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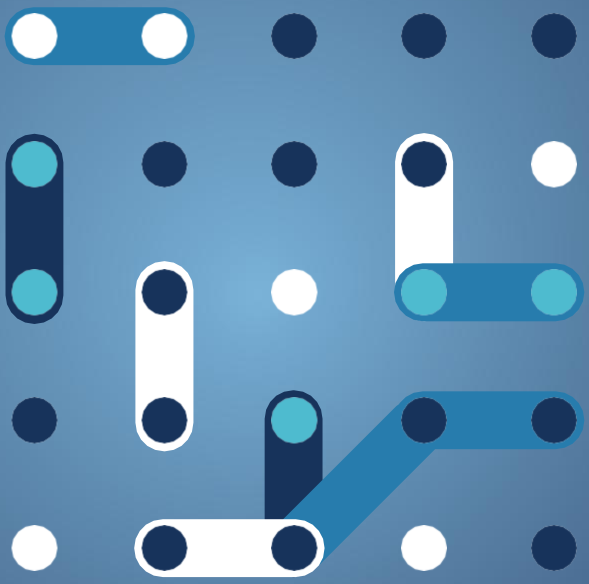
Interoperability of Home Appliances

Updated report 2025
Data Management Working Group



October 2025

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[2] **InterConnect.** “Project Website.” Available at: https://interconnectproject.eu.

[3] **Electric Power Research Institute (EPRI).** “Launch of the Mercury Initiative.” Press release available at: https://www.epri.com/about/media-resources/press-release/qxpp9egqnwuldbnvtvkj2ljuwoas8dgc.

[4] **Connectivity Standards Alliance.** “Matter: The Foundation for Connected Things.” Available at: https://csa-iot.org/all-solutions/matter/.

1 Executive Summary

This third BRIDGE Report on interoperability of home appliances provides an incremental update on the current state of affairs and activities related to this area within the BRIDGE projects. It also further elaborates on the common view on the issue and presents related external activities.

In the area of energy management in the energy grid, with all its hierarchy levels, the building level is the one where there is still a lot of potential to explore. And especially in the case of unlocking energy flexibility in residential buildings, home appliances constitute the lowest, but probably one of the most important layers of the system. These appliances indeed provide flexibility as they are the basis for successful energy management solutions, like algorithms or systems that monitor and control these appliances. The final result of the combination of these two system layers is closely related to the capabilities of the home appliances, and to the ease with which energy management can approach and exploit these capabilities. In this respect, a broader range of appliances providing flexibility and a harmonised way to monitor and control these, allows wider deployment of energy management systems and increases the available flexibility of the energy systems. Finally, to further increase the impact, trends exist to include devices outside the original definition of home appliances or to combine sectors, as well as to follow a generic approach considering all kinds of buildings with their different controllable devices to offer flexibility.

This report further refines the common ground on the interoperability of home appliances, adding the energy management layer to the considerations. But its main aim is to provide insights from the BRIDGE projects on their approaches, challenges and solutions/products related to the topic of home appliances and the ways these are applied in an energy context. The identification of these products can help the other projects to deal with the problems related to interoperability of home appliances. This third report provides an update to the previous two and compares the outputs from last two years with the current ones. It also extends the scope to the project products and external activities related to home appliance interoperability, and it draws on the next possible subjects to be covered by the DMWG Action #5 Interoperability of home appliances in the following years.

This report further refines the common ground on the interoperability of home appliances, adds the energy management layer into the considerations and provides insights from the BRIDGE projects on their approaches, challenges and solutions/products related to this topic. In this third report the potential new activities for the Action #5 Interoperability of home appliances are investigated and proposed.

2 Introduction

There are several reasons behind energy management in the energy grid. They could all probably be summarised by three main goals related to: 1) reducing the costs (for the users), 2) reducing the pollution of the environment, and 3) reliably providing a service (to the users), satisfying their needs for comfort and functionality. Even if the priority of each of these goals can be individual, they are all important, but do not always come together. Finally, any setting of fine-granular goals will most probably lead to goals that focus on satisfying a given (weighted) combination of those main goals.

The energy management exists in diverse contexts, as represented by the working groups of BRIDGE: 1) the regulatory framework sets outs the legal rules – Regulation Working Group (RWG), 2) the business models define the business relations between stakeholders – Business Models Working Group (BMWG), while 3) the customer engagement investigations focus on the needs of the users and identification of obstacles for wide adoption of the approach – Customer and Citizen Engagement Working Group (CCEWG). In the digital era, all that needs to be addressed and realised by 4) the proper exchange of data – Data Management Working Group (DMWG).

This report focuses on and summarises the activities in the Action #5 – Interoperability of Home Appliances, which is a component of the BRIDGE Data Management Working Group. It covers the third period of Action #5 – 2024-2025 and presents the state of things in the BRIDGE projects with respect to the interoperability of home appliances, the problems and the proposed approaches to deal with them. The main part of the report draws on a survey that was run among the BRIDGE projects. These results and the conclusions will be the basis for future activities in Action #5 of the DMWG.

The scope of Action #5 is related to all the other actions within the DMWG, as they all create the context and definitions for data exchange in energy management systems. *Action #1* focuses on the means to collect use cases in a structured way so that they can be compared and investigated in terms of flexibility scenarios as applied in BRIDGE projects. It helps Action #5 to identify and look at the cases where home appliances are used in order to identify and compare their interfaces and required functionalities. *Action #2* covers the global data exchange aspects, including the activities related to data spaces. From the Action #5 perspective, it identifies the data exchange infrastructure covering the appliances and the digital languages (protocols, ontologies) that can be applied. *Action #3* sets out the overall framework, taking the central role in the working group. It sets outs the generic business processes (GBPs) that synthesise the use cases into generic ones, identifying generic/harmonised roles, functions and interfaces that can be applied onto the data plane with use of standards that are then further investigated in *Action #4*. Both these actions further explain the use of home appliances for releasing flexibility and the standards that can be applied for that. Finally, *Action #6* covers the data processing aspects related to the use of AI, e.g. for control and prediction.

Within this context, Action #5 focuses on the direct interaction with the appliances towards implementing flexibility scenarios at the lowest level of the system, possibly involving prosumers. Such a scenario can represent a GBP or use case and involves data exchange. The interactions with home appliances should be generic in the sense that the flexibility-related functions (also referred to as *energy-related features*) provided by the appliances and the way to access them should be generic – supporting interoperability. The aim is to reduce the complexity and increase the universality of the control logic and to make the appliances interchangeable. The interoperability can be achieved by common approaches, set out by agreements or standards.

The report is structured as follows. Section **Context and common ground** describes the context of the activities and defines the naming used in the survey and the report. Then, chosen **home appliance interoperability approaches in BRIDGE projects** are presented. Sections **General outcome of the survey** and **Detailed analysis of specific points** provide the results of the survey in both, diagrams and deeper analysis. Then, in **Related activities towards**

harmonisation and standardisation some chosen activities are named and referred to. Finally, **Next steps towards repository creation** and **Conclusions** draw on the future plans and activities within Action #5.

3 Context and common ground

This section provides a common description of the problems related to the interoperability of home appliances, the context and the terminology used in the report. This description is being updated to cover the important aspects and is also used as the introduction to the survey distributed among the BRIDGE projects to capture their state.

In the area of energy flexibility in residential (but not only) buildings, home appliances constitute the lowest, but probably one of the most important layers of the system. The home appliances indeed provide the flexibility that can be aggregated and handled. The success of the energy management solutions, like algorithms or systems, is thus closely related to the flexibility capabilities of the home appliances and to the ease with which these capabilities can be approached and exploited. In this respect, a broader range of appliances providing flexibility, a common way to define these flexibility capabilities and a common way to control these appliances, allows wider deployment of energy management systems and increases the available flexibility of the energy systems.

The flexibility capabilities are determined by the set of features offered by a given appliance. An **energy-related feature** of a **home appliance** is a function related to monitoring and control of the appliance, accessed for **energy management (algorithm)** or energy management system (EMS) using some **home appliance API** that includes communication interface and protocol. This API allows the EMS to interact with the home appliance and to influence its energy behaviour to achieve flexibility, grid resilience and other optimisation goals. This API is intended to be used for the automated energy management and not for direct control of the appliance by the end user. For the interaction between the user and the appliance, the **user interface** is defined (see Figure 1). Appliances that provide such a home appliance API for automation are also referred to as **Energy Smart Appliances (ESA)**.

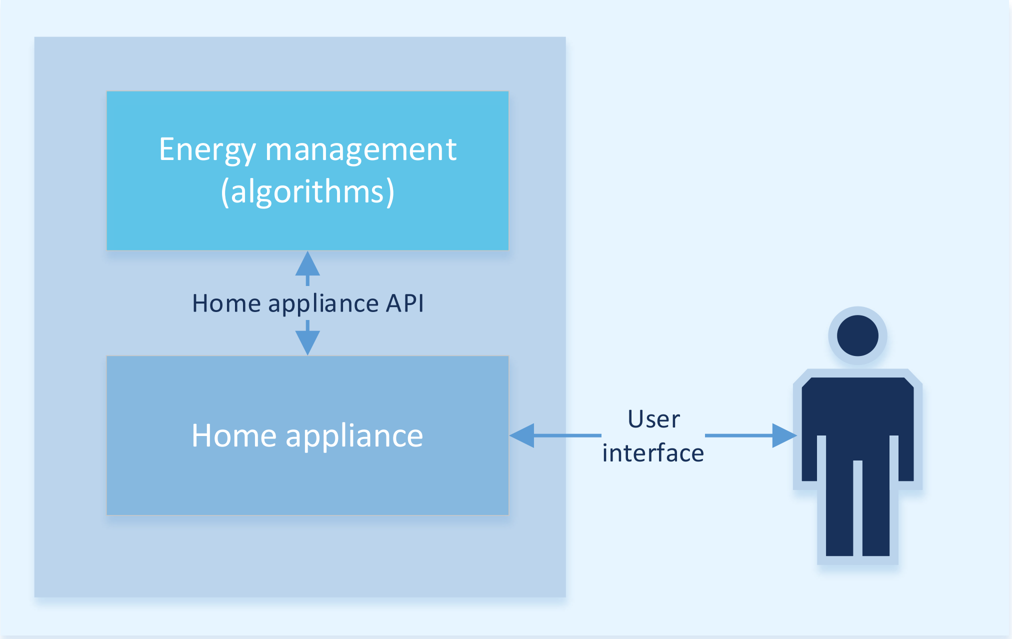

Figure 1 The interfaces of a home appliance

As shown in Figure 2 (on the left) the interaction between the energy management and the home appliance actually also covers the user of the appliance and her influence on the appliance energy behaviour (simply due to the use of the appliance) that introduces the human factor to the system (e.g., determining the usage schedule) and needs to be captured and/or predicted by the energy management based on the signals it receives over the home appliance API if no other interaction or interface between the energy management and the user exists.

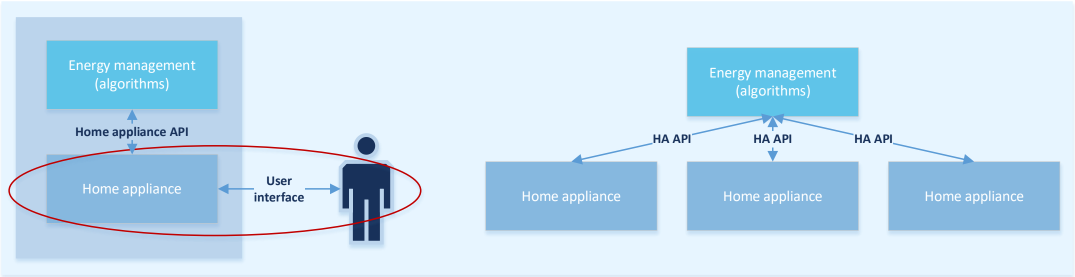

Figure 2 The detailed relation between the energy management and the home appliances

Finally, this introduction, so far, shows the interaction between the energy management and the home appliances as a single interaction only. In reality, the desired scenario is to handle multiple appliances within the same location (e.g., household). The more of them are involved, the more flexibility is available for the energy management. For better results, the energy management should interact with multiple home appliances and control them considering their synergies. But this complicates the relation between the energy management and the home appliances, and scaleability is desired. Thus, in reality, this interaction will be a complex relation between many appliances and the energy management (as shown in Figure 2, right) or even between many appliances and many (cooperating) energy management systems. In any case, each actual interaction can be realised in many ways.

The home appliance can provide the **home appliance API** directly or via an **intermediary component** (**home gateway** or **cloud service**). The intermediary component communicates with the home appliance using the **internal API**. It is important to mention that the internal API can be closed or open (it can also be proprietary or standard) and that the energy management (algorithm) does not use the internal API directly. Only the home appliance API is provided to the energy management. But since the home appliance API can also be open or closed, it may be available to every stakeholder, like the owner of the supported home appliance, or it may only be available for chosen stakeholders, like a set of associated energy management system providers.

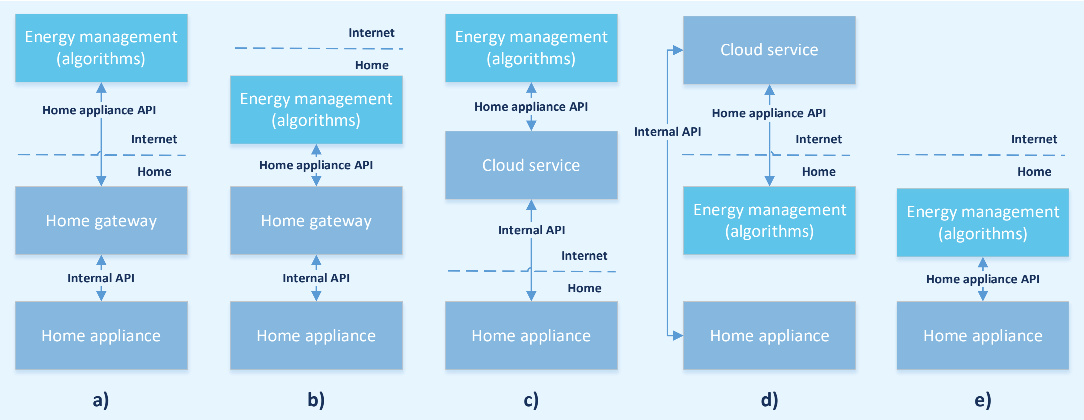

Figure 3 Possible ways for the interaction between the home appliance and energy management (algorithm)

Figure 3 presents the five main options for the interaction between the energy management (algorithm) and the home appliance. The examples a), b), c) and d) depict the approach with an intermediary component that communicates with the home appliance using an internal API and provides the home appliance API to the energy management (algorithm).

In the examples a) and b) this intermediary component is a home gateway, located within the household (and the local area network), where the home appliances are located as well. In c) and d) the intermediary component is a cloud service, thus outside the household, in the Internet. To distinguish further, examples a) and c) depict the case where the energy management (algorithm) component that is interacting with the home appliance API is located outside the home, while the examples b) and d) depict the case, where the energy management is located within the household, for both options of the intermediary component.

The last example e) depicts the case where the home appliance provides the home appliance API directly to the local energy management, allowing it to access its energy-related features. In this case, accessing the home appliance is only possible from inside the home; if the energy management was located outside the home, the home appliance would have to actively connect to it and maintain the connection, because otherwise the appliance would not be visible for the energy management, as it is behind the household router.

Further, a controllable home appliance can consist of a non-controllable part (non-smart home appliance) and a device that provides control, like a smart plug. In this case, such a combination can be considered as one controllable home appliance. In addition, a solution (e.g. a software driver) providing complex energy-related features, based on the knowledge about the appliance attached behind the smart plug, can be considered as the intermediary component.

The (energy-related) **features** mentioned here cover **monitoring and control** of the home appliance. These features include a broad set of functions. They can include simple monitoring, like reading the energy consumption, or reading the state of the appliance. But, they can also cover simple control, like switching on or off, as well as complex control like shifting load in time or controlling the consumed (and/or produced) energy in other ways. The set of features depends on the **home appliance class** (or category). Examples of such classes include washing machines, dryers, dishwashers, ovens, air conditioners. Some **specific features** can also be available only for a given **subclass**, e.g., condenser dryer vs. heat pump dryer. For the sake of the home appliance interoperability analysis, it is important to know how the logic behind more complex features is distributed between the intermediary component and the home appliance itself. But the details on energy management (algorithm) are less important here, even if the intermediary components are part of the energy management solution, for instance, the home gateway device runs the energy management algorithms. It is nevertheless important to determine where the home appliance API is located and what functions it provides to satisfy the energy management requirements and to allow it to fulfil its goals. This is also important for the interoperability of energy management components, so that these are also interchangeable.

In order to allow the energy management (algorithm) to achieve the best results, it should operate on home appliances that offer the most meaningful features. Moreover, from the interoperability point of view it is meaningful that similar features offered by different appliances are offered in a similar way, so that there is no need to change or implement the energy management (algorithm) individually for each model of home appliance. Thus, besides providing meaningful features, **interoperability** of home appliances is crucial. The intermediary component can be a solution provided by a specific home appliance manufacturer, supporting all the appliances by this manufacturer. But it can also be a solution supporting multiple manufacturers and can be considered a **framework** or **platform**. This solution already inherently supports interoperability.

Even if the energy management consists of multiple layers, the above description simplifies the architecture focusing on the layer that directly interacts with the home appliance using the home appliance API. Indeed, the energy management system may consist of multiple functional components, possibly even distributed between different physical devices within the house and/or outside. These components may actually interact with the appliances not only for monitoring and control, but also for configuration, security and maintenance purposes. These interactions also need to be covered by the home appliance API. Examples of these other interactions include:

- Device registration in the energy management system
- Set-up of security and energy management system relationship
- Maintenance of the configuration and security
- Supplying the appliance with external data (weather, energy price, etc.)

- Overall technical maintenance of the appliance

All these interactions with the home appliances are required for the energy management system to fulfil its goals. Having a defined home appliance API that allows the EMS to configure, run and maintain the algorithms involving the home appliances, the energy management may be the layer between the home appliances and external data sources (see Figure 4). The external data from reliable sources can influence the working of the energy management system and can also be provided to the appliances if needed. The energy management system is also the layer that translates the external requests and data into a set of requests to the home appliances. This is achieved in a coordinated way and by aggregating the flexibility capabilities of the home appliances.

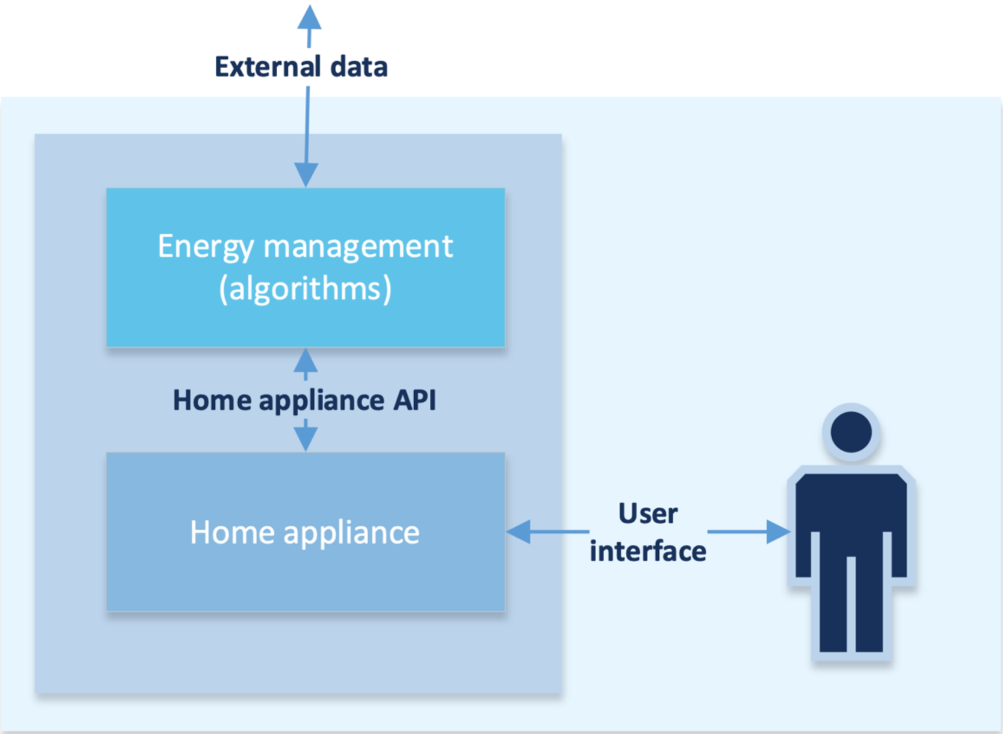

Figure 4 Interaction between the energy management system and external components

There are ongoing activities that target interoperability involving many different device classes. On the level of the European Commission (DG ENER) it is, for instance, the Code of Conduct for energy-smart appliances proposed by the Joint Research Centre[1], or the Horizon 2020 project InterConnect[2]. There are also initiatives going beyond the EU, like the Mercury initiative coordinated by EPRI. There are also approaches on the communication level that try to address the diversity in low-power home area networks (HAN), like Matter[3].

In order to capture the state of things in the BRIDGE projects, presentations were done at the Action #5 meetings and a survey was conducted. The results are presented in the following three sections. The first one summarises the presentations, the second presents the answers that can be easily analysed and presented in form of diagrams, while the third goes into the more complex text-based answers.

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[1] European Commission, Joint Research Centre. Code of Conduct for Energy Smart Appliances. Available at https://ses.jrc.ec.europa.eu/development-of-policy-proposals-for-energy-smart-appliances

[2] Interconnect [online]. Available at: https://interconnectproject.eu

[3] Connectivity Standards Alliance. Matter, the foundation for connected things. Available at: https://csa-iot.org/all-solutions/matter/

4 Home Appliance Interoperability approaches in BRIDGE projects

This section summarises the presentations on the approaches related to interoperability of home appliances that have been proposed or examined by the BRIDGE projects. These presentations were given at Action #5meetings. The approaches are diverse in how they address interoperability, the scope, the maturity in their development.

4.1 Int:net – Interoperability Network for the Energy Transition

Interoperability relies on collaboration across multiple domains. While technical interoperability in the energy sector is well-established, greater focus is needed on the interoperability of functions and businesses. Even when standards are set and interoperability models are agreed upon, framework setters, product developers, and users must align on their implementation and ensure solutions are compatible with these definitions. The Interoperability Network for the Energy Transition (int:net) project creates an open, cross-domain community that brings together all relevant stakeholders in the European energy sector.

The key elements integrated into the int:net approach, as illustrated in Figure 5, include:

1. Knowledge Base: Gathering and evaluating existing frameworks and analysing interoperability aspects in use cases
2. Int:net Maturity Model (EMINENT): Evaluating the level of maturity in how organisation manage interoperability.
3. Testing and Certification: Providing tools and methods for testing interoperability within an expanding network of testbeds and laboratories.
4. Standards and Governance: Analysing standards and how policymakers can incorporate these standards into their policies and support programmes.

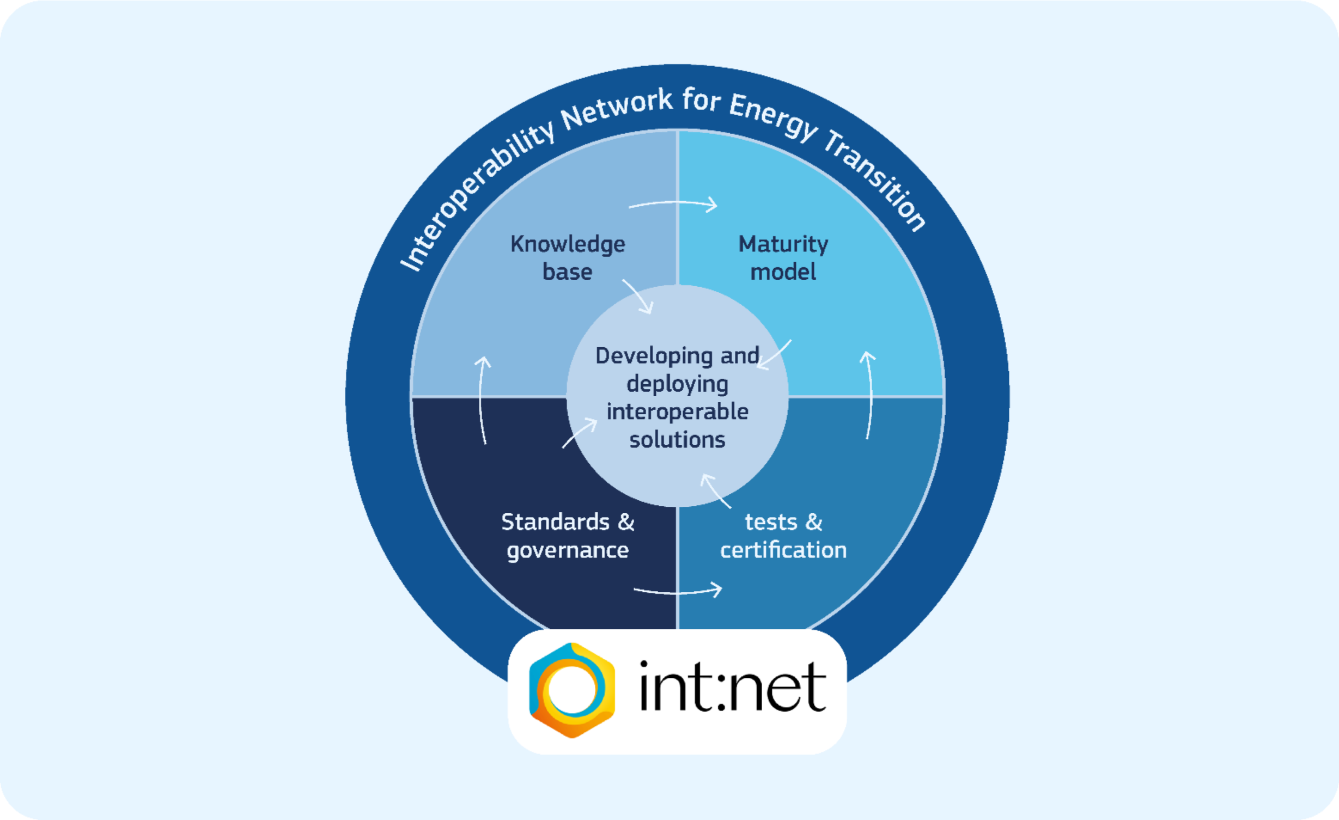


Figure 5 Int:net key elements

In the framework of interoperability for smart home appliances, the work developed by int:net can help with:

1. A comprehensive knowledge platform that offers resources and guidance on interoperability. This platform can help appliance manufacturers understand the requirements and best practices for making their products interoperable.
2. A maturity model for interoperability to measure and improve how organisations developing smart home appliances can manage interoperability related aspects.
3. Methods and frameworks for testing devices for their ability to be smoothly integrated into smart homes..
4. A community and collaboration network bringing together stakeholders from various sectors, including appliance manufacturers, int:net fosters collaboration and knowledge sharing.

In addition to the mentioned points, int:net is developing a label as a registered brand. This label is to be used to acknowledge and display efforts of an organisation towards interoperability. Specifically, it signifies the implementation of a well-defined continuous improvement process. Organisations awarded the label will be listed on a register and can use the label for their own communication purposes.

4.2 Flexibility provision from home appliances for cost optimiSation AND grid capacity enhancement

In the SUSTENANCE project the research goals have been to find technical and socio-economical solutions for decarbonisation of local energy systems via optimal integration of local available renewables using smart control of household assets. This is done via application of an energy management system, which can optimise the costs for the individual households by managing the electricity consumption for i.e. heat pumps, and EV-charging in relation to own produced power from photovoltaic systems (PV) as well as the electricity market prices and distribution grid tariffs – the latter being used mainly in relation to also taking possible grid congestion into account.

Here we will describe the technical set-up used in the Danish demonstration case, which is based on control of heat pumps and electrical vehicles (EV) of 20 individual houses according to PV power production and costs as well as provision of ancillary services to the local grid. We will also offer some recommendations in relation to the future replication of such a set-up in a European context.

In Figure 6, the monthly energy consumption of 17 houses is shown, showing that the consumption in most cases follow the same trends. Only one household (identified by the id 3342) has a very high consumption, being an old rather big house poorly insulated and not renovated.

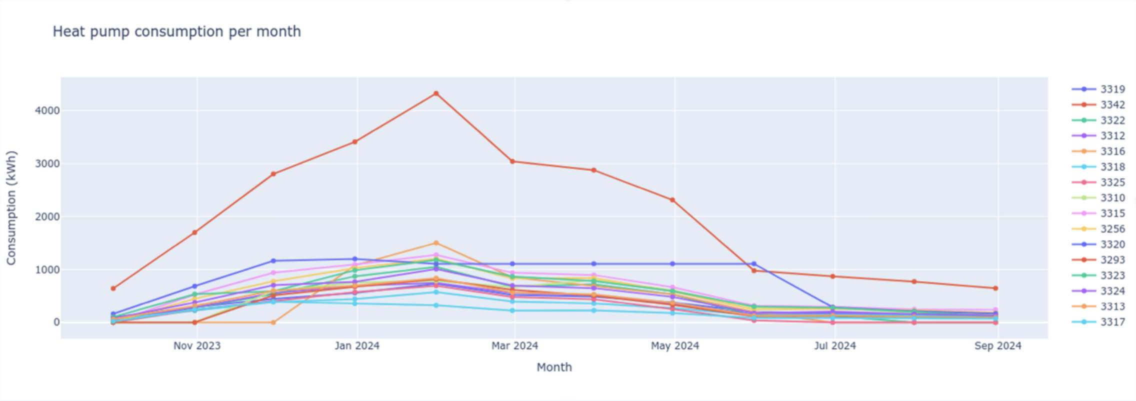
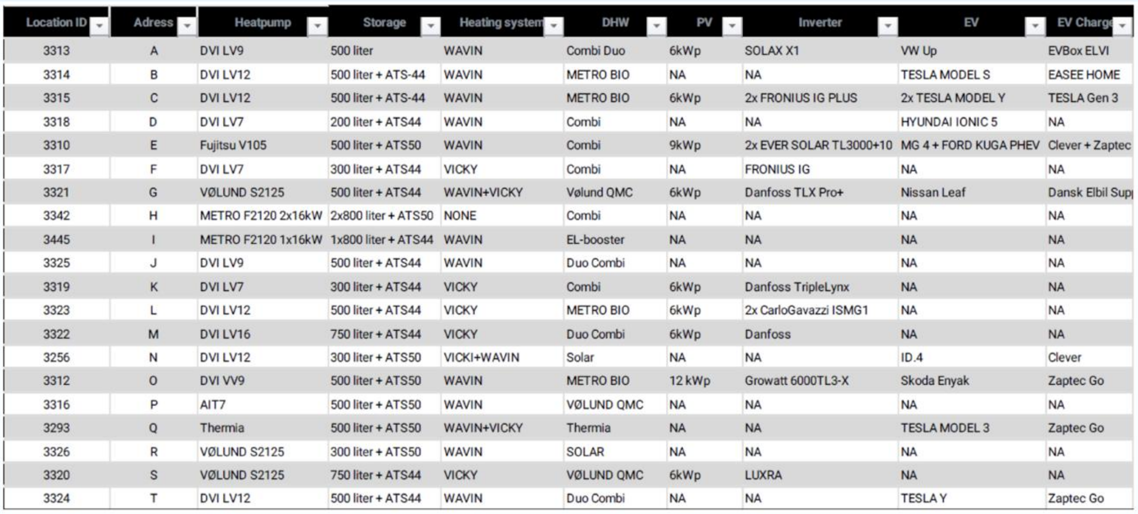


Figure 6 Heat pump consumption per month

Table 1 shows an overview of the installations in the 20 households, with heat pump manufacturer and size, heat-storage tank (Water with PCM material), possible PV, EV and EV charging installation.

Table 1 Overview of installations in the 20 households at the demonstration site



Location ID	Adress	Heatpump	Storage	Heating system	DHW	PV	Inverter	EV	EV Charg
3313	A	DVI LV9	500 liter	WAVIN	Combi Duo	6kWp	SOLAX X1	VW Up	EVBox ELVI
3314	B	DVI LV12	500 liter + ATS-44	WAVIN	METRO BIO	NA	NA	TESLA MODEL S	EASEE HOME
3315	C	DVI LV12	500 liter + ATS-44	WAVIN	METRO BIO	6kWp	2x FRONIUS IG PLUS	2x TESLA MODEL Y	TESLA Gen 3
3318	D	DVI LV7	200 liter + ATS44	WAVIN	Combi	NA	NA	HYUNDAI IONIC 5	NA
3310	E	Fujitsu V105	500 liter + ATS50	WAVIN	Combi	9kWp	2x EVER SOLAR TL3000+10	MG 4 + FORD KUGA PHEV	Clever + Zaptec
3317	F	DVI LV7	300 liter + ATS44	VICKY	Combi	NA	FRONIUS IG	NA	NA
3321	G	VØLUND S2125	500 liter + ATS44	WAVIN+VICKY	Vølund QMC	6kWp	Danfoss TLX Pro+	Nissan Leaf	Dansk Elbil Sup
3342	H	METRO F2120 2x16kW	2x800 liter + ATS50	NONE	Combi	NA	NA	NA	NA
3445	I	METRO F2120 1x16kW	1x800 liter + ATS44	WAVIN	EL-booster	NA	NA	NA	NA
3325	J	DVI LV9	500 liter + ATS44	WAVIN	Duo Combi	NA	NA	NA	NA
3319	K	DVI LV7	300 liter + ATS44	VICKY	Combi	6kWp	Danfoss TripleLynx	NA	NA
3323	L	DVI LV12	500 liter + ATS44	VICKY	METRO BIO	6kWp	2x CarloGavazzi ISMG1	NA	NA
3322	M	DVI LV16	750 liter + ATS44	VICKY	Duo Combi	6kWp	Danfoss	NA	NA
3256	N	DVI LV12	300 liter + ATS50	VICKI+WAVIN	Solar	NA	NA	ID.4	Clever
3312	O	DVI VV9	500 liter + ATS50	WAVIN	METRO BIO	12 kWp	Growatt 6000TL3-X	Skoda Enyak	Zaptec Go
3316	P	AIT7	500 liter + ATS50	WAVIN	VØLUND QMC	NA	NA	NA	NA
3293	Q	Thermia	500 liter + ATS50	WAVIN+VICKY	Thermia	NA	NA	TESLA MODEL 3	Zaptec Go
3326	R	VØLUND S2125	300 liter + ATS50	WAVIN	SOLAR	NA	NA	NA	NA
3320	S	VØLUND S2125	750 liter + ATS44	VICKY	VØLUND QMC	6kWp	LUXRA	NA	NA
3324	T	DVI LV12	500 liter + ATS44	WAVIN	Duo Combi	NA	NA	TESLA Y	Zaptec Go

As seen in Table 1, there are several heat pump manufacturers involved and they are controlled in different ways depending on this:

- Manufacturer API (Vølund and METROTHERM)
- MODBUS on device (DVI)
- MODBUS via gateway (Vølund, Thermia and AIT)
- SG Ready/ temperature manipulation via local gateway. (Fujitsu)

Further, the heating in the households are controlled by:

- MODBUS connection to underfloor heating controller
- LoraWAN connection to Smart Thermostatic Valves (STV)

Control of the EV charging proved to be rather difficult to do via the API of installed chargers. The three service providers involved (LOOAD, Spirii, and Clever) allowed API access for data retrieval, whereas control was denied, because they needed to control the flexibility according to their own unique system, operational framework and the service agreements they had made. With even more service providers generally (22 in DK at present), this complicates aggregation of local communities and we also lack standardisation, since they all operate differently.

Therefore, it was decided to control the EV-charging via direct communication with the car. This was possible for Tesla and Kia, sending preset charging schedules via the vehicle software. However, even though successful execution was achieved, the results were inconsistent due to failures leaving the car uncharged for the following day. This was probably due to the hierarchical control overlapping between the control done by the charging station and the suggested car charging control via the car software. This remains so far unsolved.

For most of the cars, the charging normally takes place during night, when the price is lowest as seen in Figure 7.

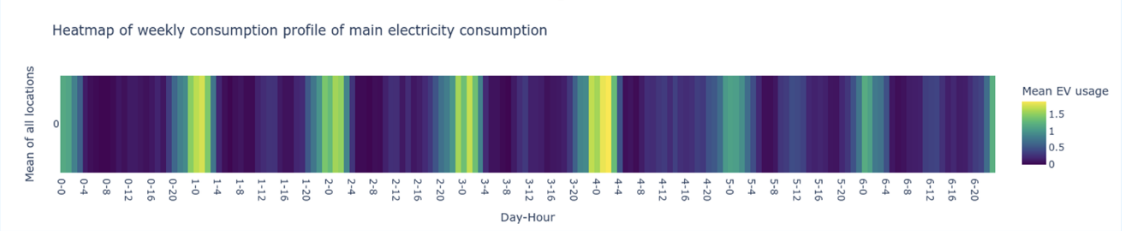


Figure 7 Heatmap of weekly consumption for EV-charging

The PV production from the eight houses from Table 1 that are equipped with PV , has been measured during the project and is shown in Figure 8. A high export is seen in summer months, and even in winter months a small amount is exported, due to missing control between consumption and production.

The PV inverters are controlled via API from manufacturers, MODBUS connections to the inverters via gateways, and measurements are performed via the sub-meters between the inverters and the main meter. The control is augmented based on historical main meter and weather data as well as forecasts.

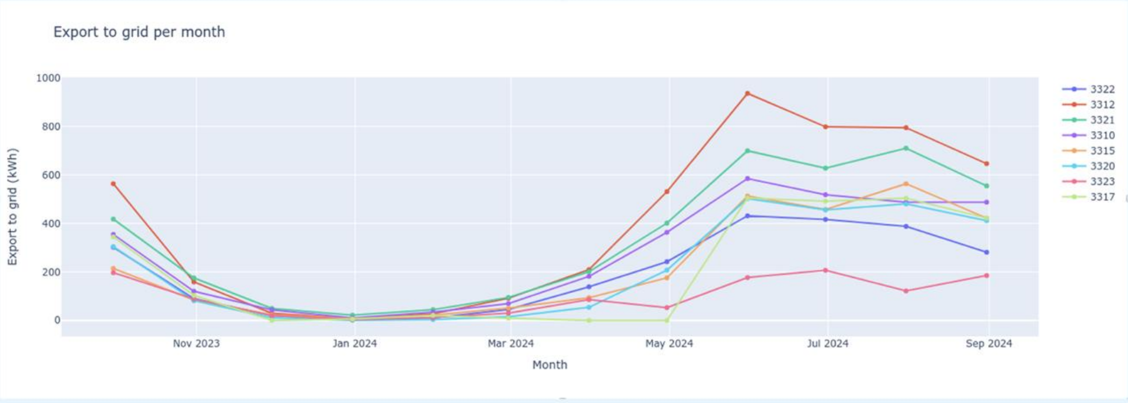


Figure 8 Monthly export to the grid

COMMUNITY ENERGY MANAGEMENT SYSTEM (CEMS)

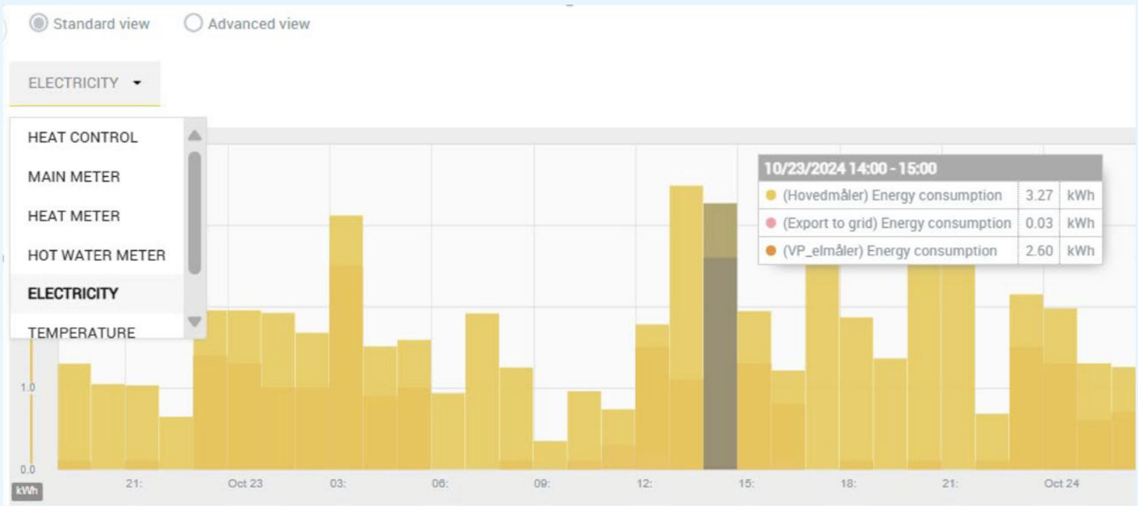
The Neogrid CEMS aggregates all relevant data within each of the connected houses and organises them in the Neogrid Building model.

The CEMS tracks the following parameters:

- Forecast heat pump demand based on historical data correlated with weather forecasts.
- Electricity prices from the grid.
- Self-produced PV electricity.

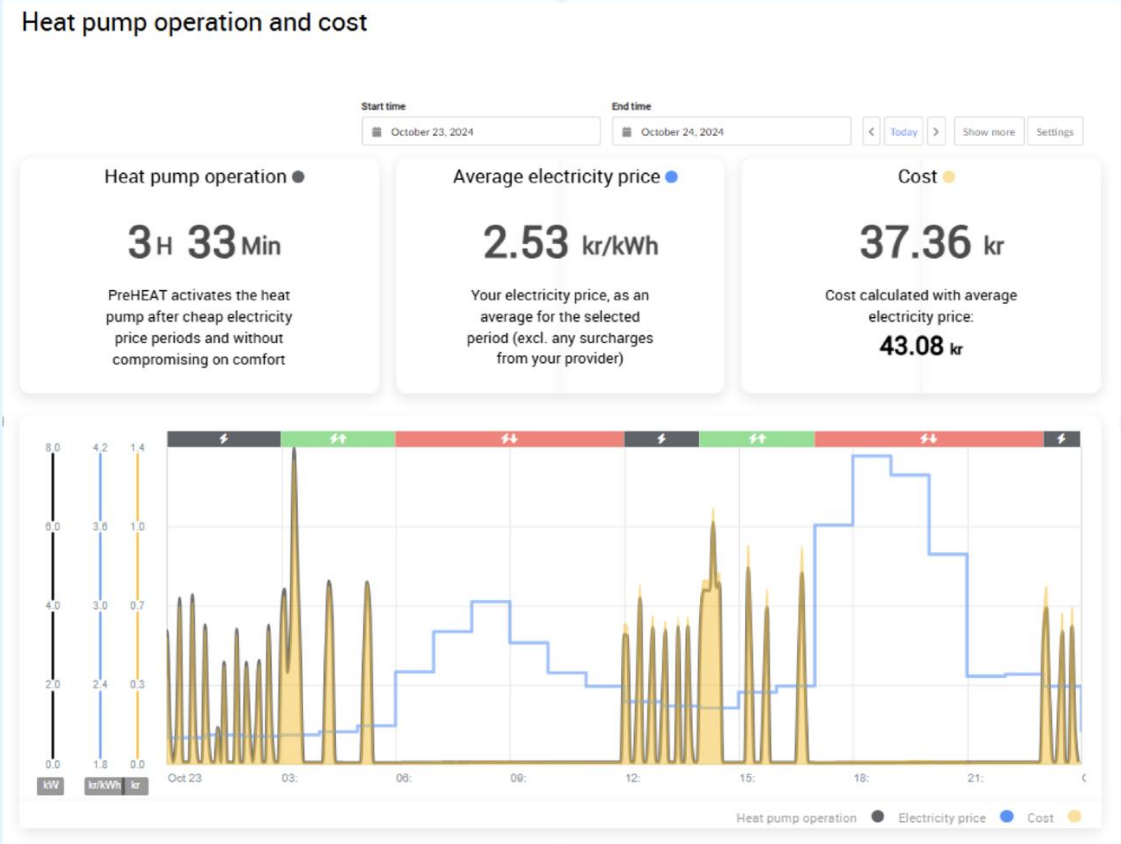
- Excess PV production from other systems within the community (this is valued at the same cost as grid-imported electricity due to regulatory constraints).

All data are logged in real time and made available for the control system. In Figure 9 data is shown. Electricity data are available as hourly values, the heat-pump data are available with 1-minute resolution. The data can also be visualised on a dashboard as shown in Figure 10.



10/23/2024 14:00 - 15:00		
● (Hovedmåler) Energy consumption	3.27	kWh
● (Export to grid) Energy consumption	0.03	kWh
● (VP_elmåler) Energy consumption	2.60	kWh

Figure 9 Neogrid CEMS data



Heat pump operation and cost

Start time: October 23, 2024

End time: October 24, 2024

Heat pump operation ●

3H 33Min

PreHEAT activates the heat pump after cheap electricity price periods and without compromising on comfort

Average electricity price ●

2.53 kr/kWh

Your electricity price, as an average for the selected period (excl. any surcharges from your provider)

Cost ●

37.36 kr

Cost calculated with average electricity price:

43.08 kr

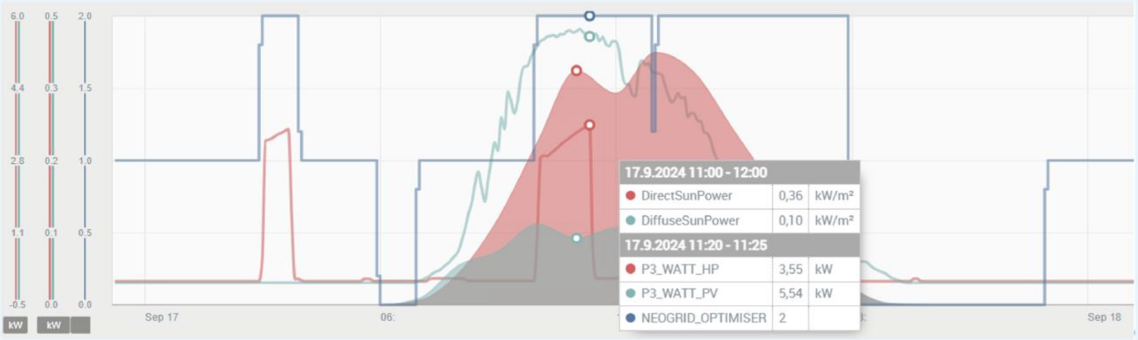
Figure 10 Neogrid Dashboard visualisation

When the data are used for optimisation, the system also measures the base consumption in the houses via the electricity meter. During the CEMS control, dynamic prices are used as well as the electricity tariffs for transporting the energy set up by the DSO. The optimisation is for both heat pumps and EV car charging based on three prices:

1. Self-consumption, where price is calculated based on the income that the energy produced from own installations would have given if it had been sold to the grid. Normally, this price is rather low.
2. Neighbour consumption, which reflects the situation when excess electricity is produced by the neighbours. If operated as a real energy community, this can be used to negotiate a reduced tariff from the DSO, making it cheaper to use local energy.
3. Grid-consumption equal to the price for purchasing energy from the local grid, normally the highest price.

Using these prices and forecast values for production and consumption, the CEMS plans the energy consumption for the next 24 hours in the community, aiming for reduced peak loads and the most cost-effective solution for the individual customers. The system is cloud-based and operated in real time, with customers able to follow the control on their dashboards (Figure 10) and understand their energy consumption patterns, for instance the **Black–Green–Red** bar in the operation dashboard in Figure 10. In this figure the heat pump operates on a normal level overnight and boosts between 9:00–10:00 to utilise the morning PV production while electricity prices are still high. Between 13:00–18:00, the system reduces production due to lower PV output.

In the backend of the system more data can be seen, and real-time data are used to demonstrate the effectiveness of the system, see Figure 11.



17.9.2024 11:00 - 12:00		
● DirectSunPower	0,36	kW/m²
● DiffuseSunPower	0,10	kW/m²
17.9.2024 11:20 - 11:25		
● P3_WATT_HP	3,55	kW
● P3_WATT_PV	5,54	kW
● NEOGRID_OPTIMISER	2	

Figure 11 Back-end data for heat-pump optimisation: SunPower: Forecast solar energy. WATT_PV: Actual PV output. WATT_HP: Heat pump energy consumption. OPTIMIZER: Signals for REDUCE (0), NORMAL (1), or BOOST (2) operation modes

CONCLUSION AND RECOMMENDATIONS

Based on the results of the SUSTENANCE project demonstration in Denmark, CEMS system has been shown to be effectively used to minimise costs for private customers. The system is able to operate according to local dynamic electricity market prices and tariffs. It enables smooth operation for a pool of customers, mitigates grid congestion and maintains customers' comfort and keeps prices low.

On the other hand, the project has also experienced several problems in relation to the implementation of the electrical system due to different regulations and missing standardisations. Therefore, in relation to the CEMS operation for local energy communities to maximise the flexibility, the project gives the following recommendations:

1. **CEMS Provider**: Partner with a reliable CEMS provider. NEOGRID has proved to be a proper candidate for this.
2. **Heat Pump Compatibility**: Verify that heat pumps are controllable. This can be assessed on a case-by-case basis by the CEMS provider.
3. **Indoor Temperature Sensors**: Ensure homes are equipped with temperature sensors connected to the heat pump, underfloor heating controllers, or the CEMS gateway.
4. **EV Charger Integration**: Choose EV chargers operated by a charge point operator that supports integration with the CEMS. For consistency, it is preferable for all chargers within the community to be managed by the same operator.
5. **DSO Partnership**: Collaborate with distribution system operators (DSOs) to develop reduced tariffs for shared electricity within the energy community. This step is crucial to the financial viability of community energy projects.
6. **Integrated Asset Management:** The service provider controlling EV chargers should also manage other key community assets, such as heat pumps and photovoltaic (PV) systems, to streamline energy optimisation.
7. **Uniformity in Service Provision:** It is important to ensure the possibility of grouping all EV chargers to have information on grid capacity and possible congestion.

8. **Integration of Enhanced Data Sources:** Use real-time data for forecast and control, and for information of grid constraints.
9. **Standardisation of Protocols:** Standards in hardware and software are needed to simplify integration across diverse service providers.
10. **Regulatory Adjustments:** Address barriers in tariff structures and incentivise local energy exchange.

4.3 Introduction to Product Data standards and DPP for supporting appliance interoperability

The European Eco-design for Sustainable Product Regulation (ESPR) is driving the harmonisation of standards for sharing product data, which is needed for fully interoperable exchange of key data, including appliances, such as within the CircThread CEN CLC workshop agreement activity (see Figure 12). This acts as a gateway to appliance data through both public direct access and private data spaces via contracts.

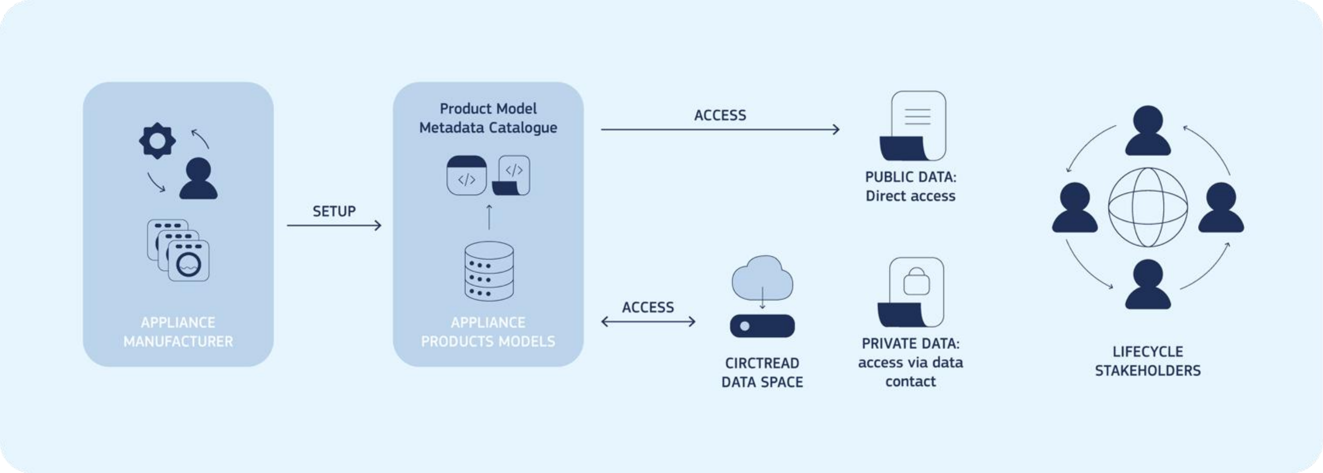


Figure 12 CircThread DPP Guidance - https://circthread.com/publication-results/project-deliverables/

The data accessible through digital product passports (DPPs) not only include mandatory product information, regarding performance and material composition, etc. but also optional additional data that can assist in optimising and using appliances for energy efficiency and flexibility services. This data can be abstracted using digital twin representations (submodels) as defined in a digital twin space, enabled by the DPP related data carrier (see Figure 13).

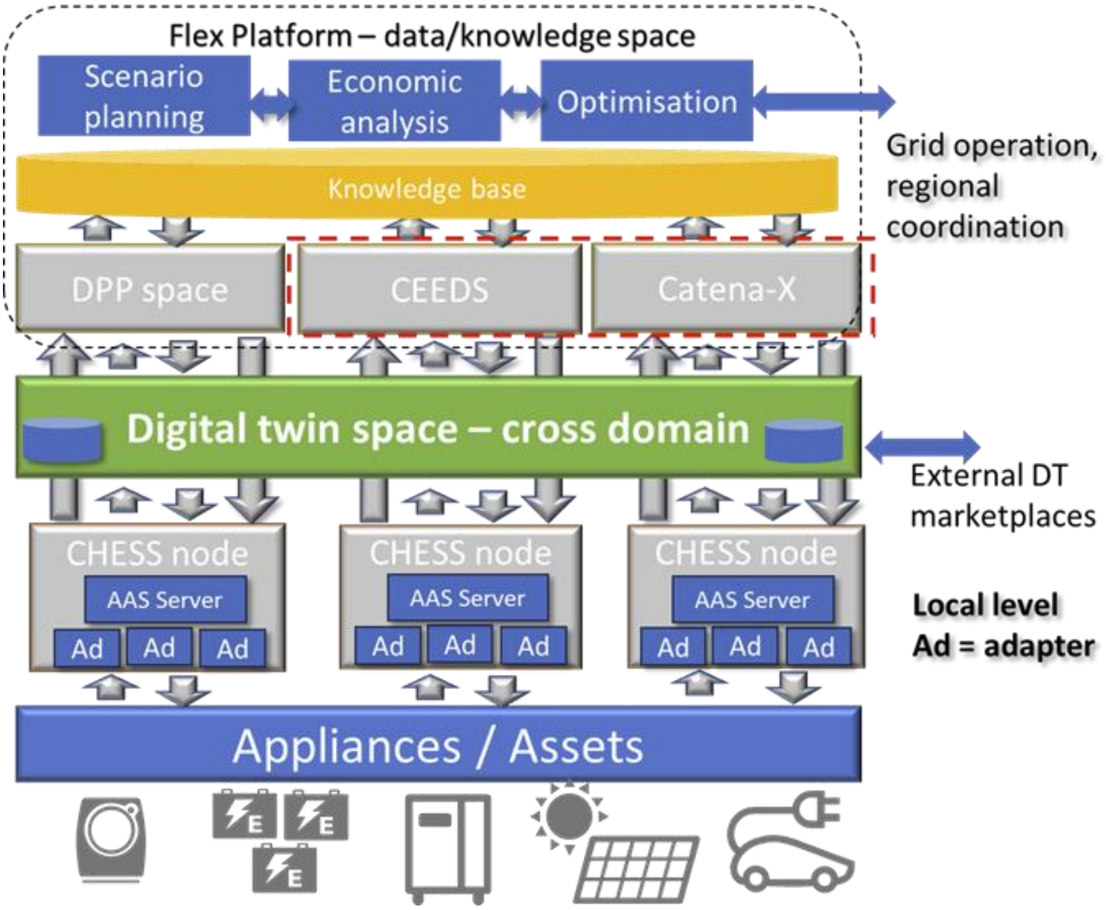


Figure 13 Relationship between data and digital twin spaces

AAS DIGITAL TWIN SPACE

The digital twin space exposes product data using standard representations, such as the asset administration shell (AAS) templates. This is a way to provide different asset views / through submodels exposed through digital twin space logically sitting below the data spaces. Digital twins can support the data space challenges:

a. Interoperability
b. Sovereignty and trust
c. Value creation

Digital twin space features provide and consist of:

a. **Catalogue / DT registry** – of what is available and who is responsible
b. **Graph database** – of complex relationships between different data sets
c. **Access control** (e.g. attribute based access control)
d. **Model and graph representations** (ontology and graph realisations)
e. Support for different **views / submodels (**e.g. simulation…)
f. **Mapping** between different representations (e.g. DTDL to AASX)

Connected hybrid energy storage system (CHESS) nodes and adapters allow for retrofitting and lightweight support for data sharing, and above the digital twin space, different data space ecosystems like DPP, Cofinity-X and the Common European Energy Data Space (CEEDS) can make use of these common digital twin representations. The

Catena-X data space is evolving and growing, and digital twins will play an important part in this as enablement services / developer resources. The digital twin registry is a successful example of this way to efficiently integrate different data models located in different physical locations (repositories) through the semantic stack based on AAS APIs. Digital twin spaces have digital twin registries or catalogues; they also utilise graph representation to capture key asset data resources and their relationships. This permits segregation and embedding access control permissions – relating to different submodels or views of assets. The different digital twin languages can also be mapped using the common basic features.

DIGITAL BATTERY PASSPORT / COMMON DATA DICTIONARY (CDD) DATA MODELS

The CDD data specification is used within the submodels to provide common set of data definitions that can be unambiguously represented. The way in which the submodel access is restricted can help with sovereignty of data as the data / digital twin providers can specify the conditions for access to individual submodels embedded into the digital twin AAS representation. The access permissions associated with submodels are evaluated at the API level to ensure that the subject seeking to access data is authorised to do so within the submodel metadata. CHESS nodes that provide the AAS API can use gateway functions to validate tokens and attribute based access control (ABAC) in the AAS Server to enforce permission rules.

The ABAC approach evaluates the rules relating to subject attributes which can be embedded into the access tokens with those residing in the registries. In this manner, specific combined attributes and permission rules can be applied for the same subjects accessing services in different domains or locations. The rules can be evaluated unambiguously using the subject attributes with which they are provided in the access or ID tokens. This is important for subject and location specific control of services as well as querying across multiple digital twin domains.

Cross-domain queries enable efficient provision of AAS registry services by using distributed database concepts, which permit high performance querying with anonymised subject attributes between domains, but requires cooperation between the digital twin registry and repository authorities. An example is using digital twins of assets in Azure digital twin environment as well as future support for other cross-domain digital twin environments for cross-domain scaleability.

The performance of scalable cross-domain registry transactions using DPP and user identity mapping approach has been evaluated, and it is 6 times faster with closer distributed registry database service coupling (e.g. using pgSpider a high performance and distributed database engine), but still acceptable with proxy-based solutions such as Apache Sharding Sphere, which act to efficiently aggregate different data registries to provide fast lookup services, much like search engines.

EXAMPLES AND SUMMARY

The DPP enables a new use case for all product data including carbon footprint (CFP), performance and material traceability data as well as energy efficiency and asset degradation to provide a harmonised way to identify assets and access all the associated appliance data regardless of where it is actually located. Hence DPP can be used to not just consider assets in isolation but for complete buildings and community asset optimisation. In doing so, the lifetime and operational value can be maximised throughout the lifecycle through close collaboration to plan, deploy, monitor and evaluate / optimise to maximise benefits seen by all stakeholders. Cross sector integration is seen as a next important step for the BRIDGE initiative, but has not been fully addressed by current projects.

In summary, DPP and digital twins have an important role to help in this process to support the new use cases in which asset data and flexibility providers offer services to users and to various stakeholders through common digital twin abstractions based on AAS. Integration of the different use-cases can spread costs while maximising value / benefits for all stakeholders.

4.4 REEFLEX project in the context of home appliance Interoperability

In the REEFLEX project, the interoperability of appliances has been achieved by developing a common data model which permits the communication of the devices in an efficient and secure way, and the integration of the required data in the REEFLEX platform. The data are represented in a standardised way, using a global standard named “the UN/CEFACT Core Components Technical Specification (CCTS). The main aspects of CCTS are:

- **Core Components** – These components help in reducing duplication, enabling consistency, and improving data interoperability in electronic messages
- **Reusable Data Elements** – Modular data units adaptable to different contexts.
- **Data Modelling Structure** – A structured method that provides flexibility and in parallel maintains interoperability
- **Cross-sectoral Usage** – makes the data model highly adaptable to different business needs and regulatory environments
- **Support for Interoperability and Data Consistency:** Ensures coherent and accurate data exchange.

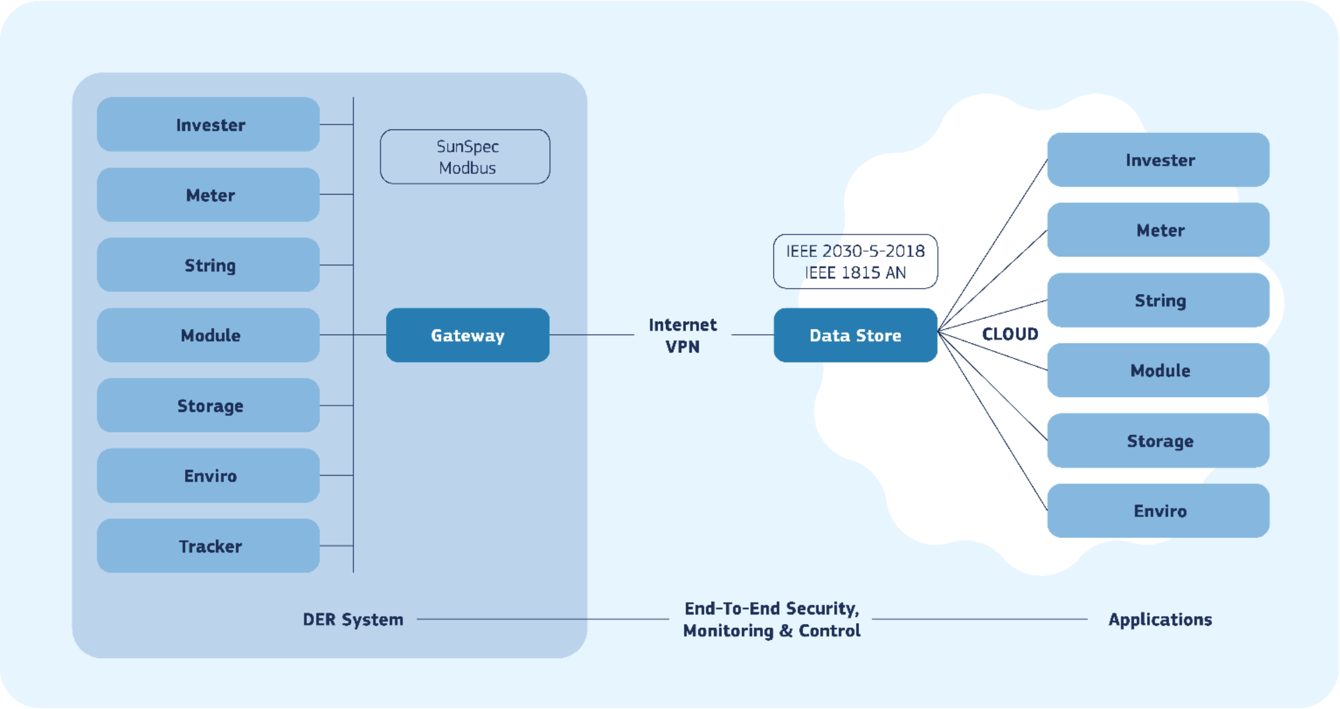


Figure 14 SunSpec Modbus data model

The REEFLEX Data Model includes 94 core concepts and 1,120 fields (not counting the relevant relations between the different concepts), which are sorted into six main categories. In this way the data model is both comprehensive and coherent, providing explicit information in each category. Moreover, the mapping to relevant standards and models was considered to facilitate interoperability across different systems and platforms. In this concept particular actions have been implemented to ensure interoperability:

- IEC 61850-7-420 standard focuses on the integration of distributed energy resources (DERs).

- Particular communication protocols such as IEC 61850, Modbus (see Figure 14), and DNP3.
- SAREF standardisation (see Figure 15)
- Matter protocol/data model
- Z-Wave protocol
- Charge Point Protocol (OCPP) for EV charging (see Figure 16)
- Open Automated Demand Response (OpenADR) 3.0 protocol
- The DNP (Distributed Network Protocol version) 3.0

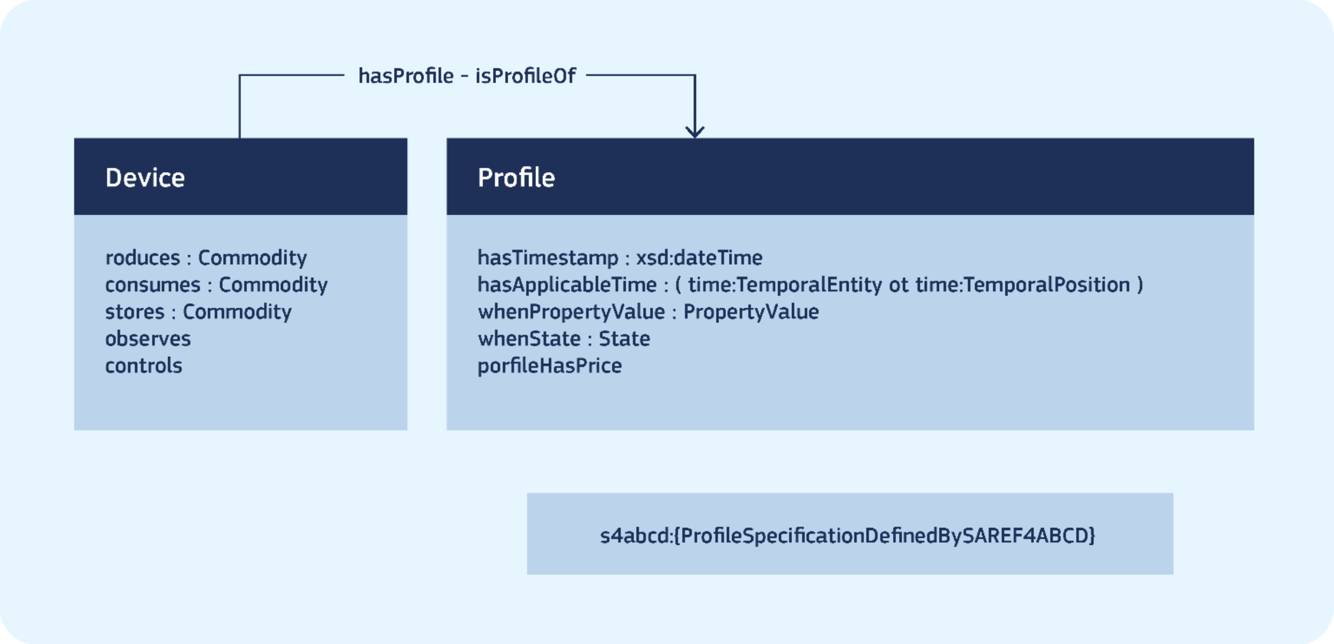


Figure 15 SAREF model principles

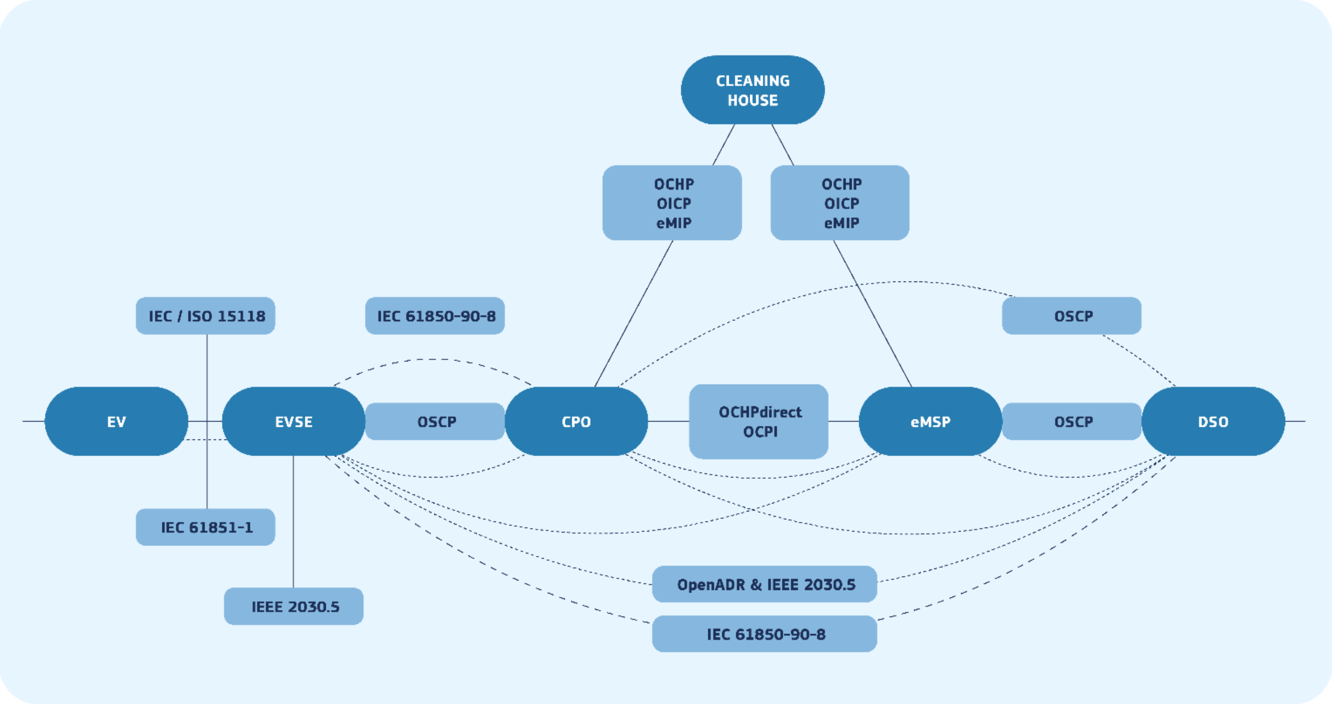


Figure 16 EV standardisation overview

4.5 Household Digital Twin for developing and experimenting with home appliances

The e-balance and the ebalance-plus projects developed solutions for hierarchical energy management ranging from households to DSO level. These solutions consisted of a hierarchical data exchange platform as a support for the implementation of hierarchical energy management (or balancing) algorithms fulfilling their set goals. Both projects involved demonstrating activities as a form of evaluation of the proposed solutions, but a discussion arose on other possible ways to evaluate these solutions in an even more precise and structured way (see Figure 17). The idea was to allow different configurations of the energy management to be compared under the same or comparable conditions and to be able to do that for multiple such configurations.

There are statistical approaches that allow a kind of statistical simulation that validates the approach in theory. Such an approach involves a series of computational tests with different defined conditions to do the theoretical validation. But the drawback here is that it is hard to prove that the proposed solutions will also perform similarly if deployed in reality, with real devices and on a larger scale. Further, such completely statistical or mathematical models of the algorithms may not reflect the fine granular details of implementation involving real devices. Thus, a more real and physical deployment would be better. The aspect of physical testing could be addressed by laboratory testing with real appliances, but this would lack the scale and could prove expensive. Additionally, it assumes that the appliances in question have to be there, available on the market, or to be provided as prototypes by the manufacturers for testing. It might not always be the case, especially if the algorithms handle novel flexibility approaches. The scale, with a limited number of real devices available, could possibly be covered by repeating (replaying) the recorded profiles of devices, but this approach would still provide a very limited set of ways to interact with the appliances for flexibility purposes. And finally, none of the above-mentioned testing approaches considers the real users, together with their diversity and variability. The human factor is the reason why the real demonstration with real users might provide the most interesting insights, even if it is not guaranteed that the evaluation covers all possible cases and situations.

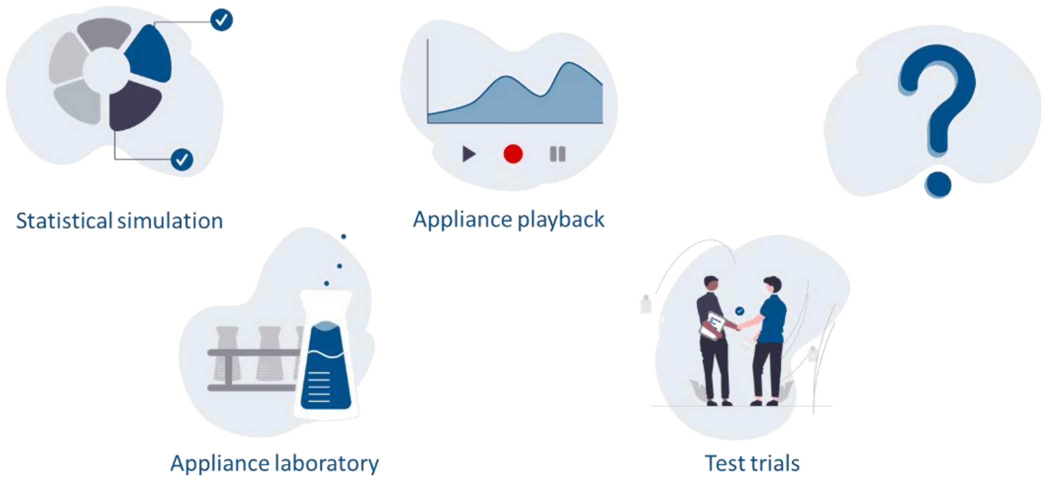


Figure 17 Ways to evaluate energy management involving home appliances

The problem with real demo sites is multidimensional. First, in order to support testing at scale, it requires relatively large deployments, which is costly. Then, to test some functionality it might be required to have users that actively participate in the tests. The kind of participation may differ, but even installing the appliances and other equipment at user premises requires participation. And that is also not always a given. Further, users may need to play along the defined rules to allow for testing specific functions of the proposed solutions. And finally, there might be some legal limitations with respect to the use of prototype appliances within a real deployment.

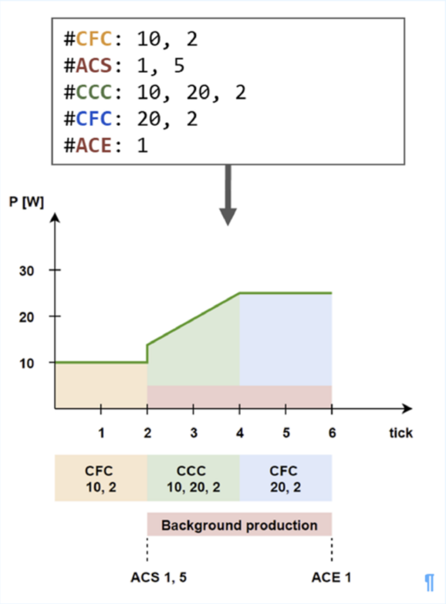
Thus, the goal was to create a test environment that enables:

- testing of the final implementation of algorithms ready to be transferred to the target environment,
- repeatable testing in a configurable environment,
- modelling various aspects of all elements of the test environment (devices, users, etc.),
- extensibility for future applications,
- possibility to include hardware-in-the-loop testing,
- compatibility with various data exchange platforms, including our own, created in the project.

The proposed software tool – the household simulator or the household digital twin – supports:

- modelling all possible kinds of household appliances with different detail depth and APIs
- modelling the user behaviour with possible deviations and randomisation
- modularity, ease of set-up, ease of use, configurability, reproducibility

The tool allows the setting up of a library of home appliance models. The language defined for that purpose is similar to assembler and can model (or describe) the internal processes of a very specific device model with almost any energy-related behaviour – consumption or production (see Figure 18). It also allows the embedding of interactions in these processes to influence these. The interactions can be based on data or events and allows modelling (or encapsulating the processes in) of the home appliance API. Thus, it allows any specific model of home appliance by any manufacturer to be described (or modelled).

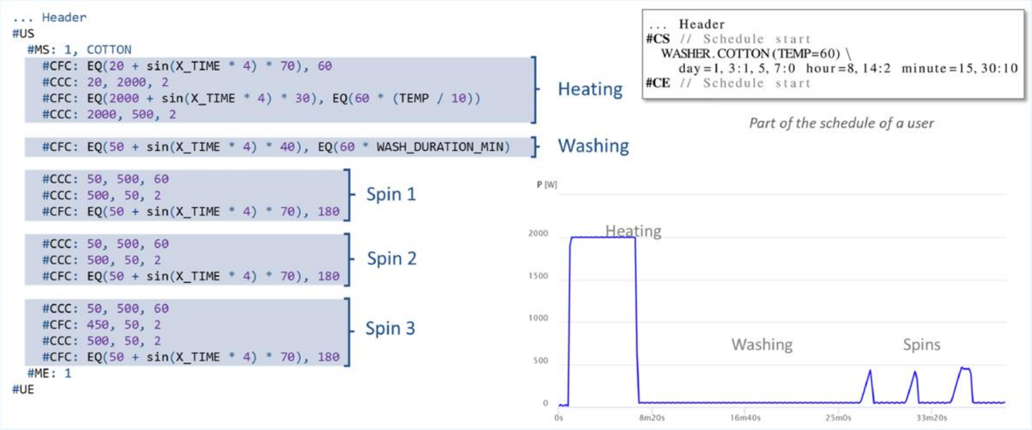


```
#CFC: 10, 2
#ACS: 1, 5
#CCC: 10, 20, 2
#CFC: 20, 2
#ACE: 1
```

Figure 18 Describing internal processes of a home appliance in the household digital twin tool

Further, another language was defined to make it possible to describe the behaviour of individual users. This second description language captures the typical schedule of the user, describing which devices the user uses and the way these are used. The schedule also considers deviations and randomisation to capture human factors. Simplifying this procedure, if the different functions (or modes) of an appliance can be considered programming language procedures (or functions), the user schedule can be considered a time plan for when these functions are to be called. Thus, it is possible to establish a library of users (and their behaviour).

The user schedule language defines the involved devices as generic device classes, like a washing machine, dryer, or fridge. Thus, the actual implementation (a model) of a specific washing machine is needed to execute the schedule in a test scenario (see Figure 19). A combination of the descriptions of users and home appliances defines the household configuration (see Figure 20). And once it is executed, the energy profile is generated and it can also be influenced by external factors, like an energy management algorithm or by external data (e.g., the temperature).



```
... Header
#US
  #MS: 1, COTTON
    #CFC: EQ(20 + sin(X_TIME * 4) * 70), 60
    #CCC: 20, 2000, 2
    #CFC: EQ(2000 + sin(X_TIME * 4) * 30), EQ(60 * (TEMP / 10))
    #CCC: 2000, 500, 2

    #CFC: EQ(50 + sin(X_TIME * 4) * 40), EQ(60 * WASH_DURATION_MIN)

    #CCC: 50, 500, 60
    #CCC: 500, 50, 2
    #CFC: EQ(50 + sin(X_TIME * 4) * 70), 180

    #CCC: 50, 500, 60
    #CCC: 500, 50, 2
    #CFC: EQ(50 + sin(X_TIME * 4) * 70), 180

    #CCC: 50, 500, 60
    #CFC: 450, 50, 2
    #CCC: 500, 50, 2
    #CFC: EQ(50 + sin(X_TIME * 4) * 70), 180
  #ME: 1
#UE
```

```
... Header
#CS // Schedule start
  WASHER.COTTON(TEMP=60) \
    day=1, 3:1, 5, 7:0  hour=8, 14:2  minute=15, 30:10
#CE // Schedule start
```

Part of the schedule of a user

Figure 19 The energy profile as the result of the appliance description and the user schedule

The household digital twin tool combines the usage of the home appliances within the household by the users in it to generate the output energy profile (see Figure 20). As the description of each appliance and each user is represented by an individual file, the configuration of a household is as simple as placing the chosen files in the right directory related to the specific instance of the tool, where one instance can run multiple households.

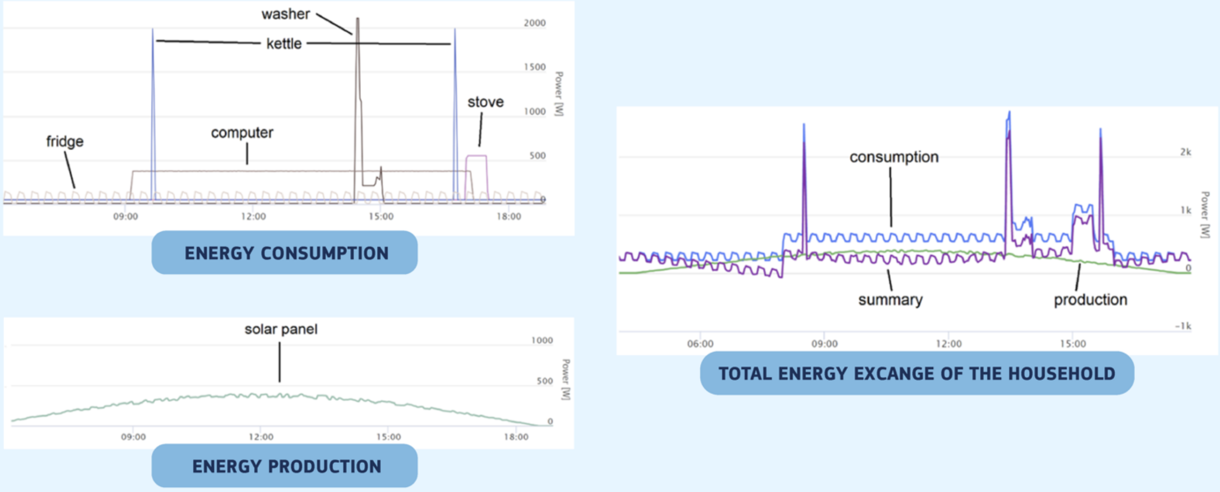


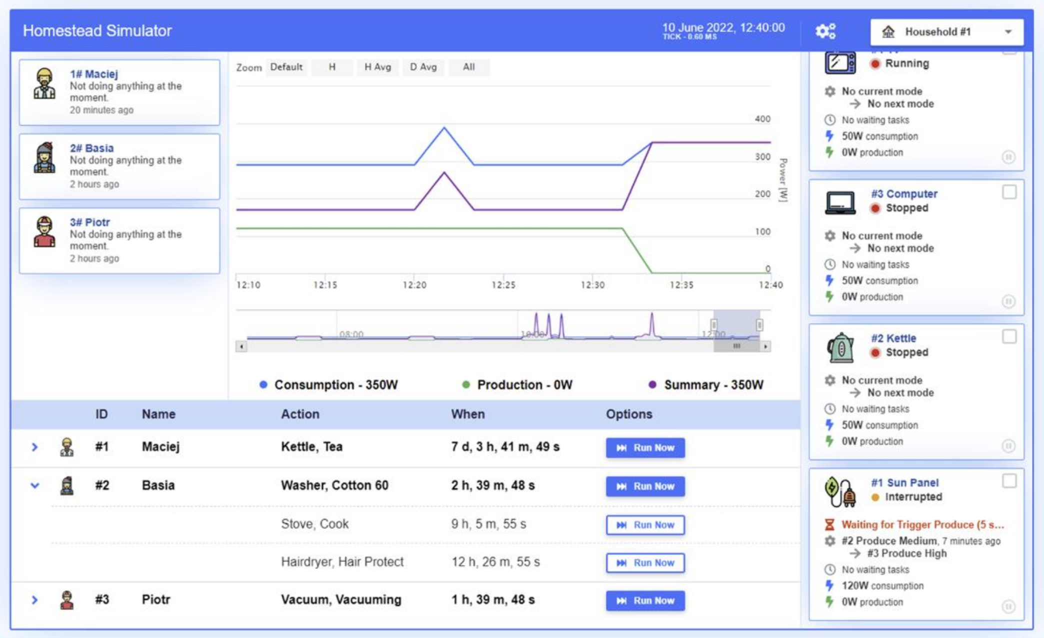
Figure 20 The combined energy profile (energy exchange) of a modelled household

As already mentioned, a household can be influenced by external factors, data or events. These interactions are realised by the API of the tool called the Simulator Adapter Library. Using this API, it is possible to change certain parameters of the simulation, like the speed it is executed at. It is thus possible to run simulations at high speed to evaluate the long-term effects in a short time.

The tool API retrieves the information about all the components involved (households, devices, schedules, etc.). It thus allows what is happening inside the simulated households to be monitored. With this functionality, several copies of a model of a given household can be run, but with slight changes between these, and their results can be compared.

With regard to influencing the households, the API allows a diversity of such activities. For instance, it can allow the start of the appliance usage by a user out of schedule and provoke an unplanned usage of any appliance in the household. Further, the interaction with the appliances goes beyond that and it is also possible to control (read and write) the internal variables in the home appliance internal processes and emitting triggers that control the execution of these processes. By exploiting this interaction features, it is possible to create drivers that allow external components outside the tool (e.g., the energy management algorithms) to interact with the devices inside the simulator. Encapsulating the powerful API in a set of simpler interfaces (like the home appliance API) allows the modelling of the communication interfaces of the home appliances, with other developers (e.g., developing the energy management) not needing to know the details on how the appliance's internal processes are implemented in order to interact with it. **Together with the other features of the household digital twin tool, its API actually supports the development of and experiments with home appliances. By using their models, the tool allows the impact of available home appliances in a diversity of scenarios to be evaluated. But it goes even beyond that, as it can help define devices with features not yet implemented and evaluate their impact on future energy systems.**

The API functionality can be accessed over HTTP, what makes it easy to interact from applications implemented in any programming language. To simplify the use of the tool, a control application with a GUI has been implemented to show the details of the simulations and to allow interacting with these (see Figure 21).



1# Maciej
Not doing anything at the moment.
20 minutes ago

2# Basia
Not doing anything at the moment.
2 hours ago

3# Piotr
Not doing anything at the moment.
2 hours ago

ID	Name	Action	When	Options
#1	Maciej	Kettle, Tea	7 d, 3 h, 41 m, 49 s	Run Now
#2	Basia	Washer, Cotton 60	2 h, 39 m, 48 s	Run Now
		Stove, Cook	9 h, 5 m, 55 s	Run Now
		Hairdryer, Hair Protect	12 h, 26 m, 55 s	Run Now
#3	Piotr	Vacuum, Vacuuming	1 h, 39 m, 48 s	Run Now

● Running
No current mode
→ No next mode
No waiting tasks
50W consumption
0W production

#3 Computer
● Stopped
No current mode
→ No next mode
No waiting tasks
50W consumption
0W production

#2 Kettle
● Stopped
No current mode
→ No next mode
No waiting tasks
50W consumption
0W production

#1 Sun Panel
● Interrupted
Waiting for Trigger Produce (5 s...
#2 Produce Medium, 7 minutes ago
→ #3 Produce High
No waiting tasks
120W consumption
0W production

Figure 21 The GUI of the control application attached to the household digital twin via its API

The household digital twin is part of the grid Emulator that was also developed in the eBalance-plus project. The grid emulator is a flexible hardware model of the energy grid. It is a modular approach for constructing small-scale models of the grid, using a small set of generic blocks representing 1) energy prosumers, 2) transmission lines, and 3) secondary and primary substations. Their combination allows different grid topologies to be built (see Figure 22). Within the blocks, the hardware components allow real energy flows based on the profiles generated by the multiple instances of household simulators. Using the grid emulator, it is possible to evaluate energy management algorithms in realistic scenarios. It is even possible to provoke events that might not be allowed in any real grid.

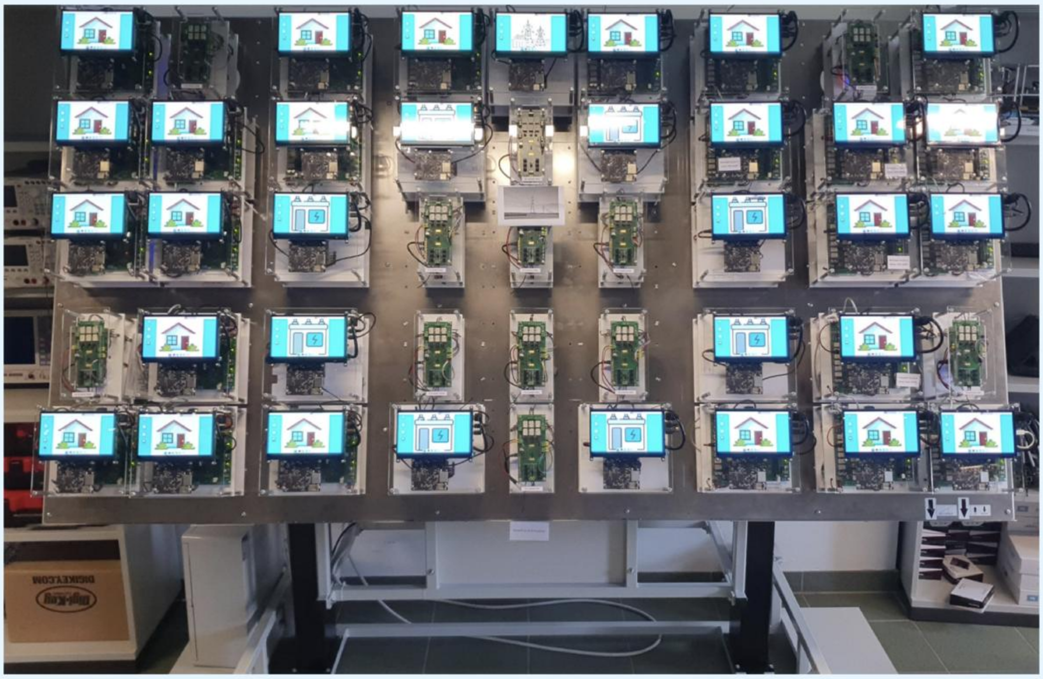


Figure 22 The instance of the Grid Emulator at IHP laboratory

Within the grid emulator, the individual households exist on their respective prosumer blocks. On each prosumer block the modelled energy profile controls the physical energy production and consumption that are also captured by the advanced metering infrastructure (AMI) elements present on the block. The energy management system (EMS) operates based on these measurements and interacts with the simulated home appliances to influence their work (e.g., to use the flexibility they offer). These interactions are shown in Figure 23. The individual households distributed between the prosumer blocks interact at the physical layer, i.e., they can observe voltage changes, etc. But if their energy management systems are not collaborating, they are like real households in the real energy grid.

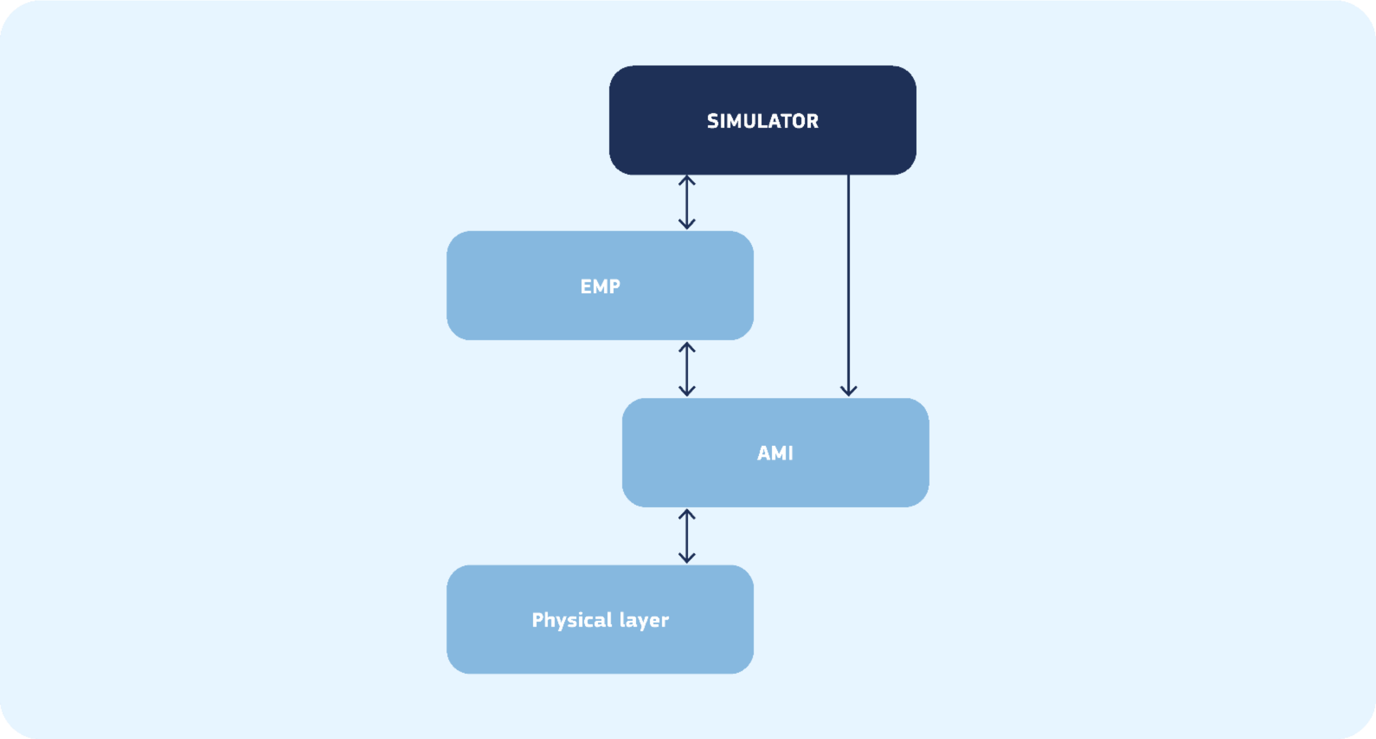


Figure 23 Interactions within the grid emulator

The tools mentioned above are constantly being improved and extended.

5 General outcome of the survey

This section presents the outcome of the survey that was conducted among the projects. It presents the answers to questions that can be covered by a statistical summary and analysed easily. An interpretation of the outcomes is also provided.

The aim of the survey was again to gather information regarding the control, monitoring, interoperability and usage of home appliances in the BRIDGE projects. It covers topics such as a project's role as a provider or consumer of home appliance interoperability, the types of home appliances used, their energy-related features, API interfaces and protocols, interoperability challenges, security measures, awareness of relevant initiatives, and areas for improvement, among others. The complete set of questions is given in Appendix 1: Survey questions.

The Action #5 survey was conducted for the third time, i.e., covering the periods: 2022/2023, 2023/2024 and this one – 2024/2025. For the following analysis and to simplify matters, they will be identified by the starting year of the period. In the third period we disseminated the survey further and we received responses from **33 projects**. Among the respondents, **22** are controlling or monitoring home appliances, as presented in Figure 24In the last two years there were 24 (2023) and 18 (2022) contributions to the survey, with **19** (2023) and **13** (2022) involving home appliances. Thus, although the ratio seems to get worse in the current survey (2024), the total number of projects involving home appliances has actually increased to 22. The falling ratio is due to the large number of projects we reached, where many of them do not involve home appliances. The following analysis considers only the answers from the 22 projects. Thus, the relations can be compared between the years to detect trends.

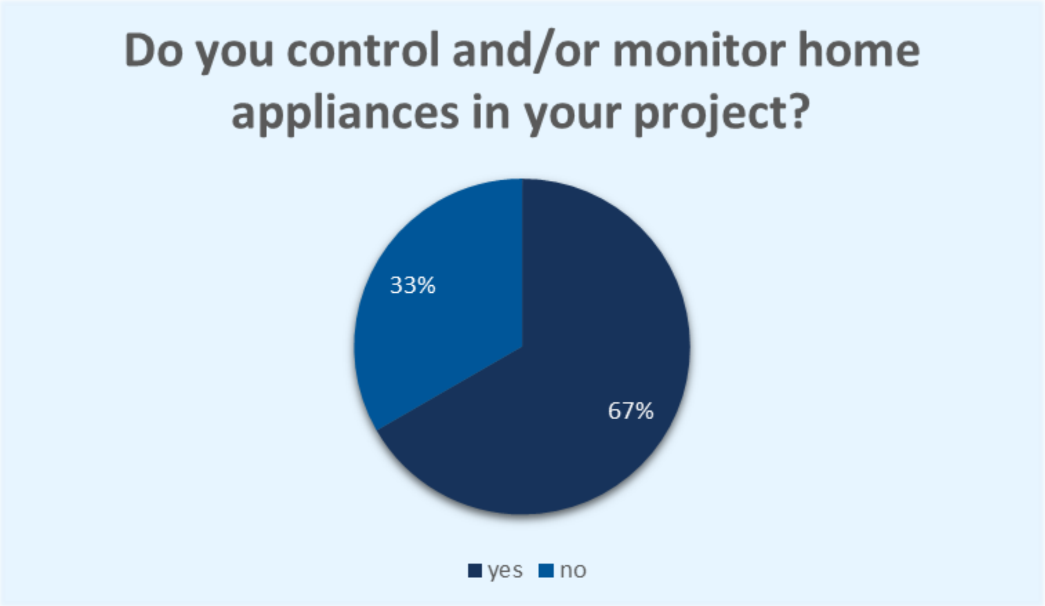


Figure 24 Q2: Do you control and/or monitor home appliances in your project?

The projects can be a consumer or a producer of approaches related to the interoperability of home appliances. If the focus in a project is related to energy management only and it is using home appliances for that purpose, then we define it as a consumer/user of the home appliance interoperability approaches. Similarly, if the project focuses on developing approaches for supporting the use of different home appliances in different contexts, then we define it as a provider of home appliance interoperability approaches. Most of the projects are a mix of both of these aspects, however, if we first ask about the main focus, the results are as presented in Figure 25. Slightly more projects identify themselves as consumers, rather than providers. The same question was also part of the 2023 survey, and at that time significantly more projects considered themselves as providers of the interoperability solutions.

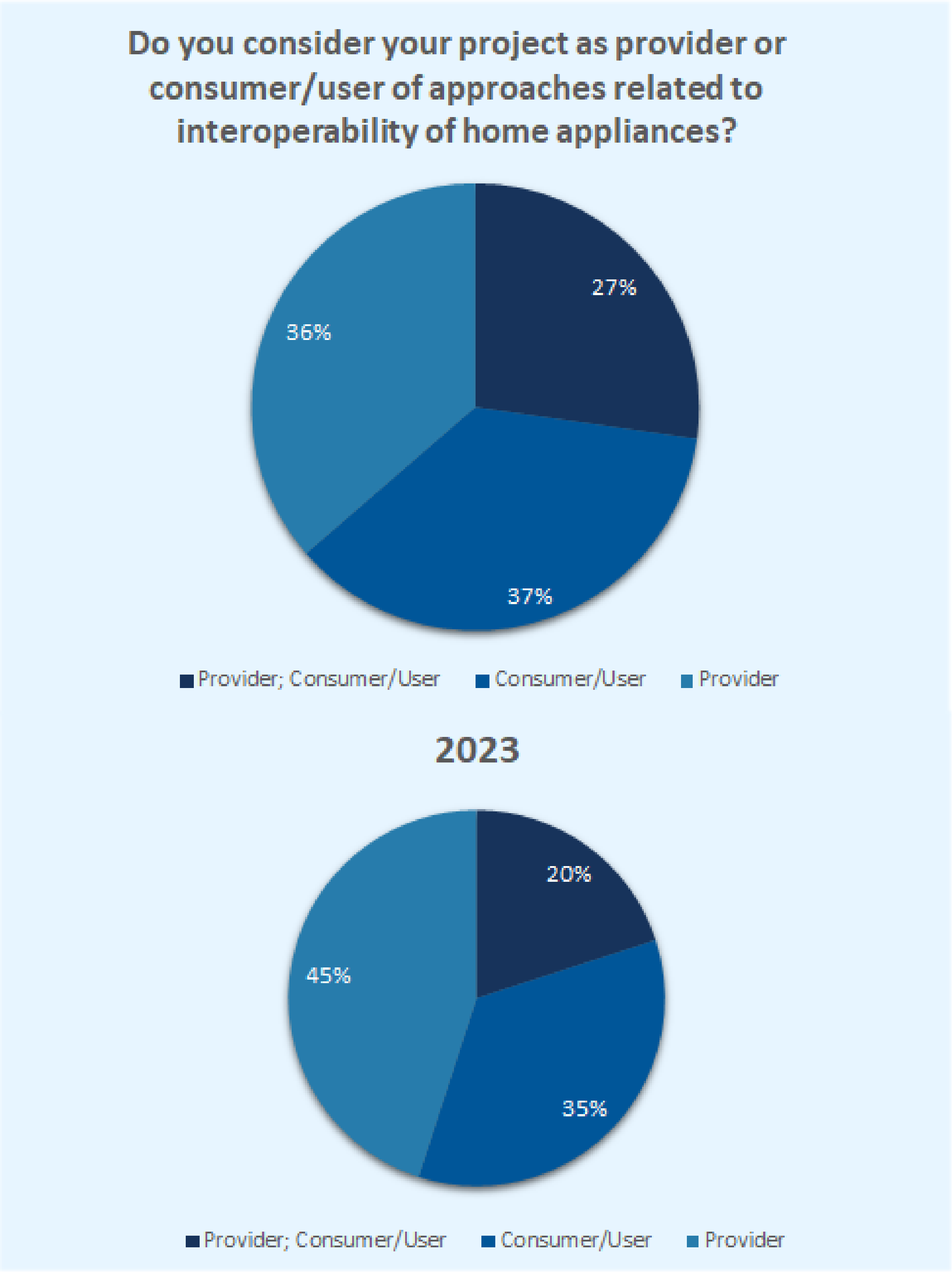


Figure 25 Q3: Do you consider your project as provider or consumer/user of approaches related to interoperability of home appliances?

A closer look at the distribution ratio between being the provider and the consumer is shown in Figure 26. It was left to the projects to define the rules for specifying the value for this ratio.

Although the question was not covered by all the answers, this distribution indicates an even greater focus on the consumer side than on the provider side – as opposite to the last year. Nevertheless, the biggest group of the projects is a compromise between providers and consumers. From the distribution, it can be deduced that slightly more projects are focused on using the appliances than on creating strategies to encourage the use of various household equipment in various situations, but the number of the latter is still significant. And it can also be the case that some projects have been forced to develop interoperability-related approaches because of their lack on the market.

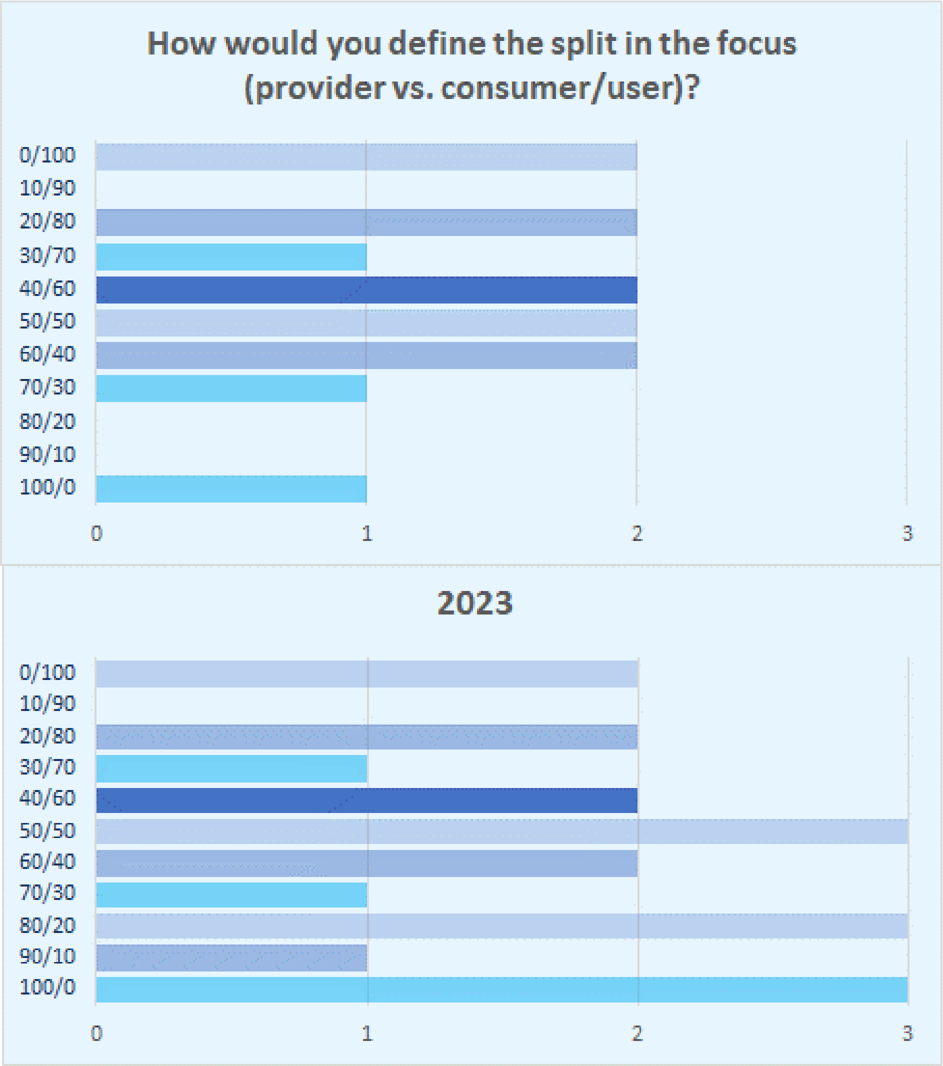


Figure 26 Q4: How would you define the split in the focus (provider vs. consumer/user)? (e.g., 40/60)

Most of the projects involve a wide range of products. Based on the responses of the survey, appliances were divided into three groups and the results are presented in **Errore. L'origine riferimento non è stata trovata.**. Additionally, respondents declare what the energy-related features are used in a given project.

We can observe a huge trend in the change of the distribution of the two groups (white goods and HVAC) that had been dominant in previous years. The white goods lose interest in favour of HVAC, and the trend is pretty strong, probably due to the fact that heat pumps and air conditioners are gaining attention because of their significant energy usage and large potential for optimisations. Both these classes of appliances show a slight drop in 2023, compared to 2022, but the increase in 2024 is significant, setting these two to levels comparable to the complete white goods or EV and storage – above 20%.

Considering the energy-related features, there has been little change. In the white goods group, the most frequently mentioned appliances are the shiftable loads, namely washing machines and dishwashers. Besides shifting, respondents also declare the possibility of pausing these home appliances. From the shiftable loads, the dryers show a constant drop over the two years, similar as the lighting systems, TVs and refrigerators. Their use dropped to 2% or less. An interesting question would be the reason for that drop. Is it because these appliances are now mature products on the market and there is less interest in their use in research and pilot projects? Or is it due to their lower potential for energy optimisation without considering the dynamic end-user behaviour? Probably the latter is an important reason for that, also explains the gain by heat pumps and air conditioning devices.

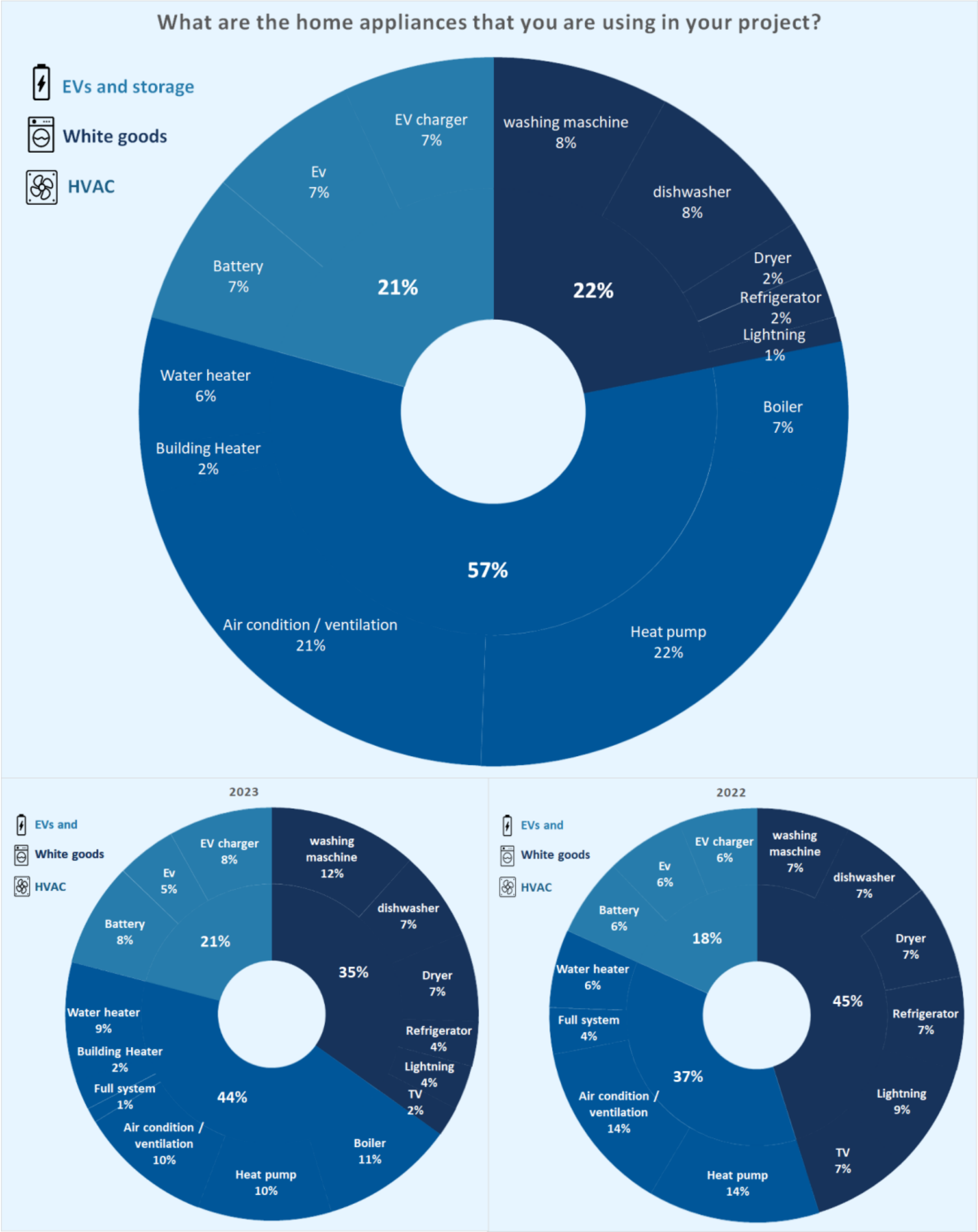


Figure 27 Q5: What are the home appliances that you are using in your project?

In the HVAC group of appliances none of the projects are using comprehensive HVAC systems, where all the functionalities are involved. Compared to previous years, the projects mainly focus only on a few or single HVAC units, with heating equipment such as boilers or heat pumps leading the way. Here respondents indicate advanced functionalities, like setpoints, holiday programmes, scheduling, price-based signals management, etc.

The last group, consisting of appliances related to EVs and storage, shows an almost constant interest at about 21%. Compared to previous years the distribution became equal between batteries, EV and EV chargers. Here charging/discharging or scheduling are widely used energy-related features. Additionally, most of these home appliances collect relevant measurements. We expect an increase in this group in the future, as these appliances become essential for energy management systems.

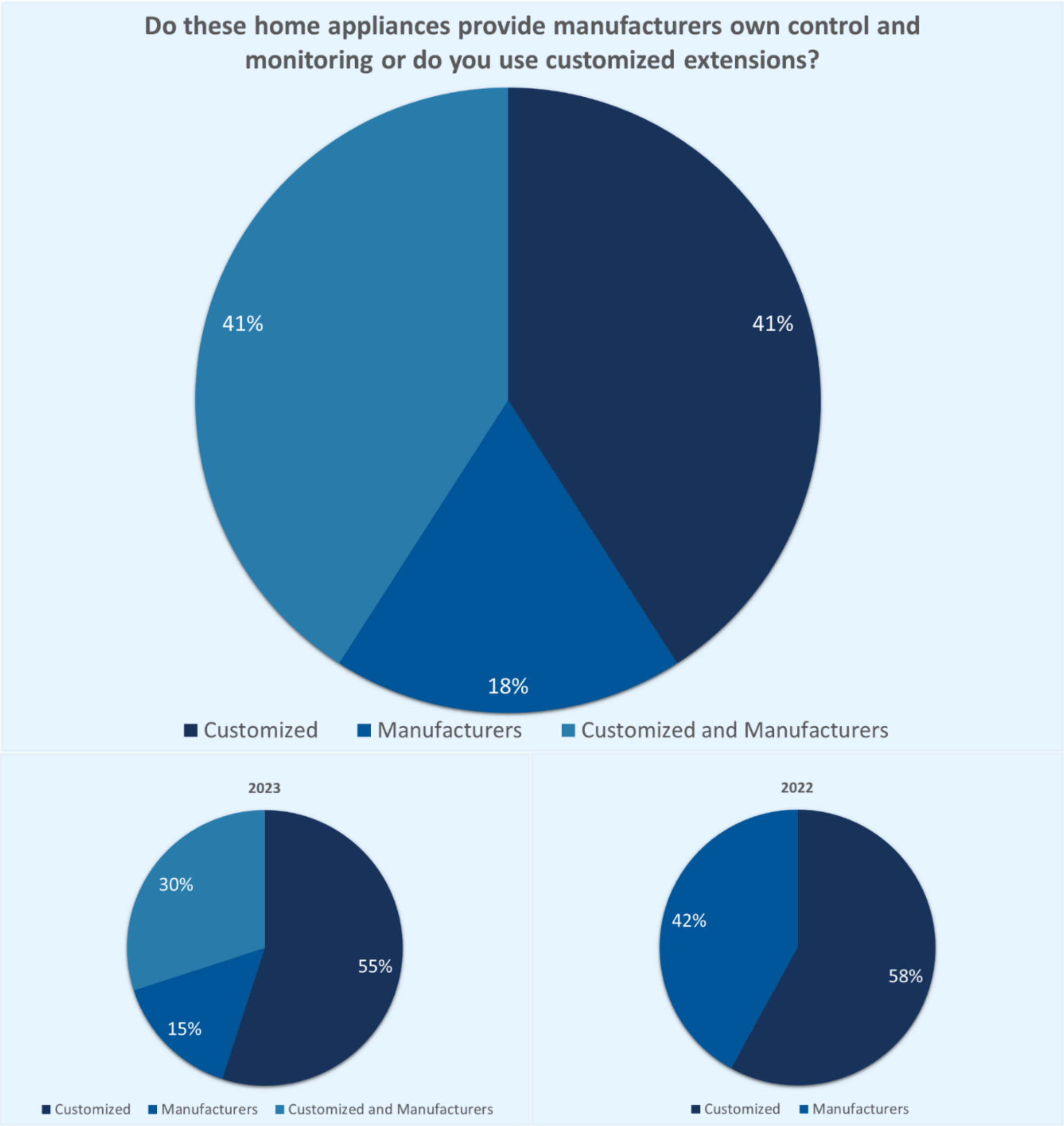


Figure 28 Q6: Do these home appliances provide manufacturers own control and monitoring or do you use customised extensions (like a smart plug)?

Advanced functionalities allowed use-case scenarios implemented in the projects to be defined. Most of the projects have developed flexibility scenarios by applying load shifting, peak load reduction, simply switching on/off, or scheduling home appliances. Additionally, some projects opt to include aggregators to manage the flexibility most optimally and create opportunities to trade flexibility on the local market. Objectives of the energy management that are frequently mentioned are: minimising the energy cost, maximising energy efficiency, maximising self-consumption, and maximising RES use. EVs, chargers, batteries and shiftable loads are also involved to enhance grid stability.

The trends in these aspects can be partially caused by the regulations and partially by the previous experience from the projects and research. The regulations enforce the use of specific appliances, like the heat pumps, or propose incentives for using these. In this case, research focuses on the majority on the market to gain more impact. On the other hand, use of appliances that provide the most flexibility allows better results to be obtained faster, but these can be further fine-tuned with the use of more challenging appliances. It is also more visible to the end users on their bills if the appliances consuming the most of the energy are better managed. Due to the current regulatory changes and the high flexibility potential we expect that the EV and storage group will gain more attention in the coming years.

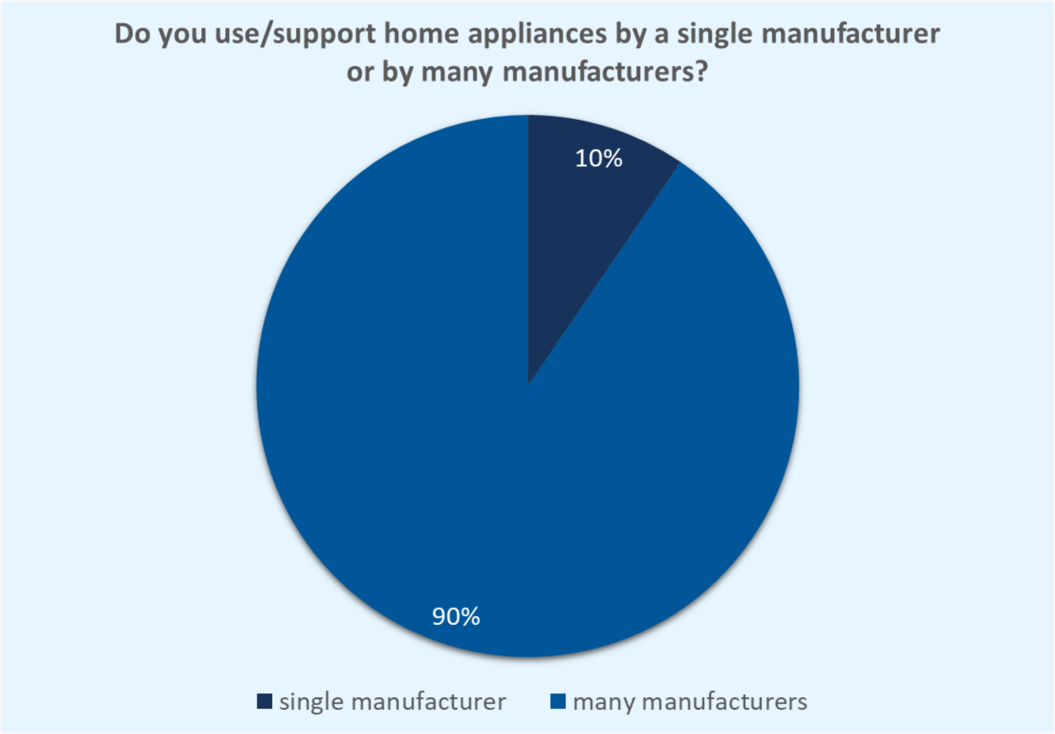


Figure 29 Q10: Do you use/support home appliances by a single manufacturer or by many manufacturers?

The following question addresses the use of customised interfaces. As home appliances delivered by manufacturers sometimes require extensions to be applicable in the energy management scenarios. The extent the projects are using customised control solutions and those originally provided by the manufacturers, is shown in Figure 28. Around 41% of the projects rely solely on customised extensions, like smart plugs. Here we can observe a significant drop from about 50-60% in the previous years. Still only 18% are using pure manufacturers' appliances. And 41% of the projects use both original and customised solutions. In the timeframe of the three years we observe a significant increase in the number of projects involving appliances that provide control interfaces offered by manufacturers, including a combination with customised ones. In total, slightly below 60% of the projects belong to these two groups. We can also observe an increase in the number of projects that use only appliances offering manufacturers' own control and monitoring. However, these still make only 18% of the total number of the projects. This relatively small number indicates that the market is still offering a limited number of appliances from all the appliance classes that are interoperable out of the box. It also indicates that there is a need for appliances that have an open control system, to be used by the projects without workarounds to cover their intended scenarios.

Another aspect determining the diversity of appliances used by the projects refers to the manufacturer diversity within a single project. Figure 29 indicates that the vast majority of projects do not rely only on a single manufacturer of home appliances. Different manufacturers may lead to different communication protocols, control and interfaces. In the previous years the ratio changed slightly changed but the projects using appliances by different manufacturers were always in a majority (80% in 2023 and even 92% in 2022). This indicates just how important interoperability of home appliances actually is.

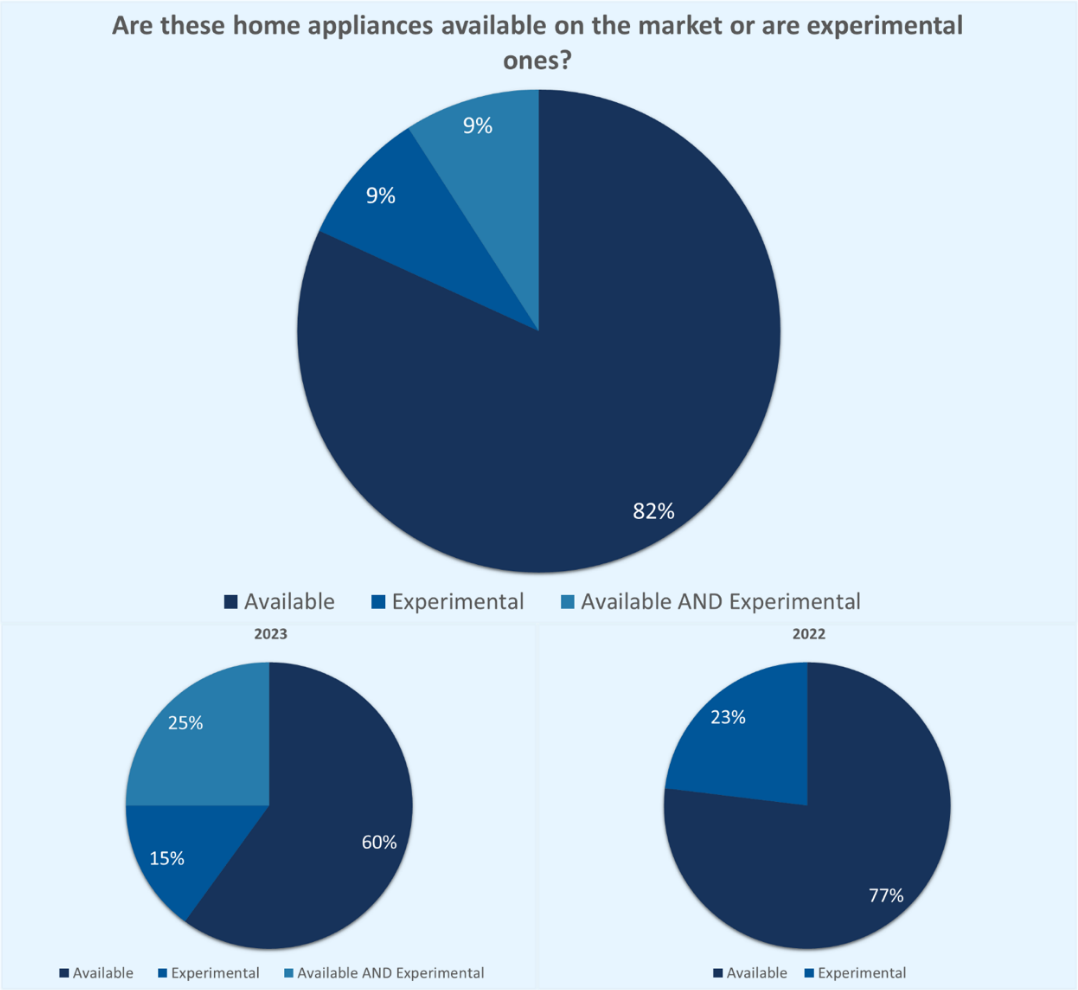


Figure 30 Q11: Are these home appliances available on the market or are experimental ones?

Considering the use of appliances available on the market compared to experimental ones, most of the projects use the former ones, as indicated in Figure 30. The use of appliances already available on the market proves that these already provide most of the features (flexibility), even if still supported by external control solutions. This is an important aspect when transferring pilots and demonstrators to the real world. Still, there seems to be potential for improvements in different aspects, e.g., related to control and ways to integrate. To address this, some projects opt for experimental home appliances, as these may offer more features than the home appliances available on the market. Figure 31 shows, on the other hand, that there is still a broad group of home appliances with closed monitoring and control systems. Compared to previous years the ratio is getting better, in the sense that more open interfaces and protocols are used (and available), but there is still room for improvement.

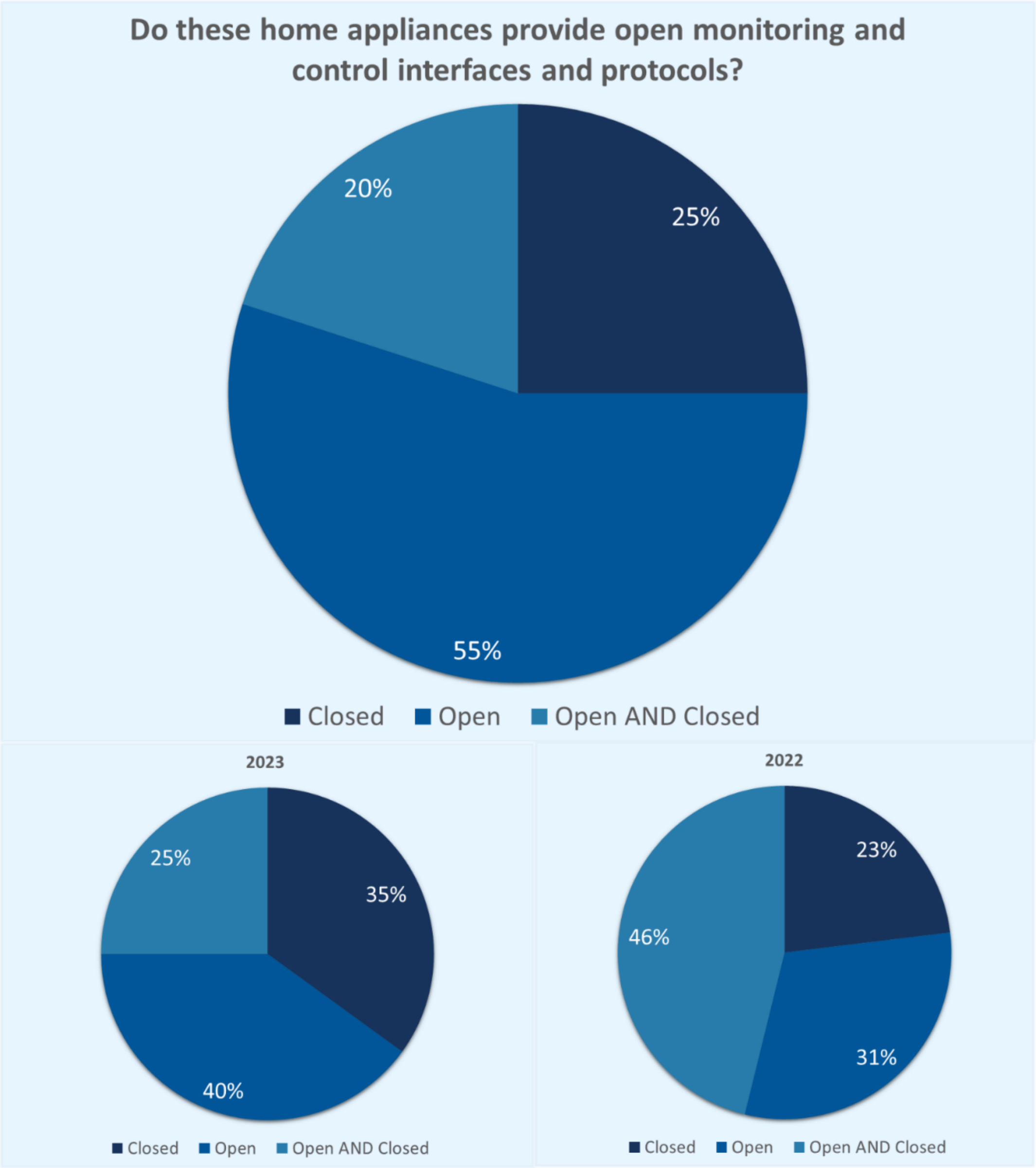


Figure 31 Q12: Do these home appliances provide open monitoring and control interfaces and protocols?

The location of home appliance API influences the system architecture and the possible choices in the context of home appliance integration within the energy management systems. It also indicates some features related to system security and reliability, due to the data exchange paths. The home appliance API locations within the projects are presented in Figure 32. In that question the responders could choose multiple locations. The shown distribution indicates the same significance (43%) of the location at both, the cloud service and the home gateway. The third option, i.e., the home appliance API provided directly at the appliance, is a minority with only 14%. We can observe some small changes between the answers, compared to previous years. In 2022 the home gateway was the most favourite option, but it lost the lead in 2023 to the cloud solutions, and now both these options are equally often used by the projects.

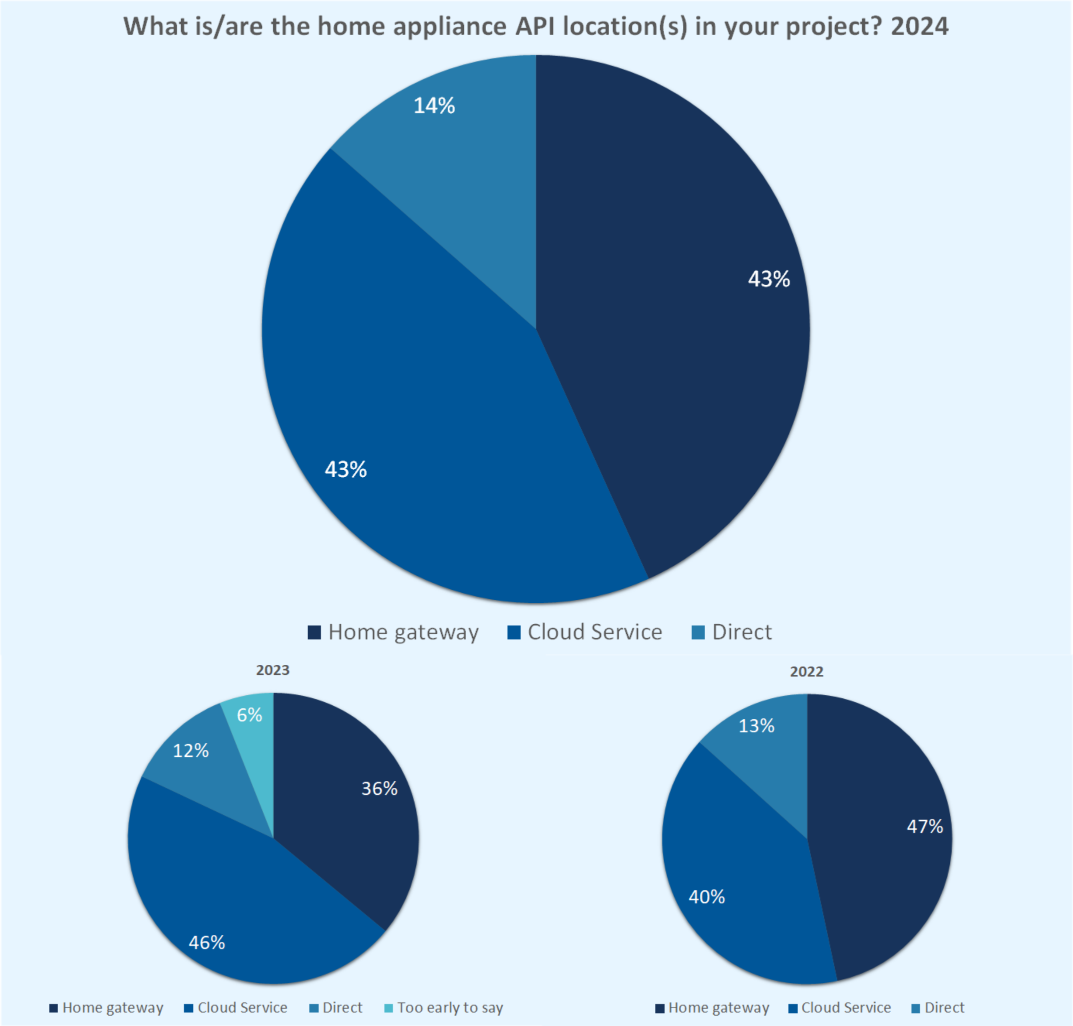


Figure 32 Q7: What is/are the home appliance API location(s) in your project?

These above results from the survey generated material for numeric analysis. These are informative and give the opportunity to draw conclusions on the current state, as well as trends over the time covered by Action #5 surveys. Their statistical value depends very much on the quality (completeness of information) of the answers and the coverage in the BRIDGE projects (completeness of the information sources), i.e., it is crucial to reach as many projects as possible with clear questions to obtain valid results. In contrast, the following section addresses the survey replies to the remaining questions that required more textual input.

6 Detailed analysis of specific points

This section provides the summary of the survey outcome related to questions with text answers that additionally present some interpretation diversity between projects. Due to this, these replies could not easily be presented in the diagrams of the previous section, but it also elaborates on some of the outcomes that were handled in a numerical way before, by sorting them according to specific subjects. These subjects will also be further investigated in the following years in the BRIDGE Data Management Working Group Action #5, and in conjunction with other BRIDGE activities. The main gain of this part is the information on the existence of specific approaches, the use of solutions and overall experience related to home appliances within the projects. This still provides an idea about the state of things, and about future trends as compared with previous years. That is why Action #5 continues to run the survey every year with the same or slightly adapted questions.

6.1 Use of standards

There are multiple standards or protocols that can be applied at different levels of the energy management system involving home appliances. Starting from the lowest layer, we can identify standards in the form of communication technologies. Based on the survey responses, among the projects we observe the existence of proprietary solutions or even analogue or digital signals, but usually we have standard solutions, like Wi-Fi, Bluetooth Low Energy (BLE), ZigBee, Modbus, ZWave or Thread. These typically already involve several layers of the protocol stack above the physical layer they use. This means mainly IP-based communication, but other approaches are also involved at the network layer, especially with low power communication stacks (like ZWave, ZigBee, Thread. LoraWAN or BLE), but these are usually anyway translated into IP at some level of the system (or combining IP-based communication over different physical layers, as done by MATTER). That is the major approach to handling the communication diversity at this level of the system. This is also the default and preferred option for many projects due to the ease of integration with the cloud. Here not much changed during the Action #5 activity.

Then, additionally, we have specific application level protocols that determine the commands or requests that can be exchanged between the devices to realise functionality related to energy management. Here we also see a diversity of solutions, including proprietary ones (in even larger scale than in the lower layers), but with a trend to be supported by standards. These proprietary approaches include the manufacturers' ones that were probably developed due to the lack of well-established standards to provide access to energy-related features (e.g., initially for own energy management solutions). There are also proprietary solutions developed within the projects, probably to capture specific energy management scenarios. These are usually based on general purpose standards anyway, like RestAPI or MQTT. But we also observe increasing application of standard approaches that focus on defining and using ontology and data semantics, either in the general context, IoT context or specifically in the energy management context. These solutions in the BRIDGE projects are based on IEEE 2030.5, SAREF, S2, EEBUS, BRICK or NGSI. The projects also mention protocols / standards like oBIX, BACNet, OCPP, ISO 15118, IEC 61851 or the labelling approach SG Ready. Interestingly, some other approaches, like the SOAP or openADR, mentioned in previous years did not appear in the responses this year.

Action #5 plans to intensity and bundle the efforts with Action #4 to monitor the activities in the standardisation area and to maintain a list of relevant standards. Such information can help projects to reduce the efforts related to the investigation and to compare different approaches and standards. And it may also limit the duplication of efforts related to developments. Further, for projects developing relevant solutions it may also help to provide a list of standardisation activities they could contribute to.

6.2 Security and reliability

There are different approaches for providing security features in the solutions developed by the BRIDGE projects. Depending on the specific function, the security approaches can be applied at the different levels of the protocol stack, as mentioned in the previous section. To provide confidentiality, approaches like TLS (SSL not mentioned anymore as deprecated) are mainly applied at the presentation layer, but are said to operate between the transport and presentation layer. Further, there are many other approaches and standards applied additionally for authorisation and authentication, like WSS, HTTPS, OAuth2 or AWS Auth. There are also other approaches, like token-based access control, password-based access control or attribute-based authentication. For the low power protocols their embedded security mechanisms are applied and relied on. Still, there are projects that do not address the security aspect yet (or that do not plan to at all). With respect to security there are only minor changes in the applied approaches, which is probably due to regulatory settings, like GDPR or the Data Act.

There are also different levels involving security, like security between each component or security at the cloud level for centralised approaches. This diversity is also related to the diversity of data exchange approaches. Depending on the level of data exchange distribution, the respective security approach needs to be applied, as security is to be addressed properly.

Finally, lack of security in data-based systems or improper security approach in use, induces the potential risk to the system reliability. This is due to possible interference from the attacker side or due to system malfunction that may cause the data flows to be affected. Such interference may go undetected (or uncorrected), leading to general or partial system failure. It is not trivial to provide an open, but protected system.

6.3 Issues and recommendations

The Smart Grid Architecture Model (SGAM) is a conceptual framework used to represent the different layers and components of a smart grid system, facilitating its design and implementation. It categorises elements into domains such as business, operations, information and communication. We asked all the BRIDGE projects we reached (so not only the ones involving home appliances) which layer of the SGAM is the most problematic from their perspective in the context of interoperability (see Figure 33). Despite the maturity of the model, not all projects are familiar with it or have no opinion about it (31%). According to the projects, the more abstract layers tend to cause more problems here, thus, the layers: communication, information and business. Interpreting the reasons behind these opinions actually reflects the well-recognised state: the lack of standardisation and the diversity of communication technologies and lower level protocols are the main issue, and the subsequent lack of semantic interoperability at the information layer on top of them.

Summarising the issues related to both the communication layer and the information layer indicated in the BRIDGE projects' report, we can identify the most challenging ones. **1) Diversity of protocols**: different devices use various communication protocols (e.g., Modbus, Zigbee, Wi-Fi), making seamless data exchange difficult. **2) Lack of universal standards**: inconsistent implementation of standards leads to compatibility issues between systems and vendors. **3) Inconsistent data models and formats**: devices may use different data models using different formats (e.g., XML, JSON), complicating data interpretation across systems. Different manufacturers and technologies use varying data formats and structures. Lack of standardisation in the information semantics makes integration complex. Challenges arise in mapping and translating data between systems. Semantic models, like Common Information Model (CIM) or NGSI-LD, require precise implementation but are often inconsistently applied. **4) Vendor-Specific Solutions**: proprietary technologies from different manufacturers hinder cross-system interoperability. Difficulty in ensuring that data exchanged between systems is understood in the same way by all components. **5) Security Challenges**: Variations in security protocols increase vulnerabilities and make secure communication harder to ensure. **6) Legacy System Integration**: Integrating older systems with modern technologies requires custom solutions, adding complexity. Legacy appliances or systems may not support modern, standardised data exchange protocols. **7) Data Volume and Complexity**: Managing real-time data streams, historical data, and metadata from appliances and energy systems. Ensuring accurate, secure, and timely data exchange across all systems is challenging.

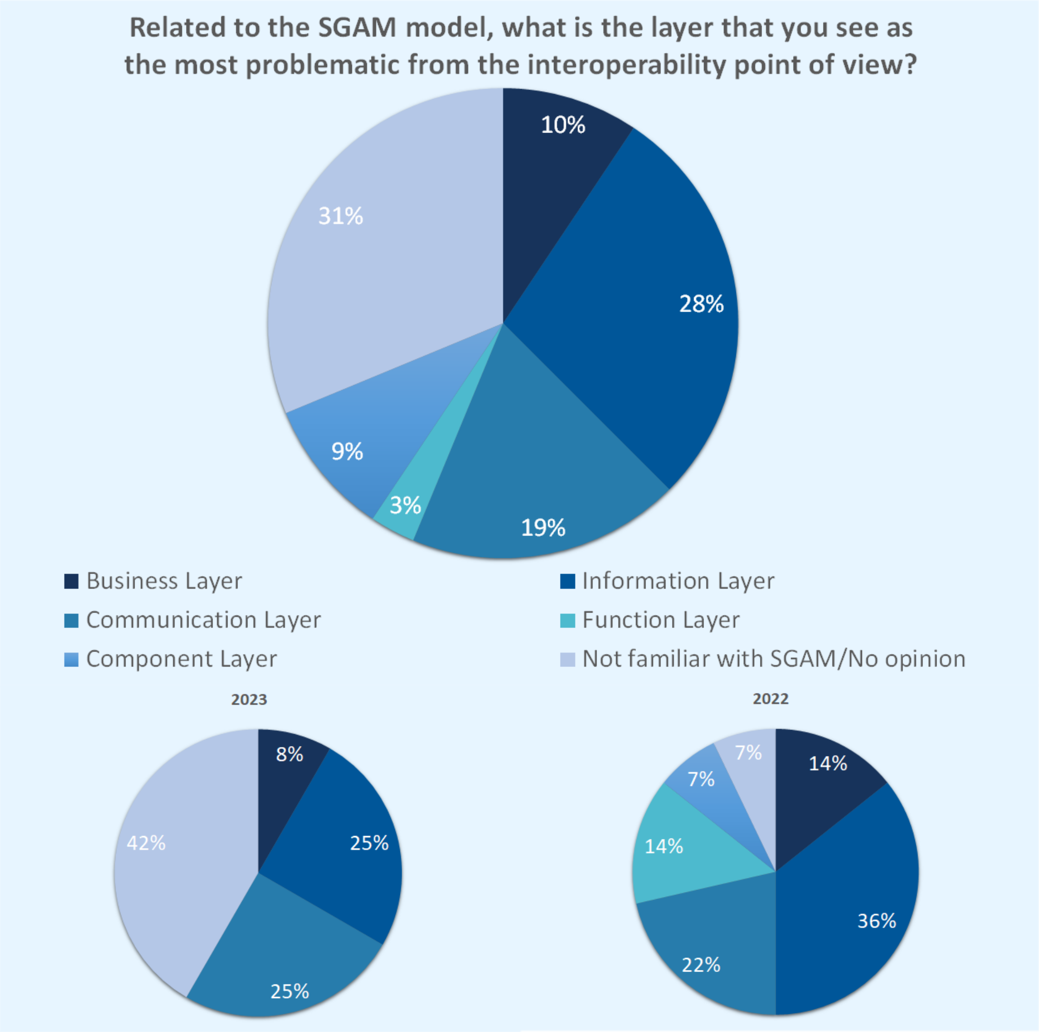


Figure 33 Q19: Related to the SGAM model, what is the layer that you see as the most problematic from the interoperability point of view?

According to the projects, the issues related to the business layer are due to the business process alignment, the existence of different regulatory frameworks and the limited selection of standards to support the business processes. To achieve interoperability in business processes, a counter-intuitive paradigm shift might be necessary. The closed nature of businesses is in conflict with the requirement for uncertain degrees of openness to achieve interoperability. Thus, there might not be so much economic benefit for companies to provide technologies that can be interoperable. Moreover, organisations at different levels (e.g., multi-company, company and department levels) develop interoperable solutions in silos, which may need to interact. This leads to the requirement of systematised stakeholder interaction and the clear objective to form a consensus among competing actors on how these business processes will be formed. Additionally, there are societal and political interests which are hard to materialise, when developing interoperable solutions. Hence, the interaction on the business layer is not limited to business actors. Further, it is not trivial to make actors on both sides of the equation agree on the ways to make a business out of (providing) home appliance interoperability and, what could be even more difficult, to get different home appliance providers to align in a common way to let these work seamlessly with each other in a transparent way for the sake of the end user.

There are also some features that the projects lack in home appliances. In general, more intelligence in existing devices, also related to system integration and predictive maintenance, is desired. Better interaction with the energy management and flexibility system is needed, automatic adaptation for load shifting and optimising energy consumption without user intervention. For this purpose, more advanced intelligent metering devices are required that provide detailed energy data. This should be accessible via control interfaces, but in such a way that the data remains secure, especially when access to this data is remote and extended to include, for example, weather data or price information. There is also a lack of functionality that is strictly device related, for example, advanced operational features in heat pumps, storage, electric vehicles or household appliances. Here it is worth highlighting the selection of operating profiles, price-based control, the establishment of setpoints or simply the postponement of operation. This is very much similar to previous years.

Other issues are related to the supported system architecture. Appliances relying on cloud services for core functionalities may experience outages or data latency issues. Further, data storage and processing in the cloud could introduce regulatory and compliance challenges.

There is also a fear that the set of energy-related features will be limited and the appliances will only comply with a limited number of use cases and, hence, can't provide some services which are necessary for exploiting the full potential of the appliance. Finally, the higher costs of such monitorable and controllable appliances will result in a limited number of consumer products available that consumers would wish to buy.

6.4 Regulations

Regulatory frameworks organise the rules that apply for energy management involving data. Unlike last year's survey, this year we received indications that GDPR and Data Act influence the work of the projects. We aim to further monitor these aspects as well.

7 Related activities towards harmonisation and standardisation

7.1 JRC CoC interoperability of energy smart appliances

The JRC activity on proposing the Code of Conduct for Energy Smart Appliances[4] has resulted, so far, in the first version of the CoC text and an initial proposal for the methodology for verifying compliance. We asked the projects if they were aware if this activity and Figure 34 shows the results. Their awareness is very similar to one year ago.

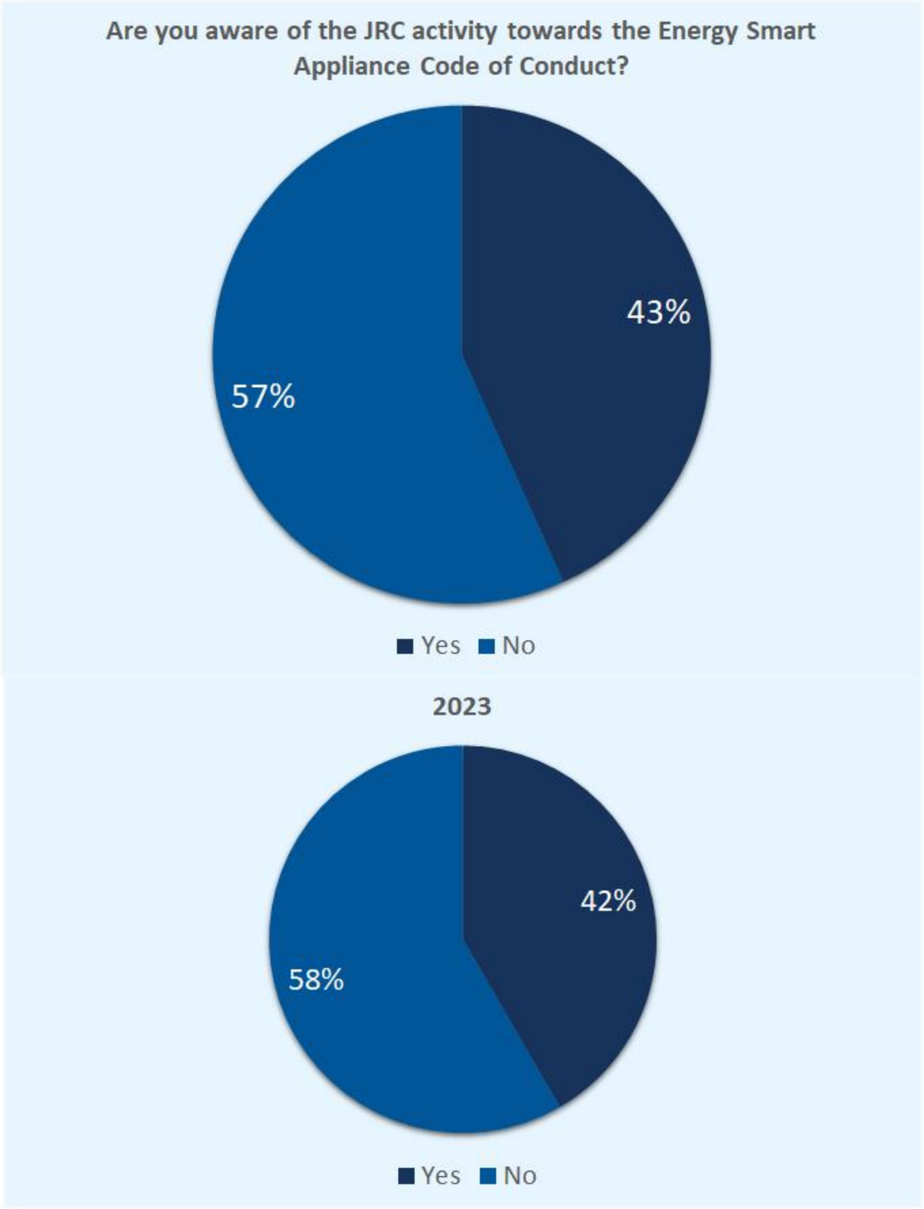


Figure 34 Q21: Are you aware of the JRC activity towards the Energy Smart Appliance Code of Conduct?

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[4] European Commission, Joint Research Centre. Code of Conduct for Energy Smart Appliances. Available at: https://ses.jrc.ec.europa.eu/development-of-policy-proposals-for-energy-smart-appliances

The first version of the CoC has been agreed and launched. The launch event took place during the EU Energy Day at the Hannover Fair on 23 April 2024. It was titled: *Energy Smart Appliances – harnessing the flexibility of interoperable energy smart appliances*. The manufacturers who signed the CoC were present at the event. Currently the work on the second version of the CoC is ongoing. It focuses on setting out a technical and governance framework for home appliance manufacturers to support interoperability in their devices.

The code of conduct fosters interoperability and enhances the provision of demand flexibility from appliances by establishing guidelines for energy-smart appliance (ESA) manufacturers. These guidelines are crucial for optimising consumption patterns in response to external stimuli, particularly in the increasingly decentralised energy landscape of the EU, where renewable energy sources are predominant. By encouraging ESA manufacturers to voluntarily sign the CoC, it outlines principles to ensure interoperability and the participation of relevant actors in the energy system. This initiative aims to unlock the potential of ESA in maximising demand side flexibility, thus aligning with EU energy and environmental policies.

On the technical level, the approach followed by the JRC CoC is to provide semantic interoperability within specific classes of home appliances. The initial approach was agnostic to specific communication technologies and focused on identifying the set of energy-related features for each class of appliances to be described by SAREF. This process actively involves the appliance manufacturers and defines which features are mandatory and which optional. This approach follows the definition that the manufacturers who signed the CoC can actively influence its scope in the future. In the second version the communication details are to be considered, as well as the procedures to test compliance with the CoC. The JRC CoC focuses on white goods and HVAC devices, but aims at extending the scope.

7.2 Mercury

Following the same goals as the JRC CoC, a new initiative, Mercury[5] led by EPRI, was launched at the end of last year (05.12.2024). The initiative aims to provide guidelines for developing interoperable appliances so that the customers are assured that these are working together and provide defined functionality. The compliant devices are then identified by labelling. Intensive work is ongoing to specify the initial specification that currently focuses on EV charging equipment. Further extension of the scope is planned.

7.3 Matter standard

Many of the projects and also external parties are working on hub-like approaches. These approaches focus on translating between different communication technologies and protocols – the hub is equipped with all the necessary communication modules and the translation is performed on the software level, involving the use of different data frames and higher-level protocols. Matter is a standard / protocol that harmonises the communication and addresses on all the devices in the home area network (HAN) by applying a common IP protocol layer on top of different communication technologies. However, this solution still requires the use of different hardware communication modules and the technologies used need to be IPv6 compatible (like Thread). But Matter provides a big step towards interoperability with its certification approach, where the certified devices are expected to work together out of the box. The latest version of Matter (1.4.1) was published in May 2025[6]. We already see applications of Matter in BRIDGE projects.

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[5] Launch of the Mercury initiative. Press release at: https://www.epri.com/about/media-resources/press-release/qxpp9eggnwuldbnvtvkj2ljuwoas8dgc

[6] Connectivity Standards Alliance. Matter, the foundation for connected things. Available at: https://csa-iot.org/all-solutions/matter/

7.4 Data spaces activities

Data spaces can enable energy smart appliances to seamlessly communicate with other upstream components of the energy system, such as smart grids and energy management systems, as well as downstream systems and devices, such as energy meters/sub-meters and actuators. This interoperability allows appliances to respond more effectively to market signals and grid conditions, thereby increasing their participation in demand response programmes and other energy market activities. Additionally, data spaces facilitate the exchange of data between of various energy system stakeholders, allowing end users not only to participate in flexibility provision schemes, but to also access a wider range of energy services from different providers.

Under this category one can also put activities related to data semantics and ontologies. These can define the meaning of the data exchanged with the home appliances as well as the relation between the different system components. There are currently several ongoing activities in this area and Action #5 will observe these in the following years.

8 Next steps towards repository creation

During the activities related to the Data Management Working Group, several kinds of information have been collected that would be beneficial for current and future projects. There have been the use cases collected for Action #1 or code components collected for Action #4. In Action #5 there has also been similar information collected for creating the appliance database, as well as standards or project products related to interoperability of home appliances. To optimise the quality of the output and to avoid duplicating effort, the approach for the following years is to bundle activities within different DMWG actions that aim at collecting and sharing of information. We also aim to bundle the data sets to be related to more actions, e.g., with an extended set of features to be stored. This approach aims to collect and combine the data more efficiently while extending the impact to more projects and stakeholders.

Following this approach, the joint Action #4 and Action #5 repository of relevant standards is scheduled and ongoing. Similarly, the code components repository will also be extended to cover the interoperability of home appliances products developed by the projects.

Finally, we monitor and will further report on the extensions to the EPREL database to be used as a comprehensive source of information on available controllable and monitorable home appliances and the specific energy-related features they provide.

9 Conclusions

This report summarises the third year of activities performed by the BRIDGE DMWG Action #5 on interoperability of home appliances. This work on interoperability can still be considered to be in its initial phase, but it is already focused, with the directions for the next years set out. The plans include investigating approaches working on the interoperability of home appliances on different levels, including security, reliability, use of standards and regulations.

We decided that the survey with similar questions run every year is a good idea, as it helps us to capture not only the current state of things, but also the trends between the years. With a deeper analysis this also allows us to monitor the progress of individual projects, the change in their experience and scope as they work on their solutions within a changing environment. However, we need to rethink, sharpen and specify the questions so that there are no doubts what we want to know. Further, in order to allow efficient analysis we need to send out the survey much earlier to secure more time for better analysis. Next year we plan to do this right after the beginning.

It was again confirmed by the results of the survey that the BRIDGE projects are at different stages of addressing the issue of home appliance interoperability. This comes from different project scopes and different stages of the projects’ progress as well. Every year there are new projects potentially unaware still of the issues they may be facing soon, but the sooner they recognise that and the more informed they will be, the easier the problem may be solved. Common approaches that simplify the use of appliances in the energy management context reduce the initial efforts needed by the projects to get introduced to the subject of home appliance interoperability. Our goal is to have a list of devices that can be applied in the different scenarios and the projects can focus on the main goal, i.e., exploiting flexibility. The ideal solution here is to use the EPREL database, but to reach this stage it will still require some time. Action #5 will observe progress in this area.

We will further work on the specific ways to approach, interact with and gather information from the three groups of projects we had already identified in previous years. The different focus of the projects is actually an interesting aspect that will be further investigated within Action #5. Depending on the scope of a project, its relation to the home appliance interoperability problem is different.

The projects that do not directly involve home appliances and seem not to be interested in their interoperability, can still identify use cases that might be relevant for Action #5, as the home appliances are often involved anyway, even if not directly considered in the first place. Thus, it is good to monitor their achievements to have an overview on the full picture, as they may probably define the context in which home appliances are used. These projects may, for instance, set energy management system goals that might determine the desired set of energy-related features provided by home appliances to be fulfilled. And the energy management system perspective is the one we want to focus as well in the next years.

The projects that focus on energy management and need home appliances to implement it might actually benefit from being able to reuse the available solutions. These projects can be considered as users and testers of solutions that provide home appliance interoperability, investigating their applicability in specific scenarios and providing feedback to the developers of the solutions, but also to other projects via the Action #5. These projects should be approached in their early phase of development with the solutions available so that they can make a meaningful choice. And approaching them in the course of the project allows us to collect feedback on the applied solutions.

Finally, for the projects that provide solutions for home appliance interoperability, it is crucial to investigate their outcomes and to make these available as soon as possible so that the interoperability clients can benefit. These projects should be monitored on their progress and their results should be linked and made available in a consistent and structured form.

In the following years we will further work on the strategy to support both clients and providers of home appliance interoperability solutions. To support them, it is also important to monitor relevant activities and projects in order to follow the changes in the requirements and goals for energy management. This also involves further investigating the sometimes contradicting requirements from the different stakeholder groups, which need to agree in order to achieve the goals set either by the economics or regulations. Here the relation between these groups could be named: the manufacturers are to develop appliances that provide the given set of features, as required by the energy managers or aggregators and they both need to operate in the cost region acceptable to the end customers. Not all of these relations are critical for Action #5, but some may be interesting to observe in order to explain the reasons behind specific issues and/or progress in designing and implementing solutions for home appliance interoperability.

This year we further observed and participated in activities related to supporting home appliance interoperability, like the DG ENER and JRC European Code of Conduct for Energy Smart Appliances Interoperability[7] or the Mercury initiative led by EPRI. These two examples show how manufacturers can be brought together in order to provide a common way for accessing their appliances. These two activities both support the main goal, despite following a slightly different approach for developing the common solution, and currently addressing different appliance classes. Thus, if interoperability can be achieved between these two approaches, then it will be possible for the projects to access a large portion of appliances in a common way. We will be further monitoring their progress.

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[7] https://ses.jrc.ec.europa.eu/development-of-policy-proposals-for-energy-smart-appliances

Appendix 1: Survey questions

In order to collect the detailed information about the relation to home appliance interoperability in different BRIDGE projects, the following questionnaire was used. It was conducted as a Google Form survey.

Project-level Survey

Explanation on the possible answers

[x] – multiple choices possible

(x) – one of many

1. Please name your project (or projects if they share the way to use home appliances)

(short text input)

2. Do you control and/or monitor home appliances in your project?

(1) Yes
(2) No → go to 19

3. Do you consider your project as provider or consumer/user of approaches related to interoperability of home appliances?*

*if the focus of your project is related to energy management only and you are using home appliances for that purpose then you are a consumer/user of the home appliances. But if your project focuses on developing approaches for supporting the use of different home appliances in different contexts then you are a provider of home appliance interoperability. Of course, your project can also focus on both these aspects, but here it is crucial to define the strength of the focus, e.g., some projects may become providers because they needed to develop solutions allowing them to use different home appliances, but their main focus is on energy management.

[1] provider
[2] consumer/user

4. How would you define the split in the focus (provider vs. consumer/user), e.g., 40/60?

(short text input)

5. What are the home appliance classes* (and subclasses if applicable) you are using in your project? Please provide comma-separated.

(long text input)

*example home appliance classes are: “washing machine”, “dishwasher”, “water boiler”, etc. Subclasses define finer differences, like “condenser dryer” vs. “heat pump dryer”.

6. Do these home appliances provide manufacturers own control and monitoring or do you use customised extensions (like a smart plug)?

[1] manufacturers own control and monitoring
[2] customised (like additional HW for monitoring and control) – please explain

7. What is/are the home appliance API location(s) in your project?

[1] direct
[2] home gateway
[3] cloud service
[4] other (please specify)

8. What are the energy-related features of the home appliance classes that you use in your project?
Please sort by home appliance class, like:
washing machine: shifting washing, pausing;
HVAC: setting temperature, reading energy consumption;
Fridge + Smart Plug: switching on/off, reading power parameters;

(long-text input)

9. For which use cases/scenarios implemented/considered in your project do you use the energy-related features of the home appliances?
Please sort by use case, like:
Energy flexibility – VPP: switching on/off, shifting load;

(long-text input)

10. Do you use/support home appliances by a single manufacturer or by many manufacturers?

(1) single manufacturer
(2) many manufacturers

11. Are these home appliances available on the market or are experimental ones?

[1] Yes (available)
[2] No (experimental)

12. Do these home appliances provide open monitoring and control interfaces and protocols?

[1] yes (open)
[2] no (closed)

13. Which home appliance API interfaces and protocols are used in your project?

(long-text input)

14. Which internal API interfaces and protocols do these appliances use?

(long-text input)

15. How do you handle interoperability for appliances from different vendors? Do you use solutions like adapters, appliance-specific drivers, or frameworks? Please describe your approach.

(long-text input)

16. Does your project use any specific framework/solution/product for controlling and monitoring the home appliances? Which one?

(short-text input)

17. Does your project provide any specific framework/solution/product for controlling and monitoring the home appliances? Which one?

(short-text input)

18. What are the security means applied in your approach? What mechanisms are used for authentication, authorisation, confidentiality, privacy protection? Are these available at home appliance level or e.g. at the cloud service level? What is the nature and extent of personal or sensitive data shared in your approach? How is it protected in the different stages of the system lifecycle (set-up, runtime, etc.)?

(long-text input)

19. Related to the SGAM model, what is the layer that you see as the most problematic from the interoperability point of view?

(1) Business
(2) Function
(3) Information
(4) Communication
(5) Component
(6) No opinion
(7) Do not know SGAM

20. Why do you see this layer as the most problematic?

(long-text input)

21. Are you aware of the JRC activity towards the Energy Smart Appliance Code of Conduct? (https://ses.jrc.ec.europa.eu/development-of-policy-proposals-for-energy-smart-appliances)

(yes/no)

22. Is the JRC Code of Conduct relevant / helpful for your project partners? Please name the kind of partner and the benefits (manufacturer, integrator, scientific, etc.).

(long-text input)

23. What are the home appliance features that you miss for useful use cases? Please sort according to use case (e.g., usecase:device_class:feature1, feature2;)

(long-text input)

24. Are there any issues related to accessing the features of the home appliances you experienced or foresee?

(long-text input)

25. Are there any issues related to interoperability of home appliances you experienced or foresee?

(long-text input)

26. Are there specific standards (e.g. ISO/IEC) that your approach follows to ensure or support interoperability of home appliances? Please, list them.

(long-text input)

27. Can we ask you additional questions related to the survey? (e.g. per email)

(yes/no)

28. Could you provide an email address so that we can contact you directly for questions?

(short-text input)

Appendix 2: Home appliance data questions

In order to collect the information about the different home appliances used by the projects the following data was collected for each device.

1. Vendor/manufacturer
2. Model
3. Class and subclass (if applies)
4. Features provided directly by the appliance (please list them)
5. Is the home appliance used with additional hardware? (yes / no)
6. Features provided with the additional hardware (please list them)
7. Application in use case (what are the features used for)
8. Home appliance API level (direct / home gateway / cloud service / other)
9. Communication technology used by the internal API
10. Communication protocols used by the internal API
11. Is the internal API open?
12. Communication technology used by the home appliance API
13. Communication protocols used by the home appliance API
14. Do you apply any interoperability framework/product for that device? Please name it
15. What are the security approaches and protocols available/supported by the internal API? (for protecting the communication / authorisation / access control related)
16. What are the security approaches and protocols available/supported by the home appliance API? (for protecting the communication / authorisation / access control related)
17. Is the appliance available on the market? (yes / no)
18. Does the manufacturer allow you to install own software on the home appliance
19. Have you developed any home appliance specific driver / adapter for this device? (yes / no)
20. Are you interested in providing the adapter/driver for the appliance to the community? (yes / no)
21. What is the licensing scheme you plan for the driver/adapter?

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