4E Efficient, Demand Flexible Networked Appliances EDNA

Residential HEMS and controllers – global market scan

February 2025

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EDNA: Residential HEMS and controllers – Global Market Scan

Final Report

Prepared for the 4E Technology Collaboration Programme of the International Energy Agency

Institute for Sustainable Futures

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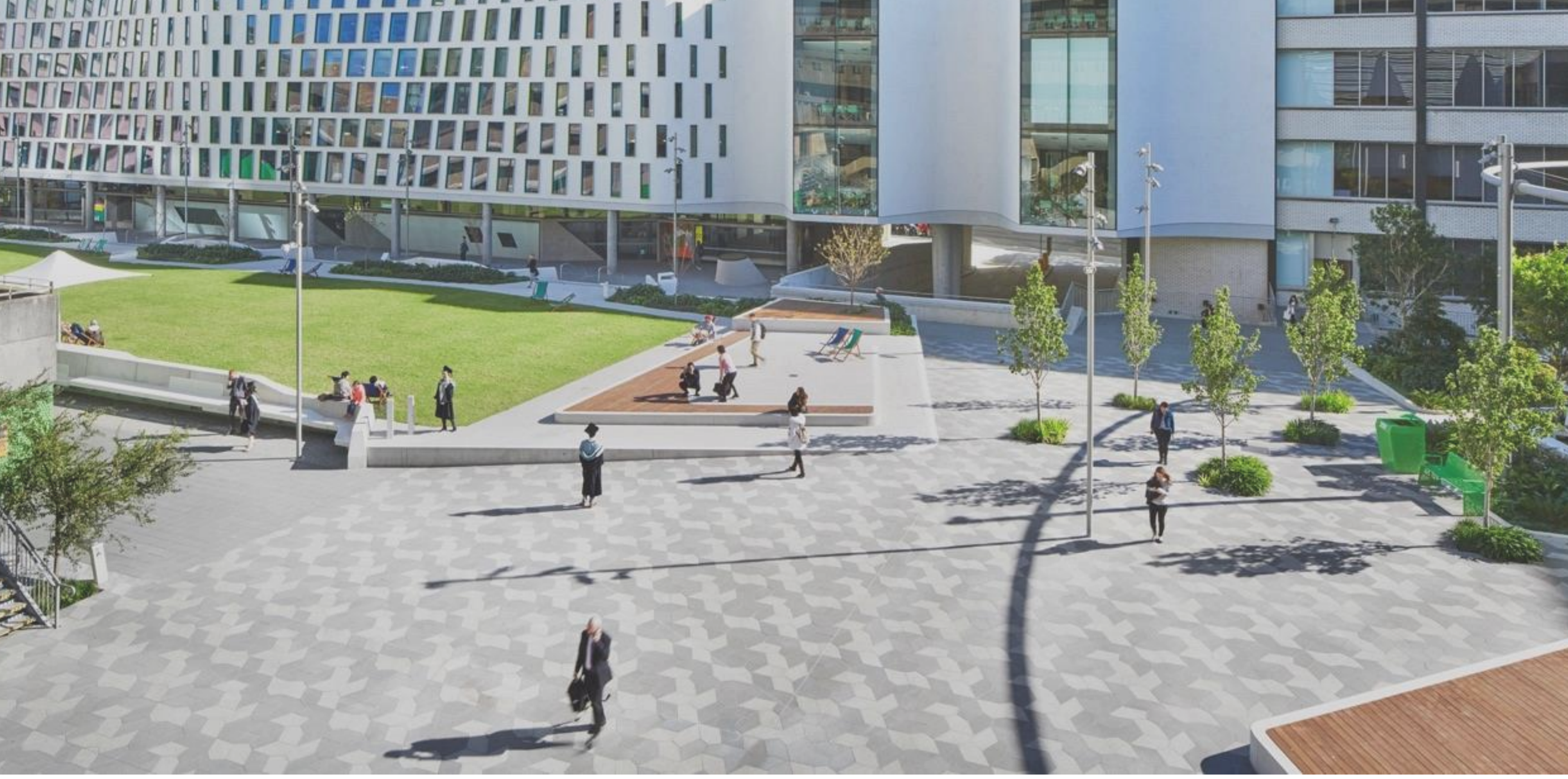
isf.uts.edu.au



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The Institute for Sustainable Futures (ISF) is an interdisciplinary research and consulting organisation at the University of Technology Sydney. ISF has been setting global benchmarks since 1997 in helping governments, organisations, businesses, and communities achieve change towards sustainable futures.

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Executive Summary

Background

As energy systems increasingly depend on variable renewable energy sources, integrating demand flexibility technologies becomes crucial. Enhancing demand flexibility, including at a household level, is essential to minimise the costs and risks associated with the transition to clean energy. Home Energy Management Systems (HEMS) are systems that can connect to multiple residential energy devices and a communications network to provide monitoring and control, optimising household energy storage, generation and consumption for the benefit of the household and the broader energy system.

The functionality and use cases of HEMS vary with the maturity of the particular system, and the household appliances integrated into the HEMS ecosystem. Customer assets connected to HEMS can include solar PV, home batteries, EV chargers, and controllable energy loads such as hot water systems, heating/cooling equipment (including smart thermostats), pool pumps, pool heating, and other smart appliances, lights or plug loads controlled by smart devices. At the basic level, HEMS provides real-time monitoring of energy consumption and production in the home, along with a level of scheduling and remote user control of appliances. As they become more sophisticated, the HEMS systems can provide optimisation of rooftop solar self-consumption, optimisation of financial benefit, as well as responding to external market and network signals (Delta-EE, 2021; gridX, 2024; Strauli et al., 2022).

This research investigates the global HEMS market addressing key questions about existing products, market penetration, product categories, interoperability, and relevant policies. The research was conducted through extensive desktop reviews of market intelligence reports, product data, and industry documents.

Current size of the global HEMS market

Publicly available data on the global and regional HEMS market is limited. The desktop review found that most publicly available information is predominantly in the form of high-level market intelligence reports, a small number of market overviews available from commercial entities operating in the HEMS space, and a limited number of academic studies. The best data currently available is on HEMS in Europe. Using a broad definition of the HEMS market, these existing projections estimated the size of the global HEMS market to be in the order of $4b USD annually with the expectation that this will treble by the end of the decade.

Findings from HEMS global market scan

This market scan aimed to provide insights into the state of the global HEMS product market in 2024. Detailed information was collected and categorised for 51 HEMS to understand the types of products available, where they are available, how they are connecting to household generation, storage and flexible loads, and what degree of information and control they provide to householders and third parties. The lack of specific sales data meant the analysis of the market focused on the spread of available products, without consideration of which HEMS devices are most widely deployed.

The scan found that there is significant diversity in available HEMS products across all classification categories (see Figure 1 for a selection of market category breakdowns). This is indicative of the diversity of current drivers of demand flexibility in global energy markets, the strategic rationale for companies entering the HEMS market, and the energy policy environments they must operate within. The differences in features and design choice have important implications for their functionality, financial viability and attractiveness to customers. Key findings include:

- HEMS can be integrated in existing equipment such as battery or solar inverters or smart meters, can be fully cloud-based (monitoring and controlling compatible appliances), but are most commonly separate devices within the home.
- About 40% of products are available globally, but most currently have a distribution confined to a particular region.

- Companies developing HEMS products are hugely diverse, ranging from solar PV/storage companies to electrical original equipment manufacturers (OEMs), tech companies and energy suppliers.
- Interoperability with other appliances behind the meter is a critical challenge. Around 1 in 5 HEMS products operates within a 'closed ecosystem' of devices of a given brand, a similar proportion use open communication standards to increase the breadth of compatible control, but most of the market (53%) currently rely on developing bespoke software integrations with each brand or even model of connected hardware. Such integrations require significant time and cost, with many HEMS and smart appliance brands duplicating work to add new connectivity. This is the focus interoperability policy options, discussed below.

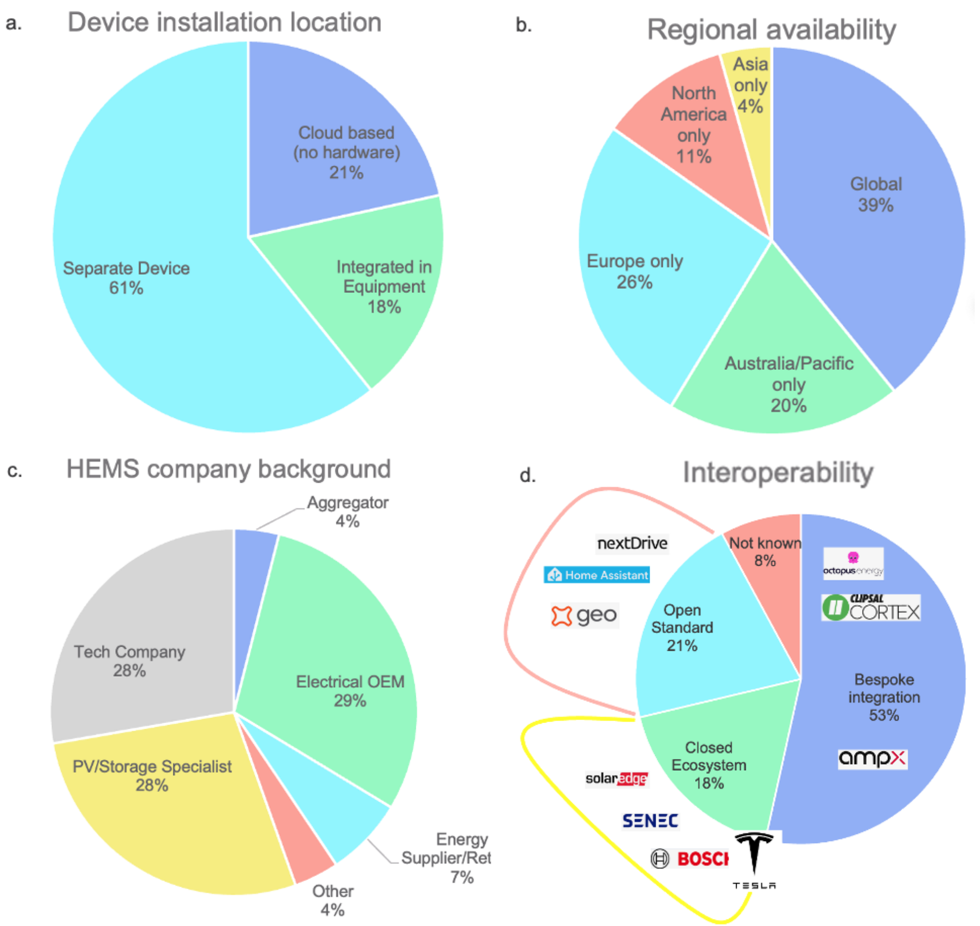

Figure 1: Proportion of products from the market scan in different product categories. Graphs show: a. installation type, b. regions in which products are available, c. background of company with HEMS products, d. interoperability categorisation; n=51 for all figures.

A classification framework was created to better understand the technical capabilities of HEMS products, categorising them into four levels of sophistication:

- **Monitoring only:** No control capability. While these devices are not considered HEMS, this category was included for completeness, as many HEMS products are emerging out of monitoring-only devices, and many HEMS have control capability for *some* appliances, but only monitoring for other devices.
- **Basic:** Scheduling of multiple devices.
- **Sophisticated:** In-home optimisation, based on user-specified criteria (such as minimising energy costs, or maximising solar self-consumption).
- **Orchestrated:** Sophisticated plus response to dynamic external market or control signals.

Applying these classifications was challenging, as it was often unclear from the available information exactly what degree of control would be delivered, over which devices, in which circumstances, and whether that control was currently available to purchase, or was expected to be available soon. To manage this challenge, the study allocated two separate functionality categorisations to each device:

- **Cautious:** cautious or minimum stated capability based on current marketing over which there was a degree of certainty, and
- **Highest stated:** generous or highest potential capability as claimed in marketing or industry news coverage. This might be higher because the company has announced additional capabilities will soon be available, or capabilities are available when additional devices are added to the system, or there are contradictory statements of capabilities present in the public domain.

As seen in Figure 2, when a cautious approach is applied, more than half of the devices are providing only basic control or monitoring functionality, around a quarter provide sophisticated in-home optimisation and only 12% can provide an orchestrated response to external market or network signals. This changes significantly when considering the highest potential capabilities, with almost 85% of devices being classed as sophisticated or orchestrated.

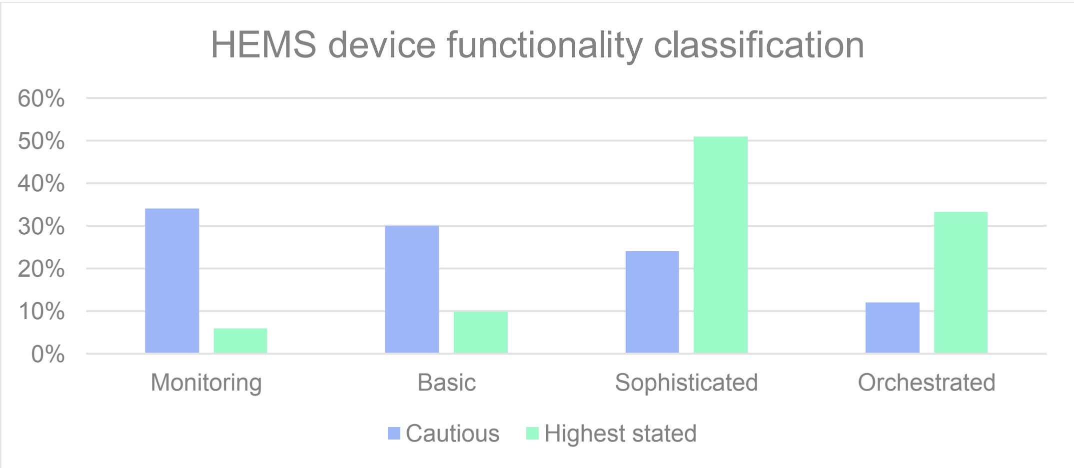

Figure 2: Levels of control sophistication of HEMS devices, categorised using both a cautious and highest stated assessment (n=51)

The difference between *cautious* and *highest-standard* interpretations of control functionality highlights the rapid trend towards greater levels of in-home optimisation functionality, along with an increase in enabling third-party orchestration. However, ***there were few, if any, HEMS devices currently available that deliver on all the desirable use cases.*** This dynamic, along with the different approaches to interoperability with household devices, makes it very challenging for customers to assess what HEMS products will work with their equipment and how they will operate.

There appears to be some regional variation in product types and functionality. For example, North America and Europe show more focus on the control of household loads, whereas in Australia advanced control and optimisation of household generation and energy storage (e.g. solar, batteries) is more common.

Globally, HEMS markets are diverse, and rapidly evolving in various directions. Possible approaches to support the development of the household demand flexibility space while ensuring customers are appropriately protects are outline below.

HEMS Policy Issues and Options

Industry opinions are divided on whether HEMS, as in-home gateways, will emerge as the dominant model of control of residential devices. An alternative pathway is *direct* integrations between OEMs of ‘major’ residential equipment (solar, batteries, hot water and heating/cooling systems) and energy industry players (energy retailers, networks, aggregators or market operators). Policy makers will need to follow emerging position on this issue closely to tailor their responses.

Policy options to support the functional development of the HEMS market could focus on the following areas:

Interoperability: Interoperability is critical for the successful functioning of HEMS products, both for how these gateway devices communicate and integrate with the energy system (to respond to signals from energy market operators, retailers or distribution networks), and for how customer outcomes are successfully optimised behind-the-meter with a wide range of appliances. To improve interoperability and underpin a more rapid scaling of the market and improved customer experience, a three-part solution is required:

- Development of **interoperability standard/s** and technical standards regarding flexible demand capability for critical consumer energy equipment.
- **Legislation** to require manufacturers of HEMS and compatible appliances to adopt a particular interoperability standard for a given market, or open protocols more generally. A key issue is that there is not necessarily a single standard that comprehensively covers all parts of the challenge at hand. As such, we understand that some jurisdictions are leaning away from specifying a single standard, instead opting to mandate that open communication protocols should be used, thereby letting the prominent standards emerge. Examples of the most prominent and emerging standards include OpenADR, IEEE 2030.5, Matter and EEBus.
- **Protocol requirements and compliance testing** regime to ensure that full compliance with a claimed protocol.

Examples of voluntary smart appliance interventions are the EU Code of Conduct on energy management-related interoperability of Energy Smart Appliances (April 2024) and Great Britain’s PAS 1878:2021 for Energy Smart Appliances. These encourage the design of appliances that can communicate with each other and energy management systems, and respond to external incentive signals to modulate their energy use. The voluntary ENERGY STAR® program in the US also includes criteria for 'connected' products, requiring open standards for communication layers. While connectivity criteria are optional for most products, they are mandatory for connected thermostats and smart home systems to achieve certification

Data sharing frameworks: Standardised data formats via web interfaces (Application Programming Interfaces, or APIs) can streamline information sharing, as seen with California's Market Informed Demand Automation Server (MIDAS), a database and API for contributing and accessing information on time-of-use, critical peak and real-time pricing structures, carbon emissions intensity of electricity generation, and ‘Flex Alert’ signals issued by the market operator.

Consumer protection: Ensuring consumer choice over how and for what purpose their appliances are controlled is crucial for the acceptance of third-party management of flexible loads. It may be necessary to consider the regulation of, or the development of principles surrounding the primacy of consumer choice when considering third party delegation for flexible load control.

Policy makers may also have other indirect levers to stimulate the market for HEMS, or promote device interoperability capabilities that enhance HEMS connectivity. These might include adding connectivity or controllability requirements to eligibility criteria for government energy efficiency incentives, or working with distribution networks on integration issues, such as dynamic connection agreements.

Contents

1 Project Context

This report presents the findings of market scan of the global home energy management system (HEMS) market undertaken for the 4E Technology Collaboration Programme (4E TCP). 4E TCP is an international platform for collaboration between governments, providing technical analysis and policy guidance to its members and other governments on energy efficiency and now 'demand flexible networked appliances'.

As energy systems increasingly depend on variable renewable energy sources, integrating demand flexibility technologies becomes crucial. Enhancing demand flexibility, including at a household level, is essential to minimise the costs and risks associated with the transition to clean energy. Home energy management is the monitoring and intelligent management of energy flows within a home. HEMS are devices that can provide this intelligent management. They connect to multiple residential energy using devices and a communications network to provide monitoring and control, potentially optimising household energy consumption, storage and generation for the benefit of the household and the broader energy system (Ford et al., 2017).

This project seeks to advance an understanding of the current global market for HEMS as a gateway to customer and (potentially) third party control over residential load flexibility. The market scan covers the types and sophistication of current product offerings, key differentiating features, the extent to which open versus closed product ecosystems pervade the market, and emerging HEMS product policy considerations.

The data collected provides a snapshot of the current product market which can be used a comparison point for future research. A complementary review of smart appliance standards and flexible demand markets across several case study jurisdictions (UK, EU, Germany, California, Hawaii, Australia and New Zealand) was simultaneously prepared by the Institute for Sustainable Futures, and can be found in an accompanying report *Product Policy Framework for Demand Side Flexibility: Case Studies.* This information will aid the 4E TCP in its role in providing analysis and clear, actionable policy guidance to members and other governments to improve the demand flexibility of connected devices.

2 HEMS and Controllers Overview

2.1 History

The management of energy usage in the home has a long history, with strong interest emerging in the 1970's following multiple energy crises, and the initial emergence of home solar energy systems. For many years, this remained a niche area of interest. As recently as 2012, researchers in the space found that 'consumers just lack the fundamental interest in spending time managing their home energy consumption' (Asare-Bediako et al., 2012, p. 4). However, developments in recent years have seen a rapid uptake of home energy management devices (Ford et al., 2017; Sovacool & Furszyfer Del Rio, 2020).

Early energy management systems operated using microcontrollers, with significant performance improvements with the advent of personal computers in the 1980s (Shareef et al., 2018). Advances in technologies such as radio frequency and ultrasonic sensors led to enhancements in functionality (Wacks, 1991). Network architecture and powerline communication were also utilised for energy management controllers that used home computers to oversee and control appliances (Inoue et al., 2003). These appliances were managed through a compact control interface installed between home appliances and a network adapter, and intelligent algorithms based on game theory were integrated into energy management schemes.

Recent advancements have led to the development of Home Energy Management Systems (HEMS) that use real-time energy control approaches to schedule or remotely manage home appliances. The Internet of Things (IoT) has also revolutionised this field, making it easier than ever to connect home appliances with user-friendly apps. In colder climates, connected thermostats were one of the first such devices to become widespread, providing householders with advanced control through a smartphone app. Other smart energy controllers have become widespread, including smart lights, smart plugs and connected appliances. Linking multiple controllers and devices together into smart home energy management systems allow users to monitor and control multiple aspects of their homes remotely using IoT-enabled devices.(Chakraborty et al., 2023) Demand response tools are also enabling appliances to participate in real-time energy control through battery charging and photovoltaic (PV) systems (Kanakadhurga & Prabaharan, 2024). Today, HEMS offer automatic control, connections to utilities via smart meters, improved visibility to support the reduction of energy consumption, and the ability to better respond to time-based pricing signals to reduce customer bills. This allows users to manage household appliances, optimise electricity use, and schedule appliances during critical peak hours based on demand response signals (Chakraborty et al., 2023).

2.2 Definitions

Home Energy Management Systems (HEMS)

HEMS come in a variety of forms and have consequently been defined in various manners (for example (gridX, 2024; Strauli et al., 2022; Zhou et al., 2016). In this review HEMS are defined as:

> *systems that can connect to multiple residential energy devices and a communications network to provide monitoring and control, optimising household energy storage, generation and consumption for the benefit of the household and the broader energy system.*

HEMS can be separate physical devices, embedded in smart distributed energy resources, or be cloud based. Customer assets connected to HEMS can include solar PV, home batteries, EV chargers, and controllable energy loads such as hot water systems, heating/cooling equipment (including smart thermostats), pool pumps, pool heating, and other smart appliances, lights or plug loads controlled by smart devices. The general layout of such devices is shown in Figure 3.

The HEMS is used to remotely control (and often optimise) equipment operations and in-home energy flows, to achieve specified objectives. These can include user scheduling and user prioritisation, optimisation of rooftop solar self-consumption, optimisation of financial benefit, as well as responding to external market signals (Delta-EE, 2021; gridX, 2024; Strauli et al., 2022).

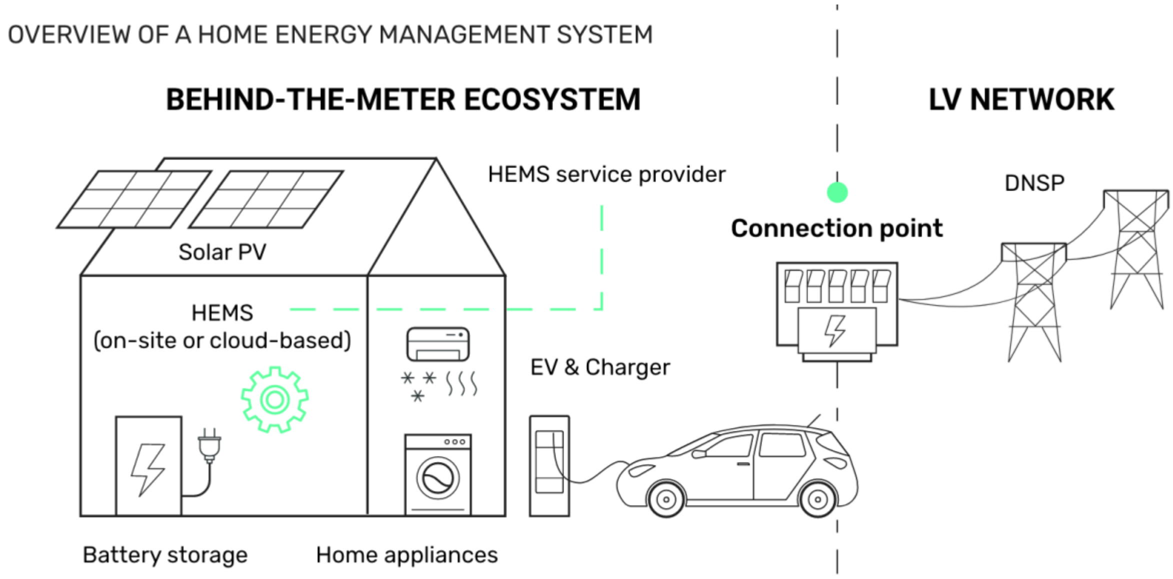

Figure 3: Overview of home energy management system (Strauli et al., 2022)

While we have opted to use the simple definition provided above, other more complex definitions exist. For example, the US Energy Star certification scheme specifies that a Smart Home Energy Management System (SHEMS) – as distinct from more simple individual product controllers – must at a minimum (Energy Star, n.d.) be accessible through a single platform interface (e.g. an app or in-home device), and provide both information and control of at least:

- 1 connected thermostat,
- 2 connected lighting products, and
- 1 plug load controller.

This definition is quite specific to the US market, however, with its origins in smart home control. As the market scan in Section 5 reveals, lighting and plug loads are often not a priority for HEMS devices in other markets, as these are typically small loads that are of less consequence to household energy consumption and bills.

Other definitions focus on the outcomes rather than the components of the system; for example, a HEMS “autonomously monitors, manages and optimises energy flows within a home to achieve a given objective (e.g. maximise self-sufficiency or minimise costs)” (gridX, 2024).

Controllers

A controller is a device which manages, commands and regulates the behaviour of other devices. Some commonly used controllers include:

- **Smart thermostats:** devices that optimise household efficiency by incorporating on board schedules with customisable temperature set points. Smart thermostats can automatically adjust the heating and cooling to maximise energy savings based on user defined schedules and real time requirements.
- **Smart lights:** devices which allow users to control the lighting functionality of the household through sensors, microprocessors, or relay/timers. While these lights do not measure power consumption, they enable the users to monitor the status (ON/OFF) remotely. The primary use case of smart lights is to add consumer convenience and comfort.
- **Smart plugs/switches:** devices that interface between electricity source and an appliance, offering information and control capabilities to the non-smart appliances. The smart plugs allow connected devices to be switched on/off, with some latest models featuring dimming functionality for lighting control.
- **Smart appliances:** devices that incorporate sensors and actuation capabilities to provide user control with advanced monitoring and control capabilities. The smart appliances include smart heaters,

humidifiers, air conditioners, vents etc.). The smart appliances are connected through a portal/app, providing the status of the appliance in use.

- **Solar diverters:** a device that directs the surplus electricity generated through the solar panels to the high load appliances such as hot water systems, heat pumps, or HVAC. Instead of sending the excess solar to the grid, the diverter ensures that electricity is used to operate the high electricity usage appliance, thus maximising the energy savings.

Such smart controllers commonly form *part* of a HEMS. Single device controllers are, alone, not considered to be HEMS themselves, but may be integrated within HEMS control if communications and interoperability is present. This scope of this report, and specifically the market scan in Section 5, *does not include individual device controllers in isolation*.

For more information on the technical capability of single device controllers, see a large-scale review of single-device controllers available in the US undertaken by Ford et al (2017).

2.3 Benefits of HEMS

Homes are significant energy users, with residential buildings accounting for 21% of global final energy consumption in 2022.(IEA, 2023) The active management or optimisation of home energy usage via HEMS thus presents a substantial opportunity to increase flexibility in electricity systems.

HEMS use cases vary with the maturity of the particular system. At the basic level, HEMS provides real-time monitoring of energy consumption and production in the home, along with a level of scheduling and remote user control of appliances. As they become more sophisticated, the HEMS systems can provide (Strauli et al., 2022):

- Energy bill optimisation
    - Maximisation of solar self-consumption: This is commonly the primary, and often largest, focus of product offerings.
    - Tariff arbitrage: This requires the residential customer to have a cost reflective tariff, such as demand charges or Time-of-Use (ToU) tariffs.
- Energy market participation
    - Access to wholesale energy trading, for solar PV, battery, and EV exports.
    - Participation in ancillary services markets, such as through a Virtual Power Plant (VPP) operator or other aggregator.
- Provision of distribution network services
    - Examples of services include peak shaving to manage grid congestion, or voltage management.

The benefits derived from this range of HEMS uses can accrue to the household, the energy system (and therefore energy consumers more broadly), and the environment.

Household benefits: HEMS offer potential for reducing energy consumption by improving user visibility, and optimisation of usage. However, the core value proposition is in increasing residential energy demand flexibility to improve solar PV self-consumption, shift or reduce peaks in demand.

For households, this can translate into lower energy bills, although there is a need to strengthen the evidence base on the scale of the impact that can be achieved. A small-scale trial in the UK (24 households, two-year pilot study 2019-21, East England location) found participants saved 49% on annual energy bills (USD495/household[1]) and reduced carbon emissions by 14%. There was significant variation in savings across households, ranging from USD104–1,064 across a 12-month period. Participant households already had solar panels and EV chargers on the properties, with smart meters and batteries added for the trial

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[1] Value converted from GBP based on USD-GBP exchange rate of 1 GBP = 1.23848 USD (4th Feb 2025)

(Green Energy Options, 2021). Other studies suggest smaller, but still substantial energy savings (e.g. 10% energy cost reduction in Germany self-sufficiency optimisation study (gridX, 2024)). The impacts on energy consumption have been found to vary widely across households (Nilsson et al., 2018), highlighting the impacts of householder behaviour. Other large-scale research has found that often there can be significant discrepancies between users' expected savings and the savings that a HEMS will deliver. Given the same study found that financial benefits and guaranteed bill reductions are dominant motivating factors for households (in Poland, Portugal and the Netherlands), it can be important to be realistic about expectations regarding the impact of HEMS on energy consumption.

While individual controllers can deliver energy benefits to households, more significant benefits are expected to be achieved when multiple devices are connected and working together in a household system. For instance, savings from programmable thermostats have been estimated at 3%, increasing to 26% for an integrated solution with monitoring and control of appliances and heating and cooling (Ford et al., 2017).

Network and energy system benefits: The flexibility provided by HEMS can result in substantial savings in energy system costs by reducing the required capacity (and thereby energy infrastructure investment) of centralised energy generation and transmission and distribution networks (Kuiper, 2024b). As these lumpy infrastructure costs are usually ultimately paid for by energy users over a long period of time, such system benefits also accrue to households and businesses over the long-term.

While energy characteristics and associated costs will differ substantially across jurisdictions, modelling of the Australian energy system found that flexible demand (to which HEMS can contribute) could achieve new build cost savings for generation and storage costs ranging from AUD$ 1-8 billion (a 1.1% - 8.7% reduction in total investment required), and consumer cost savings of between AUD$ 5-18 billion (2.4% - 12.8%) to 2042, depending on the future scenario modelled (NERA Economic Consulting, 2022). The highest benefits were achieved in scenarios with the highest penetration of Distributed Energy Resources (DER). These figures do not include network benefits. Separate modelling found that network costs could be reduced by $11.3 billion through DER, including but not limited to flexible demand (Baringa Partners, 2021).

Environmental benefits: To the extent that HEMS can facilitate reduced energy consumption, this clearly has associated environmental benefits commensurate with the carbon emissions intensity of the grid. Perhaps less obviously, the introduction of greater levels of flexible demand in the system also supports the increased uptake of variable renewable energy sources, enabling the transition to a low emissions energy grid (Strauli et al., 2022). As variable renewable energy makes up a greater proportion of energy supply, the importance and value of demand flexibility to help the system handle variable supply will increase (Briggs, Roche, et al., 2024).

3 Research approach and report structure

This work was commissioned to explore a set of specific research questions about the global HEMS market, including:

- What products exist?
- What is the market penetration of HEMS and controllers?
- What product categories exist, and what are the advantages and disadvantages of the categories?
- What is the extent of interoperability versus closed ecosystems?
- What policies exist, what are current policy issues, and any recommendations?

Desktop research was undertaken to address these questions, reviewing existing market intelligence reports, market review studies, along with detailed data collection of product information and industry documents. The findings from the research are present in the following three main sections.

HEMS market size and projections

Section 4 reviews the size and trends in the global HEMS and controllers market, drawing largely on data from market intelligence reporting and the (very limited) available product specific sales data and forecasts.

Global HEMS market scan

Section 5 presents data from a detailed scan of available HEMS products globally, collecting data from product manufacturer and supplier websites and other publicly available documentation. A data collection and classification framework was first developed, and populated with the collected information. A broad and detailed product market scan was undertaken using logical search terms, review of peak and industry body websites, memberships and reports, and snowballing from collected data. This continued until a saturation point was reached after which further search efforts did not reveal additional products with sufficient publicly available information to add to the market scan. The scan was limited to information available in English.

The focus of this market scan was Home Energy Management Systems (HEMS). The scope was therefore focused on products that control *multiple devices* across the household (or be managed as part of a household system), and provide management capabilities, in that they provide control, not just information and monitoring. Single device controllers are widespread across world markets, with available products in the hundreds if not thousands, and several studies already exist characterising these available products (Ford et al., 2017).

Issues for policymakers

Section 5.7 provides a short summary of product policies relating HEMs, and emerging priority areas for policy makers to guide or shape the development of the market. This section was not a core focus of the work, and the research team was cognisant of avoiding overlap with prior EDNA work on communications protocols and interoperability.

4 Current market size and projections

Available data on the global HEMS market is limited. The desktop review found that most publicly available information is predominantly in the form of high-level market intelligence 'summary reports'. This data is largely provided by commercial entities that charge for access to full reporting, and in public releases do not openly disclose the methodology underlying their data. It is also unclear if those companies have commercial interests in presenting overly bullish or conservative outlooks. It is therefore difficult to assess the validity of the data. Nonetheless, it provides a point of reference to understand the global HEMS market. This section provides a summary of this existing market data, highlighting broad predictions for the growth of the HEMS market over the coming decade.

The precise scope of products included as HEMS in this high-level market reporting is sometimes unclear, making comparison difficult. The figures included below are most likely to include some devices that are not the focus of this report, such as self-monitoring devices, along with smart controllers (lighting, thermostats and HVAC controllers) as well as whole-of-home HEMS.

In 2023, multiple market insights reports valued the global HEMS market at approximately USD 3.5 - 3.6 billion. It is projected to grow substantially over the decade, reaching an estimated USD 10-12 billion by 2030 (Grand View Research, 2022; ReAnIn, 2024). Current estimates and projections for global, North American (including Mexico), European, Asian, and the Australia/Pacific markets are summarised below.

Table 1: Summary of global and regional estimates of current and projected market size for Home Energy Management Systems, including single device controllers and monitoring devices

	Current (USD)	Predicted (USD)	Source
Global	3.5 – 3.6 billion (2023)	10-12 billion by 2030	(ReAnIn, 2024), (Grand View Research, 2022)
North America	1.3 billion (2023)	4.6 billion by 2032	(Credence Research, 2024b)
Europe	1.0 billion (2023)	3.5 billion by 2032	(Credence Research, 2024a)
Asia	948.8 million (2024)	1.48 billion by 2031	(Cognitive Market Research, 2024)
Australia/Pacific	143.2 million (2024)	217.1by million 2028	(Statista, 2024)

4.1 Geographical Market Focus and Trends

North America

North America is described as leading the global HEMS market, with the revenue share of 36% in 2023 (Grand View Research, 2022). The North American market is projected to grow from USD 1.3 billion in 2023 to approximately USD 4.6 billion by 2032, reflecting a compound annual growth rate (CAGR) of 15% from 2023 to 2032. The market is characterised by moderate to high concentration, with major players including Vivint Smart Home, General Electric Company, and Ecobee.

Within North America, the U.S. is the largest market, accounting for around 70% of revenue, while Canada represents approximately 20% (Credence Research, 2024b). According to consumer surveys, 60% of smart home users (e.g., those using Amazon Alexa, Google Home, and Apple HomeKit) utilise HEMS devices to manage energy consumption. It is estimated that 30% of homes with HEMS also incorporate renewable energy sources, and 25% have integrated battery storage systems. As seen in the figure below, smart thermostats are currently the largest segment of the North American market, with the proportion from advanced central controllers (HEMS) predicted to increase (Credence Research, 2024a).

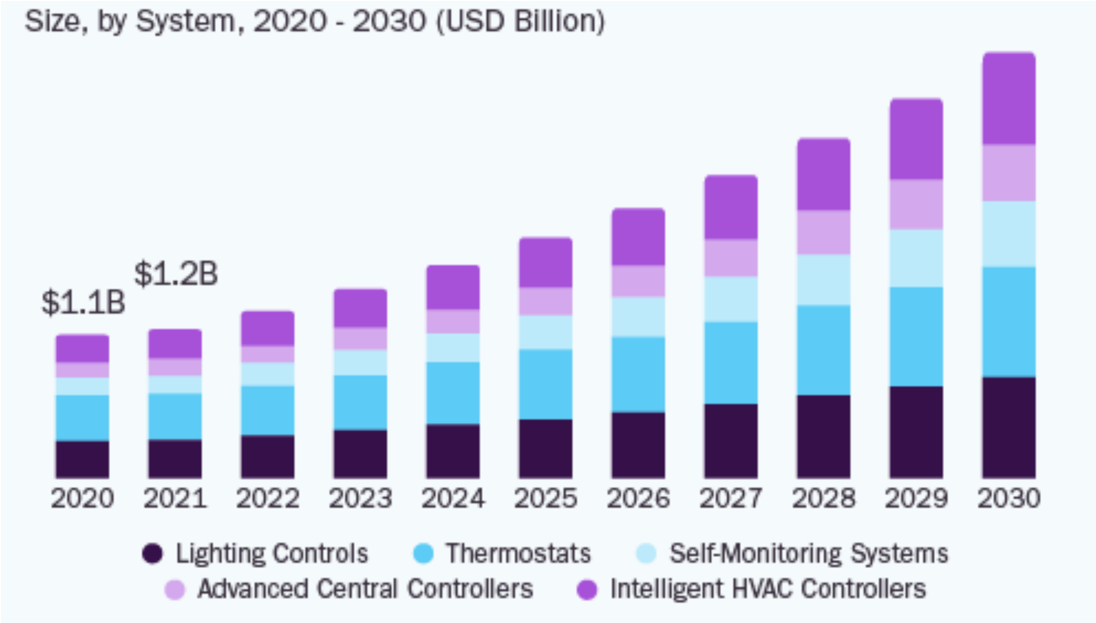

Figure 4: Size and predicted growth of the North American home energy management system market, showing approximate breakdown by product type within the market scope (Grand View Research, 2022).

Europe and UK

Europe is the second largest HEMS market after North America, with a 2023 market size of about USD 1.0 billion.(Statista, 2024) This is expected to grow at an annual rate of 14.3% (CAGR 2024-2032), resulting in a projected market volume of USD 3.5 billion by 2028 (Credence Research, 2024a). In terms of HEMS devices, the European market is expected to increase from around one million households currently equipped with a HEMS, to approximately 11 million households by 2030 (Delta-EE, 2021).

Germany is the largest market in Europe for energy management, followed by the UK. Both have a strong focus on renewable energy and smart grid technologies (gridX, 2024). This is reflected both in current uptake of HEMS and expected growth to 2030 (as shown in Figure 5). A survey conducted on German homeowners revealed that 25% want to install HEMS by 2026. Major drivers for HEMS installation in Europe were the reduction of electricity bills, maximising self-use of solar, and becoming more independent of the power market (gridX, 2024).

Different countries across Europe are at different maturity levels in terms of adoption of HEMS projects. A 2021 analysis identified HEMS projects in the product rollout phase in Germany, HEMS pilots occurring in Spain, the Netherlands and Switzerland, and HEMS projects in earlier preparatory stages in the UK, Belgium, Austria and Italy (Delta-EE, 2021). By 2030, significant growth is expected across all these markets. Expected growth ranges from a six factor increase in the already large German market, to a factor of 20 increase in Spain (gridX, 2024).

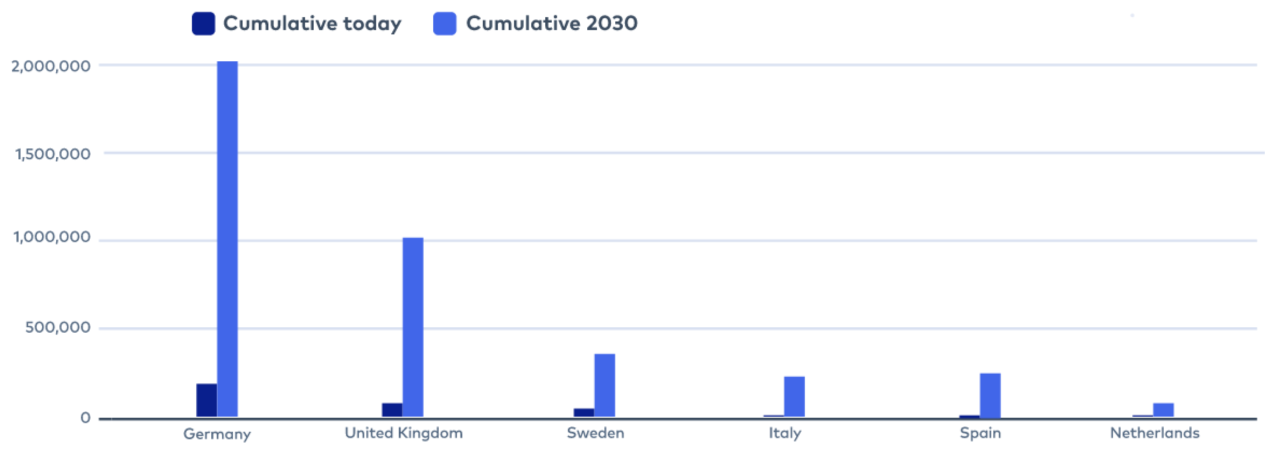

Figure 5: Expected growth in HEMS to 2030 (Source: (gridX, 2024)

Asia

The HEMS market is currently described as being smaller than Europe and North America, valued at around USD 950 million in 2024, but is expected to grow at a CAGR of 16.5% from 2024 to 2031, highlighting significant market expansion over the forecast period (Cognitive Market Research, 2024).

Australia/Pacific

Market intelligence reporting estimates the Australia home energy market at USD 143.2 million in 2024. The market is predicted to grow with a CAGR of 10.96% from 2024 to 2028, leading to a projected market volume of USD 217.1 million by 2028 (Statista, 2024).

Summary

Overall, details of the current global and regional HEMS market sizes are scarce, with the best data currently available for Europe. Using a broad definition of the HEMS market, then the global size is estimated to be in the order of $4b USD annually, and is expected to treble by the end of the decade.

5 Global HEMS Market Scan

A detailed review of HEMS products was conducted for the market scan, collecting data from websites, industry reports, and other public sources. 51 distinct HEMS products were documented across regions including Europe, North America, Asia, and Australia. Details of the HEMS products were collected and categorised, focusing on product details, market data, communications, and technical capabilities. The categories are shown in Table 2. Note that sales/market penetration data is scarce, and therefore when the analysis of this data is shown (for example, 61% of products were separate HEMS devices) is based on percentage of the 51 devices analysed, not the percentage of products installed in households.

5.1 Product classification framework

A classification framework was created for the global market scan, to document product characteristics and facilitate the functional categorisations of the current HEMS market. An overview is shown in Table 2. Further explanations of each of the 'Product characteristics' are available in Appendix A, and full details of the collected data is available in *Attachment A – HEMS Market Scan data (Dec 24).xlsx*.

Table 2: Overview of market scan data capture framework

Category (Lvl 1)	Product characteristics
Product Overview	Product and company details including description and links
	Single/multi device control
	Installation type
	Installation complexity
	Degree of cloud control
	Type of control
	Use case/sales pitch
Market Data	Market penetration
	Regional availability
	Market share
	Market forecasts
	Costs and pricing
	Business model/Revenue stream
Technical Capabilities	Solar PV Management
	Battery Energy Storage System (BESS) management
	HVAC control
	Hot water system control
	EV management
	Generation and storage control categorisation
	Load control categorisation
	Cautious overall HEMS control
	Highest stated overall HEMS control
	Virtual Power Plant (VPP) integration
Communications	Communications – wired and wireless
	Comms protocol – behind-the-meter
	Interoperability categorisation
	Upstream communications protocol

5.2 Product overview – what type of HEMS devices are available on the market?

This section provides an overview of HEMS products, focusing on their characteristics and availability in the market. Products are categorised by installation type, installation complexity, and degree of cloud integration. Each category offers insights into different dimensions and are collectively intended to build towards a more comprehensive understanding of the HEMS market.

5.2.1 Installation location and complexity

The installation location and complexity of a HEMS product refer to how and where the device is set up, impacting on its cost to install, functionality and integration within the household. In our framework, we identified three categories of installation location, with the results shown in Figure 6.

- A majority (61%) of HEMS products are installed as **separate devices** (i.e., independent of existing devices such as smart meters or inverters), requiring access to power and Wi-Fi for operation and device control.
- Next most common, at 21%, utilised no additional hardware, as household components are controlled remotely through **cloud-based** technology, enabled through common communications protocols and connectivity.
- A similar proportion of devices (18%) were products **integrated within existing equipment**, be it either a smart meter, solar inverter, or battery system.

In terms of geography, separate devices made up a higher proportion of the available HEMS products in the North America and Australia/Pacific regions, whilst cloud-based systems had a higher prevalence in Europe.

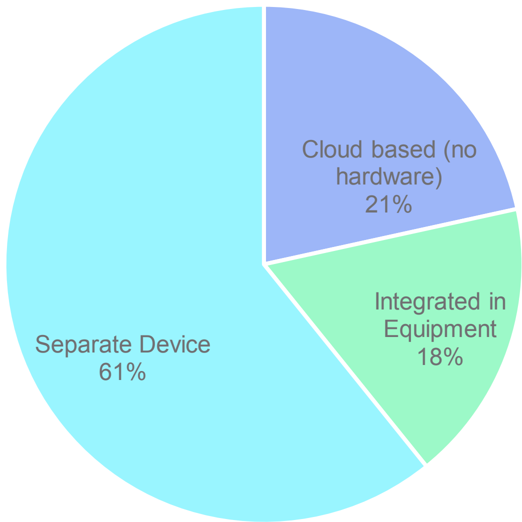

Figure 6: Installation location (n=51)

In terms of installation complexity, HEMS products were grouped into two 'head' categories: those that can be simply installed by the householder (39%), and those that require a qualified electrician for installation (57%). Of the 57% that require a licenced electrician, we have divided these into two types:

- **Separate devices** (41%), as these require a dedicated site visit – with its associated labour costs – for the HEMS to function, and
- **Integrated products** (16%) that require an electrician, but are installed with a pre-existing inverter, battery or smart meter, so the associated labour cost may be considered to already be 'paid for'.

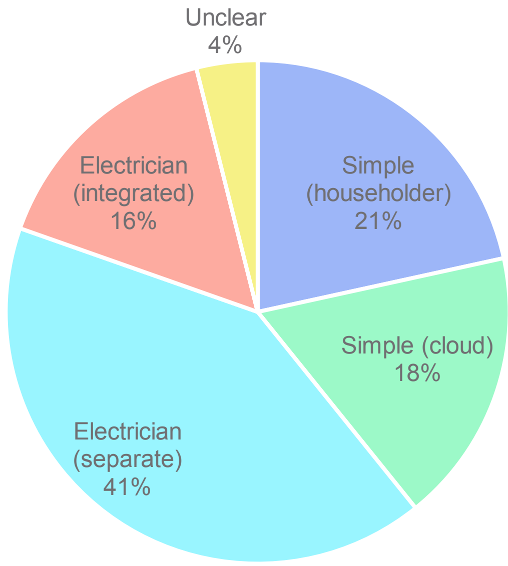

Figure 7: Installation Complexity (n=51)

HEMS products that are simple to install were sub-categorised as devices that can be **plugged-in by the householder** without special skills or qualifications (21%), and those that are **cloud-based** (18%) and so effectively rely on inbuilt communications and control in compatible appliances already with the home. Results are shown in Figure 7.

Product examples of installation type and complexity are shown Table 3 below.

Table 3: Examples of HEMS products from the market scan in the different installation and complexity categories

Installation type	Product examples (and company name if different)
Separate devices	Voltello Link (Village Energy), Clipsal Cortex, Ember Pulse (369 Labs)
Integrated in equipment	SEMS portal (GoodWe), Enphase energy system
Integrated in smart meters	Intellihub
Cloud-based	Evergen intelligent control, Xenon (Grid X)

Installation complexity	Product examples (and company name if different)
Simple (householder)	Powersensor (Powertech Energy), GroHome system (Growatt)
Simple (cloud)	Evergen intelligent control, Xenon (Grid X)
Electrician (separate)	Clipsal Cortex, Catch Power (Catch Control)
Electrician (integrated)	Energy Active Middleware (EAM SwitchDin), Sonnen Home

Implications

The significance of installation type and complexity is that it gives us some insight into how HEMS will get into homes, the associated costs, skills needs and householder decision-making pathways.

Separate devices are a discrete choice for households, so can be purchased independently of other (more expensive) CER equipment such as batteries, solar or EVs. This may allow the householder to select devices that meet the specific functionality requirements of their household, and that integrates with their existing CER setup. These devices are often referred as the local gateway or an edge device. However, separate devices that require an electrician for installation will generally have a higher upfront cost that customer installed or integrated, due to the need to pay for specialised trade to install. When the installation cost is in the order of USD 400-700 for a separate HEMS device, significant savings on energy bills are required to generate attractive payback periods for households. A lower proportion of separate devices appear to *currently* offer less advanced control as compared to many integrated HEMS products, however, as bespoke control needs to be built for a diversity of appliance types and brands. Separate devices are trending toward enhanced control capabilities. This is explored further in the section on Technical Capabilities below.

Integrated HEMS functionality in smart meters, inverters and batteries can serve as a form of ‘pre-installed’ flexible demand capability, that could be unlocked by retailers and networks even if households are not currently making use of the functionality. While technically requiring an electrician to install, the associated labour cost is essentially already ‘paid for’ by its other primary solar, battery or metering purpose, so the marginal cost of installation to enable HEMS functionality in the property could reasonably be considered to be zero.

Cloud-based platforms use APIs to connect and control existing connected devices in the home, so the upfront costs associated with physical local gateway devices and their installation are avoided. In some cases, an additional cloud connected controller can be added to devices that don’t have inbuilt connectivity. However, there are several potential limitations due to the reliance on stable and fast internet connectivity, when compared with integrated or physical devices on site that are less vulnerable to communications outages. These considerations are discussed further below, under ‘cloud integration’.

How these data points change over time (if similar scans are undertaken in future) will also reveal trends in which types of devices are gaining greater market traction.

5.2.2 Cloud integration

Another focus area in understanding product typologies was the degree of integration or reliance on the cloud. Specifically, where is the software or the intelligence that drives the HEMS functionality primarily located? Understanding the degree of cloud control helps to understand device characteristics such as control reliability, data privacy, response times, and operational costs.

In our framework, we have classified the products into two categories: ‘cloud based’ or ‘hybrid’ (which includes local and cloud-based control). This is not always completely clear from available product descriptions, so the information available was interpreted as accurately as possible, with some products determined to be unclear (8%). In some cases where companies provided multiple CER products and services, it was difficult to determine whether the HEMS service was a separate cloud-based offering or was partially integrated into other devices. Results are shown in Figure 8.

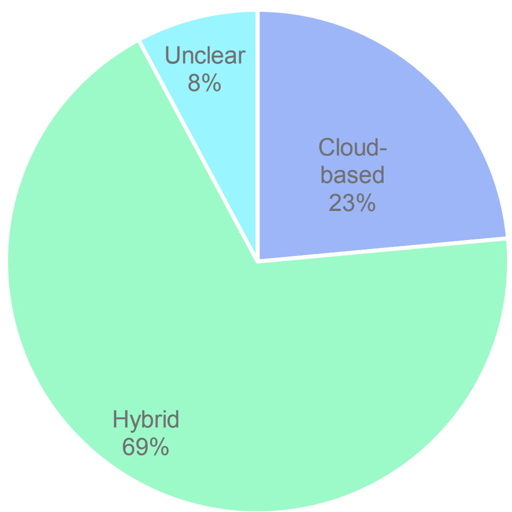

Figure 8: Types and degree of cloud control amongst products in market scan (n=51)

Hybrid devices are those that have a device located at the home that acts as a gateway, and intelligence and control functions are embedded within the device itself, as well as communicating with cloud-based systems. Some devices were predominantly locally based, while others had greater reliance on the cloud for additional functionalities, data inputs, or signals provided by an external source such as retailers or network providers. For instance, allowing retailers or third party to automatically charge your batteries based on real-time weather forecasts. While these have all been classified as hybrids, there are likely to be real differences between different systems and the degree of operation that would continue if the cloud connection was disrupted. Hybrid was the most common approach, with over two-thirds of devices (69%) operating this way.

A quarter (23%) of the products were predominantly **cloud-based**, relying on third-party cloud services for data processing, control functions, and decision-making, enabling remote management and integration with broader energy systems like demand response and Virtual Power Plants (VPPs).

A few examples from the framework are given in Table 4 below.

Table 4: Examples of HEMS products from the market scan in the different cloud control categories

Type and degree of control	Product examples (and company name if different)
Hybrid control	Catch Control (Catch Power), SunnyHome Manager 2.0 (SMA Australia), Ecobee, EMMA (Huawei), Marshall (ZecoEnergy), Home Assistant (HomeAssistant.io),
Cloud-based control	Intelligent Octopus Go, DLS solution with Alice (AmpX), Evergen Intelligent control (Evergen)

Implications

Cloud-based control allows for large-scale data collection and analysis, providing valuable insights into energy use patterns, optimisation opportunities, and predictive analytics. As previously mentioned, it also enables simple and cost-effective installation by avoiding the need to install a device at the home. This helps to overcome the potentially significant cost barrier to HEMS. Cloud systems (be it either fully cloud-based or hybrid) facilitate participation in broader energy programs, such as Virtual Power Plants (VPPs) and demand response, by allowing third parties to adjust energy usage based on grid requirements, energy prices, or market signals. However, complete reliance on cloud-based internet connectivity presents some limitations in terms of speed, reliability, connectivity and security. The reliability and speed of response will be limited by a household's internet connection speed and operational status. There will be inherent lags in the time between a device sending a signal to the cloud and a control response being enacted by the device, due to factors such as latency between and in data centres and in other parts of the internet, along with the household connection, which may limit the participation in some demand response markets. For example, one Australian study found that wireless demand response to HVAC systems in an aged care facility were able to respond within the six second period required for the local frequency balancing (FCAS) market 75-90% of the time (i-Hub, 2022). In cases when household internet is offline, control of household devices could be lost until the connection is restored. Cloud-based HEMS systems rely on being able to connect to the CER devices in the home, increasing the importance of interoperability standards if looking to connect to products outside of a particular manufacturer's ecosystem (interoperability is discussed further, below). All connected appliances face cybersecurity vulnerabilities and risks, with potential susceptibility to cyberattacks, unauthorized access, or data breaches, raising concerns for both consumers and regulatory bodies (Strategic Energy & CyberPractice.io, 2024). Cloud-based systems which store data remotely have an additional layer of risk compared with household-based devices. Consumer trust and acceptance issues can also arise over the risk of data privacy.

A **hybrid** approach shares many of the aforementioned advantages and disadvantages of separate or integrated HEMS devices, while also benefiting from cloud-functionality, to the extent that this is integrated. The local installation and control provides faster response times, which can be particularly beneficial for real-time energy management. Quick responses are essential for applications that require instantaneous adjustments, such as frequency control ancillary services (FCAS) that maintain grid stability. The local device will also typically have rules-based energy management functions onboard which are able to continue to function and run in-home optimisation even if internet connectivity is disrupted. This reliability can provide additional assurance to the network operator regarding expected behaviour of CER assets when there are communications outages. Additionally, the presence of a local device may provide householders with greater trust of the energy management processes. The hybrid approach combines the speed and reliability of local device processing with the enhanced functionality of cloud-based features. Basic functions can run locally, while advanced data analysis can be handled by the cloud, providing a balance between autonomy and adaptability. However, the need for a local gateway does lead to additional costs for consumers and manufacturers in terms of installation and commissioning, which may be a significant impediment to greater uptake.

5.3 Market Data - HEMS product availability

This section focuses on HEMS market data, detailing the regional availability of products, the companies that are offering HEMS products, available sales data, and the costs and business models for current HEMS.

5.3.1 Regional distribution and company origins

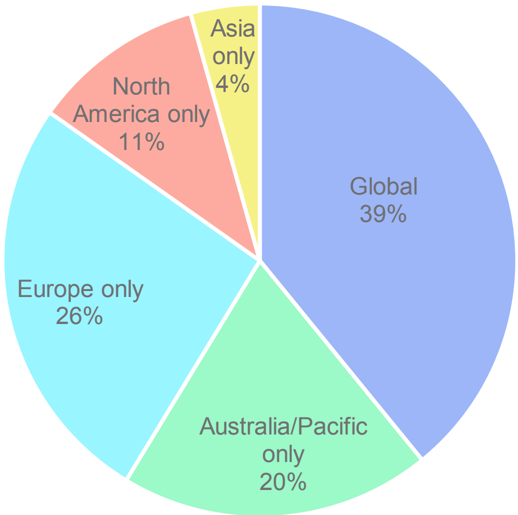

Figure 9: Geographic availability of products (n=51)

Our study examined the HEMS **product availability** across regions, based on the company website. This gives a better understanding of the level of activity in the HEMS market across different regions. The findings are summarised in Figure 9. This shows that a large proportion of the HEMS products collected in the market scan are available globally (39%). The global category means that a product was available in three or more regions. Overall, 50% of products are accessible in North America, while 65% are available in Europe, demonstrating significant regional distribution in these areas. Asia is likely a larger market than our data reflects, with language limitations restricting data collection. Australia, with its high renewable energy penetration, has seen significant activity in this space, contributing to the large number of products available in a region with a small population. Both Europe and Australia/Pacific had a significant number of devices only available in their region, 26% and 20% respectively. This may indicate a greater prevalence of smaller start-up companies entering the HEMs space in these regions, which have not yet expanded into other markets.

Figure 10 provides an overview of the data on the **backgrounds of companies** that are offering HEMS products from the market scan. It shows that companies entering the HEMS market come from a diversity of industries—many from electrical equipment manufacturing (29%), technology companies (28%), or the solar and energy storage sectors (28%).

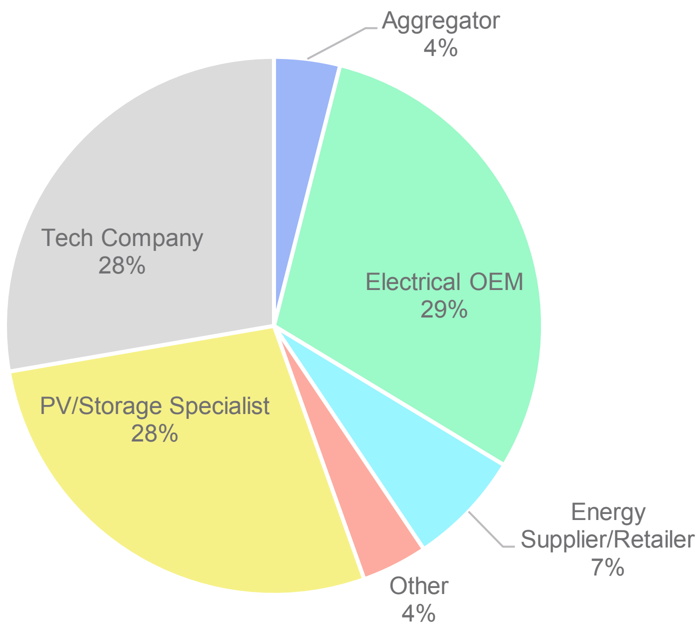

Figure 10 Company background of those active in HEMS market (n=51)

5.3.2 Costs and Sales

The **cost** to buy and install a HEMS device was difficult to determine from the market scan. Few products provided clear pricing on their publicly facing information. Where possible, this study collected information on the pricing approach: that is, did the product have an upfront cost, an ongoing subscription fee for service, or a combination. In some cases, pricing was partially available and was collected. Some indication of pricing approach was available for two-thirds (65%) of products, with most charging an upfront fee. Upfront costs can influence the affordability of HEMS solutions for different customer segments. A higher installation cost may be a barrier for some users, particularly in residential markets or smaller businesses. Of those products that provided some pricing indication, roughly one quarter (24%) had an ongoing service or subscription. In some cases, this provided additional services, whilst for others this was part of the standard offering.

When available, the cost of HEMS products varied. Some HEMS products are free when bought with other products (such as battery or smart inverter). Some products range from USD150-400, while others are priced at USD800 or above.

Market trends and **sales** data helps track the popularity of HEMS products, offering insights into consumer preferences and technology adaption trends. This also helps guide the manufacturers, and technology developers to understand the market and outlook for the emerging markets.

From our research, public data on HEMS **sales or installations** is limited. However, this research broadly suggests that successfully implemented HEMS products are in the range of hundreds of thousands to millions globally, with expectations of significant growth.

In Europe, there are currently fewer than 500,000 HEMS installed, with predictions suggesting an 11-fold increase by 2030. Germany is estimated to have 200,000 installed HEMS, expected to grow to 2 million by 2030 (Delta-EE, 2021; gridX, 2024). In Australia, company estimates from the market scan indicate that Evergen Intelligent control units are installed in more than 10,000 homes, while 25,000 Catch Power units have been sold, though these are likely primarily used for hot water system control only.

5.4 Interoperability and communications

This section explores the approaches HEMS products are using to connect with other devices behind the meter, and how these impact on interoperability between the household CER devices and the HEMS.

5.4.1 Connectivity

Connectivity in HEMS refers to how the device communicates with household devices behind the meter. This can either be wired, wireless, or a combination. This data is important because it impacts compatibility with other devices, network reliability, and help identify potential limitations in connectivity. In the framework, the devices are categorised into three predominant wireless modes (Zigbee, Wi-Fi, or 4G/5G) and wired connectivity (either power line comms or wired Ethernet), with prevalence of each summarised in Figure 11.

- **Wi-Fi** connectivity allows wireless networking, with devices connecting to the internet or communicating with each other without physical cables. This was the most common approach, with over half of HEMS products (54%) using Wi-Fi.
- About one-fifth (21%) of the products used **wired communications**, connecting to other devices either through a Local Area Network (LAN) typically using ethernet cabling or the household wiring, providing high-speed, reliable communication between devices in close proximity.
- 14% of products used **4G/5G** cellular network technologies, which provide high-speed wireless internet access over a broader area than LAN or Wi-Fi.
- Finally, **Zigbee** is a low-power, wireless communication protocol commonly used for connecting smart home devices and Internet of Things (IoT) applications. This is better suited to thermostats and lighting, rather than heavy loads such as heat pumps and HVAC, and was used by 11% of devices.

Table 5: Examples of HEMS products from the market scan in the different connectivity categories

Connectivity type	Product examples (and company name if different)
Wi-Fi	Ember Pulse (369 Labs), GroHome system (GroWatt)
Wired/Ethernet	Marshall (Zeco Energy), Sonnen Home
4G/5G	Clipsal Cortex, Sunny Home Manager 2.0 (SMA Australia)
Zigbee	Vue Home energy monitor (Emporia), SeeZero (Geo)

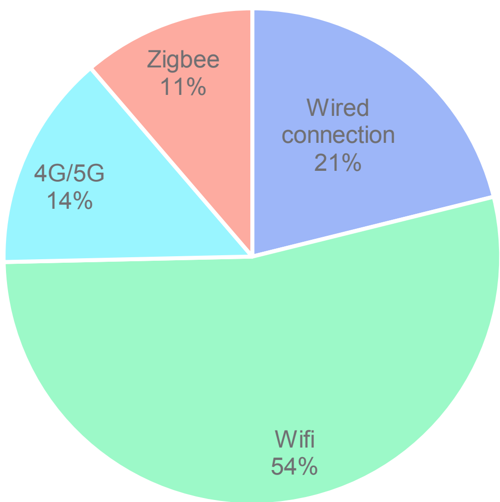

Figure 11: Connectivity (n=51)

Implications

Wi-Fi, which is widely used connectivity method, also adds an additional failure point in the system as it relies on a stable internet connection, which can be affected by network issues. Ideally, a backup connection is recommended to ensure continuous operation in case of Wi-Fi disruptions.

4G/5G connectivity provides a robust connection with wider coverage and fast speeds, which supports remote monitoring and control even outside the home. However, it may incur ongoing data and connection costs.

Wired connection offers high reliability and consistent speeds, as it is less susceptible to interference or signal loss. This stability is ideal for critical devices requiring constant connectivity. However, wired connections can limit device placement due to the need for physical cabling and may require more complex installation, which can increase setup time and cost.

Zigbee, which is known for low power consumption and extended range through mesh networking, is effective for connecting many small, battery-operated smart devices within the home. However, it may require a dedicated hub to communicate with devices on other networks (like Wi-Fi or cellular), and it can face limitations in environments with heavy interference from other wireless devices.

5.4.2 Interoperability

Interoperability refers to the ability of the HEMS to seamlessly connect and communicate with other smart devices (such as solar panels, HVAC systems, batteries, and smart meters) within the home to function cohesively. Better interoperability enables HEMS to connect and coordinate with a larger and more diverse range of devices, regardless of manufacturer, resulting in enhanced consumer choice, control, unified data management, and optimised energy use. There are three main approaches to the communications protocols for customer energy assets:

- The first is **open standards** based protocols such as Matter or SunSpec Modbus, allowing broad compatibility with different devices and manufacturers. This approach promotes interoperability by using widely accepted standards. 21% of products in the market scan claimed to be using open standards.

- The second consists of private protocols that are openly published for third-party use to interface with customer assets. This was termed **bespoke integration**, as integration requires specific customisation efforts to design and implement connections with other devices, making it more flexible than a closed ecosystem but requiring tailored development for each integration. This was by far the most commonly encounter approach, with over half of devices (53%) operating in this space.

- The third type – **closed ecosystems** – using a proprietary communication protocol layer to limit interoperability only to compatible products. 18% of products were classified as closed ecosystems. In this setup, some brands may limit third-party functionality to certain uses (VPP integration) and may not support broader applications like full home energy optimisation outside of the proprietary brand.

Some product examples from the market scan are given in Table 6, with spread of products graphed in Figure 12.

Table 6: Examples of products in the different interoperability categories.

Interoperability	Product Example (and company name if different)
Open-standards integration	Xenon (grid X), Home Assistant, Heartbeat (1KOMMA5)
Bespoke integration	Clipsal Cortex, Evergen Intelligent control, DLS solution (AmpX)
Closed ecosystem	SolarEdge energy hub, Powerwall (Tesla), The Ferroamp system

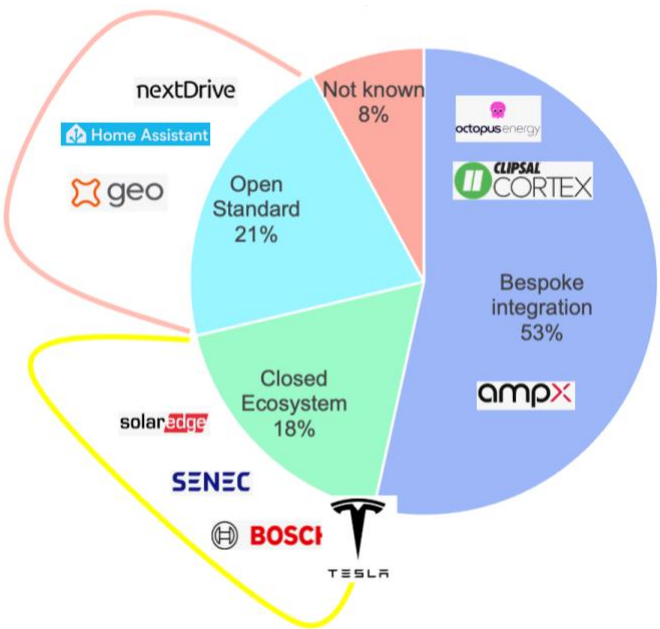

Figure 12: Product classification by approach to interoperability (n=51)

Implications

Closed ecosystems (proprietary solutions) can make it easier for a company to provide a smooth, well-integrated experience for a household by relying on a single supplier, ensuring consistent performance and ease of use. The drawback is that this relies on the customer CER products within that ecosystem, limiting customer choice and flexibility, as users are generally restricted to products within the same ecosystem, potentially leading to technology lock-in. Further implications are restrictions on the ability to optimise with other devices, along with potential inability to participate in VPPs and other programs to earn revenue. Unsurprisingly, this approach is commonly encountered when HEMS services are integrated in other CER products (see Figure 13).

Integration using **open standards** is generally seen as the preferable approach. It makes it easier for HEMS devices to connect and control the widest range of CER devices, which expands consumer choice and encourages competition and innovation within the energy market. It also makes it easier for consumers to change or upgrade household appliances or HEMS with a wider range of options, not needing to worry about compatibility. To achieve its full benefits, however, open connectivity requires compliance with supporting protocols, regulations, and testing to demonstrate reliability and compatibility across devices. A current challenge is that currently there is no clear, single, fully comprehensive and universally accepted protocol, as discussed in Section 5.7.

Bespoke integration is essentially the current working solution to the lack of widespread interoperability standards. It provides a route to integrate and retrofit with existing systems, making it adaptable to various setups and brands. However, the integration process is commonly slow and resource-intensive, which increases costs and reduce operational efficiency. This presents a barrier to the entry of new participants on the market, as well as a significant ongoing workload for current HEMS providers to maintain operable integrations with the changing CER market. The large proportion of devices using a bespoke approach means that different combinations of brands of household appliances will be managed differently by different HEMS products, meaning there is a significant degree of fragmentation in the market. This also presents a challenge for consumers to understand which device would manage their household energy demand most comprehensively.

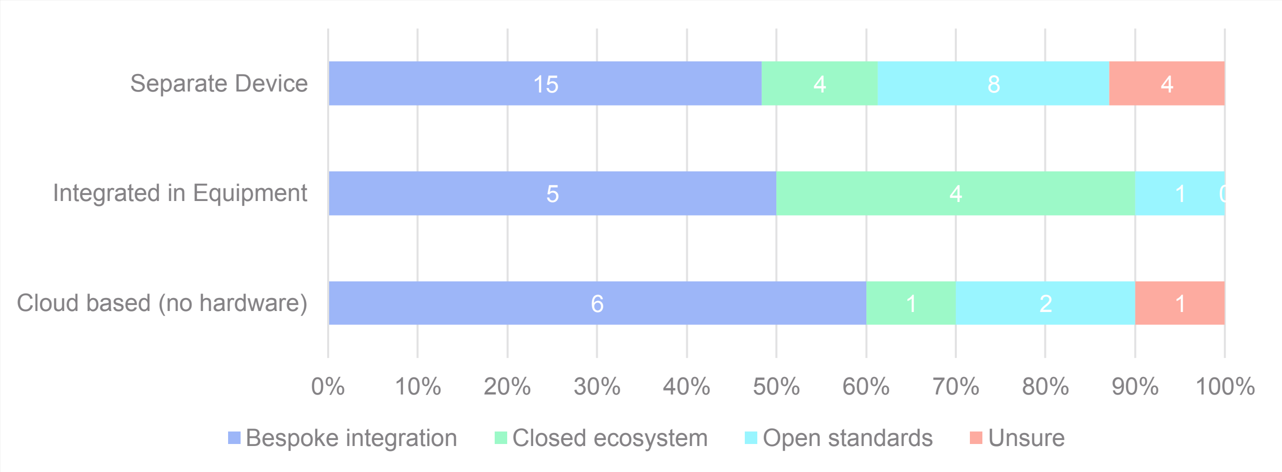

Figure 13: Prevalence of interoperability classifications by device installation type (Value in bar shows device count per category) (n=51)

5.5 Technical Capabilities - Classifying HEMS Functionality

Previous Classifications

There is no universally accepted way to classify HEMS functionality. A common approach is to consider the number of assets being coordinated (Delta-EE, 2021). This market scan focused on devices that worked across multiple assets, rather than single devices, to make it a 'Home' device.

Another key consideration is the type of use cases or value streams that HEMS can unlock for households. Potential value streams were detailed above, but can include energy bill optimisation, energy market participation, and the provision of network services to the grid operators. The value streams unlocked by a HEMS can be another means of classification, for example considering where household devices are being optimised for one value stream, or multiple streams, and if both 'home' values, and 'electricity system' priorities are being optimised for in a coordinated manner (Delta-EE, 2021).

Classification Framework: Levels of Sophistication

Drawing on elements of the above approaches, the classification approach taken in this review is to classify the 'level of sophistication' of HEMS devices according to three levels: basic, sophisticated or orchestrated. Monitoring or single device timers were not technically considered 'HEMS devices' but are also defined in

Table 7. In reality, many products included in the scan didn't clearly demonstrate current capabilities other than monitoring. However, as they labelled themselves as HEMS products, they were included in the data collection.

Table 7: Classification of levels of sophistication of HEMS devices

Sophistication	Summary	Description
Monitoring only	**Monitoring (and physical single device timers) only**	Visibility of energy consumption but no control, or simple physical timer-based controls on a single device.
Basic	**Scheduling of multiple devices**	The HEMS allows the user to schedule the operation of multiple connected devices, according to known factors such as TOU tariffs, and anticipated user behaviours. It does *not* 'optimise' for the user, based on real-time solar or other operational device data.
Sophisticated	**In-home *optimisation*, based on user-specified criteria**	The HEMS optimises the operation of multiple connected devices based on live solar/battery/EV status or energy usage data, interactive with pre-defined TOU or other electricity pricing structures.
Orchestrated	**Sophisticated + response to *dynamic external market or control signals*.**	In addition to 'sophisticated', the HEMS optimisation can curtail, divert or activate available behind-the-meter resources according to dynamic market signals received from a network, retailer or other third party (e.g. aggregators).

The decision-making pathway for applying this classification is shown in Figure 14.

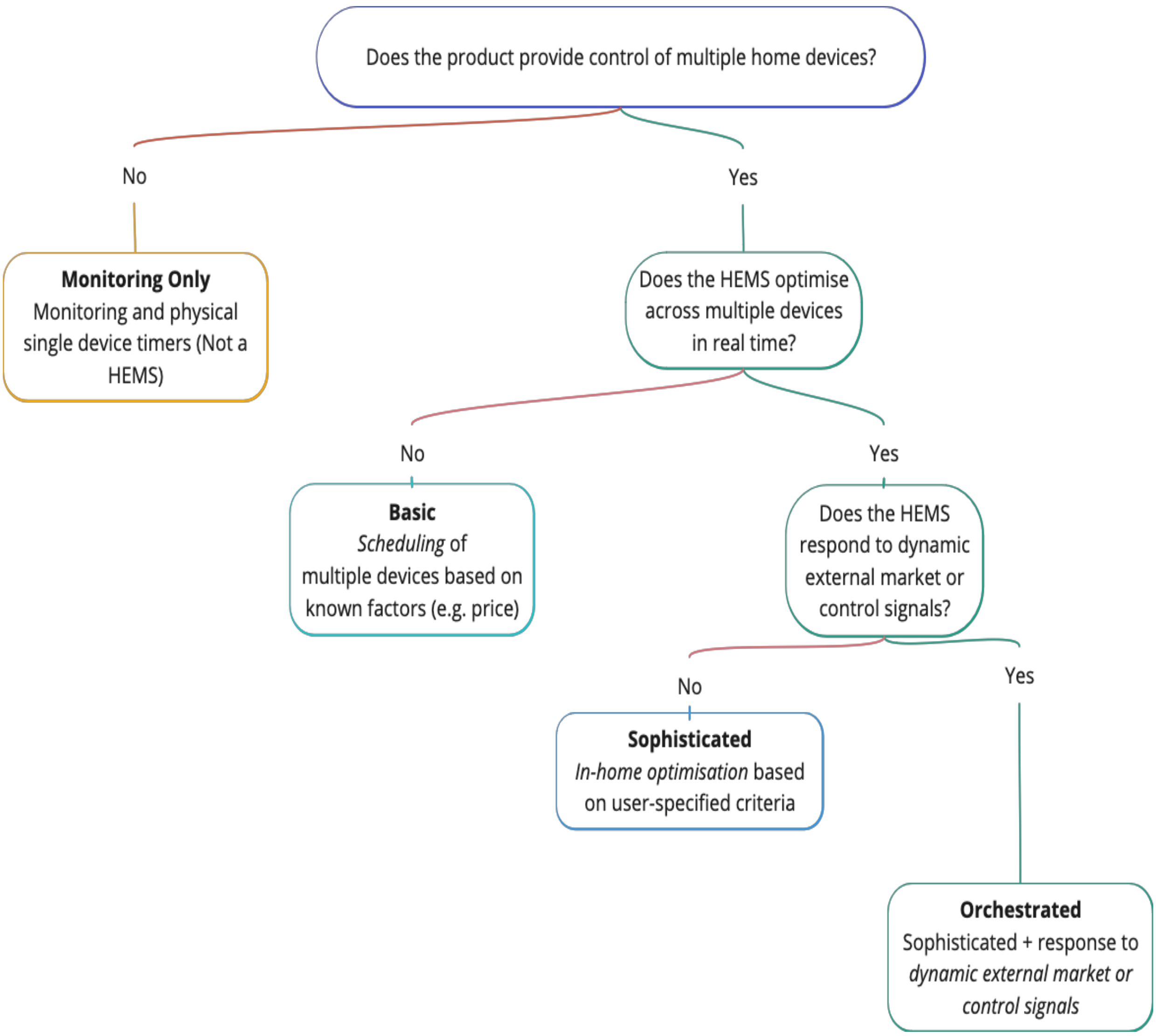

Figure 14: Decision tree for determining HEMS sophistication classification

HEMS functionality

The classification framework in

Table 7 was used to assess the level of sophistication across all the HEMS devices categorised in the market scan. This proved to be a challenging task, as it was often unclear from the available information exactly what degree of control would be delivered, over which devices, and in which circumstances, and whether that control was currently available to purchase, or was expected to be available soon. This is reflective of the rapidly changing market both in terms of devices available, as well as the range of household appliances devices can effectively integrate with. To manage this challenge, the study allocated two separate functionality categorisations to each device:

- **Cautious:** cautious or minimum stated capability based on current marketing over which there was a degree of certainty, and
- **Highest stated:** generous or highest potential capability as claimed in marketing or industry news coverage. This might be higher because the company has announced additional capabilities will soon be available, or capabilities are available when additional devices are added to the system, or there are contradictory statements of capabilities present in the public domain.

The proportion of HEMS that were categorised within each level of sophistication, for both minimum and highest stated, are shown in Figure 15. This shows that when a cautious approach is applied, most devices are providing only basic control (30%) or monitoring (34%) functionality, with one-quarter providing sophisticated in-home optimisation (24%) and a small number capable of providing an orchestrated response to external market or network signals (12%).

This changes significantly when considering the highest potential capabilities. Less than a quarter of devices only provide monitoring (6%) or basic (10%) functionality, with the majority providing sophisticated control (51%) and one-third capable of some level of orchestration (33%).

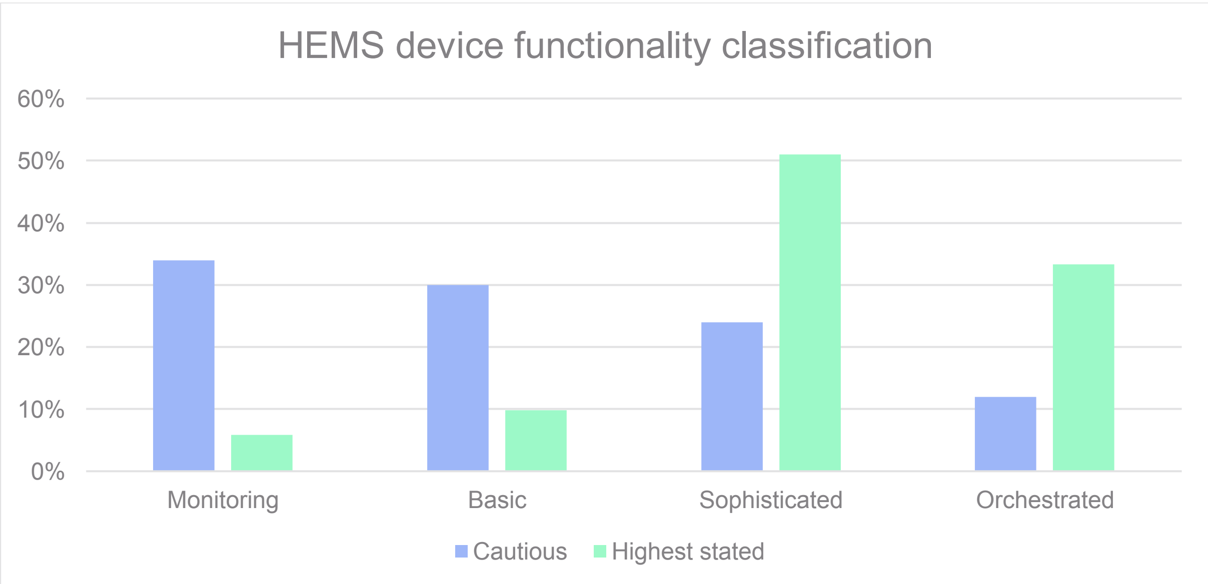

Figure 15: Levels of control sophistication of HEMS devices, categorised using both a cautious and highest stated assessment (n=51)

The scope of ambiguity within the classification of the HEMS devices is represented in Figure 15, showing the spread of HEMS sophistication and the associated uncertainty. Dark blue dots represent a cautious assessment of capabilities. Light blue dots indicate the highest stated capabilities. The analysis is also split between device location, to see how the uncertainty is spread across this categorisation.

Factors contributing to this uncertainty include planned capabilities which are not yet available, inconsistent technical descriptions of the products, the reliance of some products on additional hardware to achieve their stated functionality, or higher levels of control only available for a limited scope of household appliances (e.g. EV chargers only). The majority of devices within the scan indicated a degree of uncertainty, as reflected in

Figure 16. The most common changes were from devices categorised as monitoring or basic, to sophisticated, though there are examples of all the permutations of increasing control.

This disparity between classifications highlights both the rapidly evolving nature of the HEMS market, the near-term functional potential of HEMS, and the challenges in evaluating their capabilities both for householders and policy or industry stakeholders.

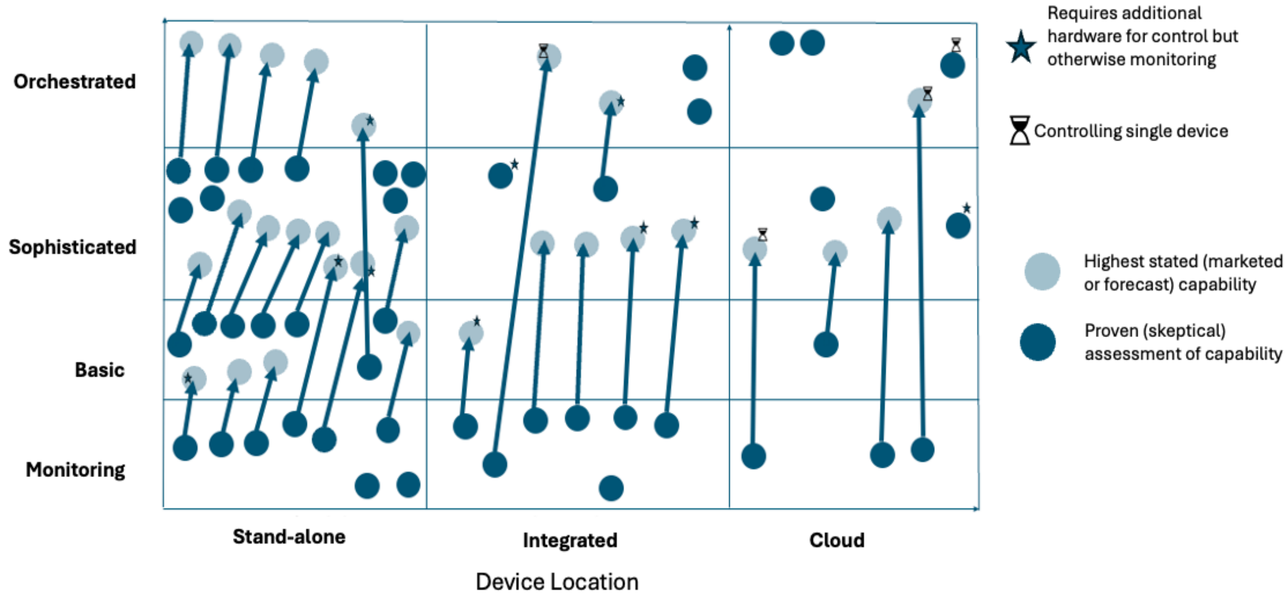

Figure 16: HEMS sophistication spread and uncertainty

HEMS functionality by region and device type

Additional analysis was undertaken to look for patterns in the functionality of HEMS products available in different regions, or in different device installation types. In both cases, the cautious approach to categorising the HEMS was used. The analysis of sophistication by region (Figure 17) that most devices available in every region offer only either monitoring or basic control features, except in the Australia/Pacific. Orchestrated control products were available in the Australia/Pacific, and Europe, with only globally available products currently providing orchestration in Asia and North America.

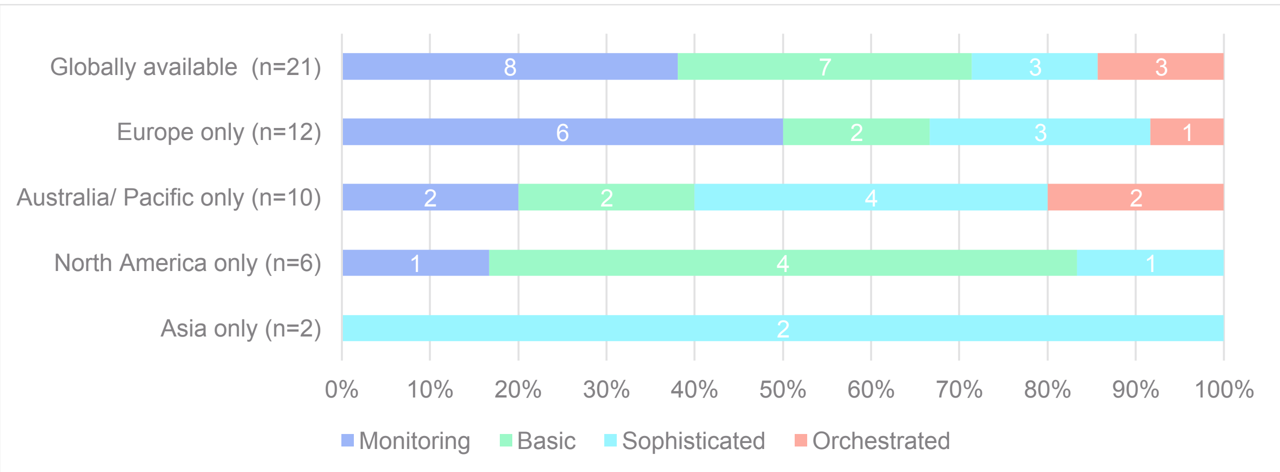

Figure 17 Sophistication of HEMS devices by region (value in bar shows device count per category) (n=51)

Figure 18 below illustrates the sophistication the HEMS devices by installation type. This shows that separate devices predominantly offer basic control, with only a few providing sophisticated control capabilities, and just one device achieving orchestrated control. In contrast, cloud-based devices exhibit a higher level of sophistication, delivering more sophisticated and orchestrated control, although fewer cloud-based devices were reviewed compared to standalone ones (less availability). Devices integrated into equipment, on the other hand, showed a split between either focusing on monitoring functionalities, or more advanced (sophisticated or orchestrated) control.

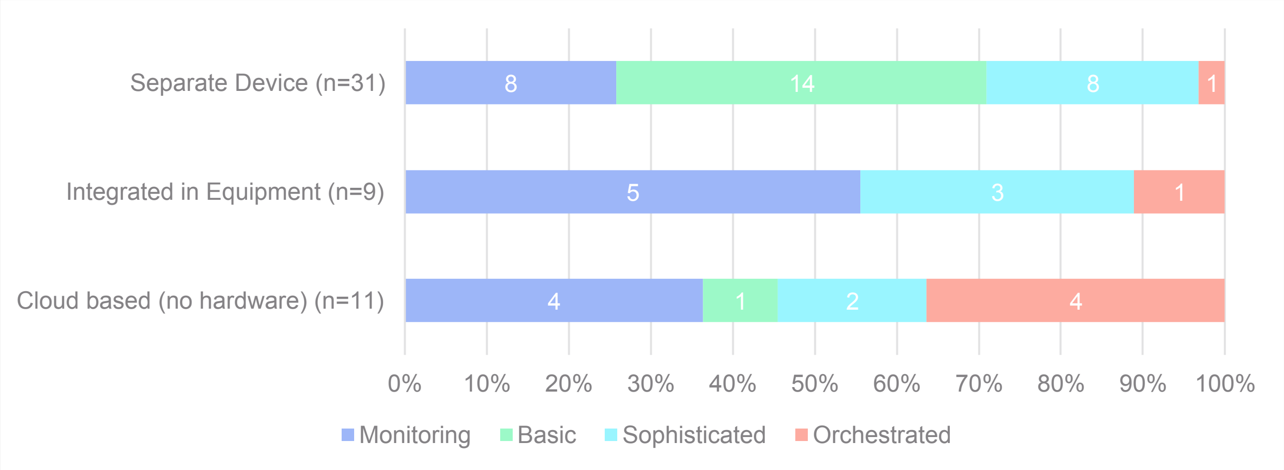

Figure 18 Sophistication of HEMS devices by installation type (value in bar shows device count per category) (n=51)

Table 8 below provides a high-level summary of the HEMS data classification framework for four case study products. It compares a separate device, a smart meter-integrated device, a CER-integrated device and a cloud-based device.

5.6 Case Studies

	Village Energy (Voltello)	Intellihub	Alpha Cloud (Alpha ESS)	DLS solution with ALICE (AmpX)
Description				
Company background	Tech Company	Tech Company	PV/Storage Specialist	Tech Company
Installation type	Separate Device	Integrated in Equipment (smart meter)	Integrated in Equipment (Battery)	Cloud based (no hardware)
Type of control	Hybrid	Hybrid (Partnership with VPP provider)	Hybrid	Cloud based (no hardware)
Availability	Australia only	Australia only	Global	Global
Generation and storage capabilities	Sophisticated	Orchestrated	Orchestrated for BESS	Basic
Load capabilities	Sophisticated with additional hardware	N/A	Orchestrated for EVs	Sophisticated
Cautious overall HEMS control	Sophisticated	Orchestrated	Sophisticated	Basic
Highest stated overall HEMS control	Orchestrated	Orchestrated	Orchestrated	Sophisticated
Notes on classification	*Trialled third party control curtailing solar export at negative price*	*Only provides CER functionality*	*Orchestrated control for EVs and BESS if connected to the AlphaESS batteries*	
Interoperability categorisation	Bespoke Integration	Bespoke integration	Open source for monitoring and closed ecosystem for sophisticated use of battery	Bespoke Integration

Table 8: Case studies of HEMS device data collection framework

5.7 Summary

This market scan aimed to provide insights into the state of the global HEMS product market in 2024. Detailed information was collected and categorised for 51 devices, to understand the types of products available, where they are available, how they are connecting to household generation, storage and flexible loads, and what degree of information and control they provide to householders and third parties. The lack of specific sales data meant the analysis of the market focused on the spread of available products, without consideration of which HEMS devices are most widely used. While this data would be very useful, it is likely to be difficult to obtain unless the registration of HEMS devices becomes widely required by regulators.

The scan found that there is significant diversity in available HEMS products. This is evident across all classification categories, from physical design of products and how they are installed, to the types of companies that are offering HEMS products, the business models underlying HEMS devices, and the control functionalities provided. The diversity of different design choices is representative of the trade-offs that HEMS providers need to consider in their products, with clear advantages and disadvantages for many of these trade-offs.

It is difficult to identify trends when conducting a scan at a single point in time, however it was obvious that the market is evolving rapidly. It was not uncommon to encounter examples of devices used and reported on from trials a few years ago, or discussed in the literature, that are either no longer available, or have substantively changed the type of device they now sell. The difference noted between *cautious* and *optimistic* interpretations of control functionality highlighted the trend towards greater levels of in-home optimisation functionality, along with an increase in enabling third-party orchestration. However, there were few – if any – devices available that deliver on *all* of the desirable use cases (as outlined in Section 2). This dynamic, along with the different approaches to interoperability with household load and CER devices, makes it very challenging for customers to assess what HEMS products will work with their equipment and yield the desired functionality.

There appears to be some regional variation in product types and functionality. For example, North America and Europe show more advanced control of loads, whereas in Australia advanced control and optimisation of household generation and energy storage (e.g. solar, batteries) is more common.

Globally, the HEMS market is clearly fragmented, diverse, and rapidly evolving in various directions. The final section of this report considers the policy landscape relevant to HEMS, and reflect on approaches to support the development of beneficial functionality better customer outcomes.

6 Issues for policymakers

6.1 Existing smart appliance standards

This is not a comprehensive review of smart appliance standards that may carry relevance for HEMS, but rather a listing of relevant standards that the research team encountered during the market scan in major markets of the EU, UK and US. A complementary review of smart appliance standards and flexible demand markets across several case study jurisdictions (UK, EU, Germany, California, Hawaii, Australia and New Zealand) can be found in an accompanying report.

European Union

The Code of Conduct on energy management-related interoperability of Energy Smart Appliances was launched in April 2024 (European Commission, 2024). It promotes energy efficiency and interoperability among devices by encouraging manufacturers to design appliances that can communicate with each other and with energy management systems. It includes an agreement by product manufacturer signatories to make all reasonable efforts to 'Ensure the implementation of interoperability profiles based on standardised open Application Programming Interface / open communication protocol'. The Code of Conduct covers the following electrical appliances that have an energy label:

- White goods: washing machines, tumble driers, washer-driers, dishwashers, and
- Heating, ventilation and air conditioning (HVAC), including water heating.

The preparation for the second phase of the Code of Conduct has started to include energy management systems (EMS), photovoltaic inverters and electric vehicle chargers.

United Kingdom

Under the Smart Systems and Flexibility Plan 2021, Great Britain has funded the development of a voluntary standard *PAS 1878:2021 for Energy Smart Appliances* (ESAs) that "are electrical consumer devices that are communications-enabled and capable of responding automatically to incentive signals (such as price) or other more direct control signals (such as specific instruction to operate at a given power at a certain time of day), by shifting or modulating their electricity consumption, storage, and/or production" (BSI, 2021). More detailed than the EU code of conduct, this standard was launched before development of the EU Code of Conduct commenced.

United States

The voluntary ENERGY STAR® program[2] for efficient appliances (which includes criteria for 'connected' products, including air conditioners)[3] has operated for several decades. Under the Energy Star program, the criteria stipulate that open standards shall be used for all communication layers. Meeting connected criteria is optional for all products where connectivity is not the primary driver of energy performance. However, it is required for connected thermostats and smart home systems to achieve ENERGY STAR certification.

[2] https://www.energystar.gov/
[3] https://www.energystar.gov/sites/default/files/ENERGY STAR Version 4.0 Room Air Conditioners Program Requirements.pdf

6.2 Policy Options

Industry opinions are divided on whether HEMS, as in-home gateways, will emerge as the dominant model of control of residential devices. An alternative pathway is *direct* integrations between OEMs of 'major' residential equipment (solar, batteries, hot water and heating/cooling systems) and energy industry players (energy retailers, networks, aggregators or market operators). Policy makers will need to closely follow emerging positions on this issue to tailor their responses. There are also active debates about the level of specificity and centralised control that national regulators and legislators should take in a fast-moving technological landscape in which business models are still forming.

Policy to aid the development of HEMS product markets and their functional application can include the development of interoperability and data sharing standards, product regulations, supporting processes such as compliance checks, legislation of consumer protection, or connectivity standards tied to incentives. These policy options are briefly discussed below.

Interoperability

Interoperability is critical for the successful functioning of HEMS products, both for how these gateway devices communicate and integrate with the energy system (to respond to external signals from energy market operators, retailers or distribution networks), and for how customer outcomes are successfully optimised behind-the-meter with a wide range of appliances. If all devices are using different communication protocols, only a fraction of flexible loads may be accessible for grid services and HEMS providers will require bespoke integrations to communicate with and control each device type. The latter results in expensive and time-consuming software coding being undertaken in parallel by numerous appliance and HEMS device manufacturers. It can also make it more difficult for new innovators to enter the market, once others technology suppliers have established integration and hold market share. From a customer perspective, the absence of interoperability constrains customer choice, given a very small subset of devices may be compatible with their existing equipment. Customer access to behind the meter orchestration is also reduced. To improve interoperability and underpin a more rapid scaling of the market and improved customer experience, a three-part solution is required:

1. Development of **interoperability standard/s** and technical standards regarding flexible demand capability for critical consumer energy equipment, such as heating/cooling equipment, inverters and hot water systems. An example is Great Britain's voluntary PAS 1878:2021 for Energy smart appliances, discussed above.
2. **Legislation** to require manufacturers of HEMS *and* compatible appliances to adopt a particular interoperability standard for a given market, or open protocols more generally. A key issue is that there is currently no single interoperability standard that comprehensively covers all parts of the challenge at hand. This makes it difficult for policy makers and regulators to dictate a universally appliable standard. As such, we understand that some jurisdictions are leaning away from specifying a single standard, instead opting to mandate that open communication protocols should be used, thereby letting the prominent standards emerge. Government support to accelerate standard development may also be warranted. Some examples of relevant standards include:
    a. OpenADR: Perhaps the most universal standard available, OpenADR is a "two-way information exchange model and global Smart Grid standard".[4] OpenADR is selected in PAS 1878:2021, and recognised by the International Electrotechnical Commission as standard IEC 62746-10-1 ED1.
    b. IEEE 2030.5: Commonly used communication standard between smart grids and consumers. The standard has been recommended as a default protocol for smart inverters communication for in California's Rule 21.[5]

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[4] https://www.openadr.org/
[5] https://standards.ieee.org/ieee/2030.5/5897/

c. Matter: An open-source connectivity standard developed for the integration of smart appliances, mobile applications and cloud services. Compliance with the standard is governed by a commercial party. [6]

d. EEBus: an open-source standard that facilitates communication between energy devices, regardless of their manufacturers or underlying technologies. Compliance with the standard is governed by a commercial party. [7]

These standards are designed to establish common protocols to ensure seamless interoperability of smart home devices with the existing smart appliances. HEMS manufacturers need to ensure that the devices are compatible with these standards to enhance smooth communication and widespread adaption of smart home devices globally.

3. **Protocol requirements and compliance testing** regime: Current experience of Australian HEMS developers suggests that claimed compliance of appliance manufacturers with interoperability protocols is commonly only partial, with effective interoperability standards also requiring clear protocol requirements (e.g. register mapping) as well as testing and verification required to ensure compliance(Briggs, Langham, et al., 2024).

Data sharing frameworks

Consistency in data sharing formats via web interfaces (Application Programming Interfaces, or APIs) can streamline information sharing. These may be integrated or separate from technical appliance or interoperability standards. As an example, the California Energy Commission has developed the Market Informed Demand Automation Server (MIDAS), a database and API for contributing and accessing information on time-of-use, critical peak and real-time pricing structures, carbon emissions intensity of electricity generation, and 'Flex Alert' signals issued by the California Independent Operator. It is hoped that product developers will harness such frameworks for communication and coordination.

Consumer protection

While the orchestration of multiple smart or flexible capabilities unlocks the best network and system benefits, consumer buy-in is crucial for acceptance of third-party control. A range of consumer protection issues may be encountered in relating to HEMS. For example, it may be necessary to consider the regulation of, or the development of principles surrounding the primacy of consumer choice when considering third party delegation for flexible load control. Such an approach may be necessary to prevent products being developed that extract value for third parties, with limited transparency or control of the household, which could erode trust in flexible demand mechanisms and limit uptake. Furthermore, there are many parties involved household participation in demand flexibility (such as retailers, aggregators, equipment manufacturers and HEMS providers), so careful consideration will be required as to who is responsible when issues arise, and how consumer protections are embedded.

Indirect mechanisms

While not directly related to HEMS, policy makers may have other indirect levers that can be used to stimulate the market for HEMS and demand flexibility, or promote device interoperability capabilities that enhance HEMS connectivity. These may include:

- **Incentives:** Many governments promote the uptake of energy efficient appliances through mechanisms such as white certificate schemes, which can be used to stimulate the uptake of voluntary product standards or features.[8] For example, in Australia, the Victorian white certificate scheme recently amended the eligibility for rebates to require hot water systems to have a timer to enable flexibility, and recommends the inclusion of an open communication protocol.(Kuiper, 2024a) Jurisdictions within the US have tied incentives under the Home Electrification and Appliance

[6] https://csa-iot.org/all-solutions/matter/
[7] https://www.eebus.org/what-is-eebus/
[8] For example; Spain - https://www.iea.org/policies/1621-energy-efficiency-obligation, France - https://www.iea.org/policies/1854-white-certificate-scheme-obligation, Australia (NSW) - https://www.iea.org/policies/1110-nsw-energy-savings-scheme

Rebates Program (part of the recent Inflation Reduction Act initiatives)[9] to ENERGY STAR certification, which carries connectivity standards for certain types of connected appliances (as mentioned earlier in this section). Thus, without mandating, governments can use pre-existing incentives to encourage smart appliance standards for many products entering the market.

- **Distribution network integration:** First developed in South Australia and being rolled out in other Australian distribution networks, operators are implementing dynamic network connection agreements. These have initially focussed on 'flexible export' (AER, 2022) arrangements to allow larger solar connections but ramp down exports for short periods when the network is congested, or the market is oversupplied. While flexible exports are of limited relevance to HEMS, some network operators are looking to extend the flexibility approach to connection agreements for the *importing* of power. Such dynamic connection agreements may become standard practice for how customer connections for EV charging are managed to avoid exacerbating peak loads. This dynamic connection agreement approach (which involves a combination of a new customer connection policies, and mandates for customer devices to be compatible with dynamic signalling) may stimulate the market for 'gateways' behind which the customer must control and optimise their usage. Normalisation of this type of network connection arrangement could drive demand in the HEMS market.

[9] Such as Hawaii, see: https://governor.hawaii.gov/main/lowering-costs-for-working-class-families-the-home-electrification-and-appliance-rebates-hear-program/

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8 Appendix A

Table 9: Overview of market scan data capture framework

Category (Lvl 1)	Product characteristics	Description
Product Overview	Product and company details inc. description and links	
	Single/multi device control	Does the product control multiple devices in households or only a single device?
	Installation type	Where is the product installed? • **Separate device** – Separate hardware product providing control of the devices. • **Integrated (equipment)** – E.g. within batteries, solar inverters or HVAC to provide control. • **Integrated (smart meter)** - Installed in smart meters to access the data and control load accordingly. • **Cloud based** – Only cloud based
	Installation complexity	**Householder** - Able to be installed by the household (mostly plug and play device provided with the set of instructions) **Electrician** - a qualified electrician is required to install the HEMS in the household.
	Degree of cloud control	**No cloud (local)** - refers to hardware-based HEMs which does not provide any cloud data or no third party control. Consumer can visualise the data, get the forecasts according to AI or other tools, and set the controls accordingly.
		Partial control - refers to control where third party is involved. This includes maybe an extent of control by the third party or getting signals from the third party. This includes getting market signals from the retailers, network providers or integrators and providing degree of device control to these entities. For instance, allowing retailers or third party to automatically charge your batteries in case of the harsh weather event. Partial control involves hardware as well as software.
		Fully cloud based does not include any hardware component. Households are being controlled by the third party to provide efficient and automatic control to the households. This allows consumers to participate in the Demand Response programs, or take part in the network stability. This also includes being the part of the VPPs or other programs.
	Type of control	**Aggregator/retailer integration** - implies the degree of control offered by the third party (retailer or aggregator). For instance, allowing the retailer to charge the batteries at the time of an upcoming harsh weathers.
		Customer based control - refers to getting insights from the system and providing access to the consumers to make smart decisions about the control.
		Energy monitoring - refers to allowing HEMs to monitor and giving data to the consumers to make decisions according to the available data.
	Use case/sales pitch	Use case refers to specific end goal which HEMs product is marketed as being designed to achieve. It could be the energy consumption, enhance affordability, network benefits, providing control to the consumers, home automation etc. While it may deliver multiple use cases, this captures the primary case in the marketing of the product.
Market Data	*Market penetration*	*Details of how widely the product is sold - e.g. XX number of countries, globally, in YY regions etc*
	Regional availability	Tick box of specific regions of interest - those that were commonly mentioned in the market scan: Europe, North America, Asia, Australia/Pacific, Other
	Market share	*Share of the total sales market, and/or position in the market (e.g. most sales)*
	Market forecasts	*Sales figures for the product, and/or information on the number of 'eligible' households using the product*

Category (Lvl 1)	Product characteristics	Description
	Affordability/Pricing	Prices of the HEMS product including upfront or ongoing (e.g. subscription for service) costs
	Business model/Revenue stream	Upfront cost, ongoing subscription, or combination
Technical Capabilities	Solar PV Management	Attempt to classify the level of control provided to each device with the system (if provided) – i.e. basic, sophisticated or orchestrated see table below for more detail.
	BESS management	
	HVAC control	
	Hot water system control	
	EV management	
	Generation and storage control categorisation	Classification of control of just the storage and generation assets in a household
	Load control categorisation	Classification of control of the hot water, HVAC and EV charging loads within a household
	Cautious overall HEMS control	Assessment of the level of functionality based on marketed *current* capabilities (a deliberately cautious approach reflecting the dynamic nature of this field)
	Highest stated overall HEMS control	assessment based on the highest potential capabilities of a product as claimed in marketing or industry news coverage – monitoring, basic, sophisticated or orchestrated
	VPP integration	Whether the HEMs allow users to participate in the VPP program.
Commun-ications	Communications – wired and wireless	How does the product communicate to behind the meter devices – wired (LAN or Wired), wireless (Wi-Fi, 4G/5G or Zigbee)
	Comms protocol – Behind the meter	Interoperability with existing devices (e.g. solar inverters, HVAC systems, HWS) through different comms protocols such as Open source, OEM API, open ADR… inc. ModBus, SunPec, RTU, or TCP
	Interoperability categorisation	**Closed ecosystem** - only works with compatible products using a proprietary comms protocol (or limited functionality)
		Bespoke integration - no restriction on API usage (private protocol, but openly published), but requires specific work to design integration
		Open Standard - specifically uses an open-standards based protocol
	Upstream comms protocol	Upstream communication refers to the data exchange from the home energy management system with external entities such as utility companies, grid operators, or energy service providers through different sets of protocols (e.g. IEEE 2030.5, OpenADR, CSIP? EEBUS, ANSI/CTA-2045)
Customer Experience	Details on the customer interface and level of detail, along with technical support and customer service	How is the customer experience with the product? Is there any app or portal or dashboard to get the information? How is the user interface of the product?
Other	Any other emerging details, or information on certification, standards and compliance	e.g. any details on if the product is in compliance with national or international standards

For clarity, these levels are interpreted for each end use, or use case in Table 10, below.

Table 10: Interpretation of HEMS levels of sophistication for each end use

End Use	Monitoring	Basic	Sophisticated	Orchestrated
Solar (Rooftop PV)	Monitoring only	N/A	Curtail solar generation or divert to hot water heating to satisfy known (static) network export limit or pre-defined export charge. If battery is present this would consider battery stage of charge (see BESS below).	Curtail solar generation or divert to hot water heating in response to dynamic network or price signals (e.g. 'Dynamic Operating Envelopes') or 'flexible exports' (i.e., other market-based signal, such as a retailer limiting their exposure to negative wholesale market prices).
Battery (BESS)	Monitoring only*	N/A	Charge rather than export, or discharge rather than import, to optimise financial gain, solar self-consumption or site resilience.	Manage charging/discharging in response to external signal(s) and may incorporate frequency, fast frequency or voltage response market participation. Virtual Power Plants (VPPs fit within this category).
Heating/ cooling (HVAC)	Monitoring only	Timer and setpoints based on daily schedule, with manual override	Heating/cooling optimised according to daily schedule and integrating solar/battery operational data (e.g., pre-cooling while solar is generating).	DRED, ripple control or smart thermostat responding to dynamic prices or other external signals. The most sophisticated functionality is setpoint or ramping control rather than on/off control.
Hot water systems (HWS)	Monitoring and physical timers	User adjustable HWS scheduling*	HEMS-optimised use of HWS scheduling according to behind-the-meter operational usage. May include control of immersion element to utilise excess solar generation.	As per sophisticated + external signals (including ripple control).
Electric vehicle (EV)	Monitoring and physical timers	User adjustable scheduling of EV charging set up to respond to anticipated solar generation or TOU tariffs.	User adjustable smart charging profiles that *limit or activate* charging in response to known (i.e. static) network import or export limits, or pre-defined solar export charges. May also activate vehicle-to-home (V2H) or vehicle-to-grid (V2G) battery discharging.	As per sophisticated + responds to dynamic external import or export signals (including DOEs, flexible exports, dynamic pricing). V2H and V2G is considered more likely in 'orchestrated' in response to external signal.

* This sophistication level is perhaps unlikely to exist in the market, as more advanced features are relatively standard or plausible.


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