different communication systems by manufacturers. Now, users can control different manufacturers' appliances with a single Home Energy Management System (HEMS) display called EchoNet Lite.	HEMS sometimes consumes more power than energy saved.  HEMS requires constant maintenance and upgrades.  Data in the cloud was not intuitive and few appliance manufacturers used the data.

Cybersecurity and privacy	Smart Meter Gateway (Germany): A highly secure and interoperable communication module and core component of the smart metering infrastructure that is being established nationwide.	High standards for data security and protection, certified by the Federal Office for Information Security, have built trust among customers.	Acceptance by customers must be strengthened further through attractive offerings and noticeable benefits.  Complex product certification schemes can delay technology rollouts.
Device energy consumption and decentralization	ENERGY STAR Smart Thermostat Certification (United States): A combination of hardware and service. In addition to laboratory testing for the hardware, real-world data from a large, randomized sample of homes with ENERGY STAR products are aggregated and analyzed to evaluate the services.	There are 64 certified products in the United States and 61 available in Canada.  Some utilities are beginning to require ENERGY STAR certified thermostats in incentive programs.	Certification of smart, connected products requires statistical evaluation of actual installed products and service performance under default operating conditions.  Service providers must periodically resubmit savings data from a new random sample of their installations to ensure ongoing energy savings.

## Acronyms and Abbreviations

AI	artificial intelligence
AMI	advanced metering infrastructure
BEMS	Building Energy Management Systems
BIM	Building Information Modeling
CO <sub>2</sub>	carbon dioxide
CSS:	customer services software
DCCM	direct compressor control mechanism
DLC	direct load control
DOE	U.S. Department of Energy
DR	demand response
DWG	Digitalisation Working Group
EB	Energy Box
EC	European Commission
EE Hub	Energy Efficiency Hub
EMS	energy management system
EPA	U.S. Environmental Protection Agency
EPC	Energy Performance Certification
EV	electric vehicle
GEB	Grid-interactive Efficient Building
GPRS	general packet radio service
GMS	grid monitoring software
HEMS	Home Energy Management Systems
HVAC	heating, ventilation, and air conditioning
ICT	information and communications technology
IEA	International Energy Agency
IoT	Internet of Things
ML	machine learning
NABERS	National Australian Built Environment Rating System
NatHERS	Nationwide House Energy Rating Scheme
NMS	network management software
PHS	plug-loads handling software
PLC	power line communication
PMS	power market software
PNNL	Pacific Northwest National Laboratory

PWh	petawatt hour
R&D	research and development
SCADA	supervisory control and data acquisition
SMGWs	Smart Meter Gateways
SP	smart plugs
ST	smart thermostat
TSCM	thermostat set-point control mechanism
WiMAX	Worldwide Interoperability for Microwave Access
WLAN	wireless local-area network

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## 1.0 Introduction

Digitalisation, the transformation of everyday processes using digital technologies, has become a profoundly important part of modern life. According to Clarke (2019), digitalisation refers to the interpretation and management of the world through processes that monitor and dynamically respond to data. This practice provides pragmatic solutions that reshape the performance, operations, and resource usage of many everyday systems, particularly those related to the energy sector. The development of new digital technologies, especially ones incorporating advanced control systems, enables the exchange of information between individual components, providing dynamic decision-making capabilities for complex systems (Jia et al., 2019). However, many of these state-of-the-art technologies are in the development phase and multisectoral obstacles to their large-scale implementation persist. Overcoming these barriers will require major developments through both regulatory and technological lenses. It is, however, already clear that these technologies offer great energy-savings potential. By enabling data communication, artificial intelligence (AI), and decision making among individual components via the Internet of Things (IoT), greater system efficiency and intelligent autonomy can be achieved, leading to significant decarbonization and energy efficiency benefits.

Digitalisation is creating new opportunities to optimize energy systems and decrease greenhouse gas emissions across key industries such as power grids, buildings, transportation, manufacturing, oil and gas, and agriculture. Among these sectors, buildings are critical to address because they constitute around 40% of energy consumption and are directly responsible for 25–30% of direct carbon dioxide (CO<sub>2</sub>) emissions (United Nations Environment Programme, 2021).

Significant potential for energy efficiency improvement has been identified in the buildings sector, and digitalisation demonstrates a significant role in these improvements as exemplified by the case studies in this report. These active solutions are less expensive to implement and generally lead to faster return on investment than traditional solutions like improving insulation and other physical renovations (Tricoire, 2021). Compared to passive solutions, costs for digitalisation can typically be recouped three times as fast, and digital technologies can renovate 10 times the space with the same budget (Tricoire, 2021). Hence, digitalisation provides an opportunity to extract additional energy efficiency benefits, beyond physical renovations or in situations where physical renovations are not feasible.

One particularly promising technology is active controls, which, assuming widespread deployment and limited rebound effects, could “save up to 65 PWh [petawatt hour] cumulatively from 2017 to 2040, or twice the energy consumed by the entire buildings sector in 2017” (IEA & Digitalization and Energy Working Group, 2017). Figure 1 visualizes this scenario in terms of both individual technologies and building sectors. For commercial buildings specifically, estimates suggest that “integrating state-of-the-art sensors and controls [...] can lead to savings of as much as 29% of site energy consumption through a high-performance sequence of operations, optimized settings based on occupancy patterns, and correcting inadequate equipment operations or installation” (Fernandez et al., 2017). Furthermore, buildings have a cascaded indirect decarbonization impact on other connected systems, such as power grids and transportation, and digitalisation assists by helping integrate renewable energy in these systems.

Although digitalisation has already demonstrated capabilities for decreasing energy consumption in the operation of building systems, even greater energy efficiency goals can be achieved with digitalisation strategies and increased deployment of these tools. The International Energy Agency (IEA) estimated that widespread implementation could reduce total energy consumption in residential and commercial buildings by 10% by 2040 (IEA & Digitalization and Energy Working Group, 2017). Additionally, device interconnectivity can help provide building occupants and owners with relevant data to make informed decisions. Many countries are driving the adoption of new technologies targeted toward building and appliance performance, motivated by energy efficiency priorities in their national energy transitions

(United Nations Economic Commission for Europe, 2021). Smart meters, digital twins, and other digitalisation tools have the potential to cut energy losses in the buildings sector while unlocking a range of decarbonization opportunities, including the ability to create more flexibility for the energy grid and integrate variable renewable energy, such as solar and wind.

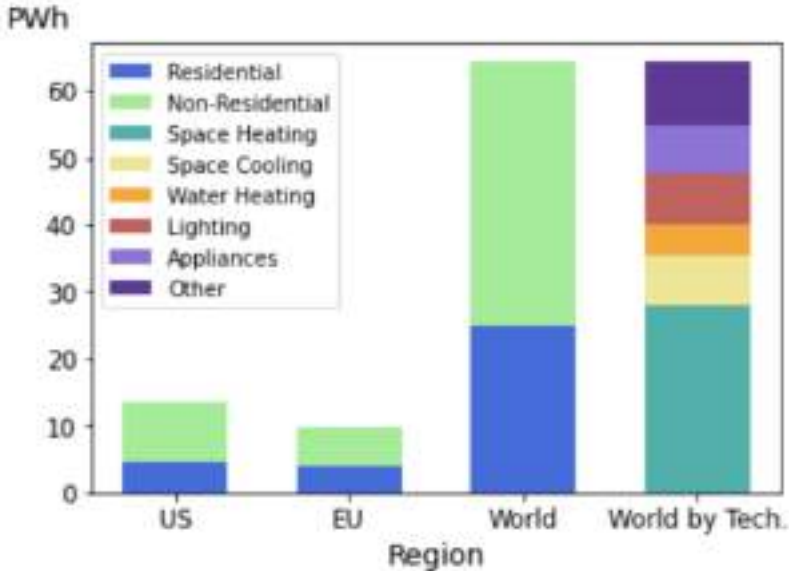


Figure 1. Cumulative energy savings in buildings from widespread digitalisation between 2017 and 2040 (IEA & Digitalization and Energy Working Group, 2017)

Despite these capabilities for efficiency improvements, the penetration of digitalisation remains marginal in the buildings sector. A multitude of tools exist that are capable of meeting emission reduction goals, yet implementation challenges influence the slow pace of smart technologies adoption by the building industry in some countries (Lau, 2022). While advancing the development of digitalisation technologies is an important dimension of improving the energy efficiency of building operations, regulatory measures and incentives are required for the widespread adoption and management of these technologies. The ability of governments to develop policies and programs that evolve as technologies in the market continuously advance is essential to ensuring that digitalisation drives energy savings and economic growth while ensuring privacy conserving protections for consumers. Policies must work synergistically with the financial interests of stakeholders to enable large-scale utilization. Additionally, information campaigns, certifications, and labeling can contribute in complementary fashion with regulatory and incentive measures to promote digitalisation if these tools are underpinned by robust institutional capacity and implemented proactively or simultaneously. Member countries of the Digitalisation Working Group (DWG) within the Energy Efficiency (EE) Hub have led efforts to improve the accessibility of digital technologies in terms of financial factors, technological capabilities, and user acceptance. In particular, the DWG member countries highlighted in this report are active in accelerating decarbonization in buildings through a wide variety of policy and technology initiatives. In the context of this working group, countries contributed expertise, case studies, insights, and analysis that helped identify the potential benefits of digital transformation as well as the barriers to implementing digitalisation.

In January 2022, the DWG released prepared a white paper on Digitalisation for the Energy Efficient Operation of Buildings for internal use. That white paper, published in March 2022, included analysis and contributions from three countries: Denmark, Germany, and the United States. This report reflects an update, expansion, and reformulation of that original white paper. This report provides technology and

policy analysis, as well as identification of associated barriers from the full array of countries represented in the EE Hub DWG. These improvements, each of which directly benefits informed decision making, are included herein:

**Relevant Digitalisation Tools:** This report update describes key tools (technologies, methods, platforms, and software) that have demonstrated potential to transform the efficiency of the building operations sector, focusing on their associated utilities and usefulness, as well as challenges to their wide-scale deployment.

**Barriers:** This report update includes many more case studies and examples from a larger selection of DWG countries to characterize both technology and policy barriers to deploying energy efficiency digitalisation.

**EE Hub Member Countries:** This report update incorporates insights from all participating DWG countries, using inputs from these countries to demonstrate policy and technology solutions to the key barriers.

This report presents key insights, examples, and analyses that have been collected through a survey of available literature as well as interviews with subject matter experts from DWG member countries conducted during April and May 2022. These interviews focused on insights regarding policy dimensions, technology opportunities, and the state of building operations digitalisation for energy efficiency in each country. While this report aggregates information across all building types, Appendix A contains additional barriers to widespread digitalisation identified in the previous white paper that are relevant to specific building sub-sectors. The interview protocol is in Appendix B, and completed case study templates from the member countries are in Appendix C.

## 2.0 Energy Efficiency Hub: Digitalisation Working Group

The member countries represented in this report have taken strides to improve the penetration of digitalisation in the buildings sector. The DWG, led by the United States, was established as a Task Group of the EE Hub in 2021. Hub Task Groups are comprised of interested members that share information, best practices, and research between countries, international organizations, and the private sector. Additionally, they work toward outlining a path forward via the creation of best practices while learning from each other's experiences. The nine EE Hub members featured in this report are Australia, Brazil, Canada, Denmark, France, Germany, Japan, the United States, and the European Commission. The member countries represented in this report have taken strides to improve the penetration of digitalisation in the buildings sector. The objective of the DWG is to analyze the efficacy of policies and approaches that use digitalisation technologies to advance energy efficiency, share case studies from several countries, and engage with member countries to identify lessons learned and needs for additional data and analysis.

The DWG seeks to collectively address the following questions:

What analyses, case studies, and policies best embody members' current efforts toward digitalisation for energy efficiency of building operations?

What analyses and case studies featuring digitalisation policies and technologies can we build on or update?

What new data requirements and analysis need to be considered to address digitalisation barriers?

Is it possible to quantify the value proposition, costs, and benefits of the above case studies for easy and fair comparison?

What challenges prevent scaling up of the technologies and policies demonstrated in these case studies, and what lessons have been learned about market penetration, scalability, and deployment from these case studies?


## 3.0 Relevant Digitalisation Technologies

Each of the technologies, methods, platforms, and applications below can significantly decrease energy consumption in buildings. Some tools overlap each other in purpose and utility, while many can be deployed in tandem to enhance each other’s functionalities, including energy efficiency capabilities. However, many of these tools are currently in a state-of-the-art phase rather than achieving state-of-the-practice, which has limited market penetration so far. Multiple barriers, both technological and regulatory, must be overcome to transition these tools to be scalable across a wide range of applications and building types. Sometimes, a tool can be a solution to one barrier while exacerbating a second barrier. The following section defines a list of many digitalisation technologies, methods, platforms, and applications relevant to building operations while highlighting their energy efficiency potentials.

### 3.1 Technologies and Software

#### 3.1.1 Digitally Connected Devices

Often referred to as “smart” devices, digitally connected devices are a significant tool for reducing a building’s energy use. Heating, cooling, and lighting account for 23%, 16%, and 5% of total building energy use worldwide, respectively, based on statistics from 2020 and 2021 (Delmastro et al., 2021;

<p style="text-align: center;"><b>SMART THERMOSTATS</b> </p> <p><i>Smart thermostats are the most prevalent of all U.S. smart energy residential technologies; as of 2018, 11% of U.S. single-family households used a smart thermostat and 2021 projections showed smart thermostats in 40% of all U.S. residences (King, 2018). Since greater than half of U.S. residential energy consumption is accounted for by heating and cooling, and only 7% of that consumption comes from renewables, smart thermostats offer great decarbonization and energy efficiency potential (Holger &amp; Chin, 2021). Companies based in many DWG countries, for example Google Nest (U.S.), Danfoss (Denmark), Siemens (Germany), offer smart thermostats.</i></p>
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Abergel & Delmastro, 2021; González-Torres et al., 2021). Appliances also consume large quantities of energy; for example, appliances accounted for 23% of the total energy consumed by the U.S. residential sector in 2016 (King, 2018). Digitally connected devices can optimize the operation of a building’s energy-consuming systems, including heating, ventilation, and air conditioning (HVAC) systems, water heating, and lighting. Consequently, energy use becomes more efficient and can lead to other benefits, such as decreases in utility bills, more convenient system control, and better occupant comfort (King, 2018). Lower utility costs, in particular, could aid equity efforts by enabling more people to afford heating and cooling, which in turn could create healthier

home and work environments (Lund et al., 2018). Smart devices that can contribute to a residential or commercial building’s energy savings include appliances, lighting, outlets and power strips, window coverings, HVAC systems, elevators, water heating, and thermostats.

#### Energy Benefits

**Improved Response to Surrounding Conditions:** A subset of smart devices use sensors to measure occupancy and environmental factors, and then they use this information to determine when devices are active. For example, smart window shades, blinds, and films can adjust to light conditions and “yield [energy] savings of 11–20% in space heating and cooling and approximately 3% in lighting” (King, 2018).

**Scheduling and Remote Access:** Many smart devices can be programmed to turn on and off and/or adjust intensity based on a schedule. This functionality enables users to dynamically adjust their energy

consumption in response to load shifting and load shedding incentives offered by utility companies as part of demand response (DR) programs. These programs are designed to lower peak electrical demand through incentives for users. For instance, smart lighting controlled through an app and smart switches can incorporate automatic dimming and other advanced features to reduce light levels and operating hours. Many devices can also be accessed remotely from a smartphone app to be turned on and off (King, 2018).

**Increasing Share of Renewables:** Some smart devices can communicate with the grid and be programmed to run at times when a higher share of the energy supply comes from renewable sources (Holger & Chin, 2021).

### 3.1.2 Smart Meters

Smart meters refer to electronic utility monitoring meters that have networks to transmit data remotely between consumers and utility companies. They generally take higher temporal resolution measurements and are more accurate than traditional utility meters, and these devices enable tracking on a building, unit, system, or appliance level. For example, smart meters can track individual HVAC units; lighting; other powered devices; and power-generating equipment (Swedberg, n.d.). Data transmitted from smart meters combined with submetering is beneficial to utility companies, building managers, and individual consumers. Examples of benefits include the ability of utility companies to quickly and flexibly set load-shifting financial incentives which consumers may take advantage of, lowering peak electric load demands and consumers' cost of energy while creating a more stable grid. These benefits typically increase in magnitude as the smart meter network grows. Widespread deployment means that utility companies can quickly and flexibly set load-shifting financial incentives that consumers may take advantage of, lowering peak electric load demands and consumers' cost of energy while creating a more stable grid.

#### Energy Benefits

**Identify Demand Patterns:** When utility companies understand energy demand patterns, including peak times, they can more accurately forecast needs for infrastructure improvements and provide dynamic rates to customers. Time-based electricity rates and detailed individual usage information can help consumers minimize their utility bills in terms of both energy consumption and cost (Nabi, 2012).

#### QUICK STATS: SMART METERS IN JAPAN

*Japan aims for total deployment of smart meters by 2024.*

*Nationwide: 85.7% deployment in March 2021*

*Tokyo Electric Power service territory: 100% deployment in 2020*

**Immediate Data Access:** The availability of real-time metering data creates the basis for DR and transactive energy programs.

**Measurement and Verification:** The data from smart meters allows buildings with power-generating equipment to track how much energy is used, how much is sold, and how those numbers vary, which enables return on investment and payback period calculations (Swedberg, n.d.). Smart meter data can enable the same calculations for energy efficiency improvements such as vacancy lighting.

### 3.1.3 Building Information Modeling

At its core, Building Information Modeling (BIM) is a process and a technology; it is both the procedure and outcome of integrating physical properties with functional data into a three-dimensional representation of a building. BIM is applicable to all stages of a building's lifecycle, from design to deconstruction, and it can be part of a building's digital twin. BIM functions with many building types (e.g., residential,

commercial, municipal), although the specific building type alters the “level of detail and its supporting functionalities [...] due to stakeholders’ requirements” (Volk et al., 2014). During the operations phase, BIM is often deployed for energy analysis and simulations. Often, external data input and output applications are necessary to support these services.

### **Energy Benefits**

**Green Building Certifications:** The results of a 2017 assessment of BIM capabilities illustrate that BIM can support all the energy requirements of LEED, BREEAM, and DGNB and bolster the efficiency of these rating processes (Romano & Riediger, 2019).

**Energy Analysis:** A partial list of analyses possible in existing buildings using BIM includes daylight simulation, thermal analysis, carbon foot printing, retrofit planning, performance measurement, and lifecycle assessment (Volk et al., 2014).

### **3.1.4 Energy Management Systems**

Useful for owners and managers of all building types, this term applies to tools that monitor and strategically control a building’s energy utilization with the main objective of improving efficiency. The type of building influences which management strategy to deploy, and these computerized systems work in both existing and new buildings. They can integrate multiple pieces of hardware and software that contribute to energy consumption into a single, controllable system. Energy efficiency goals are typically accomplished by enabling “the implementation of key energy management tasks such as automating DR approaches, overseeing energy costs, detecting energy use anomalies, and arranging energy use information” (Mariano-Hernández et al., 2021).

Building Energy Management Systems (BEMS) generally refer to systems deployed in large commercial or multifamily residential buildings. Companies that provide these technologies often have end-to-end architectures that include all necessary software and hardware. IoT devices can be part of these packages; however, many solutions are hardwired and have dedicated computers on site. ISO 50001 is an existing international standard that aims to help users develop policy and goals, gather data, measure results, and review goal effectiveness regarding BEMS implementation (International Organization for Standardization, 2018).

Home Energy Management Systems (HEMS), used in the residential space for smaller scale buildings, often consist of IoT devices and noninvasive load-monitoring methods. Information and Communications Technology (ICT) allows end-users to take an active role in HEMS. These end-users typically strive to reduce the cost of utility bills; however, more and more end-users are becoming concerned with reducing energy consumption and integrating distributed renewable energy sources, such as residential solar panels (Gomes et al., 2022).

### **Energy Benefits**

**Continuous Monitoring:** Many commercial energy management solutions provide capabilities for monitoring real-time metrics such as electricity load profile, energy prices, and available energy generation mix. An example outcome of this data availability could be the decision on “when to increase or decrease the electricity load of the building, based on the cost or carbon-intensity of electricity at any given time” (IEA, 2019).

**Energy Use Control:** These systems can control the use of energy in industry, equipment, and building according to different developed functions or control logics (Mariano-Hernández et al., 2021).

### 3.1.5 Digital Twins

Digital twins further enhance the capabilities of energy management systems. As digital models of physical buildings, digital twins can simulate their real-world counterpart and inform decision making. These models can use historical data, maintenance data, and operational performance from the physical twin to either represent building operations in real-time or show the predicted outcomes of operational changes (Shahzad et al., 2022). This data can come from embedded sensors, wireless sensor networks, digitized building lifecycle data and systems (digitally connected devices, BIM, etc.), or external sources, such as climate or cloud data (Johnson Controls, 2019). If this data flows only from the physical building to the digital model, the model is called a digital shadow, whereas bidirectional data flow signifies a true digital twin (Shahzad et al., 2022). Machine learning (ML) and other tools can be incorporated to realize benefits from digital twins, a few of which are listed below.

#### Energy Benefits

**Improved Simulation Capabilities:** Using a digital twin, scenarios for control sequences and other operation changes can be simulated virtually before deployment to determine building-wide effects and mitigate unintended consequences.

**Lower Maintenance Costs:** Equipment downtimes can be shortened via experimental tests using a digital twin. Preventive maintenance can also be accomplished since digital twins better estimate when replacement parts are needed (Johnson Controls, 2019).

**Augmenting Interoperability:** Modeling how equipment from various manufacturers and years relate to each other helps further understanding of interoperability challenges and opportunities.

## 3.2 Computational Methods and Platforms

In this section, we describe the computational methods and platforms that act as building blocks for the digital technologies described in Section 3.1. In practice, many digitalisation tools work together to create a comprehensive solution for building operations energy efficiency and decarbonization.

### 3.2.1 Internet of Things Platforms

An IoT platform is a collection of tools and computational resources that deliver the central process and management, and the vertical services for device and data lifecycle management (Asemani, 2019). No centralized standard exists for IoT platforms. Existing as commercial and open-source entities, they rely on interoperable ICT and can be sponsored on cloud and fog computing resources (Asemani, 2019). IoT platforms provide an infrastructure that connects sensors, such as IoT-enabled thermostats, data management, and communication elements, namely data pipelines and cloud databases, with cloud-based high-performance computing (HPC) resources. This results in an ecosystem that allows the opportunity to implement applications such as advanced control, monitoring, fault detection and diagnosis, and even grid services aimed toward decarbonization and indoor environment quality (Ledbetter, 2022).

#### Energy Benefits

**Improved Interoperability:** Some IoT platforms offer the ability to integrate proprietary home energy technologies with utility systems via designated or custom communications protocols. Therefore, products and software from various vendors can coexist on a single platform (Volttron, 2017).

**Automation Opportunities:** IoT platforms can enable autonomous control of various building systems as well as automated services like load control and fault detection (Volttron, 2017).

### 3.2.2 Advanced Control Algorithms

In large buildings, technicians must generally be present to adjust settings for optimal performance. Advanced control algorithms automate these tasks. Due to the large quantity of data and data sources, as well as the complexity and variability of building conditions, “it is reasonable to assume that a well-

#### **LEANHEAT SMART CENTRAL HEATING CONTROL AND MAINTENANCE**

*With Leanheat, an IoT solution, data from the heating room and IoT sensors are joined to optimally control heating in multi-family residences while adapting to shifts in “weather, living patterns and thermodynamic behavior” (Lund et. al., 2018). Leanheat’s product also identifies maintenance issues quickly and conducts a root-cause analysis. Deployed in over 35,000 apartments worldwide, including Germany and Denmark, Leanheat’s advanced controls system has realized up to a 5% decrease in maintenance costs, 10-20% decrease in energy consumption, and 15-30% increase in peak capacity. While this system can be retrofitted to existing buildings, it only works in apartments with central heating (Lund et. al. 2018).*

designed automatic controller would perform better than a human at such tasks” (Maddalena et al., 2020). By reducing the need for a human-in-the-loop, both residential and commercial buildings of varying sizes become candidates for advanced control algorithms in terms of economic investment capability and energy savings potential.

Generally, advanced control algorithms take in data from building sensors, operate on that data using ML algorithms (e.g., reinforcement learning and forecasting) or other data-driven methods, and develop decision logic to optimize building operational parameters. This optimization process can occur based on a list of priorities and constraints. For instance, HVAC systems are a popular subject of control algorithms, and occupant comfort is typically the priority while “temperature, carbon dioxide levels, air humidity and pressure, and the presence of particles might also be controlled” (Maddalena et al., 2020).

#### **Energy Benefits**

**Continuous Decision Making:** Some automated controllers are capable of unsupervised learning and decision making, relieving the need for the human-in-the-loop and enabling continuous updates to a building’s settings, therefore allowing them to automatically adjust to environmental shifts, operational changes, and prioritization of goals, including energy savings objectives (Maddalena et al., 2020).

**Immediate Response to Faults:** When faults are found in a system or piece of equipment, automated control and monitoring algorithms can instantaneously make decisions about implementing potential solutions or alerting the building manager. Quickly identifying and fixing faulty systems and equipment reduces energy waste (King, 2017).

**Peak Demand Reduction:** Technology and DR assessments in the United States demonstrate that state-of-the-art controls, combined with advanced sensors, can decrease the peak demand of commercial buildings by 10–20% (Kiliccote et al., 2016; Piette et al., 2007).

### 3.2.3 Machine Learning

ML is a concept describing “the capacity of systems to learn from problem-specific training data to automate the process of analytical model building and solve associated tasks” (Janiesch et al., 2021). Training a supervised learning model requires input data that have label answers or target values for the output, whereas unsupervised learning is when the learning system is supposed to detect patterns without any preexisting labels or specifications. Reinforcement learning is used when the aim is to enable a model

to work toward an objective alone through trial and error to maximize reward. All three types of ML models are applicable at the intersection of building operations and energy efficiency. For example, unsupervised learning can be deployed to identify actionable patterns among building occupant preferences, productivity, and behavior. ML can integrate with many other digitalisation solutions listed in this section since this tool's functionality includes observation, prediction, adjustments, data management, and human-building interaction improvement (Alanne et al., 2022).

## Energy Benefits

**Forecasting and Analysis:** ML can be used to create time-series forecasts or classification predictions for building metrics, such as sensor measurements, enabling building managers and owners to make data-informed decisions about energy consumption (Alanne et al., 2022).

**Fault Detection, Prediction, and Prioritization:** Unsupervised learning can be used for anomaly detection, which identifies if a fault has occurred in the building. Supervised learning can then categorize the type of fault and root cause (Alanne et al., 2022). ML can also be used to predict when faults will occur, allowing managers and owners to set more effective predictive maintenance schedules. The tool's third capability in this category is determining the severity of identified faults and subsequently prioritizing which alarms human intervention should focus on first (King, 2017).

### 3.2.4 Cloud Databases

Traditional building management systems are costly to create, install, and maintain. Particularly in large buildings, a hardwired system contributes greatly to the cost (Minnovation Technologies, 2021). Cloud-based building management systems are cheaper and alleviate some data availability, quality, and analysis issues; "cloud-ready buildings [are] designed to share and leverage data across functional boundaries" (Bennett, 2019). Strategies like data analytics and optimization on data from IoT devices with control capabilities can easily take place in the cloud. Cloud integration is possible during both construction and retrofitting phases. Since cloud databases essentially provide a service to support other components of the digitalisation infrastructure, it is difficult to perform an energy benefit analysis dedicated to them alone.

### 3.2.5 High-Performance Computing

Unlike traditional computers, HPC can run transactions in parallel and use all available resources and processors. HPC often resides on supercomputers and uses fast disks, high-speed memory, and more powerful graphic processing units. It can scale horizontally via clusters or vertically by improving the central processing units. HPC systems can be, and often are, integrated with cloud technologies as well.

HPC has several applications for buildings, including scenario testing, digital twins, and optimization. Compared to the fastest laptop, HPC is up to one million times more powerful and can enable calculations that use up to terabytes of data (IBM, n.d.). Therefore, HPC can reduce the computational time required for the complex data analytics, control, optimization, and predictions used in building digitalisation. Similar to cloud databases, HPC essentially provides a service to support other components of the digitalisation infrastructure, and hence it is difficult to perform an energy benefit analysis dedicated to HPC alone.

## 3.3 Applications

### 3.3.1 Demand Response

DR is a subcategory of demand flexibility, which is the use of communications and controls technology to shift electricity use across hours of the day or more granular time intervals (Bronski et al., 2015). The

U.S. Federal Energy Regulatory Commission defines DR as “actions by customers that change their consumption (demand) of electric power in response to price signals, incentives, or directions from grid operators” (Honarmand et al., 2021). Integrated DR furthers this concept by enabling end-use customers to shift their energy consumption and also change their energy source (Honarmand et al., 2021). DR is a powerful tool for decarbonization; for example, it can facilitate the reduction of peak demand, which in turn can eliminate the need for increased power generation capacity and associated infrastructure. According to the IEA, 500 GW of DR should be brought onto the global market by 2030 to meet the pace of expansion required in the Net Zero Emissions by 2050 Scenario (Bertoli et al., 2021). An array of active DR programs exists throughout the world, varying in control mechanisms, incentives, and decision-making variables. Many different utility-domain and end-user-domain technologies are involved in operating these programs, as illustrated in Figure 2.

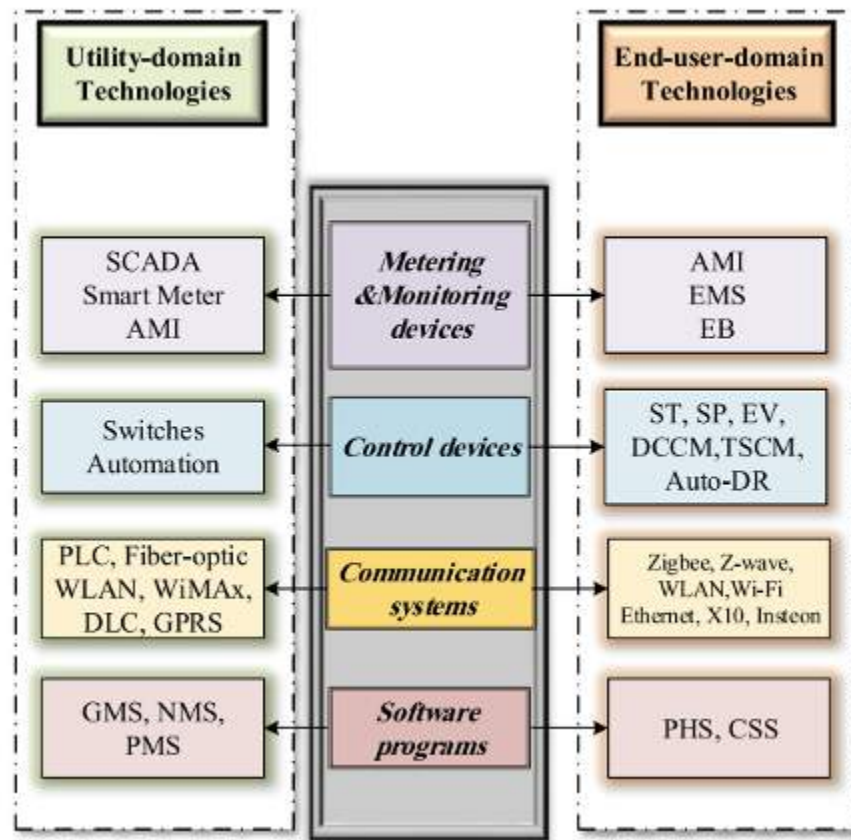


Figure 2. Classification of DR enabling technologies (Honarmand et al., 2021)

DR: demand response; SCADA: supervisory control and data acquisition; AMI: advanced metering infrastructure; EMS: energy management system; EB: energy box; ST: smart thermostat; SP: smart plugs; EV: electric vehicle; DCCM: direct compressor control mechanism; TSCM: thermostat set-point control mechanism; PLC: power line communication, WLAN: wireless local-area network; WiMAX: worldwide interoperability for microwave access; DLC: direct load control; GPRS: general packet radio service; GMS: grid monitoring software; NMS: network management software; PMS: power market software; PHS: plug-loads handling software; CSS: customer services software

## Energy Benefits

DR involves communication between grid operators, utilities, and customers to shift or reduce end-use electricity consumption, providing flexibility to the power grid so it can cope with grid concerns including but not limited to:

**Incorporating Alternative Energy Sources:** Additional resources can be added to a grid's energy sources composition due to DR's ability to enhance the alignment of demand with currently available supply. DR reduces the risks associated with adding resources with uncertain generation, like variable renewable energy, to the grid. In the Net Zero Emissions by 2050 Scenario, the share of renewables grows from 29% in 2020 to over 60% in 2030, while flexibility from by thermal power plants is set to decrease in many markets, with decommissioning of conventional power plants already in progress in countries such as Germany, France, Chile, and the United States (Bertoli et al., 2021).

**Peak Events:** Although peak events represent a very small percentage of total energy use time per year, energy companies will need to build more power plant distribution infrastructure to accommodate customer behavior during these events unless DR programs that conserve energy during peak events become more popular (Nest Labs, 2014).

### 3.3.2 Transactive Energy

Researchers in DWG countries—including Australia, Germany, and the U.S.—and non-DWG countries are examining an advanced version of demand flexibility called transactive energy. This idea incorporates real-time, two-way communications for demand flexibility and electricity price signals, enabling the coordination of energy generation, consumption, and delivery when stakeholders communicate directly or indirectly to negotiate energy needs and costs (PNNL, n.d.). The basic premise of transactive energy involves a rapid and repetitive process in which smart devices electronically communicate energy needs and the preferred price to a transactive node, which serves as a general interface between buyers and the electricity market. As the node collects requests over a specified service area, it transfers these requests to the electricity market and returns to the devices an energy price based on current supply and demand (PNNL, n.d.). Once the devices know the current energy price and/or the carbon intensity of the current energy supply composition, they can choose to accept the price or postpone operations until an acceptable price is reached.

## Energy Benefits

**Effective Coordination:** Transactive energy would enhance the energy grids' ability to quickly pivot to bring other energy resources online during renewable energy production decreases throughout the day, thereby reducing risks associated with using a greater share of renewables in energy production composition (PNNL, n.d.).

**Sustainable Efficient Energy System:** Transactive energy would boost electric grid resiliency and allow it to meet more needs with its existing infrastructure (PNNL, n.d.).

## 4.0 Barriers to Deployment

As described in the previous section, digital solutions in the buildings sector demonstrate significant potential to improve energy efficiency and drive future decarbonization efforts. However, in order to harness this potential through the large-scale deployment of digital technologies, several barriers must first be addressed.

The DWG, supported by Pacific Northwest National Laboratory (PNNL), conducted a series of interviews in April and May 2022 with representatives of the DWG member countries. The diagram in Figure 3 represents the frequency that the main barriers identified in the white paper were mentioned in these interviews. According to the results (a total of six interviews), DWG member countries believe interoperability to be the most significant barrier to the widespread deployment of digitalisation for the energy efficiency of building operations.

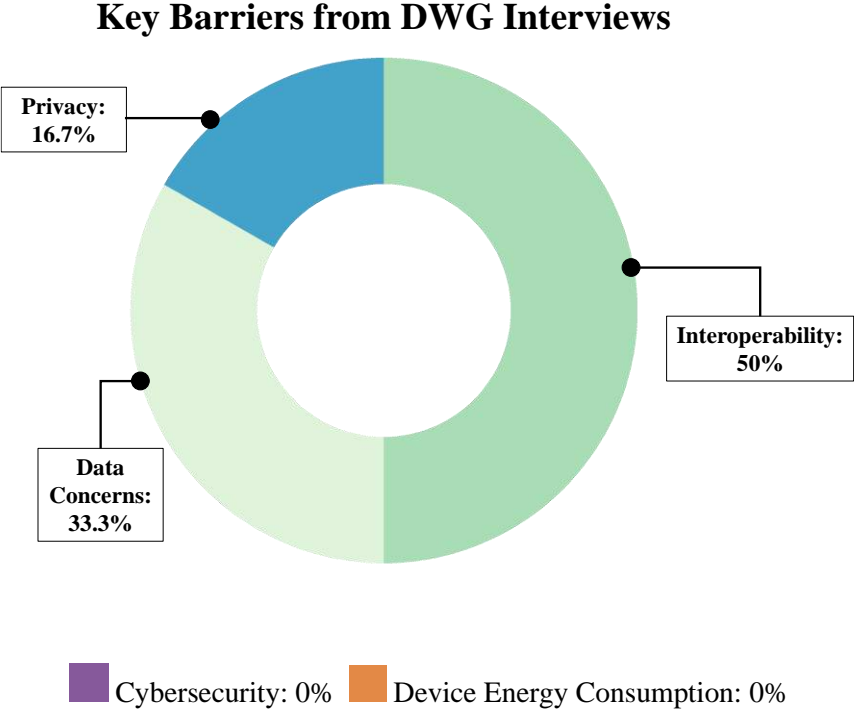


Figure 3. Frequency of main barriers based on six DWG member interviews

### 4.1 Privacy

Deployment of digitalisation technologies in a manner that achieves each country’s energy efficiency and decarbonization goals requires the mass collection of personal and machine data for analysis. One such metric is occupancy data, which help determine ventilation, heating, and cooling needs to enable dynamic, zone-controlled HVAC systems that ensure lower emissions and energy use (Thieme, 2021). However, occupancy data also reveals when someone is away from their home, which can present physical security concerns. Smart meters are a particularly worrisome technology for privacy-minded consumers. Data collected from this type of utility meter tend to be very granular information over short intervals that can provide detailed picture of the appliances being used and other household activities. A

study in 2014 demonstrated that high-resolution electricity consumption data may reveal information about socioeconomic status and appliances, with an accuracy of more than 70% (Lee & Hess, 2021).

Consumers are worried about how data will be used, where the data are stored, and who can access the data (Brown, 2015). They are concerned about entities using mass data collection to gain influence via social engineering and blackmail threats. These worries decrease the attractiveness of digitalisation technologies in buildings and therefore limit potential market penetration. Currently, data ownership and oversight rules can be vague, furthering concerns and generating a need for improved regulatory measures (Brown, 2015; Tesler, 2020). When regulatory measures do exist, monitoring and enforcement tend to be a challenge for governments.

Regulatory solutions to digitalisation privacy concerns can include mandating companies obtain consumer consent and use the data only for specified purposes. Policies might also define how frequently data can be collected (e.g., every half hour, hour). Several DWG members are subject to the European Union's General Data Protection Regulation, which is considered one of the most significant privacy regulations worldwide (Lee & Hess, 2021). The United States limits the extent of Fair Information Practice Principles in digital privacy to federal government regulations while much of the regulation of investor-owned utilities occurs at the state level (Lee & Hess, 2021). Only some U.S. states have policies regarding third-party access to utility and energy use data (American Council for an Energy-Efficient Economy, 2020). Canada, on the other hand, has also approached privacy from the design side; Ontario's Privacy Commissioner developed systems design principles that support privacy objectives. The country additionally enforces the Personal Information Protection and Electronic Documents Act, applicable to private sector companies collecting and using consumer data (Lee & Hess, 2021).

## 4.2 Cybersecurity

All connected appliances and systems are at risk for attacks, as attackers can gain access to the building management system or a single system. As building managers and homeowners rely more on internet connections and computer networks, cyber risks increase. For example, a hacker could access the lighting (a single system) and then gain access to many or all other systems in the building, regardless of whether or not those other systems are connected to a shared network (Bhattacharyya, 2021). Subsequently, other types of information (e.g., corporate communications and databases) could be accessed. This vulnerability to cyberattacks presents a substantial barrier for many consumers to adopt energy efficiency digitalisation in their buildings. The Director of Cybersecurity at *Intelligent Buildings* gives an example in which a ransomware attacker gained entry through a hospital group's building systems, and the hospital was unable to do anything with the systems, so they had to cancel surgeries (Bhattacharyya, 2021). Among his company's clients, ransomware attacks grew 600% in 2020 and 1.8 billion square feet in commercial real estate was attacked compared to 100 million square feet in 2019, representing an almost twentyfold increase in footprint (Bhattacharyya, 2021).

Efforts to improve consumer participation in the grid have generated concern in terms of cybersecurity. In Australia, the application of dynamic export limits has become a topic of conversation regarding their cybersecurity impacts. Dynamic export limits are standards set on the amount of power that can be exported to the grid through connection points, preventing reverse power flow from exceeding the capacity of the network. However, due to the new lines of communication through smart technologies and the IoT, the ability for third parties to manipulate the flow of electricity through connection points has increased. In these cases, proactive planning and strong cybersecurity protocol are key to minimizing cybersecurity risks (FTI Consulting, 2020).

A variety of measures to reduce risks exist, but many of these strategies require time, capital investment, skilled network engineers, and all users to be digitally competent and attentive to security needs. All

building services can be linked to a single network that is monitored and controlled by cyber experts, and network segmentation can be used to construct barriers so that someone accessing one system cannot access any other parts of the network. Improving authentication and identity management methods is also important (Bhattacharyya, 2021). The World Economic Forum provides a comprehensive list of methods for boosting smart building cybersecurity, diagrammed in Figure . However, despite protections, cybersecurity breaches are still possible.

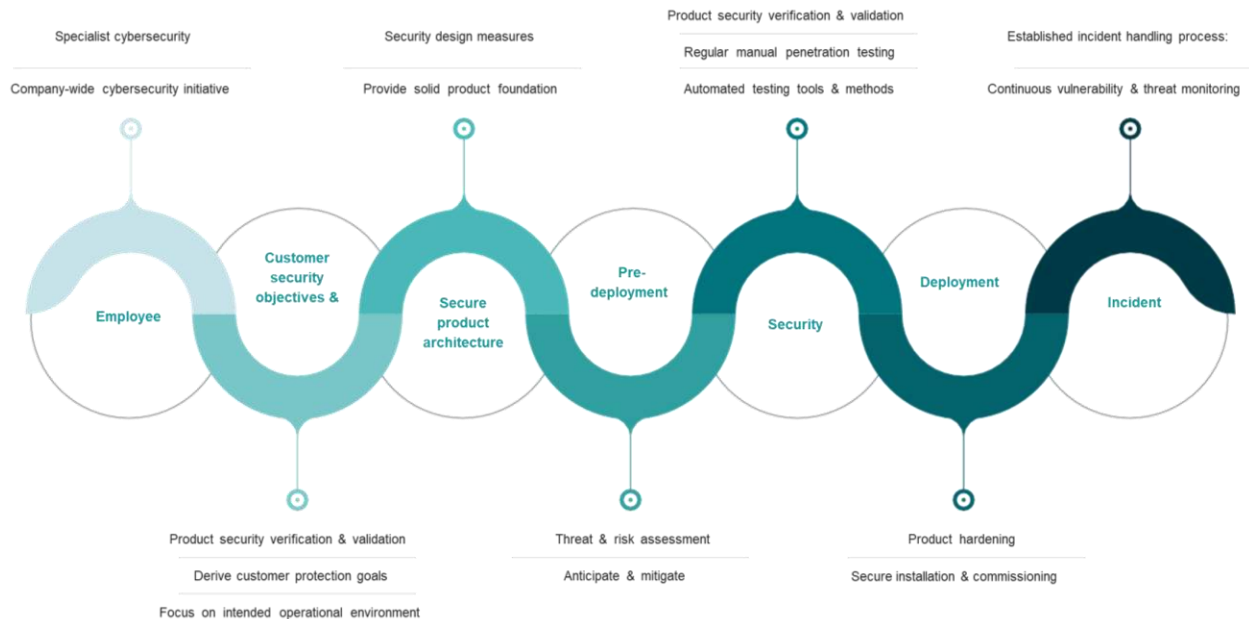


Figure 4. Seven principles to ensure products contribute to smart buildings' cybersecurity (Sandfort & Matyukhina, 2021)

### 4.3 Interoperability

A lack of interoperability—open communications protocols that allow software products and devices to communicate with each other within a building, among other buildings, and with the electric grid and its components—severely limits the effectiveness of digitalisation technologies. For example, interoperability is the main challenge to provide an efficient HEMS (Rosselló-Busquet & Soler, 2011). Issues associated with interoperability must be solved before many of the digitalisation tools described in this report can become widespread, such as those associated with ICT and advanced control algorithms. As digitalisation becomes more prevalent in buildings, owners, managers, and occupants will want access to information from across a range of manufacturers and product types, and these devices will need to work together to achieve maximum operational efficiency and energy savings (King, 2017). Advanced data standardization and tool interoperability are also key to ensuring a robust market for energy providers to compete in. When providers participate in a competitive market, this can help to drive greater choice, innovation, and lower barriers for consumers to switch between providers (FTI, 2020). In so doing, consumers are empowered with dynamic decision-making capabilities and are more able to achieve cost savings.

A specific aspect within interoperability is semantics. In addition to interoperability at the technical level, a lack in the semantic level poses a barrier for streamlined integration of interdependent applications. Semantics refers to expressing information in a way that can be consistently understood by applications (Bergmann et al., 2020).

Interoperability is important to the function of many digitalisation technologies and tools, such as energy management systems. A disconnect exists between the communications protocols applied to power facilities and HVAC systems (e.g., Modbus) and communications protocols used in energy management systems (e.g., BACnet), which makes interoperability hard to establish and maintain without easy-to-use utilities (Moxa, 2021). Without easy protocol troubleshooting, tasks including device configuration, installation, and maintenance can require additional time and costs.

The IoT has improved functionality and works when retrofitting in many scenarios, but it has not necessarily improved how data are extracted or presented, since many devices only work with their individual cloud platforms. A need exists to combine sensing, computation, control, and networking across manufacturers and years into a holistic smart building interoperable from a single platform that incorporates AI and ML into an analytics engine for optimization (Zimmerman, 2021). To prevent additional cybersecurity issues, these systems can gather data in web-based dashboards so that only the relevant stakeholders can see the information.

#### 4.4 Data Availability, Quality, and Analysis

Siemens estimates that by 2030, 50 billion IoT devices will exist with 65% of customers demanding access to data from any location at any time (Hatcher, 2016). In terms of efficiency, data accessibility can inform consumers of their energy use and drive them to adjust behaviors, leading to energy savings (King, 2018). Good data availability promotes innovation, efficiency, and reduced costs. Open-source data allow businesses to develop enhanced energy efficiency digitalisation solutions (Agency for Digitisation, 2016). Furthermore, by creating programs directed toward the least efficient buildings, deployment of emission-reducing digitalisation technologies becomes more systematic and successful. However, accurate and current data are needed to quickly identify these buildings and create targeted improvement plans (Lund et al., 2018). Cities should have access to up-to-date metrics that “measure the condition of their building stock – via macro-indicators that help assess the best set of technologies and incentives to be deployed” (Tricoire, 2021). Similarly, renovations and retrofits of existing buildings are typically advantageous compared to new construction in terms of reducing both costs and CO<sub>2</sub> emissions. Data and evaluation tools are necessary (and currently insufficient) in the early planning stages to assess these tradeoffs of potential energy retrofits and ensure optimal decision making (Andersen et al., 2021). Additionally, more data and analysis are needed for policymakers and utilities to create robust incentives to convince businesses and individuals to adopt digitalisation technologies.

Furthermore, data are vital to achieve and measure energy savings and prioritize the most effective digitally connected devices. Many estimates currently come directly from manufacturers’ claims rather than independent studies, and limited performance and energy savings data exist for smart home technologies other than thermostats. Studies are lacking to compare the various smart building technologies across different applications to measure energy savings potentials (King, 2018). Some energy efficiency technologies and their related programs, such as DR, require real-time data. While smart meters exacerbate the privacy barrier, they are a potential solution to this data availability issue due to the frequency, volume, and granularity of data collected (Lee & Hess, 2021).

Even when a building can provide all requested data types, the datasets are not necessarily robust since many building operations are critical and cannot be disturbed for the sake of testing and evaluating digitalisation tools. For example, changing the occupancy schedule or sending strongly exciting input signals for advanced control algorithm HVAC tests is usually unacceptable since safety and/or occupant comfort constraints might be violated (Maddalena et al., 2020). Testing can instead be performed during periods when the building is unoccupied, but these tests would not indicate the interactions and effects of building occupants. Occupants impact indoor climates actively by acting on windows, doors, shading devices, and adjustable temperature setpoints, and passively through heat gains and increasing CO<sub>2</sub> levels

(Maddalena et al., 2020). Digitalisation tools for energy efficiency therefore need to be robust to a wide range of building conditions and possible events, accomplished through lab testing or simulations rather than field testing, since aggressive excitation is generally not permitted in real-world building operations (Maddalena et al., 2020).

Data quality is similarly challenging. While buildings, particularly in the commercial realm, often have measurement sensors including temperature probes, occupancy detectors, lighting and air-pressure transducers, and power meters, the data gathered from these sensors are sometimes low resolution and missing entries (Maddalena et al., 2020). Occasionally, the sensors themselves are poorly calibrated. For some applications, such as DR, high-time resolution data are necessary, but the sampling periods supported by measuring devices are low resolution.

Addressing these data gaps requires some fundamental questions to be answered. For example, Zimmerman asks: How do you create a robust, interoperable, integrated smart building automation system that can provide the data you want in the format you need? and How do you extract and present that data from this system so that it is actionable, and without suffering from paralysis by analysis? (Zimmerman, 2021). In addition to these questions, the DWG poses the question: How can these data then be integrated into the overall electricity system? Another question that is relevant in this context: How do building operators ensure that complete, accurate building controls and utility consumption data are continuously acquired and stored for future analysis? These questions arise because data are not intrinsically valuable without analysis that turns them into useful information and a methodology for practically implementing the results of this analysis.

Tools such as ML and advanced control algorithms are therefore paramount to digitalisation energy-efficiency solutions. However, these tools are mainly in state-of-the-art rather than state-of-the-practice, so efforts must continue to enhance their functionalities and applicability. Furthermore, these tools might encounter conflicting scenarios, such as a gas leak or CO<sub>2</sub> alarm that causes a smart window to open while the smart air conditioning detects the temperature increase and causes the smart window to close, so continuous scenario development and tool training/learning should take place (The Institute of Energy Economics Japan, 2022). Simultaneously, connectivity and local storage challenges along with a lack of data synchronization across devices can result in data quality issues. Unless these problems are addressed, downstream analytical applications, including ML and advanced control algorithms, will not produce useful or reliable outputs.

Software and tool developers should make use of visual analytics to clearly and accurately display the findings of various data analysis efforts. Models may include highly disparate data with tens or hundreds of features, making manually understanding analysis outputs challenging. Ideally, data dashboards for tools should be customized to each user type so they only see relevant information that they are capable of comprehending. Visualizations can ensure that information is accurately transferred between user groups and highlight findings, such as patterns and dependencies, that may otherwise remain hidden. Furthermore, visualizations can encourage trust, currently a barrier to digitalisation tool adoption among building operators and managers, in complex models by providing insight into black-box decision-making units (Kandakatla et al., 2020).

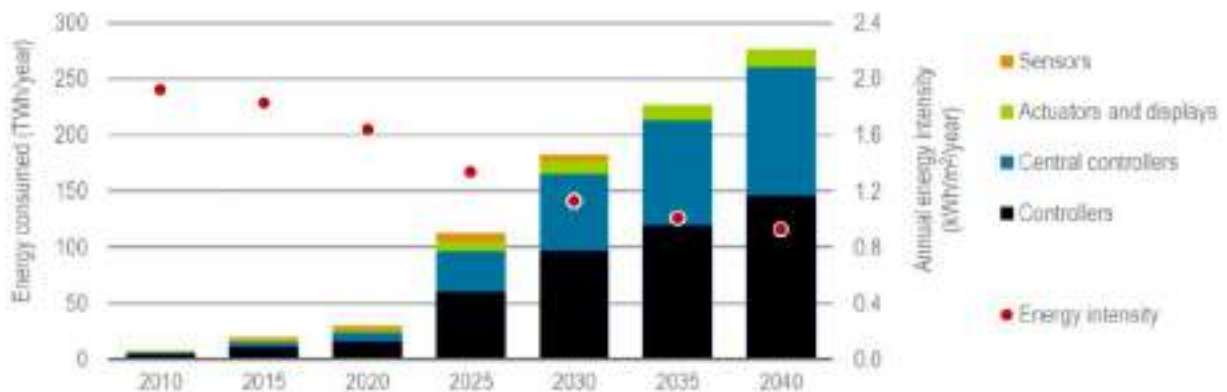
## 4.5 Device Energy Consumption and Decentralization

Investing in renewable energy capacity and storage is expected to fuel a transition to more locally, independently produced power (Verma et al. 2020b). Correspondingly, to increase renewable energy usage, new methods will be needed to monitor their performance and efficiency, requiring the integration of millions of consumption and generation devices (United Nations 2021; Verma et al. 2020b). The sheer

number of devices connected through the IoT requires methods to dynamically monitor system performance and ensure that devices are performing efficiently (Verma et al. 2020b).

Moreover, these information systems must operate in both a cost-effective and environmentally friendly manner. Each computational capability, such as AI, IoT, and blockchain, has associated power consumption needs. The exact power consumption levels associated with these technologies can vary, and a more detailed analysis is beyond the scope of this report. However, it seems logical these additional power needs should be met in an energy-efficient manner as much as possible to prevent the growth of future electricity demand as an unintended consequence. Furthermore, the data centers that underlie these systems are, in some instances, not subject to energy efficiency standards or regulations regarding the energy and raw materials (The Federal Ministry for the Environment, Nature Conservation, and Nuclear Safety, 2020). While the energy consumption of data centers may pose a concern in terms of their energy demand, recent assessments suggest that the energy these centers consume is increasingly composed of renewable energy sources (University of Cambridge, 2022).

In order to mitigate these impacts and ensure that digital technologies are operated in both an efficient and environmentally conscious manner, digitalisation must be balanced by improvements in the fields of data storage, data communication, and software management (Verma et al. 2020b). Considering economies of scale and continued product improvement, worldwide projections suggest that smart control energy savings (4,650 TWh in 2040) will outweigh smart control energy usage (275 TWh in 2040) as seen in Figure (IEA & Digitalization and Energy Working Group, 2017). Forecasts from Transforma Insights and 6GWorld predict that while AI and IoT solutions will require 653 TWh of electricity consumption to operate, they will collectively save 1.8 PWh of electricity and 3.5 PWh of hydrocarbon fuel in 2030 (Transforma Insights & 6GWorld, 2021).



**Key message:** The energy intensity of active controls is expected to improve to 2040, consuming far less than the potential energy savings achieved by smart controls in buildings.

Notes: Sensors include occupancy and daylighting sensors; central controllers collect data from an entire dwelling or building and monitor operating units; controllers only operate on a specific zone of the building.

Figure 5. Global energy use and average energy intensity of active controls in buildings (IEA & Digitalization and Energy Working Group, 2017)

## 5.0 DWG Member Country Overviews and Case Studies

### 5.1 Australia

In Australia, buildings constitute around 19% of total energy use and 18% of direct carbon emissions.<sup>1</sup> The Australian Government has legislated to reducing greenhouse gas emissions by 43% below 2005 levels by 2030 and reaching net zero emissions by 2050 (Prime Minister of Australia, 2022; Parliament of Australia, 2022). As part of these efforts, the country has experienced large-scale energy transformations driven by the transition toward low carbon distributed energy sources such as rooftop solar, electric vehicles, and energy storage. As decentralized energy sources like these proliferate, estimates show that, by 2050, consumers will control the allocation of over \$200 billion in system energy expenditure as well as support 30–45% of Australia’s electricity needs through customer-owned generators (Commonwealth Scientific and Industrial Research Organization, 2017). These low-carbon sources can play a role in significantly reducing Australia’s carbon footprint. However, to fully realize their potential, enhanced energy system connectivity is required to ensure they can participate in the grid in real time (IEA Digitalization, 2017).

Historical efforts by the Australian government have focused on building energy-efficiency certifications. Through a series of parallel programs called National Australian Built Environment Rating System (NABERS) and Nationwide House Energy Rating Scheme (NatHERS), consumers are provided energy-efficiency ratings that are measured in accordance with standards set by the government. NABERS ratings are administered to a wide range of commercial building types on a voluntary basis and are mandated only for office buildings over 1000 m<sup>2</sup> when offered for sale or lease. Ratings are based on the actual performance in the previous 12 months of energy efficiency, water conservation, and waste management practices. NatHERS ratings are currently given to new residential home design to evaluate their efficiency and include determining the total energy consumption over the course of the year. NatHERS is being extended to offer nationally accredited energy efficacy ratings and opportunities for improvements of existing buildings. These ratings systems play a strong role in ensuring that Australia’s buildings sector is operating with minimal energy-efficiency loss.

Recent attention has focused on leveraging digital technologies to adapt to Australia’s rapidly evolving energy system. The Post 2025 project, administered by the Energy Security Board, examines regulatory frameworks for electricity to be able to better integrate distributed energy resources. These tend to be customer owned and connected at the distribution level. This project encompasses technical and distribution requirements. There is a push under this effort to provide incentives for consumers to integrate flexible demand and generation, providing options for participation, and using a consumer protection framework (Energy Security Board, 2021).

Australia has made beneficial policy developments to increase the impact and range of DR in recent years. The country approved a Wholesale Demand Response Mechanism, opening up the DR market to large industrial and aggregated customers capable of curtailing demand (Bertoli et al., 2021). The Wholesale Demand Response Mechanism was approved in July 2020 and commenced on October 2021. The Mechanism allows aggregated loads, but only large customers are able to participate in this program. In terms of data availability, Australia’s Energy Demand and Generation Exchange Project incorporates a data exchange component to assist stakeholder, operator, and aggregator coordination in DR programs. The jurisdiction of South Australia is also proposing technical standards for specific appliances and equipment to ensure these technologies are DR capable (George Wilkenfeld and Associates, 2020). They have introduced technical standards for inverters.

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<sup>1</sup> Source: <https://www.energy.gov.au/government-priorities/buildings>

As part of their initiative to promote flexible DR, the Energy Security Board led an assessment of key policy barriers to deploying DR technologies. A key challenge highlighted by their assessment was device interoperability. The ability for devices to communicate with providers in real time is paramount to ensuring users can make informed decisions between providers, as well as promoting market competition between those providers (Collyer and Savage, 2021). Figure 6 outlines the considerations proposed in this assessment framework, including system reliability, system and network costs, data privacy and security, flexibility and adaptability, and compliance (FTI Consulting, 2020). Additional selected case studies demonstrating the breadth of Australia’s efforts are summarized below.

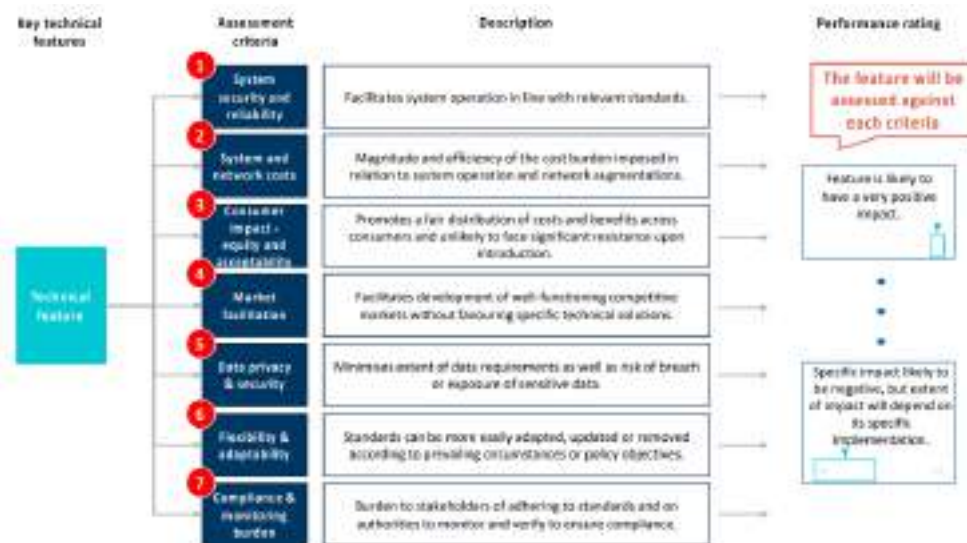


Figure 6. Assessment framework for applicability of new features for smart technology operation (Collyer and Savage, 2021)

### Technology Example: WideSky

WideSky developed BEMS for two different residential apartment complexes owned by LendLease in 2013. For optimal operation, the building installed 6,900 monitoring devices that collect readings every 5 minutes, allowing for frequent collection of data with high resolution. WideSky developed a cloud software that validates and encodes data into regulated standard formats, and then collects and stores the files, which are made available to the building services provider. Due to the success of this project, the model now makes up the foundation of a number of other major LendLease projects (WideSky, 2022).

### Policy Example: Bank Australia

To incentivize the use of clean and renewable technologies in the building sector, Bank Australia offers low-interest loans for ecofriendly renovations. This includes investments in smart technologies, renewable energy generation, and structural attributes aimed toward sustainability improvements. Bank Australia provides three options for customers—Eco, Eco Upgrade, and Eco Plus—based on whether the residence is newly constructed or renovated, if the home includes solar panels, and which NatHERS and/or Green Energy Star rating the home achieves (Bank Australia, 2022). The Clean Energy Finance Corporation provides \$30 million for the Eco Plus level, which is the highest interest rate discount option (Aubrey, 2022). Energy Home Loan allows customers to receive a discount for 5 years for variable rates, or the length of their fixed rate period depending on which option the customer chooses (Bank Australia, 2022). Since the program’s inception in 2020, Bank Australia has provided 300+ Clean Energy Home Loans, and this type of loan makes up 1+% of its home loan portfolio (Aubrey, 2022).

## Policy Case Study: Affordable Heating and Cooling Innovation Hub

From 2020 to 2022, Australia's *i*-Hub supported R&D efforts for GEBs and digitalisation scalability to better understand the potential for nonresidential buildings to contribute flexible demand services. One of the main projects within *i*-Hub involved creating a real-time data management platform now deployed in 60+ buildings and nine software applications. In addition to addressing the barriers of interoperability and data accessibility, this R&D project progressed efforts in product uncertainty and procurement complexity through digitalization trials in pilot buildings, with focus on proving the efficacy of the data management platform. The results of this initiative will assist Australia in developing future policies through research into barriers to digitalisation uptake and other key lessons learned. One important discovery is that two steps exist when employing flexible demand and digitalisation tools in existing nonresidential buildings. Step one is establishing digital connectivity of the building so that it can 'talk' to the outside world, and step two deploys software (analytics, market participation, etc.) to manage the operation of energy-consuming equipment in the building (Appendix C.5). Performing step one as part of regular equipment lifecycle investments reduces implementation barriers, including costs.

## 5.2 Brazil

Unlike the majority of DWG countries, decarbonization in the traditional sense is a less urgent goal of digitalisation since much of Brazil's energy mix is already sourced from hydropower. The central aim is rather making energy use rational and sustainable, since the building segment accounts for about 50% of electricity consumption (Peres Suzano e Silva, 2022). Brazil is also different in that it has only cooling and no heating needs. Digitalisation is possible mainly in southeastern Brazil and can be applied to certain projects in northeastern Brazil. DR is not yet a reality in this country, but the government is interested in exploring methodologies for deploying smart meters. Recent efforts to increase digitalisation in Brazil include a study on how to adopt state-of-the-art methodologies from Europe and focus on how distributed generation would affect Brazil's buildings and grid. One main project is the National Energy Plan 2050, which is a set of studies and guidelines for long-term energy sector strategy and structure. This plan addresses recommendations for cybersecurity, supplier reliability, interoperability, and standardization.

Brazil has a few main concerns regarding the implementation of digitalisation. Capital costs of new technologies, such as smart meters, can be passed from the utility companies to consumers. When this trend occurs, digitalisation can exacerbate existing inequality rather than mitigate it. A related goal of building digitalisation in Brazil is to bring these technologies to low-income housing programs, but the project payback period compared to effects on energy consumed over time is important in these instances. Data availability and control are common issues, so project payback and estimation of benefits are difficult to ascertain in many cases. Data aggregation from regulatory agencies is often hard to connect to end-use cases, particularly how consumers utilize energy, and sometimes results in privacy concerns. Many companies do not favor sharing data. The current unavailability of data, particularly lifecycle analyses, makes deciding which devices to prioritize and which business models to implement difficult. To combat this problem, Brazil aims to develop a rational and systematic method of registering consumer data. Brazil is also concerned with the availability of trained professionals in the digitalisation field. A study was conducted to identify the demand for new professionals in this market and if any changes are needed in the Brazilian university system to accommodate this demand. Cybersecurity is another barrier at the forefront of these emerging efforts.

After examining the results of a previous study about digitalisation in many sectors, a new study specifically on digitalisation in the building sector, called "Digitalization and Energy Efficiency in the Building Sector in Brazil" was funded by the German Federal Ministry for Economic Cooperation and Development in conjunction with the German Cooperation for Sustainable Development. The study partnered with Brazil's Department of Energy Development, Ministry of Mines and Energy, National

Housing Secretariat, and Ministry of Regional Development. Three scenarios, varying in building digitalisation implementation pace, were outlined and analyzed. In the slow digitalisation scenario, only public buildings, particularly public housing, adopt digitalisation technologies and tools. In this case, reducing the housing deficit is a higher priority outcome of implementation than energy efficiency. Moderately paced digitalisation would occur simultaneously in public, commercial, and service buildings with a focus on increasing private investments in the effort. Public housing still serves as a large part of the application for digitalisation, but multipurpose technologies would be emphasized. On the other hand, fast digitalisation would involve significant private investment and state-sponsored regulation, and incorporate digitalisation into all building types. In this scenario, the goal is for “any commercially available digital solutions [to be] adopted in all phases of the building life cycle already in the first decade” (Peres Suzano e Silva, 2022). A comparison of potential success metrics from these three scenarios is visualized in Figure 7.

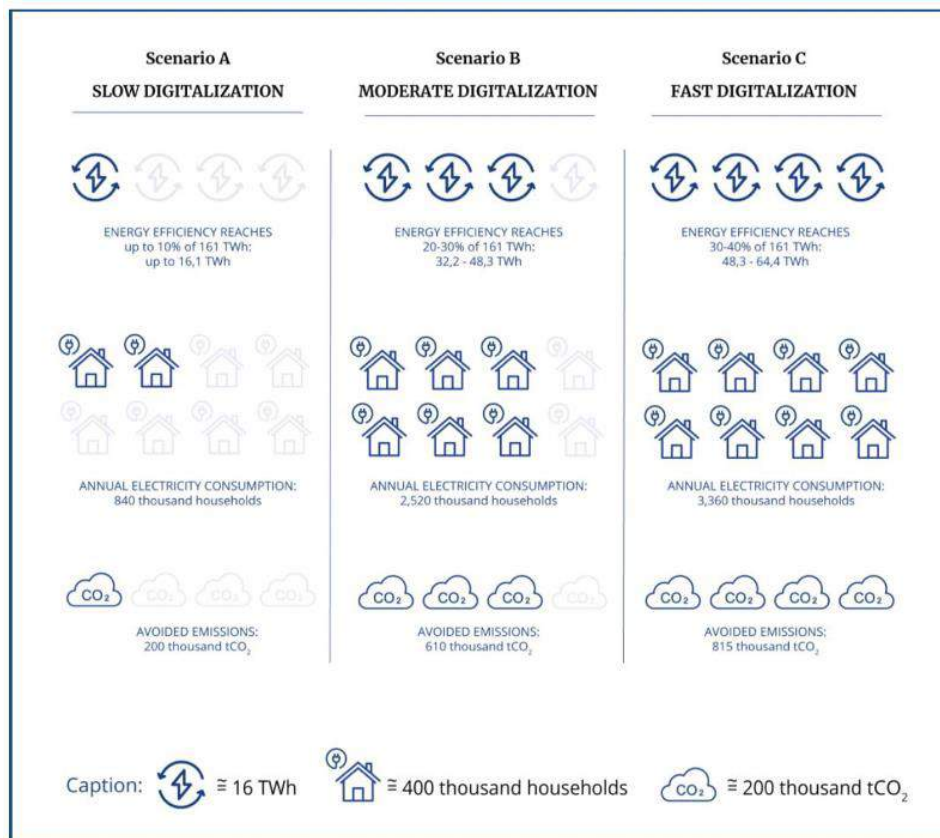


Figure 7. Potential effects of Brazil's three digitalisation scenarios (Peres Suzano e Silva, 2022)

In addition to the five main barriers, this report highlights marketing and financial barriers. Key among these difficulties to the adoption of building digitalisation are the absence of credit lines, high cost of early adoption, and the low purchasing power of users. This report emphasizes that overarching data concerns exacerbates these financial issues due to the low availability of information on the costs of energy-efficiency opportunities. Data are also a common theme in the category of behavioral and skilled workforce qualification barriers in addition to concerns about the rapid pace of technology advancements and an obsolete curriculum in professional education courses and higher education (Peres Suzano e Silva, 2022).

As part of the analysis done by the German-Brazilian Energy Partnership, multiple case studies of digitalisation were examined at varying stages of development, including the project and operation phase.

### **Technology Case Study: São Paulo Corporate Towers**

This study is in the project and operation phase. The building contains features unique to both design and operation, including the division of thermal zones that are cooled through variable air distribution and indirect expansion. Additionally, the building has a building management system that can access controls and ensure optimal energy efficiency. In total, the building demonstrated significant energy efficiency improvements, measuring a reduction in energy consumption of 48% per year (*Centro de Tecnologia de Edificações, n.d.*).

### **Policy Case Study: Law 9991 of 2000**

Law 9991 of 2000 mandated that energy utilities in Brazil invest in energy-efficiency research and development (R&D) using 1% of their net operating revenue. Between 2010 and 2016, these investments focused on evaluating digitalisation demands. With a total investment of USD \$54 million, the National Regulatory Agency of Electricity supported 43 projects focused on smart grids, cybersecurity for networks, smart metering, communication, and processing intelligence. Projects funded under this policy address the cybersecurity and data concerns barriers. One main success is understanding the demands related to the adoption of smart meters, while the challenges include data protection, maintaining client relations, and supporting ICT systems. Brazil has learned a few important lessons from these projects, including the importance of standardization and sharing information among energy utilities and regulatory agencies, as well as specific policies regarding smart meters and energy utilities' obligations (Appendix C.4).

## **5.3 Canada**

Canada is a new member of the DWG as of August 2022, so the authors of this report did not have the opportunity to conduct the informational interview process for this report. Therefore, the information in this section results from an internet search of sources only. Additional work by the DWG may include more detailed information and case studies from Canada on the state of digitalisation for the operation of buildings.

Canada announced the recent target of 40% reduction in greenhouse gas emissions by 2030 below 2005 levels, with goals of achieving net-zero in the buildings sector by 2050. Buildings represent a significant focus in this climate mitigation strategy, with the country spearheading several efforts to monitor and improve energy efficiency. Under the Pan-Canadian Framework on Clean Growth and Climate change, governments at the federal, provincial, and territorial level announced commitments to energy-efficiency improvements through updating building codes, energy use labeling, retrofits, and new appliance standards (Government of Canada, 2018).

Through this framework, Canada has incentivized energy-efficiency upgrades for consumers, sponsoring the Green Ontario Fund. This fund subsidizes the cost of building energy audits, upgraded insulation, solar walls, window and door upgrades, lighting systems, building envelopes, and retrofits (Niagara Regional Housing, n.d.). Energy-efficiency incentives were also balanced by expansion in regulations. In the BC Step Code of 2017, regulations were applied for buildings, setting minimum energy-efficiency standards over which provincial governments could apply their own incentives (The Government of British Columbia, 2019).

The government of Canada has led the Smart Grid Program as another lever in achieving Canada's long-term climate mitigation and energy-efficiency strategies. Under the Smart Grid Program, over \$100 million subsidized demonstration and deployment programs for smart grids (IEA, 2022). Among these was the Residential DR Program led by the Yukon Energy Corporation, where 400 homes were equipped with smart devices, allowing customers to shift their energy consumptions toward off-peak hours (Yukon, n.d.). In 2018, Natural Resources Canada classified more than 83% of customers as "smart meter users" (Lee & Hess, 2021).

## 5.4 European Commission

In the Climate Target Plan 2030, the European Commission (EC) outlines a goal to reduce 2030 greenhouse gas emissions by 55% or more relative to 1990 levels. The EC recognizes buildings as an important piece of this target, acknowledging that "by 2030 the EU should reduce buildings' greenhouse gas emissions by 60%, their final energy consumption by 14% and energy consumption for heating and cooling by 18%" (EC, 2020). Accomplishing climate neutrality across the European Union by 2050 is an additional goal for the EC. In October 2020, the EC published "A Renovation Wave for Europe – greening out buildings, creating jobs, improving lives" with a target audience of the European Parliament, European Council, European Economic and Social Committee, and European Committee of the Regions. Throughout, the EC emphasizes not only the environmental benefits of this renovation plan, but also the socioeconomic benefits, including job creation, COVID-19 pandemic recovery, energy affordability, and energy accessibility.

In this communication, the EC strongly encourages renovation of existing buildings for energy-efficiency gains since 85% of the EU's building stock were built before 2001 and 85–95% of the buildings that exist today will still be standing in 2050. By renovating these existing structures, the European Union can address inefficient appliances, use of fossil fuels for heating and cooling, and energy poverty, which is a major challenge for millions of Europeans (EC, 2020). However, current rates of energy renovations in the European Union are very low at about 1% and deep renovations, i.e., those that reduce energy consumption by 60+%, at 0.2%. The target is to at least double these rates and maintain this progress past 2030 to accomplish future energy goals.

Current challenges to energy-efficiency renovations include the dearth of public education on end-use benefits and upfront organizational challenges, particularly regarding costs. Funding, especially from governments, is hard to access due to public administration capacity limits, regulatory obstacles, and the difficulty in measuring and monetizing successes. In order to incentivize tenants and owners to make energy renovations, the EC will implement a phased introduction of mandatory minimum energy performance standards as well as require more buildings to have EPCs. To combat funding issues, the EC has proposed to increase the volume and impact of European Union funding by providing more grants, technical assistance, project development support and loans, and making it possible to combine them (EC, 2020). The EC's Renewed Sustainable Finance Strategy will work to enable greater access to private funding.

As for the difficulty in measuring and monetizing successes, the EC recommends that smart building adoption take place alongside these building renovations to assist in creating and measuring energy consumption reductions for funding and certification purposes. According to the EC, "buildings will host smart and digitalised appliances, providing real time data on how, when and where energy is consumed" (EC, 2020). Digitalisation tools will also help target funding first toward the most inefficient buildings and buildings with tenants suffering from (or at risk of) energy poverty. The EC believes that pairing minimum energy performance standards with financing that limits tenants' monthly costs will accelerate the rate of renovation by removing socioeconomic barriers.

Moreover, coupling digitalisation with energy renovations furthers the transition of buildings to low or zero emissions through the integration of renewables and DR schemes. In order to accomplish Climate Target Plan 2030 goals, the annual share of energy from renewable sources and waste heat must be 38–42% of total energy consumption, a significant increase. The EC endorses BIM and digital twins as example digitalisation tools that can make a noteworthy difference in a building’s energy-efficiency after renovation. These tools will create large pools of data, generated during construction, renovation, and operation, that can be used throughout a building’s full lifecycle (EC, 2020).

### **Technology Case Study: BIM4EEB BIM-based Fast Toolkit for Efficient Renovation in Buildings**

From January 2019 to June 2022, the EC funded the R&D of an interoperable BIM-based toolkit for retrofitting buildings. Fifteen organizations from nine European Union countries agreed to develop a common data environment with connected tools that will enable users to “rapidly reconstruct 3D digital models of existing buildings and to seamlessly integrate semantic data in order to perform advanced evaluations of design options for renovations” (BIM4EEB Project Presentation, 2019). Three pilot demonstrations for BIM4EEB exist in Italy, Poland, and Finland. The energy-focused goals of this project include decreasing the time required for energy audits by 50% and decreasing the net primary energy use in buildings the tools are deployed to by 10%. The BIM4EEB organizations aim to increase the uptake of BIM-based renovation by construction companies by 50% and the uptake of BIM-based dynamic energy assessment plus 30%. This suite of tools will address interoperability concerns by making building data more accessible in a central, reusable platform and standardizing data exchange formats. The R&D team is also prioritizing data privacy and protection.

## **5.5 Denmark**

Denmark is widely regarded as a frontrunner for its readiness to incorporate smart technologies in the buildings sector (De Groote et al., 2017). With progressive policies that have enabled the efficient rollout of smart metering technologies by 2020, Denmark is well on its way toward digital transformation (IEA, 2017). Multiple Danish companies provide smart central heating control systems that use tools such as AI technologies. These tools enable optimal control of buildings, accounting for thermodynamic behavior, ventilation, and comfortable living patterns, and demonstrate energy-efficiency improvements of 10–20% as well as reduced maintenance costs (Jansen et al., 2020).

Denmark has announced ambitious climate mitigation targets, including the incorporation of a 50% share of renewables in its energy mix by 2030 and a complete phasing out of fossil fuels by 2050. The ability to flexibly integrate variable renewable energy into the buildings sector is paramount in Denmark’s announced decarbonization strategy. This integration will require cross-sector coordination, demanding digital technologies that can communicate across diverse energy systems to provide data both efficiently and in real time (IEA, 2017).

Key obstacles to deploying smart technologies in Denmark are cybersecurity and privacy. As progress continues in developing digital infrastructure for the energy system, the threats of cyberattacks increase. Existing efforts are being developed toward building a robust digital infrastructure and standards capable of meeting these new security challenges (SGTF EG2 – Cybersecurity, 2018). As part of Denmark’s privacy and cybersecurity platform, building energy consumption data have largely been anonymized.

Additionally, data availability presents an ongoing challenge, particularly in the context of district heating systems. Individual companies have historically been given flexibility in terms of their willingness to share data. However, recent efforts, particularly the European Union’s Energy Efficiency Directive and

the Energy Performance of Buildings Directive have been developed as a means of collecting data and ensuring it is aggregated in a standardized format. The Denmark Digital Strategy (2016–2020) aimed to increase access to and use of data via “common data standards, standardised data formats, common IT architectures and a robust IT infrastructure” (Agency for Digitisation, 2016). In the energy-efficiency realm, the strategy suggested better display and accessibility of existing utilities data on energy consumption as well as open data on energy supply. This strategy enabled analysis on the potential for making building energy data publicly available and incorporating building consumption data with utilities sector data. Denmark’s energy transition goals create strong demand for “coherent energy data supply, smart energy management tools, and data-driven decision support systems so that the transition can be as cost-effective as possible” (Agency for Digitisation, 2016). Therefore, the Denmark Digital Strategy created the Basic Data Programme, Figure 8, which addresses many data barriers listed above.



Figure 8. Danish Basic Data Programme description (Agency for Digitisation, 2016)

### **Technical Case Study: Building Hub Test Facility**

In April 2022, the Danish Energy Agency set up a test facility, referred to as a Building Hub, focused on building optimization methods. The Building Hub, which is set to run through the remainder of 2022, has the goal to collect data on buildings’ energy consumption from electricity and heating and make these data more accessible for companies and other industry professionals. The Building Hub collects and presents data on energy consumption, buildings, and weather in a new digital infrastructure. The purpose of this initiative is to encourage sector coupling and demand flexibility in addition to energy efficiency. Through the Building Hub, the Danish Energy Agency will provide advice to companies on how to optimize different buildings, whether through renovation or automatic smart systems. The Building Hub is also working on building pumps. Given its recent creation, the impacts of this test facility cannot yet be assessed.

### **Technical Case Study: Middelfart**

This Danish city supports multiple initiatives to increase energy efficiency in both public and private buildings. It was the first municipality to introduce Building Analytics with Schneider Electric using big

data and analyses “to bridge the gap between analysis of building performance and decision making” (Lund et al., 2018). This approach establishes which actions are sound from an economic perspective and lists actions for building operations that account for health and comfort. It prioritizes humidity, CO<sub>2</sub> concentration, and temperature while optimizing building performance by an average of 7%. Middelfart also supports energy coaching for homeowners via a model and decision-making platform (Lund et al., 2018).

### **Technical and Policy Case Study: Public Building Data for Retrofits**

A group of researchers from the Technical University of Denmark hypothesized that “public building registers can provide easily accessible and cheap data needed to make sound planning decisions” for retrofits and examined Danish building registers to decide if existing data could be used to create the necessary performance indicators (Andersen et al., 2021). These performance indicators should be able to optimize retrofit designs, monitor progress, evaluate end results, and contribute to sustainability certifications. As part of this study, the researchers identified six laws and public data registers relevant and useful to building performance indicators. Results from their analysis of these registers indicate that several limitations exist, including: 1) a lack of up-to-date data, i.e., data is not always updated after building changes and digitalisation deployment; and 2) uncertainty stemming from gaps and/or low-quality data. Recommendations for existing and future registers from this research team include aggregating similar data in one register for cross-validation, increasing digitalisation to autogenerate building information including energy certifications, and standardizing data collection.

### **Technical and Policy Case Study: Copenhagen**

Copenhagen is the first city in the world to have a completely centralized building monitoring system that collects remote data from heat, water, and electricity meters on an hourly basis (Lund et al., 2018). The monitoring system helps identify areas with highest energy usage or potential problems. The city updated construction standards to mandate that hardware in buildings must be remotely accessible. The resulting detailed consumption data provide precise and reliable business intelligence for senior management and politicians use in retrofitting and project proposals. The business case for sharing data in this manner is strong; the projected payback time for the project was 6 years, allowing large-scale energy reduction projects to happen based on an efficiency agenda.

### **Policy Case Study: Energy Performance Certification**

The Danish Energy Agency maintains a central database and public website containing issued EPCs that rate buildings on energy efficiency from A (high energy efficiency) to G (poor energy efficiency) and list cost-effective measures for improving energy efficiency performance. The certificates are issued by independent and certified companies. These ratings are valid for 10 years and apply to both residential and nonresidential buildings. Buildings meeting certain size requirements must publicly display their Energy Performance Certification. In addition to the rating for each building, the Danish Energy Agency lists cost-effective measures for improving building energy performance (Lund et al., 2018). This Danish certification system is based on Directive 2010/31/EU of the European Parliament and of the Council on the energy performance of buildings.

### **Policy Case Study: Releasing Electricity Distribution Data**

According to a Danish law effective December 2021 (LBK No. 984 of 12/05/2021), electricity providers in Denmark will be obligated to release specific data according to the formatting and other requirements

set by the executive order on data release. The objective, once this executive order is out of development, is to provide market participants with a more efficient and data-driven basis to develop electricity market products as well as better access to utility data and more layers of actors gaining value (Appendix C.1). While this policy will address data availability, current obstacles include anonymization of data (privacy concerns) and the varying levels of digitalisation in the power sector. The primary challenge involves identifying the data available from power distribution companies and the use cases for different data types.

### **Policy Case Study: ICT in Public and General Construction**

According to Danish regulations effective as of April 2013 (LBK No. 118 of 06/02/2013 and LBK No. 119 of 07/02/2013 [Regulation on requirements for the use of information and communication technology in public construction and Regulation on the application of information and communication technology in general construction, respectively]) apply to new construction, additions, conversions, renovations, and maintenance of buildings that meet certain contract sum requirements. These laws standardize the creation, handling, and digital archiving of information and communication regarding the building project and requires that these activities take place digitally. Key points include requiring object-based construction models to be available in IFC format and digitalized information for projects must include access control, therefore addressing privacy concerns (LBK No. 118 of 06/02/2013; LBK No. 119 of 07/02/2013).

## **5.6 France**

France views buildings as an important sector to accomplish decarbonization goals; “France aims to reduce energy consumption in the building sector by 28% by 2040 and achieve carbon neutrality for the buildings stock by 2050” (Construction & Smart Building, n.d.). Since 2012, a standard exists to enforce construction for low-consumption buildings, and energy-plus homes to be the norm by 2021 (Construction & Smart Building, n.d.). These standards are enhanced by France’s Energy Transition for Green Growth law (Energy Transition Law), effective as of August 2015, which embraces the building sector as a significant target for improvements in addition to goals such as diversifying energy supplies and updating carbon reporting and pricing. Retrofitting France’s residential buildings is one of these building-related targets, since about 50% of energy consumption comes from residences, partly due to their old age (Grantham Research Institute on Climate Change and the Environment, n.d.). Beginning in 2017, the law states that energy renovation should occur in 500,000 homes per year, with half of those being occupied by low-income residents in an effort to reduce fuel poverty by 15% in 2020. Among its additional building provisions, the bill stipulates continuity for government funding of energy upgrades and establishes additional minimum energy efficiency requirements for specific building types, including social housing (Energy Transition for Green Growth, 2015).

Laws such as these are possible in France due to the financial community’s embrace of responsible investment, a history of extra-financial reporting regulation, and the proactive application of innovative approaches to environmental, social, and governance integration and climate risk (Mason et al., 2016). In the Paris region, for example, 46% of companies that rent offices are willing to increase their amount spent on rent by 10%+ for smart buildings according to Global Commercial Real Estate Services (Construction & Smart Building, n.d). Pressure from civil society in France, as well as global entities and agreements, also creates an environment conducive to such laws (Mason et al., 2016).

Paris is the center of France’s building digitalisation efforts, with more than 90% of stakeholders, including 45% of smart building startups, located in the region. In terms of technologies, BIM is very

common in France, and its growth rate is about 10–15% per year with a current business adoption rate of greater than 35%. The increases in BIM adoption are “largely driven by public procurement, which affirms the government’s commitment to promote this type of collaborative methodology” (Construction & Smart Building, n.d). France also emphasizes small-scale DR; almost 50% of the expected DR volume for 2022 is reserved for sites of 1 MW or less (Bertoli et al., 2021). A section of the Energy Transition Law mandates smart meter installation and individual utility billing, which supports these DR efforts. However, privacy is a key concern against smart meters, so metering data shared by the utility company with building owners or managers must be aggregated on a building level to ensure anonymity, and the cost of aggregating these data cannot be charged to individual consumers (Lee & Hess, 2021; Energy Transition for Green Growth, 2015).

## 5.7 Germany

Germany has announced an ambitious strategy of reducing the carbon emissions of its building stock to virtually net-zero by 2045 (IEA/IRENA Renewables Policies Database, 2022). To meet these targets, significant national attention has focused on digital technologies as a solution for enabling energy efficiency and intermittent renewable energy integration (Koenen, 2019). Germany’s digital transformation has principally involved rolling out smart meters as a cross-sectoral platform for the energy system, however, initial efforts were hindered by certification issues (Germany Interview, 3-21; Lee & Hess, 2021). Through augmenting smart metering technologies, legislation is targeted toward allowing flexible demand-side management while still meeting data security needs.

The Act on the Digitalisation of Energy Transition in 2016 (Gesetz zur Digitalisierung der Energiewende) spearheaded Germany’s smart meter rollout initiative, providing both regulatory and technical guidelines that ensure these systems are economically viable, interoperable, and secure (Federal Ministry for Economic Affairs and Climate Action, 2022). Germany’s smart metering systems comprise two components: smart meters and Smart Meter Gateways (SMGWs). Smart meters are responsible for collecting detailed energy consumption data that are then communicated by SMGWs. The SMGW devices transmit this energy consumption data to external market participants, allowing provision of incentives and commands for load adjustment. The combination of these two components enables automated demand-side management with limited human interaction (Förderer, 2019). Under the German Metering Point Operation Law (Messstellenbetriebsgesetz), smart metering devices will be mandatory for new installations in the future. Until 2032, smart metering devices must be installed in all households. Accompanying SMGWs will eventually be required for buildings that operate at above 6,000 kilowatt-hours per year.

Interoperability represents the most significant barrier associated with deploying smart home solutions according to Germany’s Standardization Roadmap (BSI, 2015). While many system solutions have achieved market readiness, the willingness of consumers to adopt those technologies is limited by their complexity and difficulty of use (BSI, 2015). The Smart Home and Building Certification Programme was built to develop smart technology application guidelines on the basis of use cases. Additionally, government-sponsored programs, including the Wireless Media and Control at Home Program are aimed toward improving the ease of use and interoperability of shared devices. This program enables user devices to configure themselves automatically and for components to be incorporated by Universal Plug and Play technology (Fraunhofer-Gesellschaft, 2008).

Alongside energy efficiency improvements, a core component of Germany’s announced climate mitigation strategy involves increasing the share of renewables in the energy mix (IEA & Digitalization and Energy Working Group, 2017). Accommodating high shares of renewable energy will require a more resilient and flexible grid able to deliver information at rapid speed for real-time decision making, all while maintaining optimal efficiency for system operation (Ruud, 2013). The use of ICT has the potential

to improve integration of renewable energy, particularly for decentralized electricity systems such as heat pumps or block heating power plants. With adequate building models supported by BIM technologies, there is potential for energy efficiency improvements. Despite recognized potential, there is relatively little penetration of BIM technologies into the buildings sector. Therefore, new government-led initiatives have focused on funding for BIM in the buildings sector (Müller, 2017). This includes financing under the Federal Office for Economic Affairs and Export Control, which sponsors programs such as the Federal Funding for Efficient Buildings. According to the BIM Master Plan for Federal Buildings, BIM will be mandatory in all new federal construction beginning in 2023.

The German government has stated that digitalisation is underexploited and can greatly contribute to the equitable restructuring needed to combat climate change, but digitalisation must first reverse its growing ecological footprint. The country's Digital Policy Agenda for the Environment states that digitalisation must be environmentally sound by reducing energy consumption through data management, closing the cycle on raw materials and supply chain consumption, and creating energy and resource-efficient software, data centers, and devices. As digitalisation allows resources, time, money, and energy to be redirected to additional production and more consumption, this agenda states that a regulatory framework and incentives are needed to avoid rebound effects and ensure that resources saved are invested in future (Kammerer et al., 2020).

### **Technology and Policy Case Study: SMGWs**

The SMGW is a highly secure and interoperable communication module. It is the core component of the smart metering infrastructure that is being established in Germany nationwide. Starting in 2021, installation of SMGWs is mandatory for certain groups according to a defined rollout scheme. Until 2032, digital metering devices must be installed in all households in Germany. The main benefits of mandating this technology are standardized integration of assets for electricity generation and consumption including smart and sub metering, smart grids, smart mobility, smart homes, smart buildings, and smart services. High standards for data security and protection, certified by the Federal Office for Information Security, enable trust in this technology. However, the roadmap for implementing this policy regarding SMGWs is challenging due to its complexity and the time-consuming nature of the standardization process. Additionally, consumer acceptance must be strengthened through further attractive incentives and noticeable benefits.

### **Policy Example: BIM Master Plan for Federal Buildings**

BIM will be mandatory for all new federal buildings constructed in or after 2023. The master plan describes the goals and implementation strategy of the BIM method for federal buildings. It provides these implementation strategies and BIM manuals (work assistance) in order to simplify the introduction of and work with this planning method. The German government supports BIM in federal buildings since this tool allows for effective communication, justified decision making through visualization and simulation, consistent information management, high transparency, and lifecycle-oriented data management.

### **Policy Example: Energy Certificates**

The Building Energy Act regulates energy certificates in Germany. These certificates are market instruments that provide information on the energy characteristics of buildings. They contain general information on the building as well as data on the building's energy efficiency. These certificates are supposed to enable a rough comparison of buildings, including those in both the residential and nonresidential categories. Future tenants and buyers can use this information in their purchase decision.

Additionally, energy certificates include nonbinding modernization recommendations for cost-efficient energy improvements to the building.

### **Policy Example: Blue Angel Ecolabel**

Germany's Federal Environment Agency created the Blue Angel ecolabel to identify resource- and energy-efficient software products and certify that software uses hardware resources efficiently, conserves energy, is can be used with older hardware, and that updates will be available in the long term. This ecolabel can be applied to products in the following categories: data centers, software, and server and data storage. Government data centers will need to follow the Blue Angel ecolabel criteria according to the Climate Action Programme 2030 and Climate Change Act. The federal government also uses Blue Angel ecolabel criteria for information technology procurements (Kammerer et al., 2020).

### **Policy Example: AI Strategy of the German Federal Government (2020 Update)**

Part of this strategy document outlines the federal government's funding and research that links digitalisation and ecological sustainability goals. Germany aims to create an environmental impact assessment for AI and commission research on the "collection of empirical data and a systematic analysis of the CO<sub>2</sub>-saving potential of AI, duly taking into account possible negative effects (such as rebound effects)" (The German Federal Government, 2020).

## **5.8 Japan**

Japan views digitalisation, particularly technologies such as HEMS and BEMS, as an important tool to meet emissions savings targets and potentially set higher targets. The Japanese Ministry of Economy, Trade and Industry promotes digitalisation in the energy sector as one of the strategic policies in "Energy System Transition with Reform of Energy Supply and Demand Structures" in the form of increasing demand for new technologies, deploying smart meters, and promoting IoT-AI equipped devices (Resources and Energy Agency, 2021). Recently, local governments began providing subsidies to assist with the introduction of these technologies, whereas in previous years this responsibility was held by the central government.

In particular, the current goal is to focus on digitalisation in smaller buildings since large-scale buildings with greater than 10,000 m<sup>2</sup> of floor space already have standards to include BEMS and buildings with 10,000 m<sup>2</sup> or less floor space account for 98% of total commercial building spaces (The Institute of Energy Economics, 2022). Commercial buildings must reduce energy consumption by 1% each year, but building managers are responsible for determining how these targets are achieved, and they do not necessarily need to accomplish this energy savings through BEMS. The commercial buildings in Japan that do have BEMS typically focus on system monitors and controls for lighting, heating, and cooling. Japan is particularly interested in deploying digitalisation to support the transition to a hybrid workplace and maximizing the energy efficiency of partially or fully unoccupied office buildings (The Institute of Energy Economics Japan, 2022).

In the residential sector, central heating and cooling with a thermostat is uncommon. Separate room air conditioning is widely used, with some differences between high-density residential and single-family homes. Some major home construction companies are starting to promote IoT Homes with central HVAC among other technologies such as smart speakers, lighting, and locks. Residents and owners can also buy and install these smaller IoT devices. These differ from the Smart Home concept in Japan that incorporates onsite power generation (typically rooftop solar), home battery storage, and the HEMS dashboard, generally installed by professionals. While Smart Homes are costly and focused on energy efficiency and net-zero targets, IoT Homes have a broader application, and subsequently the IoT device

market in Japan was expected to grow by tenfold from 2017 to 2022 (The Institute of Energy Economics Japan, 2022).

Interoperability is a major barrier to digitalisation deployment in Japan. Stakeholders do not often work in both the residential and commercial building realms, and industry tends to have a business mindset focused on higher market share, resulting in low levels of cross-company collaboration and rejection of standardization efforts. Digitalisation solutions tend to vary between buildings. The Commerce and Information Policy Bureau sponsored a discussion series with IoT appliances and communications stakeholders between June 2017 and April 2019 regarding building standards. These discussions focused mainly on the slow deployment of digitally connected appliances (mainly air conditioning systems) and the lack of interoperability across manufacturers. More recent proposals include universal platform solutions for integrations of different systems through open connection with standardized interfaces (The Institute of Energy Economics Japan, 2022).

Consumer skepticism is another factor with consumers questioning how much greater savings need to be achieved through advanced controls since most appliances in the Japanese market are already highly efficient. They are not often appreciative of the added cost of digitally connected devices or aware of the benefits that result from communication using systems like EchoNet Lite. Consumers still have only a moderate awareness rate (52% in 2020) regarding IoT devices. Additionally, Japanese consumers are more interested in the nonenergy benefits of digitalisation, for example remote monitoring systems to support those with health conditions, children coming home from school alone, or elderly citizens who live alone (The Institute of Energy Economics Japan, 2022).

Privacy concerns, however, are less prevalent. The switch to smart meters, for example, has been easy and quick, partly because few concerns exist about how to protect personal information from smart meters (Lee & Hess, 2021). Grid operators who own the smart meters must provide the data to all competitive players in the market based on a standard, but personal information is removed when data are shared. New market players receive the data one month after the grid operators and only use to provide competitive rates. Consumers also instill a high level of trust in electric utilities since many have been in the market for decades. The smart meter deployment program has accomplished high success rates toward its 2024 target completion goal. The Tokyo Electric Power service territory succeeded in 100% deployment in 2020, and nationwide deployment levels were at 85.7% as of March 2021. Japan would like to reform energy supply and demand using dynamic tariffs as well as demand-side management programs that require communication, monitoring, and control, aided by smart meters. Japan determined that DR emergency peak reductions could reduce loads by 1.8 GW in 2021, and “4 GW of demand response have been awarded in the capacity market, to deliver services in 2024” (Bertoli et al., 2021).

At the DWG meeting in March 2022, delegates from Institute of Energy Economics Japan presented on case studies of digital building technologies for both new and retrofitted buildings. These case studies, along with a selection of other examples provided by Japan’s representatives, are described in the following sections.

### **Technical Example: Obayashi Gumi Corporation’s “Wellness BOX” Retrofit**

In 2017, the Obayashi Gumi corporation, a major building construction company in Japan, developed a smart building solution platform called Wellness BOX, which can apply to both retrofits and new construction. This example focused on its deployment in a Tokyo office building and demonstrated the use of digitally connected devices and BIM for the main purpose of occupant comfort with a secondary goal of energy efficiency, achieving 5% reduced energy consumption. Wellness BOX in this office building included preferred lighting and ambient temperature control using smartphone global positioning system and sensor data. Additionally, the building used preset HVAC, lighting, and elevator system

settings optimized by ML. Wellness BOX in other building applications can incorporate existing BIM data to enable forecasting of equipment troubles and scheduled replacement and maintenance (The Institute of Energy Economics Japan, 2022).

### **Technology Example: Takenaka Corporation Net-Zero Small Office Building Retrofit**

Takenaka Corporation, a building constructor, operates a small office building out of Chuo-Ku, Chiba City. Retrofitted in 2015–2016, the building contains design features that prioritize personal comfort and wellness through digital technologies while still improving renewable energy integration. Key features include auto-controlled blinds, double-paned windows, natural daylight usage, natural ventilation, and radiant cooling and heating panels. Occupants also have wearable devices that can adjust building conditions associated with the HVAC system and diffusers. In general, Takenaka Corporation prioritizes retrofits of small to midsize buildings that can take place while occupants continue to use most spaces (The Institute of Energy Economics Japan, 2022).

### **Technology Example: Misawa Home’s LinkGates**

Misawa Home is a home builder company in Japan that developed a system called LinkGates to centrally control room air conditioners across a house, a heat pump boiler, smart locks, smart shades, IoT devices, and a rooftop solar converter through the home’s Wi-Fi. LinkGates AI ties hot water consumption patterns with weather information to control the heat pump boiler and rooftop solar use. Residents can view current and historical usage data from their smartphones or tablets as well as designate wake-up controls for individual systems and access physical security alarm alerts (The Institute of Energy Economics Japan, 2022).

### **Technology Example: LIXIL Link Life Assist Platform**

The Link Life Assist platform, developed by major home material manufacturer LIXIL, can centrally control room air conditioners, lighting, curtains and shades, smart locks, monitor cameras, and smart speakers, although only LIXIL appliances work with this platform. In addition to energy-efficiency applications like web portal controls for lighting and temperature, Link Life Assist prioritizes functionalities important to Japanese consumers, such as remote lock checks and monitoring children and seniors (The Institute of Energy Economics Japan, 2022).

### **Technology Example: Device Connectivity Assessment**

The National Institute of Advanced Industrial Science and Technology conducted IoT device connectivity and usability tests using MisawaHome’s model room in Tokyo. In the first phase of the project, a total of 66 IoT devices were tested for connectivity and operation. The technical challenges resulting from Phase 1 were (a) Wi-Fi connection issues at a three-floor single-family home (the router on first floor did not support third floor devices), (b) a lack of power outlets, and (c) cable management. Phase 1’s technical challenges emphasize that IoT homes need mesh Wi-Fi systems, ample power outlets, and organized power cable casings. Phase 2 tested a total network security router (SECURIE from Softbank BB Service), which is a secure router that protects all Wi-Fi-connected devices and identifies vulnerable devices. The main technical challenge in Phase 2 involved conflicting scenarios, as described in Section 4.4. The solution to this issue is continuous scenario developments by each region/country and use of ML to avoid conflicting cases (*The Institute of Energy Economics Japan, 2022*).

### **Policy Example: EchoNet Lite Standard**

Universal Home Network Connection Standard Development is supported by Japan’s Smart Community Alliance Global Standard Working Group, which is a collaboration between manufacturers and Japan’s Ministry of Economy, Trade, and Industry. This group officially endorsed EchoNet Lite as its recommended national standard in December 2011 and the international Smart Home standard in February 2012. The goal of EchoNet Lite is to enable consumers to visualize electricity consumption and control digitally connected appliances from different manufacturers using a HEMS dashboard. It is intended to be deployed in Smart Homes, so it connects rooftop solar, home battery storage, and major appliances with a HEMS display (Appendix C.2). While the working group has continued to update the standard, a 2016 conference noted that it is the least popular app in the Smart Home market due to:

- Upfront costs around USD \$1,200–1,600 that might not be recoverable in energy savings even within 7–8 years of deployment

- HEMS power consumption resulting from constant monitoring and inefficient low-voltage direct current use

- The need for constant maintenance and upgrades since the HEMS was not designed as a Service product

- Cloud data in raw sensor format with privacy and ownership concerns.

Despite these challenges, EchoNet Lite may gain more popularity as the IoT device market for homes grows, although homeowner interests are shifting to maximizing home energy generation and obtaining cheaper home battery storage (Appendix C.2).

## 5.9 United States

The United States is aiming for a 50–52% reduction in greenhouse gas emissions from 2005 levels by 2030 (White House, 2021). Improving energy efficiency is a key strategy toward reducing carbon emissions and, as part of this effort, the United States has unveiled new programs targeted at bolstering the presence of smart technologies in the buildings sector. The use of digital technologies for energy efficiency, particularly smart home devices, has grown appreciably in recent years. For example, the purchase of smart thermostats doubled between 2014 and 2016 (from 3% to 6% of total residential thermostat sales), and the revenue for smart thermostat sales is expected to grow in future years (IEA & Digitalization and Energy Working Group, 2017). Additionally, new government investments and partnerships with industry have focused on developing grid-interactive efficient buildings (GEBs) as an energy efficiency solution (Department of Energy, 2021).

The United States has seen an advancement in innovative energy-efficiency solutions, both in industry and government. The Unisphere, the largest net-zero emissions building in the United States, is a key example of industrial advancement, demonstrating a unique synergy between energy-efficient design and advanced system control. The building’s design features a natural ventilation system that is reactive to outdoor temperatures as well as day light harvesting. Innovative design is paired with advanced centralized control systems that enable the building to optimize and monitor system performance (United Therapeutics, 2019). Under the Smart Building Acceleration Act of 2019, the United States government has also taken on a leadership role in deploying smart technologies in federal buildings and developing the Federal Smart Building Program.

The United States has seen an increase of around 27% in DR enrollment since 2013 (U.S. Energy Information Administration, n.d.). It is presently the strongest market for demand-side flexibility and states are continuously adding DR programs such as “bring your own thermostats schemes” that offer consumers incentives to adjust their thermostats at peak times. Another key technology deployment supporting this trend is advanced meters; as of 2018, advanced meter penetration rates, charted in Figure

9, were at or above 50% in residential, commercial, and industrial buildings (Burns et al., 2020). At the end of 2020, the United States aimed for smart meters to reach 80% of households, which supports this commitment to enabling demand flexibility (Lee & Hess, 2021). Recent instances of extreme weather and failing power systems in the United States provide motivation for the government to reassess and bolster DR programs. In August 2021, the Federal Energy Regulatory Commission ordered six capacity and ancillary services markets to “remove barriers to the participation of distributed energy resources of more than 100 kW, including demand response, renewables, EVs and energy efficiency” (Bertoli et al., 2021).



Figure 9. U.S. advanced meter growth from 2007 to 2018 (Burns et al., 2020)

Despite the extensive effort to bring demand-side management to large scale, the relationship between energy efficiency and demand flexibility, as well as the technologies that optimize this relationship, are relatively unexplored (Neukomm, 2019). In order to realize the potential of GEBs in the United States, the DOE Building Technology Office developed a series of key research areas targeted toward addressing this research gap. This includes research focus on the end-use equipment that optimizes energy-efficiency and demand-flexible solutions. It also involves a focus on the cost effectiveness of these technologies as well as their associated interoperability (Neukomm, 2019).

The United States emphasizes the role of cost-effective, demand-side management with regard to digitalisation. Buildings account for a significant portion of electricity consumption in the United States and consequently contribute a great deal to peak power demand. With greater interconnectivity across the energy system via digital technologies, there is improved opportunity to manage electricity loads dynamically and mitigate the impact of peak power loads. The vision provided by the Buildings Technology Office is one where buildings can “operate as part of a low-cost, reliable electricity grid while still meeting the needs and expectations of building occupants” (Office of Energy Efficiency & Renewable Energy, 2020).

### Technology Case Study: Kent State University, Kent, Ohio

This case study focuses on central plant optimization. The campus has a state-of-the-art district energy system including a 12 MW combined heat and power plant that provides steam and about 60% of the campus electricity along with seven separate chilled water plants. The objective of this case study was to

further reduce energy consumption to meet Ohio’s target goals. To achieve this, Brewer-Garrett Company, which provides energy to campus, partnered with Johnson Controls to implement their central plant optimization technology. This involves (1) optimizing utility cost not just energy use, (2) optimizing across all cooling, heating, and power generation systems, not just chiller plants, and (3) optimizing over a 7-day horizon. The optimization software continuously monitors approximately 1,000 variables that serve as inputs. The algorithm includes factors such as current loads and operating conditions; 7-day weather forecasts; real-time market prices for economic load DR; forecasted electricity, water, and natural gas rates; campus events that may impact loads; and equipment availability. Physics-based models of thermal and electrical performance for each specific piece of equipment was used. The process, known as predictive cost optimization, is repeated continuously in near-real time, generating dispatches of more than 150 control decisions to ensure that all central systems are constantly optimized and efficiently meeting heating, cooling, and electric power needs across the campus. The impacts of the project include cost savings over \$1 million annually in utility cost savings and DR revenues, better insight to operators on plant operations, increased productivity of management and plant operations personnel, and better informed maintenance planning.

### **Technology Case Study: Unisphere Building**

The Unisphere is the largest net-zero energy commercial building in the United States, inaugurated in September 2018. It showcases some unique design features and systems, such as 3,000 solar panels installed on the curtain wall array, rooftop, and parking garage producing over 1 MW of energy; 52 geothermal wells; a pool in the lobby, which is served by heat from these wells; an underground concrete maze that acts as a natural ventilation system; and heat sink. The building’s energy performance is displayed at several places and in an innovative manner, for example through an “energy wheel” in the lobby and a giant energy dashboard wall on the fourth floor, and several simple, clean infographics on the walls around the office. The building uses renewable technologies, a high-performance electrochromic envelope, Earth-coupled heating, natural ventilation, and centralized controls. Through implementation of digital technologies, this building was able to achieve net-zero and has a LEED Silver Rating through the United States Green Building Council.

### **Policy Case Study: National Roadmap for Grid-Interactive Efficient Buildings**

The GEBs roadmap, a novel guideline designed by DOE, aims to help buildings emit less carbon and act smarter about the amount and timing of energy use. GEBs can remake buildings into clean and flexible energy resources by combining “energy efficiency and demand flexibility with smart technologies and communications to inexpensively deliver greater affordability, comfort, productivity, and performance to America’s homes and buildings” (Satchwell et al. 2021). During the 2020s and 2030s, DOE estimates that GEBs could save the United States electric system \$100–200 billion. By 2030, GEBs could save 80 million tons of CO<sub>2</sub> emissions per year relative to 2020 levels (Satchwell et al., 2021). This roadmap characterizes barriers to GEB technology development, valuation, use, and deployment while recommending multiple solution paths and opportunities. The Northeast Energy Efficiency Partnerships subsequently published a review of grid-interactive buildings and appliances codes and standards to assist the Northeast and Mid-Atlantic regions in adopting these technologies. Several individual states in the western United States have already taken strides to “adopt building energy codes and appliance standards, requiring grid-interactive functionality for appliances, homes, and buildings more generally” (Port et al., 2021). This review noted that in these states, electric storage water heaters are emerging as the lead appliance category for grid-interactive requirements and many policies emphasize a requirement for DR capabilities.

### **Policy Case Study: The Green Button Initiative**

Responding to data availability concerns, in January 2012, an industry-led group launched the Green Button Initiative to enable consumers to digitally view their natural gas, electricity, and water usage data and take advantage of a growing number of online services to help them manage energy use and save on energy bills. The Green Button Initiative was modeled after multiple successful policy models and standards, such as the Energy Services Provider Interface standard from the North American Energy Standards Board and the Blue Button for health information access from the Department of Veteran Affairs and Department of Health and Human Services. The Green Button Initiative mimicked the Blue Button's developers prize by sponsoring the Apps for Energy challenge, which offered \$100,000 in prizes.. This effort responds to consumer demand for third-party energy management applications to assist programming home energy management devices, sizing, and financing rooftop solar panels, and helping a contractor to verify home energy savings more cost effectively (Appendix C.3). In a reinforcing cycle, software developers and other companies have more incentives to design supporting services as more utility companies adopt this data accessibility initiative. While adoption is voluntary, a marketing campaign from the U.S. government assisted the launch; 50+ utilities and 35 third-party service providers are participating thus far. The Green Button Initiative also addresses some privacy concerns, since the digital usage data are only accessible post-authentication and customers must first grant the utility permission before the data are shared with third-party service providers. Industry consensus, testing, and compliance were challenges to the program, but nonprofit support and public-private partnerships overcame these difficulties.

### **Policy Case Study: ENERGY STAR Smart Thermostat Certification**

The ENERGY STAR certification exists for smart thermostats based on their potential for energy savings, as demonstrated by required device and HVAC energy savings (Energy Star 2017):

Energy Savings – “Thermostat electrical consumption  $\leq 3.0$  W and the average time to enter network standby after user interaction (on device, remote or occupancy detection)  $\leq 5.0$  minutes.”

HVAC Energy Savings - “To earn the ENERGY STAR, field savings studies shall show a run time reduction of at least 6% for heating and at least 7% for cooling. In addition, no more than 20% of homes in the study shall have savings of 1% or lower in heating or cooling.”

Data comparison is challenging for this program, since aggregated real-world, randomized data are used to evaluate ENERGY STAR services, while controlled laboratory tests or engineering estimates evaluate the products initially. This certification addresses privacy and proprietary information concerns by enabling the software to run in the service provider's data environment and only transfer the aggregated data to the EPA or other certification group. So far, 64 thermostats in the United States and 61 in Canada have achieved this certification, and some U.S. utilities require that thermostats used in incentive programs are ENERGY STAR certified. Some key features and lessons learned from this program are to require ongoing analysis of a new random sample of service provider data, require DR capabilities, and evaluate real-world data from installed devices operating under default conditions (Appendix C.3).

## 6.0 Conclusions

With vast energy requirements and associated greenhouse gas emissions, the buildings operations sector represents a significant opportunity for energy efficiency and consumption improvement. A key component to decarbonization targets announced by EE Hub DWG countries is leveraging digital tools to foster improvements in the capacity of buildings to operate both efficiently and in an environmentally friendly manner. Digitalisation provides an effective means of optimizing the performance of energy-consuming systems in buildings, but to fully realize the potential of digital technologies, large transformations in industry and government are needed. In this report, we surveyed the state of digitalisation by reviewing technologies with significant potential for transforming building operations energy efficiency, such as digitally connected devices and smart meters, as well as computational methods including ML and advanced control algorithms. We conducted a literature review and series of interviews with DWG members representatives to identify key barriers to implementing these technologies at large scale in their countries. Through this analysis, we identified five key barriers: privacy, cybersecurity, interoperability, data concerns, and device energy consumption and decentralization.

Large-scale device connection via the IoT is a core component to the widescale adoption of digitalisation, providing the ability to monitor and dynamically respond to changes in the energy system. However, the deployment of large numbers of devices has generated a new set of concerns. Principal among these are data concerns (availability, quality, and analysis) and interoperability. Both policy and logistical obstacles present challenges in terms of effectively aggregating and sharing data between a large number of interconnected devices. Improved data collection, storage, and sharing methodologies can help mitigate these barriers.

Information sharing services can be computationally intensive and create substantial electricity demands. Therefore, a need exists for improvement in data storage capacity and software management to balance these potential unintended consequences. Additionally, improvements in energy management systems will be required to address the decentralization of the energy system that new locally sourced power is expected to bring.

Barriers to the adoption of digital technologies on a user level include high upfront capital costs, device installation and programming complexity, and privacy concerns. Government-funded financial incentives for digital tools are expected to promote further adoption of digitalisation. Several countries have announced programs that incentivize users to bring smart technologies into their homes. The EE Hub DWG seeks to promote an in-depth understanding of these barriers on both a country and global level as well as explore possible solutions, promoting large-scale building operations digitalisation for energy efficiency and decarbonization.

This report represents an extensive catalog of barriers and potential solutions to effectively increase the deployment of digitalisation for the energy efficiency of buildings operations. The findings and analysis from this report inform the need for a set of key implementation steps and benchmarks that will augment this technological expansion effort to improve energy efficiency. This information will be reflected in an upcoming roadmap document reflecting input from DWG member countries at the end of 2022.

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## Appendix A – Barriers by Building Type

### A.1 Barriers to Deployment in Residential Buildings

Digitalisation can be challenging in the residential building space due to the individualized nature of consumer behaviors and capabilities. Some of these challenges are highlighted below:

**Upfront Capital Costs:** Smart home devices can have much higher upfront costs than traditional solutions. For example, smart thermostats cost USD \$130–\$300+ depending on the model and many can be self-installed by tech-savvy customers. Mechanical, nonprogrammable thermostats cost USD \$15–\$35 per unit. If an electrician is needed for the install, licensed electricians can cost about USD \$65–\$100 per hour depending on location.

**Return on Investment:** Smart home technologies can lower utility bills for many consumers. For example, smart thermostats have been shown to save 10–15% (USD \$131–\$145) on heating and cooling costs per year, and after enough years of use, these savings can exceed the additional upfront capital costs. However, this return on investment is only realized if these devices are used correctly with all optimization features (HomeAdvisor & Cutrona, 2021).

**Perceived Complexity:** Many smart home devices are wireless, easier to self-install, and more retrofit friendly than traditional ones. For example, 59% of U.S. customers installed smart thermostats themselves in 2019. However, some people view these devices as difficult to program to achieve energy savings (Brown, 2015; Hodgson, 2019). Smart home technologies are more commonly used by younger populations, as seen in Figure A.1, since these generations tend to be more technologically adept.

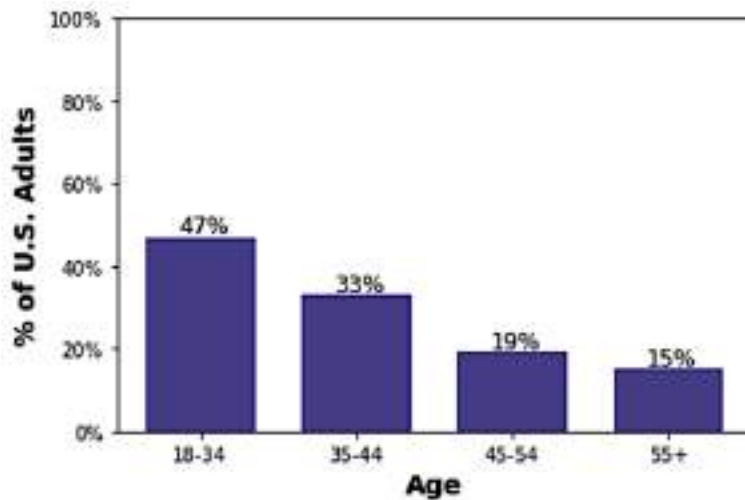


Figure A.1. Percent of U.S. adults with smart home technology (Brown, 2015)

**Connectivity Across Platforms:** Questions in this category that are pertinent in consumers' minds include whether smart home appliances will work with all smartphones or just a specific brand (reducing market penetration abilities), and if all smart home appliances can be managed from a single platform or if multiple platforms are needed (creating more complexity) (Hodgson, 2019). Current operations are complex since most communications protocols are proprietary to each product manufacturer (King, 2018).

**Cybersecurity and Privacy:** Among other concerns in these categories, consumers of smart home appliances worry that previous owners and occupants might be able to access the devices after they move out (Hodgson, 2019).

**Fixed Broadband Access:** Most smart home devices are internet-enabled and require fixed home broadband to achieve their full energy efficiency optimization potential. However, not all households have access to fixed broadband, limiting the maximum market penetration of these devices (King, 2018). Fixed broadband subscriptions per 100 inhabitants can be seen in Figure A.2 for each of the DWG member countries. For countries with lower fixed broadband penetration rates, disadvantages to digitalisation are particularly impactful for specific demographics. In the United States, those with lower incomes are less likely to fully access energy efficiency digitalisation since these Americans are much less likely to have a fixed home broadband connection, seen in Figure A.3, and are much more likely to use their smartphone for internet access at home (Vogels, 2021). Older Americans, those without advanced degrees, and those in rural communities are also less likely to have fixed broadband access (Pew Research Center, 2021).

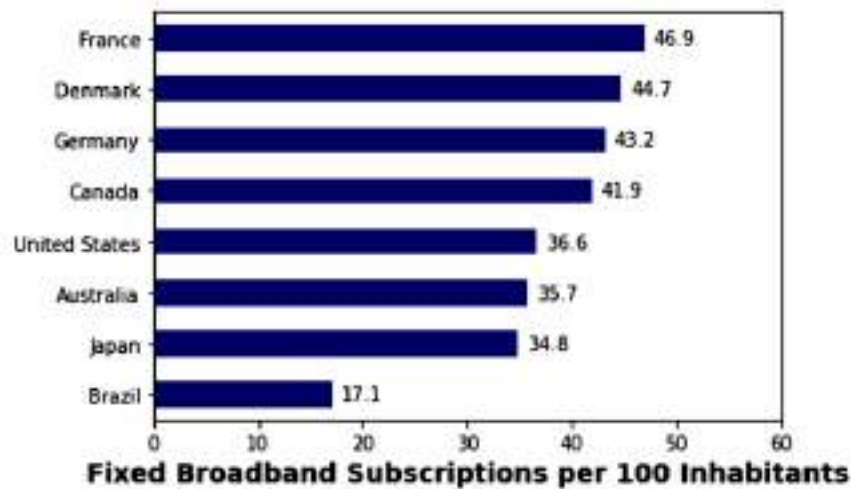


Figure A.2. Fixed broadband subscriptions per 100 inhabitants

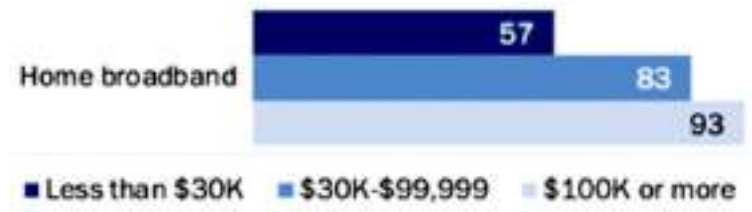


Figure A.3. Percent of U.S. adults who have home broadband by household income (Vogels, 2021)

**Longevity of Company or Product:** Many consumers worry that smart home appliances they install will no longer receive updates (security, programming, etc.) from the company they were purchased from. Due to the number of companies in this market, consumers are also concerned that the company they purchase from might go out of business, leaving their device unsupported (Hodgson, 2019).

**Lack of Data:** For both innovators and consumers, calculating the amount of energy savings from installing smart home devices is difficult due to the lack of data (Nest Labs, 2015). To make informed purchases, many customers want to know which devices will save the most energy and money.

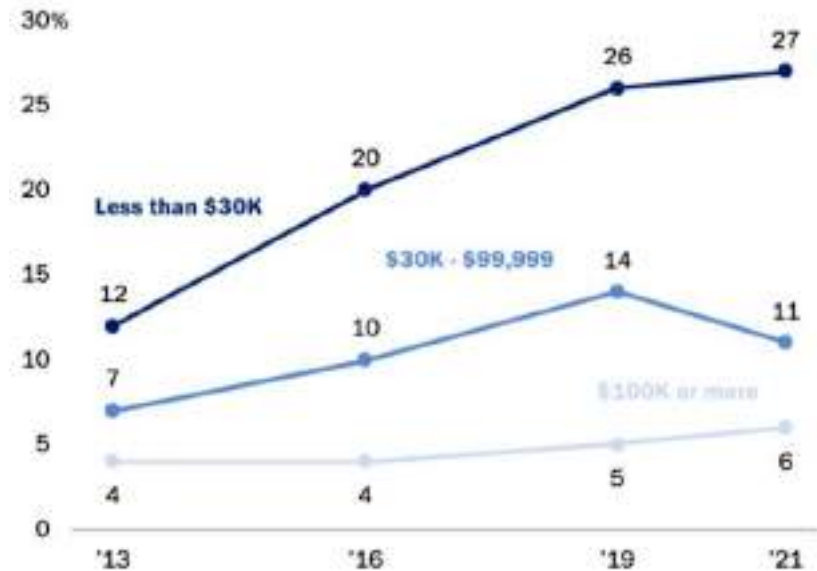


Figure A.4. Percent of U.S. adults who say they have a smartphone but no broadband at home, by household income (Vogels, 2021)

**Device Electricity Consumption:** As more and more network-enabled appliances enter homes, according to projections seen in Figure A.5, household electricity consumption will grow. Without increasing energy efficiency and decreasing energy intensity of the actual devices, monetary and energy savings from smart home appliances could be negated by standby power consumption.

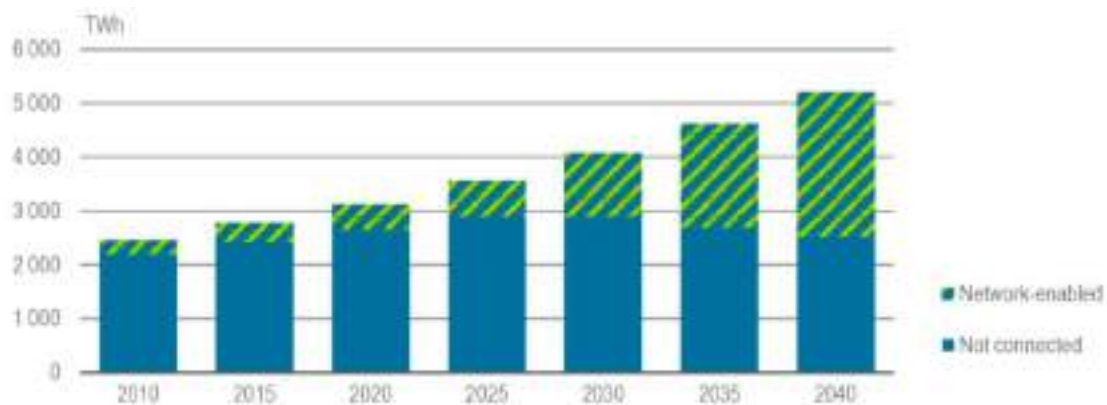


Figure A.5. Household electricity consumption of appliances and other small plug loads (IEA & Digitalization and Energy Working Group, 2017)

## A.2 Barriers to Deployment in Commercial Buildings

Barriers unique to commercial buildings derive from contract and budgeting interactions as well as the scale and age of commercial property portfolios. Some of these challenges are highlighted below:

**Data Aggregation:** Within commercial real estate, demands for data include access to key performance indicators for entire property portfolios at once instead of just a single property (Hatcher, 2016). Users should be able to access aggregated data from various energy efficiency digital technologies across a range of buildings in a single platform.

**Modernization:** Most commercial buildings already have a controls system in place, but incorporating cutting-edge energy efficiency digitalisation technologies is complex because most commercial buildings

were built before 2000, and most control systems are older than that, so these buildings contain a mix of new and outdated systems, while new systems are added in a piecemeal fashion (Zimmerman, 2021).

**Trust Issues:** Operators of commercial buildings are generally unwilling to completely trust what appear to them as black-box technologies that deviate from how they traditionally operate buildings. This discrepancy becomes especially important in the context of the 3-30-300 rule, which provides a breakdown of what an organization pays per square foot, in terms of total occupancy costs (\$3 for utilities, \$30 for rent, and \$300 for employee costs like salaries, benefits, etc.). Hence, the highest priority is given to mitigating occupant complaints (Kandakatla et al., 2020).

**Leases and Contracts:** The type of contract can have a significant bearing on whether a digitalisation technology can add value to the operation of a building. For example, triple net lease contracts, which are widely prevalent, provide limited incentives to the building owners and tenants to adopt new technology paradigms (He et al., 2013). However, green contracts are becoming popular for new construction, which positively incentivize such technologies.

**Risk Aversion:** In the context of building to grid integration aspects such as DR, consumers can exhibit risk-averse behaviors. For example, in the event of stochastic real-time pricing, they can become less responsive or sign up for programs such as price hedging, lessening the realized impact of digitalisation (Faruqi et al., 2013).

### A.3 Barriers to Deployment in Government Buildings

Challenges pertaining to digitalisation in the government sector stem from the wide range of building uses, sensitive proceedings and information in buildings, and large property portfolios. Some of these challenges are highlighted below:

**National Security:** Cybersecurity concerns are a significant obstacle to national security in terms of digitalisation deployment in government buildings. With the potential capability of hackers to access classified information, information system management is of particular importance in terms of developing rigid monitoring systems and barriers to cyberattackers. Recent efforts have moved control systems away from public networks onto secured servers (Government Accountability Office, 2018). Insider threats are another source of security concern, as disgruntled building occupants (including employees and contractors) have extensive knowledge on system operation and can potentially present security threats from within (Government Accountability Office, 2014).

**Inaccurate Cost Projections:** Due to the vast property portfolios among government agencies and entities, a high degree of variability exists in the cost of fully incorporating digital technologies, ranging from USD \$48,000 to \$155,000 (Government Accountability Office, 2018). For incorporating digital technologies in large property portfolios, as was done by the U.S. Government Services Administration which actively maintains approximately 1600 buildings across the United States, the inability to accurately predict capital expense vastly complicates the already complex topic of government budgeting. In addition, the cost of retrofitting these government buildings with digital technologies through secure servers can be costly and varies based on building infrastructure.

## Appendix B – Interview Protocol

Below, a series of questions are included to engage countries in conversation around the unique challenges to adopting digitalisation in their respective countries:

How do you define digitalization?

Digitalization in the current draft of the white paper refers to the use of digital technologies - such as smart technologies, building automation systems, and technologies that enable demand flexibility - as a tool to decrease the energy consumption of building operations.

How do you view the role of digitalization in your country’s long-term energy / climate strategy?

What policies govern digitalisation for buildings in your country?

What ideas does the word “digitalization” evoke in terms of your country’s practices and legislation?

Incentives: what incentives exist to bolster the use of smart technologies in your buildings sector?

Accountability: has digitalization created transparency and accountability for energy consumption behaviors? Have digital technologies enabled the enforcement of penalties for violating emissions / energy use standards?

Have new or existing policy domains been enhanced by the improvement of digital technologies?

What do you see as the largest technological barriers or research gaps for digitalisation in buildings?

For example:

Interoperability, Data Availability, Analysis and Predictive Modeling, Device Energy Consumption, Privacy

For each barrier:

What are the technical challenges concerning this barrier?

Is there any research in progress to overcome this barrier? Are there any case studies that exemplify the need to make progress in this area?

Have any solutions been discovered? What tools might be helpful to explore in overcoming this barrier? Might solutions to one barrier also make progress to addressing other barriers?

Are there interesting examples/case studies of implementing digitalisation in buildings in your country or interesting cases where a jurisdiction in your country has successfully addressed past challenges to digitalisation?

What buildings, energy usage, and digitalisation data is publicly available? Do industry users have more access to data?

Digitalisation Case study ID	Short description (2-3 sentences)	Regulatory/policy framework applicable	Key findings (benefits and shortcomings)	Additional references and point of contact
1				
2				

## Appendix C – Policy Case Studies

This appendix provides detailed examples of policies that were developed to address the barriers identified in Section 4.0.

### C.1 Australia

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Policy name	<b>Mission Innovation: Affordable Heating and Cooling Innovation Hub (<i>i</i>-Hub)</b>
Date/year enacted:	2020 to 2022
Description:	<p>The Innovation Hub for Affordable Heating and Cooling (<i>i</i>-Hub) explored the potential for digitalisation to support delivery of flexible demand services from buildings.</p> <p>The <i>i</i>-Hub conducted research on the barriers involved in implementing Grid Interactive Efficient Buildings.</p> <p>The <i>i</i>-Hub investigated various innovations that could make digitalisation a more scalable proposition. This included developing a real-time data management platform to address interoperability barriers, and to better understand the digital infrastructure that might be required to underpin future institutional arrangements for data management.</p> <p>The <i>i</i>-Hub conducted a number of digitalisation trials in pilot buildings, with focus on proving the efficacy of the data management platform. Some preliminary flexible demand trial results were obtained.</p>
Intended impact:	Better understand the potential for non-residential buildings to contribute flexible demand services in support of a reliable affordable and clean electricity system.
Barriers addressed:	<ul style="list-style-type: none"> <li>Interoperability</li> <li>Data accessibility</li> <li>Data quality</li> <li>Product uncertainty</li> <li>Procurement complexity</li> </ul>
What metrics are in use to evaluate the impact of this policy?	<p>The number of buildings and software applications utilizing the data platform (uptake)</p> <p>A ‘National HVAC Demand Response Atlas’; an interrogatable substation-level analysis of the amount of flexible demand available from buildings across Australia</p>
What successes / progress have been achieved by this policy?	<p>Over 60 buildings and 9 software applications are utilizing the data management platform.</p> <p>A self-service IPMVP Option C measurement and verification “App” has been developed, which could be used to streamline settlement processes for various policy initiatives.</p> <p>Preliminary trials of three demand response applications.</p> <p>Significant interview and focus group research on barriers to adoption.</p>
What were / are the primary challenges to implementing this policy?	This R&D policy initiative is a highly valuable precursor to future policy initiatives, providing insights necessary to ensure good future policy design. However, this work takes significant time and coordination effort, prior to being able to deliver a large-scale program.

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What are the key lessons learned from the policy implementation?

Implementing flexible demand, utilizing digitalisation technology in existing non-residential buildings, should be viewed as a two-step process

1. Establishing digital connectivity of the building so that it can ‘talk’ to the outside world
2. Deploying software (analytics, market participation etc.) to manage the operation of energy-consuming equipment in the building

The second step is generally very cost effective and relatively easy to implement.

The first step is where most of the barriers currently exist.

Establishing digital connectivity in existing buildings is very expensive if done, in isolation, for the sole purpose of implementing energy productivity applications. However, costs can be very low if done as part of normal equipment lifecycle investments.

This highlights the importance of coordinating first with existing property industry processes. This may require separately incentivizing each of the two steps.

Related policies: (i.e., EU legislation, international agreements, etc.)

Mission Innovation

[EU Directive amending the Energy Performance of Buildings \(2018/844/EU\)](#)

Hyperlink / Citations:

[Smart Building Data Clearing House - i-Hub \(ihub.org.au\)](#)

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## C.2 Brazil

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Policy name

**Law 9991 of 2000:** Energy utilities must invest every year in R&D and in energy efficiency using 1% of their net operating revenue. The R&D resources, between 2010 and 2016 have been applied in a strategy to evaluate digitalisation demands.

Date/year enacted:

2000

Description:

Under the resources of Law 9991, the National Regulatory Agency of Electricity supported 43 projects focused on smart grids, cybersecurity for networks, smart metering, and communication and processing intelligence. These projects were aggregated by utility, totaling an investment of US\$ 54 million. The following is a list of highlighted projects:

Pilot project in Parintins, AM by Manaus Eletrobrás Company  
Smart City Project Búzios, RJ, by ENEL/AMPLA  
Pilot project on the island of Fernando de Noronha, PE, by CELPE  
Cities of the Future Pilot in Sete Lagoas, MG, for the CEMIG Company  
Pilot project in São Luis do Paraitinga, SP, by the Electro  
Smart Grid Program in Rio de Janeiro, by Light  
Eletropaulo Digital Structuring Project in the city from Barueri, SP, by AES-Eletropaulo  
InovCity Project, in Aparecida do Norte, SP, for EDP Bandeirante

Detailed data is available at:

<https://www.gov.br/mme/pt-br/assuntos/noticias/mme-lanca-estudo-sobre-uso-de-tecnologias-digitais-para-medicao-de-niveis-de-eficiencia-energetica>

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Intended impact:	To represent for the concessionaires the different conditions of the operation of a network with minimal digitization in the customers' smart meters and in the reclosers.
Barriers addressed:	Data availability and cybersecurity: The energy utility companies were challenged in using smart meters in their networks. The project required adaptation and, many times, complete replacement of their everyday operations, having to restructure/create new operating conditions for the new processes. The pilots were also carried out during the stages of changes in the concession period, also competing internally with restructurings, shareholding changes and limitations of investment in general. The available smart meters in the Brazilian market were mostly not certified by the National Institute of Metrology. So, some installations had to be made in parallel to old meters, it increased the costs. Because of a weak and individual communication in the areas of the pilot tests, some consumers were resistant to a new installation in their homes (sometimes judicialized). The energy utilities haven't done an evaluation about the use of consumers information and its protection from bad use.
What metrics are in use to evaluate the impact of this policy?	U\$/energy saved
What successes / progress have been achieved by this policy?	Understanding the demands related to the adoption of smart meters in the energy net
What were / are the primary challenges to implementing this policy?	Data protection, relation with the client, communication systems, information management.
What are the key lessons learned from the policy implementation?	The results of these pilots will be a reference for the development of a specific policy to make smart metering part of Energy Utilities' obligations. These results were also fundamental to point out the importance of establishing standards to be adopted, considering the exchange of information among the energy utilities and the regulatory agencies.
Related policies: (i.e., EU legislation, international agreements, etc.)	
Hyperlink / Citations:	<a href="https://www.gov.br/mme/pt-br/assuntos/noticias/mme-lanca-estudo-sobre-uso-de-tecnologias-digitais-para-medicao-de-niveis-de-eficiencia-energetica">https://www.gov.br/mme/pt-br/assuntos/noticias/mme-lanca-estudo-sobre-uso-de-tecnologias-digitais-para-medicao-de-niveis-de-eficiencia-energetica</a>

Policy name	<b>Law No. 14.300, of January 6, 2022</b> “Establishes the legal framework for distributed microgeneration and mini-generation, the Electric Energy Compensation System (SCEE) and the Social Renewable Energy Program (PERS); amends Laws No. 10,848, of March 15, 2004, and 9,427, of December 26, 1996; and makes other arrangements.”
Date/year enacted:	2022
Description:	This law regulated the procedure for crediting energy injected into the grid. In addition to local self-consumption, the modality of remote self-consumption was also regulated (also known in the literature as virtual net metering), where the energy generated is not necessarily

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	<p>consumed in the same location. It also establishes that concessionaires and/or licensees must serve consumers with distributed micro or mini-generation.</p> <p>The Law brings greater legal certainty to the modality of distributed generation. In addition, it is determined that the CDE (Energy Development Account) will pay the tariff components not associated with the cost of Energy incidental and not remunerated by the consumer-generator on the compensated electric energy, establishing the legal basis for a tariff referring to unrelated costs with the power supply.</p> <p>This Law also establishes the possibility for the concessionaire to contract ancillary services of distributed micro and mini-generators, to benefit their distribution networks, in addition to promoting public calls to promote the accreditation of distributed generators interested in marketing the surplus of distributed generation. from micro and mini distributed generators.</p>
	<p>More details in:  <a href="https://presrepublica.jusbrasil.com.br/legislacao/1348064891/lei-14300-22">https://presrepublica.jusbrasil.com.br/legislacao/1348064891/lei-14300-22</a></p>
Intended impact:	<p>This law creates a stable and balanced legal framework for the use of clean and sustainable sources, such as solar photovoltaic, in the own generation of electricity in homes, small businesses, land, rural properties and public buildings, contributing to the continuous growth of the sector.</p>
Barriers addressed:	<p>Possible barriers to implementation of the Law:</p> <ul style="list-style-type: none"> <li>Access to technical information about the benefits of solar energy for consumers;</li> <li>Technical training of professionals for the installation of distributed generation modules.</li> <li>Adaptation of bureaucracy and practical issues (connection of new microgeneration plants and distributed mini-generation) by energy distributors.</li> </ul>
What metrics are in use to evaluate the impact of this policy?	<p>Metrics that can be used to track the impact of the Law:</p> <ul style="list-style-type: none"> <li>Power installed by the micro and mini-generation segment distributed in Brazil (MW)</li> <li>MMGD generation units in Brazil (units)</li> </ul> <p>The Energy Research Company makes the projections of the installed power for the micro and mini-generation segment distributed in Brazil in the document Ten Year Energy Plan (EPE/MME) published annually.</p>
What successes / progress have been achieved by this policy?	<p>The Law is very recent, but it has already brought greater predictability to the MMGD market and consumers, enabling the continued growth of this market.</p>
What were / are the primary challenges to implementing this policy?	<p>Possible challenges related to the Law: Modernization of the electricity sector, new forms of remuneration for ancillary services, the insertion of storage systems, improvement of the tariff methodology for consumers served at low voltage.</p>
What are the key lessons learned from the policy implementation?	

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Related policies: (i.e., EU legislation, international agreements, etc.)	RESOLUÇÃO NORMATIVA Nº 482, DE 17 DE ABRIL DE 2012 <a href="http://www2.aneel.gov.br/cedoc/ren2012482.pdf">http://www2.aneel.gov.br/cedoc/ren2012482.pdf</a>
Hyperlink / Citations:	<a href="https://presrepublica.jusbrasil.com.br/legislacao/1348064891/lei-14300-22">https://presrepublica.jusbrasil.com.br/legislacao/1348064891/lei-14300-22</a>  <a href="https://www.gov.br/mme/pt-br/assuntos/noticias/mme-lanca-estudo-sobre-uso-de-tecnologias-digitais-para-medicao-de-niveis-de-eficiencia-energetica">https://www.gov.br/mme/pt-br/assuntos/noticias/mme-lanca-estudo-sobre-uso-de-tecnologias-digitais-para-medicao-de-niveis-de-eficiencia-energetica</a>

### C.3 Denmark

Policy name	<b>Releasing electricity distribution data in Denmark</b>
Date/year enacted:	Rooted in a “Stemmeaftale” from June 4th, 2021. Executed through the Electricity Supply Act (Elforsyningsloven) January 1st, 2022.
Description:	Framework and standards are being developed in an executive order. The electricity 'net companies' are obliged to release relevant data per the law on electricity supply LBK nr. 984 af 12/05/2021. These data has to meet requirements and formats set in an 'Executive order on data release', which is currently under development.
Intended impact:	Political objective: (among other) to provide market participants with a more efficient and data-driven basis in order to develop electricity market products etc. Better access to utility data and more "layers" of actors gaining value
Barriers addressed:	The power sector is a “first mover”, therefore there are multiple barriers i.e.: - Anonymization - Different levels of digitalization in the sector
What metrics are in use to evaluate the impact of this policy?	
What successes / progress have been achieved by this policy?	
What were / are the primary challenges to implementing this policy?	To map the use cases for the different data types and map the data available in the distribution companies
What are the key lessons learned from the policy implementation?	- Yet to be determined. (perhaps that there are different levels of digitalization in the sector)
Related policies: (i.e., EU legislation, international agreements, etc.)	
Hyperlink / Citations:	

Policy name	<b>Database for energy performance certificates (EPC)</b>
Date/year enacted:	LBK nr 1923 af 08/10/2021 Promulgation of the law on the promotion of energy savings in buildings  BEK nr 1651 af 18/11/2020 Executive Order on energy labeling of buildings Since 2006 - now

Description:	<p>The aim of energy certification of buildings is to promote energy savings in Denmark's building stock. An EPC consists of two parts, which together illustrate the building's energy performance and its potential for savings:</p> <ol style="list-style-type: none"> <li>1. Part of which the building is placed on the energy label scale from A (high energy efficiency) to G (poor energy efficiency).</li> <li>2. Part that contains suggestions for energy-saving and energy-saving measures in the building.</li> </ol> <p>All issued EPCs are stored in a database where both the reports (pdf) and the underlying data files are stored. The Danish Energy Agency maintains a central database and public website which provides access to and displays data. These certification ratings are valid for ten years and apply to both residential and non-residential buildings.</p> <p>4 Facts:  2006 – now  Approx. 65.000 EPC/year  &gt; 650.000 EPC in database  Approx. 80 % single-family houses in the database</p>
Intended impact:	Originally, the database was established in order to be able to recreate issued EPCs. However, the large and growing amount of data in recent developments has also contributed to knowledge about the building stock in general, research, and control efforts for issued EPCs and policy development.
Barriers addressed:	Data in EPCs are about buildings and therefore not sensitive information. It has provided the basis for a relatively easy presentation of data. Barriers have arisen to a greater extent as the use of the database has changed from having a focus on the individual EPC to contributing to strategic efforts across the building stock. It has been a challenge that the database structure has not been intended for such purposes from the beginning.
What metrics are in use to evaluate the impact of this policy?	The policy is more the scheme of the EPC and not the database itself. Therefore, the impact of the database is not evaluated on its own.
What successes / progress have been achieved by this policy?	<p>It has been valuable that a database over a number of years has collected data on the building stock at a detailed level, such as the areas and qualitative characteristics of building parts. It has, for example, been used in subsidy schemes.</p> <p>The database has also been the basis for implementing risk-based control of the issued EPCs, and has enabled a geographical display of data on maps – see link.</p>
What were / are the primary challenges to implementing this policy?	<p>Maintenance: It requires the establishment of an IT infrastructure that must be maintained and continuously developed.</p> <p>Ease of use: The data can be complicated and require in-depth knowledge of the buildings sector</p>
What are the key lessons learned from the policy implementation?	<p>It is useful - in many contexts - to have a structured collection of data on buildings. Thus, data is usable for multiple purposes than simply recreating EPC reports.</p> <p>At the same time, it requires a great deal of IT knowledge to bring data into applications in new ways and to adjust the IT infrastructure. Overall, publicly available data can have large impacts in terms of equipping policymakers and consumers with relevant information on cost-effective energy management in buildings.</p>

Related policies: (i.e., EU legislation, international agreements, etc.)

The scheme for EPCs comes from the EU directive on energy performance of buildings – EPBD (Directive 2010/31/EU of the European Parliament and of the Council of 19 May 2010 on the energy performance of buildings). There have been no requirements for the establishment of databases, but many countries have done so. It is expected to be introduced as a requirement in future amendments to the Directive.

Hyperlink / Citations:

Link to EPBD: <https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX:32010L0031>

Link to map: <https://sparenergi.dk/demo/addresses/map>

Link to the database: <https://emoweb.dk/emodata/test/>

Link to EU study: <https://x-tendo.eu/toolboxes/epc-databases/>

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## C.4 Germany

Policy name:	<b>Act on Digitalisation for the Energy Transition (GDEW)</b>
Country:	Germany
Date/year enacted:	January 29, 2016
Description:	<p>The Act on the Digitization of the Energy Transition (GDEW) is the legal framework for the gradual modernization of the energy network to an intelligent energy network (smart grid) including the deployment of smart meters and smart meter gateways. Digitization is the networking of all players in the power supply of the smart grid to meet demands of consumers, generators, grid operators, aggregators, direct markets, and suppliers. This framework defines by whom and how technical specifications must be developed but it does not determine specific technical details. The technical guidelines created by the Federal Office for Information Security (BSI) contain the technical details.</p> <p>The focus of the GDEW was on the new Metering Point Operation Act (MsbG), which came into force in September 2016 and bundled the requirements for metering and metering point operation, including technical requirements, financing and data communication. This was the basis for the introduction of smart meter gateways as core component and standardized communications platform of the intelligent energy network.</p> <p>The Standardization Strategy for Cross Sector Digitization defines the roadmap for further development of technical standards.</p> <p>The publication “Barometer Digitalisierung der Energiewende” (barometer) is a yearly report that evaluates progress made on digitization of the energy transition (mainly the GDEW) based on 8 factors that often have interdependencies.</p>
Intended impact / Projections on energy savings potential?	Digitization is not an end goal, rather it is a central function of the grid in order to integrate renewable energies. The goal is to create a central system solution for safe measurement, control, and communication infrastructure of the energy system.
Barriers addressed:	Privacy; cybersecurity; interoperability; and data availability, quality, and analysis
	<p><b>Privacy</b></p> <ul style="list-style-type: none"><li>• Each actor can only access data needed to carry out its tasks and receives it directly from the SMGW where possible</li></ul>

- 
- Enact regulations for data handling, including data protection, data security, and data sovereignty (storage on-site in SMGW)
  - Measurements are anonymized, pseudonymized, and aggregated in the SMGW
  - Logbooks allow end consumers to understand data processing steps, identify and verify misuse, and enforce consumer rights

### **Cybersecurity**

- Utilize certified SMGWs as communication platform so all links are encrypted and only known participants/devices are trusted
- Protect networking and data exchange → state of network, generation data, and consumption data are necessary for system functions so protect these data against attacks
- Use Privacy and Security by Design concept
- Create and use protection profiles
  - Commissioned with the help of industry representatives and developed with the help of data protection officers
  - Basic specifications for security architectures and detailed specifications for data protection and data security
  - Initially implementation-independent, but can be tailored to a concrete security target
  - Specify functionality and trustworthiness requirements
  - Grouped to cover specific sets of security objectives
  - Contains general security properties and conditions for safe use of product
  - Describes value of data, how it is processed, and assumptions made about typical usage
  - Uniform structure based on Common Criteria (international standard for testing and evaluation of IT products security properties in lab environments)
  - Gives manufacturers leeway in technical design of security requirements but ensures minimums are met
- Enforced separation of HAN (home network), LMN (local metrological network), and WAN (wide area network)
  - Firewall mechanisms used in addition to the separation of the communication links by the SMGW
- Communication paths secured cryptographically to ensure confidentiality and integrity of values
- SMGW collects, processes, and stores values which are then signed and encrypted by a security module and sent to authorized market participants
- Data is time stamped and requirements exist for regular time synchronization
- SMGW must provide secure software update mechanism that verifies authenticity and integrity of the update
- Security and calibration events are logged in the SMGW
- Continuous development of standards in modular approach is employed
- Use electronic identifies – mutual authentication of electronic identities forms basis of trust in digital communication infrastructures
- Use encryption to ensure integrity, authenticity, and confidentiality of the information being shared within the communication channels

- 
- Create use cases for areas of application
  - Measuring Point Operation Act contains a detailed catalog of permissible dedicated data communication as well as conditions under which SMGWs can be installed and used
  - Exchange of personal data, master data, and network status data happens using smart metering public key infrastructure so that data exchange is between registered PKI participants only and allows for mutual authentication
  - Employ rigorous certification process, annual surveillance audits, and recertifications
  - If security incidents/problems with rollout occur, BSI determines need for standards update based on criticality of issue
    - Software update (certified first) or hotfix (certified after implementation) published by manufacturers are both possible

#### **Interoperability**

- Create and use technical guidelines commissioned with the help of industry representatives
  - Detailed specifications to ensure interoperability
  - SMGWs must demonstrate technical conformity through a test to ensure they can be connected and operated uniformly via different gateway administrator systems
- Work with entities from all relevant and potentially relevant sectors
- Modular SMGW components must demonstrative conformity according to provided standards and be certified
- SMGW must allow possible applications and value-added services so providers in areas such as smart homes and smart buildings can use the SMGW as a platform for their services to increase benefits and acceptance among end consumers
- Continuously develop protection profiles and technical guidelines to enable SMGWs to be used in other areas of application
- Develop app for other application areas on existing platforms
- Consider different communications requirements of various application areas (smart buildings, wind turbines, etc.) when creating common minimum security requirements

#### **Data Availability, Quality, and Analysis**

- SMGW performs plausibility checks and substitute value entries
- SMGW sends data directly to actors, maximizing the benefits of intelligent measuring systems since no detours are taken
- Concrete services are developed by the market
- Support the development of applications, products, and business models related to the main product (smart meters/SMGWs)

Federal Ministry for Economic Affairs and Energy launched the SINTEG program called “Intelligent showcases Energy – Digital Agenda for the Energy Transition”

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What metrics are in use to evaluate the impact of this policy?

1. Status of certifications
2. Implementation of new Market communications
3. Rollout by meter operators
4. Status of standardization for cross-sector digitization of the energy transition

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5. Scope of technology offerings
  6. Availability of devices
  7. Availability of telecommunications infrastructure
  8. Customer awareness, level of knowledge, acceptance, and use
- 

What successes / progress have been achieved by this policy?

The barometer's evaluation of the above 8 factors have found:

- 41 companies offer administrative services related to SMGW operations and are registered with BSI. Services range from software or IT infrastructure service provider to complete SMGW administration
  - A fully integrated solution for a data platform in the building realm is being developed to integrate measuring point operation, sub-metering, consumption visualization and analysis
  - 4 manufacturers have certified smart meters/SMGWs, 5 manufacturers are in the certification process
  - A 7% annual decrease (55% to 48%) in the percent of consumers worried about the misuse of their smart meter data
  - A 6% annual increase (49% to 55%) in households that support smart meter installation
- 

What were / are the primary challenges to implementing this policy?

- Rollout process is slow due to:
  - Requiring 1. Publication of protection profiles and technical guidelines by BSI 2. Market availability of certified SMGWs from 3 different companies and 3. Approval from BSI.
  - Lab tests and small field tests are conducted before SMGWs can be operated in gateway administrator systems in the backend, test mode is used here too with a test PKI since no certification exists at this point, all processes of the whole device life cycle are tested prior to certification this way
- Intensive coordination and planning are required.
- Digitization affects economic interests across sector boundaries – even seemingly technical regulatory decisions can fundamentally shape market design, potentially trigger redistribution, and affect cross-sectoral economic interests
- Emergency decision made by a higher administrative court on the mandatory rollout of smart meters shows that there may be a need for action to implement technical guidelines, particularly the certification of interoperability of smart meters, in a legally secure manner
- Despite advances in technology and standards, business models largely did not progress beyond the concept and pilot phase
- A need exists to prioritize measures that increase the number of units installed for faster market penetration of SMGW solutions
- Technical challenges – smart meters more complex than conventional ones and require specific skillsets to master the transmission technology, causing metering point operators to purchase additional services for installation from the service providers
- Proprietary solutions still dominate the market and these usually only cover a special application, have relatively low interoperability, and usually lower data protection and security → these are considered interim solutions. SMGW can be a permanent solution, but technical guideline creation needs to be sped up to increase the functionality of SMGWs

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- Supply chain issues: 3-6 months for SMGW delivery
  - Sometimes regulatory obstacles exist to the use of the most technically suitable communication technology
    - Ex. a draft law makes use of data about terminal equipment more difficult
    - Regulatory requirements and technological advances must be reconciled to promote industry cooperation and speed up deployment
  - Consumer acceptance is low but slowly increasing:
    - 43% of households feel badly informed and feel energy suppliers and the government are equally at fault
    - Data misuse is most frequently cited reason for not wanting smart meters installed
    - 33% of respondents are fearful of losing control through digitization
    - 48% (down from 55%) are worried about the misuse of their data for other purposes and theft by unauthorized third parties
  - Technical developments outpace regulations and certifications
  - Uncertainty in businesses regarding technological, regulatory, and legal standardization perspectives as well as technological and regulatory risk
  - Lack of scaling of smart meters which makes it difficult for providers to develop profitable business models
  - Initial potential customer base is small, including for value-added services based on the SMGW platform

Low level of active consumer demand partially due to low consumer awareness, especially in private and household customer segment

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What are the key lessons learned from the policy implementation?

- Information security is a prerequisite to successful digitization.
- Standards on data protection, data security, and interoperability ensure reliability, efficiency, and market competition.
  - Security standards can only be successful if it was shaped by manufacturers in the innovation phase and has breadth acceptance from users. BSI worked with entities in telecommunications, IT, energy, housing, and consumer protection and data protection officers from the very beginning of the development process
  - Communication with industry, authorities, data and consumer protectors ensure trust through transparency
- Certifications create trust because they are part of an officially monitored test procedure
- Application of technical guidelines in practice (ex. implementation of recertification procedures and calibration examinations should be accelerated and handled more flexibly)
- Far-reaching consequences require early consideration in opinion-forming, early planning stages
- A helpful tool could be a holistic digitization map that depicts components, assigns responsibilities, and shows connections to stakeholder interests (business models, market design, etc.)
- Consumers are motivated by attractive solutions so the provider side has significant responsibility
- Legal frameworks should support all relevant sectors
- Create a “hub of hubs” with existing startup networks, funding and cluster initiatives, technology centers, incubators, universities,

	<p>etc. that are already working on development of digital solutions in energy</p> <p>Manufacturer must show ability to update software without replacing hardware components</p>
Related policies: (i.e., EU legislation, international agreements, etc.)	<p><a href="#">Building Energy Act</a> (effective November 1, 2020)  <a href="https://www.bmwk.de/Redaktion/DE/Downloads/S-T/standardisierungsstrategie.pdf?__blob=publicationFile">https://www.bmwk.de/Redaktion/DE/Downloads/S-T/standardisierungsstrategie.pdf?__blob=publicationFile</a></p> <p>Third internal market directives on electricity and gas (2009/72/EU and 2009/73/EU)</p> <p><a href="#">Metering Point Operation Act</a></p>
Hyperlinks / Citations:	<p>Barometer Digitization of the Energy Transition: Digitization 2020  <a href="https://www.bmwk.de/Redaktion/DE/Publikationen/Studien/barometer-digitalisierung-der-energiegewende-berichtsjahr-2020.pdf?__blob=publicationFile&amp;v=20">https://www.bmwk.de/Redaktion/DE/Publikationen/Studien/barometer-digitalisierung-der-energiegewende-berichtsjahr-2020.pdf?__blob=publicationFile&amp;v=20</a></p>
Policy name	<b>Building Energy Act, regulations on energy certificates</b>
Date/year enacted:	2020
Description:	The energy certificate is a market instrument that provides information on the energy characteristics of a building. It contains general information on the building as well as data on the energy efficiency of a building. It is supposed to enable a rough comparison of buildings. There are energy certificates for residential and non-residential buildings.
Intended impact:	
Barriers addressed:	Data availability
What metrics are in use to evaluate the impact of this policy?	
What successes / progress have been achieved by this policy?	Future tenants and buyers can use this information in their purchase decision. The energy certificate includes non-binding modernisation recommendations for cost-efficient energy improvements to the building.
What were / are the primary challenges to implementing this policy?	Not yet digital form but possible research for “Digital Building Passport”
What are the key lessons learned from the policy implementation?	
Related policies: (i.e., EU legislation, international agreements, etc.)	
Hyperlink / Citations:	<p>Federal Ministry of the Interior and Community  <a href="https://www.verbraucherzentrale.de/wissen/energie/energetische-sanierung/energieausweis-infos-fuer-alle-die-immobilien-besitzen-kaufen-mieten-36522">https://www.verbraucherzentrale.de/wissen/energie/energetische-sanierung/energieausweis-infos-fuer-alle-die-immobilien-besitzen-kaufen-mieten-36522</a></p>
Policy name	<b>BIM Master Plan for Federal Buildings</b>
Date/year enacted:	Published 2021, mandates for 2023
Description:	Building Information Modeling (BIM) must be mandatory for federal buildings from 2023. The master plan describes the goals and implementation strategy of the BIM method for federal buildings; implementation strategies and BIM manuals (work assistance) are to simplify the introduction of and work with this planning method.

Intended impact:	Effective communication, justified decision making through visualization and simulation, consistent information management avoids media gaps, high transparency, life-cycle oriented building information management
Barriers addressed:	Data analysis, data availability
What metrics are in use to evaluate the impact of this policy?	
What successes / progress have been achieved by this policy?	Not yet mandatory.
What were / are the primary challenges to implementing this policy?	Strict time schedule for the Federal Buildings Master Plan, including the development of a handbook and training courses and academic support.
What are the key lessons learned from the policy implementation?	Not yet mandatory.
Related policies: (i.e., EU legislation, international agreements, etc.)	
Hyperlink / Citations:	Federal Ministry of the Interior and Community <a href="https://www.bmi.bund.de/SharedDocs/downloads/DE/veroeffentlichungen/2021/10/masterplan-bim.pdf?__blob=publicationFile&amp;v=3">https://www.bmi.bund.de/SharedDocs/downloads/DE/veroeffentlichungen/2021/10/masterplan-bim.pdf?__blob=publicationFile&amp;v=3</a> <a href="https://www.bmvi.de/SharedDocs/DE/Artikel/DG/digitales-bauen.html">https://www.bmvi.de/SharedDocs/DE/Artikel/DG/digitales-bauen.html</a>

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Policy name	<b>Smart Meter Gateways</b> Act on the Digitalization of the Energy Transition (GDEW) Metering Point Operations Act (MsbG)
Date/year enacted:	2021
Description:	The Smart Meter Gateway (SMGW) is a highly secure and interoperable communication module and the core component of the smart metering infrastructure that is being established nationwide. Starting in 2021, installation of this SMGW infrastructure is mandatory for certain groups according to a defined roll-out scheme. Until 2032, digital metering devices must be installed in all households in Germany. The Act on the Digitalization of the Energy Transition (GDEW) is the regulatory basis for the step-by-step modernization toward a smart grid. The Metering Point Operations Act (MsbG) defines the roll-out of the infrastructure.
Intended impact:	
Barriers addressed:	Cybersecurity Interoperability Privacy
What metrics are in use to evaluate the impact of this policy?	
What successes / progress have been achieved by this policy?	Standardized integration of assets (generation and consumption); including a range of applications: smart/sub metering, smart grid, smart mobility, smart home, smart building, smart services Trust through high standards for data security and data protection, certified by the Federal Office for Information Security (BSI).
What were / are the primary challenges to implementing this policy?	Challenging roadmap due to complex and time-consuming process of standardization.

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What are the key lessons learned from the policy implementation? Acceptance by customers must be strengthened further through attractive offerings and noticeable benefits.

Related policies: (i.e., EU legislation, international agreements, etc.)

Hyperlink / Citations:

Federal Ministry for Economic Affairs and Climate Action  
 Federal Office for Information Security (BSI)  
[https://www.bmwk.de/Redaktion/DE/Publikationen/Studien/barometer-digitalisierung-der-energie-wende-berichts-jahr-2020.pdf?\\_\\_blob=publicationFile&v=20](https://www.bmwk.de/Redaktion/DE/Publikationen/Studien/barometer-digitalisierung-der-energie-wende-berichts-jahr-2020.pdf?__blob=publicationFile&v=20)  
[https://www.bmwk.de/Redaktion/DE/Downloads/S-T/standardisierungsstrategie.pdf?\\_\\_blob=publicationFile](https://www.bmwk.de/Redaktion/DE/Downloads/S-T/standardisierungsstrategie.pdf?__blob=publicationFile)

## C.5 Japan

Policy name	<b>Next Generation Smart Meter System Study Group Summary</b>
Country	Japan
Date/year enacted:	Summary of findings published May 2022
Description:	This document summarizes the work of the Next Generation Smart Meter System Study Group on topics including major and standard functions added to next generation smart meters, security measures, and efforts toward unification of specifications.
Intended impact:	Enhance cybersecurity, interoperability, and effectiveness of next-generation smart meters deployed in Japan. Identify which functions will maximize net social benefits.
Barriers addressed:	Privacy; cybersecurity; interoperability; and data availability, quality, and analysis
What metrics are in use to evaluate the impact of this policy?	There are few quantitative studies on success metrics related to this case study. The design of next generation smart meters focuses on increasing data use by electricity suppliers and other service providers, so one potential metric is the number of business users from the newly developed licensed data bank entity.
What successes / progress have been achieved by this policy?	Identified various best practices including but not limited to: <ul style="list-style-type: none"> <li>Privacy             <ul style="list-style-type: none"> <li>• Collect data via joint meter reading, which means equipment owned by externally connected businesses and smart meters will be connected via wireless communication terminals and supply/demand adjustments will be made using acquisition of highly granular values. Power transmission and distribution business operators must store measured values for required period without falsification.</li> <li>• Time resolution for smart meter measurements and data type determines data retention period, where data is stored, and how often data is transmitted.                 <ul style="list-style-type: none"> <li>○ Example practice: 5-min intervals is arbitrary period that takes into consideration the time required to transfer data to server and time required to collect data after a disaster occurs.</li> </ul> </li> </ul> </li> </ul>

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- Example practice: retention period on servers set to 3 years for active energy, reactive energy, and voltage data for 5-min interval measurements.
  - Example practice: 15-min active energy can be stored in the meter, transmission of data can be switched to 30-min intervals
  - Example practice: for low voltage meters, have a function that enables remote meter reading on hourly basis, measurements are sent once per day

#### Cybersecurity

- Properly manage information and leaks and strive for continuous improvement.
- Conduct the following steps for external connection security requirements:
  - Creation of external connection standards and guidelines
  - Implementation of risk assessment
  - Vulnerability management
  - Distinction and separation from external connection networks
  - Acquisition and monitoring of logs related to communication with external connection networks
- Conduct the following steps for the management of external connection providers:
  - Obligation to report
  - Maintenance and operation of system
  - Disconnection and reconnection of network connections to external devices and systems
  - Establishment of demarcation points of responsibility
  - Security considering system lifecycle, design, procurement, operation, and disposal
  - Effective risk assessment with detection, response, and recovery
- Set minimum service level that must be met by business operators and ensure their security framework allows this level to always be met
- Ensure new functions such as remote ampere control will not cause unintended control or malfunctions that result in large-scale blackout or other supply disruptions.

#### Interoperability

- Each type of meter allows for multiple communication methods including WiFi, Wi-SUN, and Ethernet. Each meter allows for 1-to-1 connections or 1 to many connections (sharing with consumer network and multiple consumer devices).
- Communication unit within meter is designed to be exchangeable.
- Data collected via IoT route to enhance scalability, security, and outcome of cost-benefit analyses. IoT route is smart meters connected to special meters/joint meter reading meters.
- Have all 10 general power transmission and distribution companies adopt multiple unified data provision methods. Specifically, an API will be available when setting and acquiring

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necessary items, measurement period, etc., and a file download will be available when acquiring all items that are a large amount of data.

- Consider regional characteristics but promote standardization of specifications to reduce procurement costs, increase supply chain sustainability, and facilitate data utilization.
- Collaborate with other companies to consider standardization specifications for measuring instruments, communication systems, joint procurement (server standardization and centralization).
- When designing communications systems, conduct a comparative study and adopt highly flexible design specifications (expansion and change of targets, application to control, etc.) to respond to future needs.

#### Data Availability, Quality, and Analysis

- Enable different types of meters to have various measurement periods.
- By saving data for 60 minutes at the meter, data can be reacquired when data is missing, making it easier for aggregators, energy management companies, etc. to acquire and use data.
- By saving data on a daily basis, the amount of redundant meta information such as supply point ID numbers can be reduced.

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What were / are the primary challenges to implementing this policy?

- Data loss occurs when measurements are taken every minute, so it may be necessary to introduce separate devices such as CT (current transformer) sensors to measure data at 1-minute intervals.

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What are the key lessons learned from the policy implementation?

- Begin cybersecurity awareness/planning during the planning and design stages; follow cyber physical security framework and security by design concepts.
- Include all relevant stakeholders in countermeasures discussions.
- Create variations in rules/best practices based on meter type and measurement frequency.
- Visualization of power consumption could enable further energy conservation and reduction of CO2 emissions.
- Conduct studies with relevant companies to ensure rules/best practices will continue to support future needs.

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Related policies: (i.e., EU legislation, international agreements, etc.)

Hyperlink / Citations:

- [https://www.meti.go.jp/shingikai/energy\\_environment/jiseda\\_i\\_smart\\_meter/pdf/007\\_04\\_00.pdf](https://www.meti.go.jp/shingikai/energy_environment/jiseda_i_smart_meter/pdf/007_04_00.pdf)
- [https://www.meti.go.jp/shingikai/energy\\_environment/jiseda\\_i\\_smart\\_meter/pdf/20220531\\_1.pdf](https://www.meti.go.jp/shingikai/energy_environment/jiseda_i_smart_meter/pdf/20220531_1.pdf)
- [https://www.meti.go.jp/shingikai/energy\\_environment/jiseda\\_i\\_smart\\_meter/index.html](https://www.meti.go.jp/shingikai/energy_environment/jiseda_i_smart_meter/index.html)

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Policy name	<b>Standard: Universal Home Network Connection Standard Development</b> (This standard was developed by Japan Smart Community Alliance [Global Standard Working Group], consisting of manufacturers and METI [Ministry of Economy, Trade, and Industry]).
Date/year enacted:	METI's Smart House Standard Meeting endorsed the proposed standard (EchoNet Lite) as an officially recommended connection standard in December 2011. EchoNet Lite standard was also recommended as an international smart house connection standard in February 2012.
Description:	EchoNet Lite was developed to connect roof-top PV, home battery storage, and major appliances (initially 8 types, 80 models) with HEMS (Home Energy Management System) display.
Intended impact:	HEMS dashboard constantly shows electricity consumption and users can use HEMS dashboard to control connected appliances.
Barriers addressed:	Interoperability: Before EchoNet Lite, Smart Home management systems were provided with different communication systems by manufacturers. There was less interoperability across different manufacturers.
What metrics are in use to evaluate the impact of this policy?	Users can control different manufacturers' appliances with a single HEMS dashboard.
What successes / progress have been achieved by this policy?	Japan Smart Community Alliances has been constantly updating the EchoNet Lite and it has been promoting more appliances to be connected. However, in a 2016 conference, one of the Alliance experts noted that "EchoNet Lite [is] the least popular app in the Smart Home market." EchoNet Lite connections are equipped with a limited number of high-end models. The deployment of EchoNet Lite appliances has been lower than what was initially expected.
What were / are the primary challenges to implementing this policy?	EchoNet Lite, a universal communication standard, was designed starting around 2007 when it was expected that connected appliances over the cloud would comprise Smart Homes. The priority back then was "interoperability". Initial barriers included the following: <ol style="list-style-type: none"> <li>1) High initial cost: HEMS dashboard and HEMS-enabling Power Distribution Board typically cost 1,200-1,600 USD. Users may not be able to recover the initial cost with energy savings within 7-8 years. The HEMS cost may further affect the Home Battery Storage deployment. Municipal subsidies usually require HEMS installation along with Home Battery Storage.</li> <li>2) HEMS consumes power: There were many cases when HEMS consumes more power than energy savings, due to constant monitoring and inefficient low-voltage direct current use in communication.</li> <li>3) HEMS needs constant maintenance and upgrades; HEMS was not designed "as a Service" product. In 2017, a new challenge was also acknowledged by Japan Smart Community Alliances. New IoT appliances started to emerge in the home appliance market, smart speakers, smart locks, and smart monitoring cameras provided by new players, namely IT gadgets startups. There are also new communication technologies, and there are also</li> </ol>

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increasing middle-ware platforms, offered by IT giants (e.g., Amazon Echo, Google Home, and Apple Homekit). EchoNet Lite HEMS did collect usage data, and such data was accumulated in the dedicated cloud, but appliance manufacturers did not use such data. Data in the cloud was not in an intuitive format, they are raw measured/sensor data. There are new players who want to use different sets of data, and the data privacy concern and data ownership concern got immediate attention along with the roll-out of smart meters.

What are the key lessons learned from the policy implementation?

Experts from the Japan Smart Community Alliance commented in a 2016 conference that EchoNet Lite was introduced to the market too early. The Smart Home market, which initially focused on energy savings, garnered more interest after 2019 when many roof-top PVs started becoming ineligible for Feed-In-Tariff purchase programs, and many PV owners became interested in maximum use of solar power with cheaper home battery storage use or battery EVs. Home Appliances connection may have emerged in the IoT Home market, with increasing IoT devices.

Related policies: (i.e., EU legislation, international agreements, etc.)

[None reported]

Hyperlink / Citations:

[https://www.jisa.or.jp/it\\_info/engineering/tabid/1635/Default.aspx](https://www.jisa.or.jp/it_info/engineering/tabid/1635/Default.aspx)  
<https://www.ipa.go.jp/files/000053939.pdf>

## C.6 United States

Policy name

**The Green Button Initiative**

Date/year enacted:

The Green Button initiative was officially launched in January 2012, in response to a White House call-to-action.

Description:

The Green Button initiative is an industry-led effort to provide utility customers with easy and secure access to their energy usage information in a consumer-friendly and computer-friendly format. With access to their own energy data, consumers can take advantage of a growing number of online services to help them manage energy use and save on energy bills.

Intended impact:

*Innovation* - Voluntary adoption of a consensus industry standard for energy and utility data access by utilities and companies both enables and incentivizes software developers and other entrepreneurs to build innovative applications, products, and services.

*Energy Savings* - A survey in the U.S. found that almost half of respondents are interested in third-party applications that support energy reduction through rewards, advice, or other means.

*Energy Services* - Access to energy data can help in programming home energy management devices, sizing, and financing rooftop solar panels, and helping a contractor to verify home energy savings more cost effectively.

Barriers addressed:

*Data Availability* – The Green Button standard enables utilities to report customer electricity-, natural gas-, or water-usage data in any interval they choose including 1-minute, 15-minute, hourly, daily, or monthly as long as the data interval can be provided by the utility’s meters.

	<p><i>Data Privacy and Security</i> - Green Button is consistent with current privacy and security practices, since customers must first authenticate themselves on a utility portal with a login and password before they see and download their own information. If they want, customers can share their own data that they have downloaded, by independent choice and action, with those they trust.</p>
<p>What metrics are in use to evaluate the impact of this policy?</p>	<p><i>Data Access by Service Providers</i> - Some utilities deploy <i>Green Button Connect My Data</i> (the full ESPI standard), thereby enabling automated transfers of Green Button data from a utility to a third-party service provider if a customer has granted explicit permission.</p> <p><i>Data Access</i> - Number of households and businesses able to access their energy data via Green Button</p> <p><i>Utility Participation</i> - Number of utility and electricity suppliers supporting Green Button</p>
<p>What successes / progress have been achieved by this policy?</p>	<p><i>Service Provider Participation</i> - Number of service providers supporting Green Button</p> <p><i>Data Access</i> - over 60 million homes and businesses can securely access their own energy information in a standard on-line format.</p> <p><i>Participation</i> - Over 50 utilities and electricity suppliers are participating in the initiative and over 35 companies have developed applications which take advantage of Green Button data.</p>
<p>What were / are the primary challenges to implementing this policy?</p>	<p><i>Voluntary Adoption</i> - Utilities, electricity suppliers and service providers voluntarily committed to adopt the Green Button standard. A strong marketing campaign with White House support was needed to successfully launch the initiative,</p> <p><i>Industry Consensus</i> - The data standards development process was facilitated by the Smart Grid Interoperability Panel, a public private partnership that is facilitated by the National Institute of Standards and Technology (NIST).</p> <p><i>Testing and Compliance</i> – The non-profit Green Button Alliance (GBA) offers Green Button testing programs for electricity, natural gas, and water utilities and helps them prepare for testing and standards compliance.</p>
<p>What are the key lessons learned from the policy implementation?</p>	<p><i>Leverage Successful Policy Models</i> – The Green Button is modeled after the successful “Blue Button”—a web-based feature through which patients may easily download their health information and share it with health care providers, caregivers, and others they trust. Initial implementation of the Blue Button was by the Department of Veterans Affairs (VA) and the Department of Health and Human Services (HHS).</p> <p><i>Leverage Existing Standards</i> - Green Button is based on the Energy Services Provider Interface (ESPI) data standard released by the North American Energy Standards Board (NAESB) in the fall of 2011.</p> <p><i>Use Challenges to Drive Innovation</i> – An Apps for Energy challenge was inspired by a Blue Button developer’s prize in which 18 companies competed for a \$2,500 prize.</p>
<p>Related policies: (i.e., EU legislation, international agreements, etc.)</p>	<p>In 2017, the Ontario (Canada) Ministry of Energy released a Green Button proposal for public consultation as part of the Ontario Long-Term Energy Plan.</p>

Hyperlink / Citations:

<https://www.energy.gov/data/green-button>  
<https://www.greenbuttondata.org/cmd.html>  
<https://green-button.github.io/library/>

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Policy name	<b>ENERGY STAR Smart Thermostat Certification</b>
Date/year enacted:	The ENERGY STAR Program Requirements For Connected Thermostat Products was published in January 2017.
Description:	ENERGY STAR smart thermostats are third-party certified to deliver reliable performance and heating and cooling energy savings. The ENERGY STAR specification is designed to focus on actual delivered savings, rather than on the specific strategies that thermostats might use to achieve those savings. Thermostats that have earned the ENERGY STAR label are certified to deliver savings by default in typical use.
Intended impact:	Device Energy Savings – Thermostat electrical consumption $\leq 3.0$ W and the average time to enter network standby after user interaction (on device, remote or occupancy detection) $\leq 5.0$ minutes  HVAC Energy Savings - To earn the ENERGY STAR, field savings studies shall show a run time reduction of at least 6% for heating and at least 7% for cooling. In addition, no more than 20% of homes in the study shall have savings of 1% or lower in heating or cooling.
Barriers addressed:	System Efficiency – Smart, connected thermostats use data and information from external sources (weather, geo-fencing, multi-zone occupancy and temperature) so combined product/service performance-based testing is required.  Data Privacy - The EPA-produced software resides and run in the service provider’s data environment.  Proprietary Information - Only the analyzed and aggregated output of the software is seen by a certification body or the EPA.
What metrics are in use to evaluate the impact of this policy?	Device Availability – Number of certified thermostats available in the market.  Utility Programs – Number of utility programs requiring the use of certified thermostats for incentives.  Energy Savings - Annual % run time reduction for heating and cooling.
What successes / progress have been achieved by this policy?	Device Availability – There are 64 certified products in the U.S. and 61 available in Canada.  Utility Programs – A number of utilities are beginning to require ENERGY STAR certified thermostats in incentive programs.
What were / are the primary challenges to implementing this policy?	Product versus Service Certification - ENERGY STAR product certification is generally based on engineering estimates and/or laboratory measurement of key metrics. ENERGY STAR certified smart thermostats are a combination of hardware and service so rather

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than laboratory testing, real-world data from a large randomized sample of homes that use the product are aggregated and analyzed to understand energy usage.

What are the key lessons learned from the policy implementation? Performance Evaluation – Certification of smart, connected products requires statistical evaluation of actual installed product/service performance under default operating conditions.

Technology Independence – Smart, connected thermostats are a dynamic product category with lots of innovation. Additional room occupancy sensors, temperature sensors, humidity sensing, geofencing and various communication options are widely distributed across products.

Demand Response - While demand response functionality is not specifically evaluated, the ability to respond to demand response signals is a requirement for certification.

Energy Savings Persistence - Service providers must periodically resubmit savings data from a new random sample of their installation to ensure ongoing energy savings.

Related policies: (i.e., EU legislation, international agreements, etc.)

ENERGY STAR Smart Thermostat certification is applicable across Canada in addition to the U.S.

Hyperlink / Citations:

<https://www.energystar.gov/sites/default/files/asset/document/Smart%20Thermostat%20Fact%20Sheet%20for%20Manufacturers%20and%20Contractors.pdf>

<https://www.energystar.gov/sites/default/files/ENERGY%20STAR%20Program%20Requirements%20for%20Connected%20Thermostats%20Version%201.0.pdf>

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