Interoperability for HEMS and smart devices

A guiding framework to accelerate residential flexibility

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To make residential flexibility actionable for customers and enable commercially viable market propositions, smart devices and HEMS must first become interoperable. This paper shows a path to a scalable European reality.

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Executive summary

This paper sets out a workable route for interoperable HEMS and smart devices. This route starts with priority use cases for residential flexibility and builds on clear architecture and protocol choices. Then it moves directly towards implementation, testing and adoption.

Europe can act now. The building blocks are available and implementation work has started. The proposed route supports local, cloud-based and hybrid HEMS models and uses a limited set of protocols to reduce fragmentation and accelerate convergence. For communication to the home, OpenADR is selected. For communication to devices in the home, the selected protocols are EEBus, Matter, OCPP and S2. Together, these choices create a practical basis for product development, market alignment and scalable interoperability.

The presented roadmap also takes the installed base seriously. Many existing smart devices still rely on legacy integrations, often based on Modbus. Bridge and converter solutions can help connect these devices during the transition, while new products increasingly support the selected protocol set directly.

ElaadNL has already moved this approach into practice in the Netherlands. Market parties have started developing reusable open-source software modules, and interoperability test events are underway. This pre-normative way of working brings acceleration: product and protocol implementation, testing, standardisation and market development can move forward in parallel and reinforce each other. It allows solutions to be validated early, improves implementation quality and helps the market mature around what works best in practice.

The urgency is clear: rapid household electrification, grid congestion, and dynamic tariffs drive the need for smarter coordination. The way forward starts with a focus on three priority use cases for residential flexibility: dynamic tariff, self-consumption, and grid limit optimisation. HEMS acts as the coordination layer, linking external signals and device capabilities to household preferences.

Interoperability is what allows HEMS-based flexibility to scale. It makes smart energy easier to install, easier to combine and easier to trust. For households, this means more plug-and-play solutions, lower barriers to use and better control over their energy bill. For suppliers, it means fewer custom integrations, more reusable interfaces and a stronger basis for services that can scale across devices, homes and markets.

The next step is to broaden adoption of HEMS by using the current momentum through collaboration among all key market stakeholders. By aligning technical and policy initiatives, Europe can establish interoperable HEMS as a market reality, supporting households, strengthening flexibility markets, and enhancing energy system resilience.

1. Residential flexibility

Europe is entering a new phase of the energy transition. A growing number of households is adding electric vehicles, heat pumps, home batteries and solar PV. These devices increase electricity demand, change load patterns and create new peaks on local grids. At the same time, they create a clear opportunity: households can use these assets more intelligently, shift consumption in time, reduce peaks and make better use of locally generated electricity. Which increases sustainability and lowers the energy bill.

1.1 Residential flexibility in a fragmented market

Residential flexibility is becoming a practical requirement for a more electrified energy system. Grid congestion is increasing, dynamic tariffs are becoming more relevant, and the value of self-consumption is increasing. The home is no longer only a place where electricity is consumed. It is becoming an active part of the energy system.

Without smarter coordination, growing electrification will put more strain on local grids, increase integration complexity and leave households dependent on fragmented solutions. It also creates a security challenge, since fragmentation results in many interfaces, one-off integrations and higher costs. This makes it harder to deliver robust, well-maintained solutions. In addition to this, households under cost pressure may choose cheaper options that are less future-proof, less resilient and less secure. In a more electrified Europe, this directly affects consumer protection, system resilience and the reliability of the energy transition.

For households, the need is simple: energy solutions must remain understandable, reliable and future proof. Consumers should be able to combine devices and services easily, benefit from lower energy bills, make better use of their own solar generation and avoid becoming trapped in closed ecosystems.

Earlier work by ElaadNL and its partners showed that the current market is still highly fragmented. Many different protocols, interfaces and integration routes are used in practice. As a result, suppliers face unnecessary integration effort, and scalable market uptake remains difficult. It also showed that the market needs clearer choices, a practical architecture and a realistic path to implementation.

1.2 Pressure on the home energy system is increasing

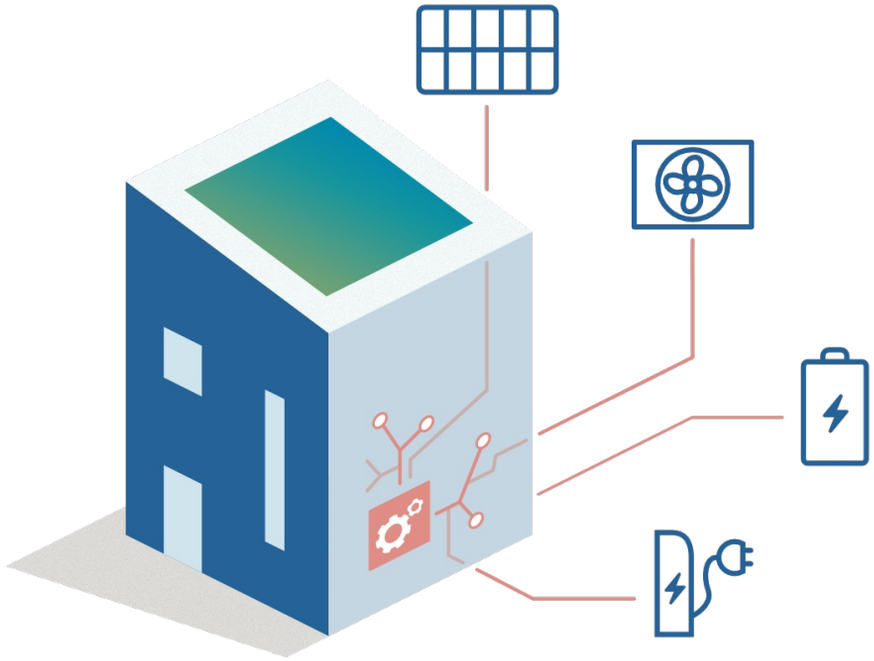
Three factors play a role in the changing home energy system:

1) The number of smart devices in and around the home is growing rapidly. EV chargers, heat pumps, home batteries and PV inverters are no longer exceptional technologies. Together, they are becoming the core assets of the electrified household.

2) The energy system is placing higher demands on how those assets are used. Local grid congestion is increasing, available capacity is under pressure, and households are increasingly exposed to price signals and changing incentives for self-consumption.

3) The market is not yet organised to deal with this efficiently at scale. Many technical routes exist, but they do not yet create a simple and scalable reality for suppliers or consumers.

Together, this makes residential flexibility a European priority. It is where pressure on the energy system, the growth of electrified households and the need for affordable and smarter coordination come together. This paper therefore starts from residential flexibility as the place to turn urgency into action.



The main smart devices controlled by HEMS in the home energy system are charging points, batteries, heat pumps and PV inverters

1.3 Purpose and scope of this paper

This paper sets out a practical Dutch view on how smart energy in and around the home can become more open, scalable and resilient. It does not aim to write a formal standard, but aims to support policymakers, market actors and standardisation initiatives with a practical path that can be implemented, tested and scaled. It starts with the most relevant use cases for residential flexibility, then explains why Home Energy Management Systems (HEMS) form the key coordinating layer in and around the home. From there, it sets out why more open and scalable communication between smart devices, HEMS and external services is needed, and translates that into architecture choices, protocol choices and a practical implementation path. The paper ends with concrete next steps for market actors, standardisation bodies, national policymakers and the European Union.

The core message is simple: the pressure is real, the market is moving, and the need for practical action is immediate. Europe now needs a smart and workable path that helps households, supports market development and strengthens the resilience of the energy system.

Residential flexibility is now an urgent practical need. Growing electrification, grid congestion and changing market incentives are putting pressure on households and energy system at the same time.

2. Priority use cases for residential flexibility

The pressure described in the previous chapter only becomes actionable when it is translated into concrete functions in and around the home. Households increasingly want to organise their energy use around their own situation: make better use of self-generated electricity, consume when prices are low, avoid exporting when prices are low or negative, and keep their power consumption within available capacity. At the same time, the energy system needs more flexible users who can respond to grid constraints and market signals. These two needs can reinforce each other when flexibility in the home is connected to incentives from grid operators and price signals from the market.

2.1 Use cases

Three use cases define the first practical scope for residential flexibility. They have been selected as a starting point because they are already relevant in the market and address the most immediate needs of households and the energy system. They are not intended to capture the full scope of residential flexibility, but to provide a focused and practical basis for implementation.

Dynamic tariff optimisation. HEMS responds to changing electricity prices by shifting consumption or storing energy when prices are favourable. This creates measurable savings for households and makes demand more responsive to market conditions.

Self-consumption optimisation. HEMS uses local flexibility to make better use of self-generated solar energy, for example by charging a battery or EV instead of exporting surplus generation to the grid. This becomes even more relevant when feed-in incentives disappear.

Peak grid demand limiting. HEMS receives information on available grid capacity and coordinates devices so that the household connection remains within defined limits. This helps households manage their connection more actively and directly supports congestion management and more efficient use of scarce grid capacity.

2.2 From use cases to implementation

Use cases turn urgency into practical direction. They show what HEMS and smart devices must be able to do: receive signals, exchange status and measurement data, apply limits or schedules, and respond in a coordinated and reliable way.

They also link household value, system value and technical choices. In doing so, they help structure testing, guide protocol selection and identify which interfaces matter most in the first phase. Starting with a limited set of use cases creates focus and allows faster progress. This helps manufacturers, HEMS providers and protocol communities move from broad ambition to practical deployment, while leaving room to expand over time.

Three priority use cases put residential flexibility into practice: dynamic tariffs, self-consumption, and response to grid limits.

3. HEMS as the coordination layer

The priority use cases described in the previous chapter all depend on one practical capability: coordination in and around the home. HEMS is where the home meets the energy system. It is the layer that receives external signals, reads what smart devices can offer and decides what happens in practice. With HEMS, flexibility can be coordinated across devices in a way that creates value for households and for the energy system.

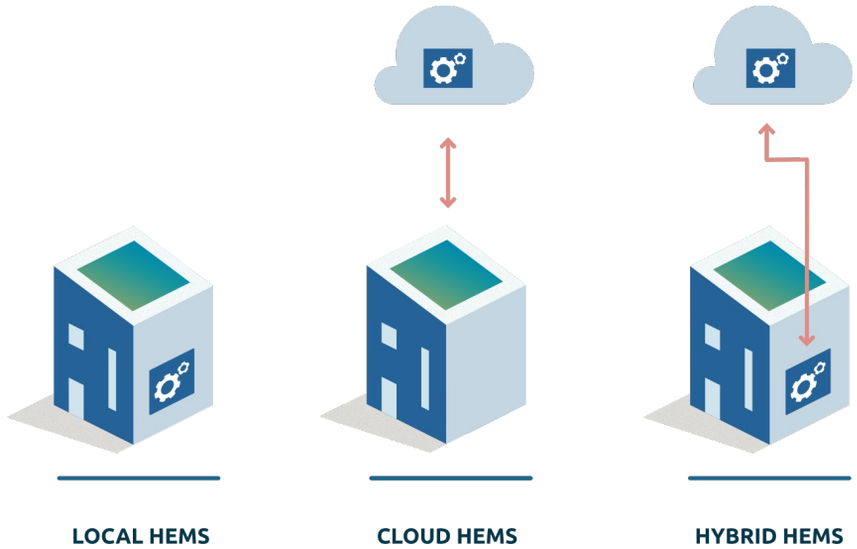
3.1 The coordinating role of HEMS

HEMS plays a central role because it connects external signals, local measurements and device control in one coordination layer. As more flexible assets are added to the home, that role becomes more important. A household with an EV charger, heat pump, battery and solar PV needs choices to be made about timing, power use, self-consumption and available grid connection capacity. HEMS can receive information on prices, grid limits or local generation, combine that with household settings and device availability, and translate it into coordinated behaviour across devices in and around the home.

3.2 Local, cloud and hybrid HEMS

HEMS does not exist in one single model in the current market, it is available through local and cloud-based solutions, and hybrid combinations. It is expected that all three models will coexist in the near future. HEMS should be understood first as a functionality, not as one fixed technical setup. This also means that the need for HEMS functionality can grow from a simple setup with one device using embedded control to a dedicated HEMS coordinating multiple devices.

In a local model, coordination takes place mainly inside the home. In a cloud-based model, coordination takes place mainly through an external platform. In a hybrid model, control and intelligence are shared across both. These are not competing end states, but practical implementation models that already coexist in the European market. The next chapters build on this reality and will explain why more structured communication is needed and how architecture and protocol choices can support this in practice.



Residential flexibility requires coordination in and around the home. HEMS is the coordination layer that can turn signals, device capabilities and household preferences into action.

4. Interoperability

Urgency of residential flexibility, priority use cases, and the need for HEMS as the coordination layer have been made clear. The next question is what allows that coordination to scale across households, smart devices and services. The answer is interoperability. It turns separate technical connections into a practical market reality in which devices, HEMS solutions and external services can work together more easily, more reliably and at lower integration cost.

4.1 From connectivity to interoperability

Residential flexibility will only be adopted at scale when it is easy to understand, install and trust. Many smart devices can already connect to internet for monitoring and steering, but that does not automatically create a workable market for residential flexibility. In practice we see fragmentation, too many different protocols, interfaces and vendor-specific integrations. This slows down deployment of HEMS and keeps flexibility locked inside separate devices. Consumers do not want a collection of loosely connected apps and one-off integrations. They want solutions that work together, respond automatically to prices, grid limits and local generation, and fit naturally into daily life. In practice, that means smart energy must become plug-and-play.

The cost of fragmentation for consumers

- **Connection difficulties.** Devices from a different brand often cannot connect to an existing HEMS or to other devices. Integration requires specialist help most households cannot arrange and afford.
- **Constrained choice.** Households replace devices with the same brand for (technical) convenience not because it is the best option.
- **Vulnerable position.** When a vendor closes a platform, connected devices can lose smart functionality overnight. Open interoperability is the protection against this.

Interoperability solves the fragmentation problem, by making communication between smart devices, HEMS and external services consistent. That is what turns connectivity into practical value. It allows use cases to work regardless of brands and service models, it reduces integration effort for suppliers, and creates a more scalable basis for market growth.

4.2 What makes HEMS scale

HEMS will scale when it becomes easier for households to adopt and for suppliers to implement. For households, the value must be clear: lower costs, better use of self-generated energy, and reliable automation. For suppliers, the route to market must be simpler: fewer custom integrations, more reusable interfaces, and a clearer basis for building services across brands.

Interoperability connects consumer value to technical implementation, making plug-and-play solutions more realistic and lowering the adoption threshold. This allows HEMS-based flexibility to move from isolated pilots to a functioning European market.

It also strengthens quality and resilience. When communication works in a structured, repeatable way, suppliers can focus on robust, secure solutions. Interoperability is a practical condition for making residential flexibility trustworthy, scalable, and future-proof.

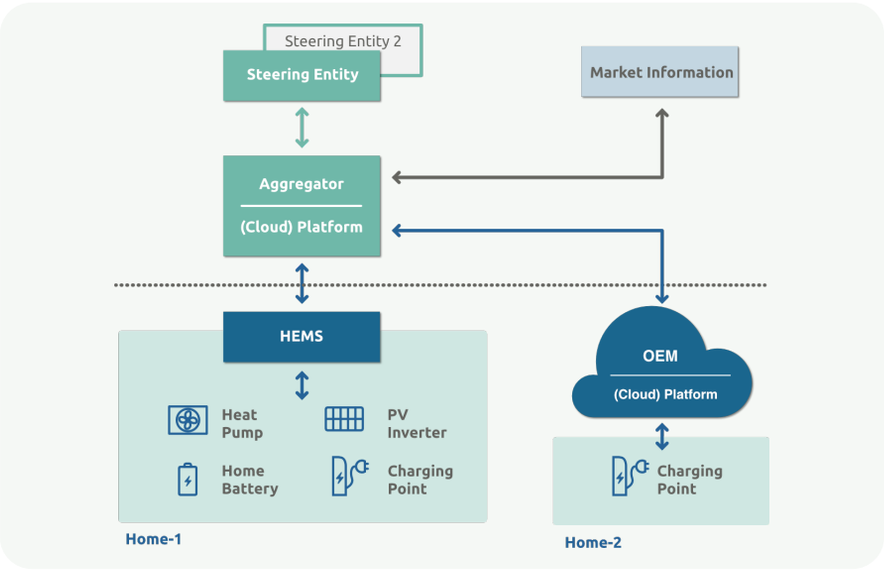
Interoperability is the condition for scaling residential flexibility through HEMS in a robust, secure and future-proof way.

5. Architecture and protocol choice

The aim is to accelerate interoperability by building on existing architectures, standards and protocols. That means creating an architecture that works across local, cloud-based and hybrid implementations, without assuming one single market model from the start. Interoperability will only scale if architecture and protocol direction are grounded in what real use cases require in practice.

5.1 High-level architecture

No single HEMS implementation model currently dominates the market. Local, cloud-based and hybrid models already coexist, often in combination with OEM cloud platforms. The architecture should acknowledge this diversity as a given. A practical interoperability strategy therefore needs to operate across these varying implementations, reflecting how the market already functions and how it is expected to evolve in line with European energy market developments.



Example of existing architecture with local HEMS for Home-1 and OEM cloud HEMS for Home-2.

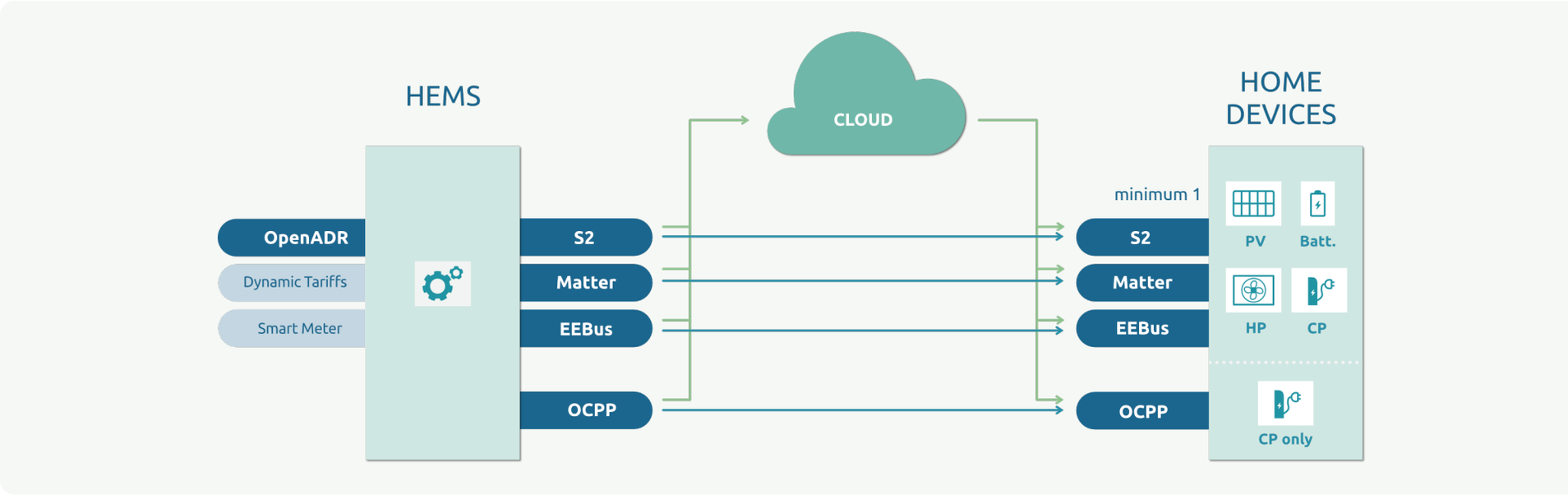
This chapter starts from a high-level architecture that can position the main roles in residential flexibility without assuming one fixed market model from the start. It should be able to accommodate actors such as the home, HEMS, smart devices, service providers, energy suppliers and grid operators, and show how flexibility can be coordinated between them. The next section then goes one layer deeper into the technical architecture and the protocol choices that support it in practice.

In this high-level architecture, a clear distinction becomes visible between communication to the home and communication with devices in the home. External signals from grid operators or market parties (steering entities) reach the household directly or via service provider (e.g. aggregator), while HEMS coordinates the response of connected devices.

5.2 A limited set of protocols

Interoperability does not require supporting every possible protocol equally. Instead, it requires narrowing it down to a manageable set of existing options that match the core functions and roles in the chain. This also reflects the need among manufacturers for a limited set of protocols across the European market. The current protocol landscape is far too fragmented to scale efficiently.

The protocol set for interoperable HEMS should follow a simple logic: the selected protocols must be internationally relevant, usable for delivering energy flexibility and suitable for secure implementation. For communication to the home, OpenADR is the selected protocol. For communication within the home, the selected protocols are (in alphabetic order) EEBus, Matter, OCPP and S2, with OCPP specifically positioned for EV charging. In this model, the HEMS should support these protocols across both domains (local and cloud), while device manufacturers should support at least one of the four in-home protocols.



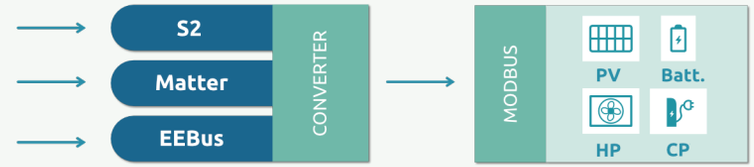
Technical architecture for interoperability with 5 necessary protocols on HEMS and a minimum of 1 out of 4 protocols on devices.

Together, this protocol set provides the starting point for the next steps in convergence, implementation, testing and further advancements of the protocols and services. Building on existing protocols means moving from broad optionality to a limited and workable set of choices. This creates a clear basis for market alignment, reduces unnecessary integration effort and supports faster implementation across local, cloud-based and hybrid models.

A clear architecture and a limited protocol set turn interoperability into something practical, scalable and implementable. Together, they create a workable path for both new products and the installed base.

Note

The selected architecture and limited protocol set also create a path for the installed base. Many existing home devices still rely on legacy integrations, often based on Modbus. Narrowing the target set of in-home protocols makes converter and bridge solutions easier to build, as they only need to support one selected protocol on the HEMS side. This helps connect the installed base while keeping the market focused on convergence around the selected set.



At EEBUS, we believe that HEMS should adopt a carefully selected set of protocols based on international standards, while each smart device only needs to support one of these protocols. With this approach, we can build a strong and flexible energy management that offers users a variety of choices and simplifies device integration, helping us move towards a more sustainable energy future.

— *George Hallak, Director Standardisation EEBus Initiative e.V.*

The proposed architecture aligns well with the vision of the Connectivity Standards Alliance. Within this architecture, Matter provides energy management capabilities across the broadest range of devices and appliances, while ensuring interoperability with all major global smart home ecosystems, an essential enabler for mass consumer adoption.

— *Musa Unmehopa, Chairman of the Board of Directors - Connectivity Standards Alliance*

The Open Charge Alliance is helping the EV charging industry connecting their charging stations to Energy Management systems. ElaadNLs polyglot EMS approach will enable charging station manufacturers to integrate seamlessly. It will allow them the freedom to choose and efficiently reuse their protocol implementations. It will expand their market opportunities and reduce their development time.

— *Lonneke Driessen, Director Open Charge Alliance*

Over the last decade, residential homes have become increasingly electrified. This represents both, challenges and opportunities for the electrical grid. Managing and aggregating loads and generation in individual or groups of homes will be a key for the future success of energy management. Interoperability for HEMS and Smart Devices is a must-have in these programs.

— *Rolf Bienert, Managing & Technical Director OpenADR Alliance*

The Residential Flexibility initiative by ElaadNL is an important catalyst for the adoption of the S2 standard. The open-source S2 libraries will lower the barrier for implementation while the ElaadNL testing events allow HEMS providers and manufacturers to validate the interoperability of their S2 solutions in a very early stage.

— *Mente Konsman, Board Member Flexiblepower Alliance Network*

6. Path to implementation

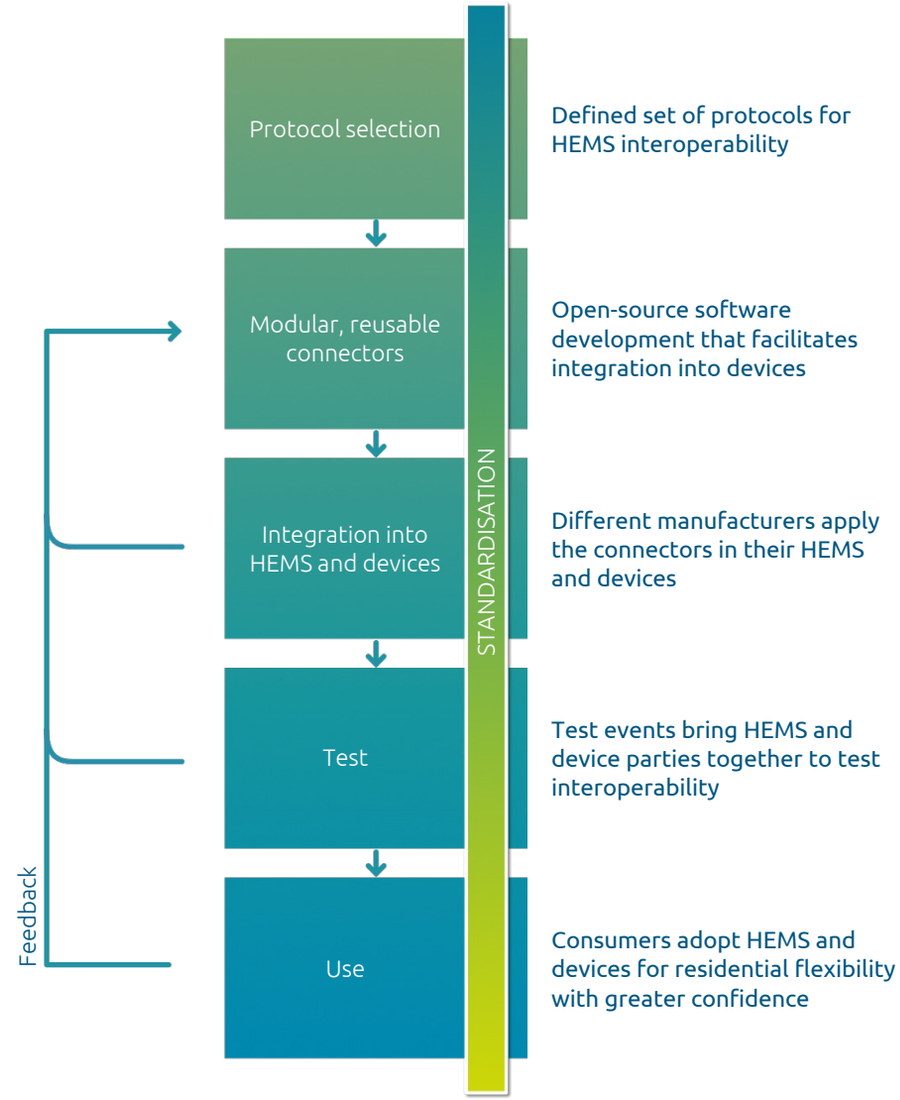
Interoperability requires more than a shared vision. Choosing a protocol set is only the starting point. ElaadNL has already moved into the next phase by making open-source implementations of the protocols available and organising a series of interoperability test events. The task now is to move step by step from fragmented connectivity towards practical, testable interoperability that suppliers can adopt and scale.

6.1 From concept to implementation

Interoperability needs concrete implementation building blocks. In practice, that means modular software, reusable connectors and practical integrations that suppliers can use in HEMS solutions and connected devices. ElaadNL kicked off this phase by issuing a Request for Proposal to market parties for the development of concrete implementation building blocks for the selected protocols. Several parties were selected to build open-source software modules as reusable connectors for HEMS and device integration[1]. This creates tools that can lower integration effort, support more consistent implementation and accelerate market adoption.

Open implementations are useful because they can lower barriers, improve transparency and make uptake easier, but they are a means rather than the end goal. The real objective is broader market convergence around interoperable solutions that can be deployed in practice. What matters is not only that software is available, but that it helps manufacturers to build reliable products and suppliers to create services faster and with less duplication.

An equally important part of this implementation path is pre-normative interoperability testing in realistic environments. That step has already been taken: a first interoperability test event has taken place, and follow-up events are planned[2]. These test events help identify interpretation differences early, validate implementation choices and show what already works across suppliers.



Pre-normative testing in parallel of standardisation efforts.

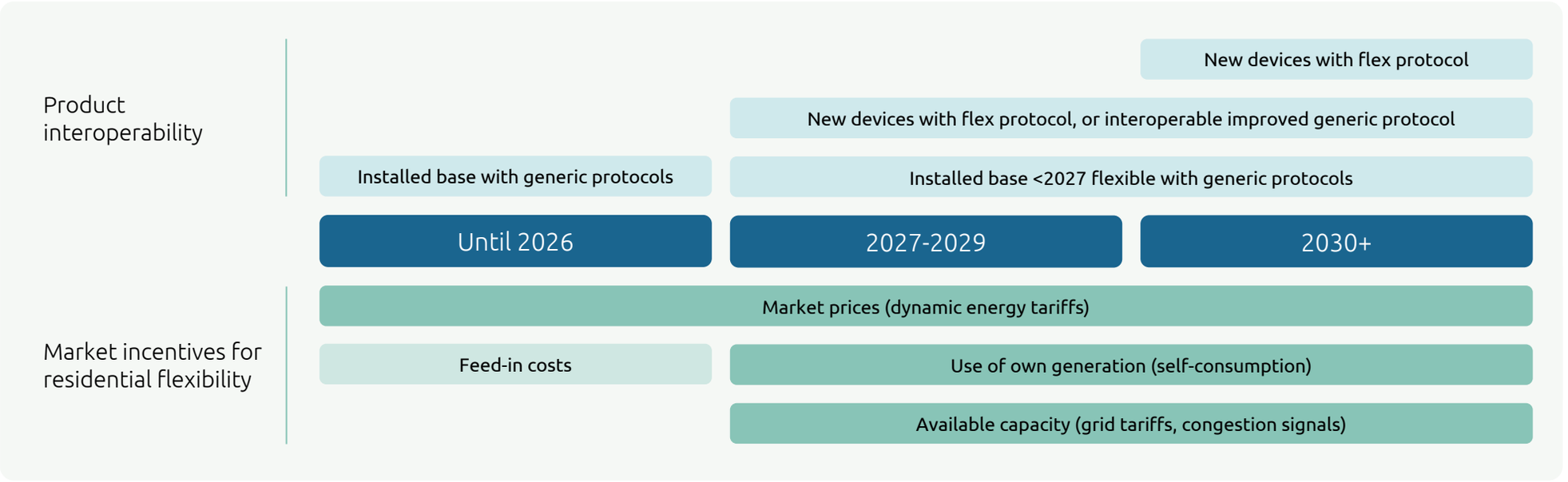
[1] Find more information at: https://elaad.nl/en/projects/residential-flexibility/core-aspects/open-source/
[2] Announcements for events can be found at http://elaad.nl/en/events/

and protocols. In doing so, they turn vision into implementation evidence that manufacturers, HEMS providers, policymakers and standardisation organisations can use.

Together, the open-source connector development and the first test events have done more than produce individual results. They have started a movement. Protocol organisations, HEMS providers and device manufacturers are now participating in a shared implementation path in which development, testing and market learning reinforce each other. That is exactly the kind of progress needed to move from selected protocols to practical, scalable interoperability.

6.2 Product and market roadmap

The transition to interoperable residential flexibility follows two parallel developments. On the one hand, there is a product roadmap: the market contains a mix of installed-base devices, newer smart devices and different flexibility capabilities. On the other hand, there is an energy market in development, in which new tariffs, incentives and flexibility signals are emerging. Both developments are visible in the roadmap, and both need to progress together.



For the product side, the installed base still needs a practical route into residential flexibility in the early phases, for example through bridge and converter solutions for older integrations such as Modbus. At the same time, newer products are expected to support the selected set of protocols from the moment they enter the market. This allows existing devices to remain useful during their economic lifetime, while the selected protocols take on a growing role over time and the market gradually converges around them. In the roadmap, this is reflected in the transition from an installed base with generic protocols to new devices with dedicated flexibility protocols or improved interoperable generic protocols.

For the market side, residential flexibility is also shaped by changing incentives. In the early years, households will mainly respond to feed-in costs and dynamic market prices. Over time, the role of self-consumption and available grid capacity becomes more important, and flexibility is increasingly rewarded through a broader set of market and system signals. In the roadmap, this is shown by the shift from feed-in costs towards market prices, use of own generation and available capacity as relevant control signals.

These two developments do not follow each other sequentially. Standardisation, testing, product development, market cooperation, grid incentives and supporting policy measures all move forward in parallel. This is already the way of working: protocol organisations are involved, market parties are contributing, testing approaches are being developed, and broader policy and programme efforts are beginning to align around interoperability. Progress on one side strengthens progress on the other. As products become better able to respond, market incentives become more effective; as market signals become clearer and more valuable, the case for interoperable product development becomes stronger.

For suppliers, this creates a practical roadmap. They do not need to solve every interoperability issue at once, but they are offered a visible path toward broader support in both product development and market application.

Pre-normative development makes progress possible now. Product and protocol implementation, testing, standardisation and market development move forward in parallel, allowing interoperability to be proven in practice while the market and standards mature together.

The movement has started. The next phase is to broaden adoption by connecting implementation, testing, product development and policy, so that interoperable HEMS can scale into a functioning European market for residential flexibility.

7. Next steps to interoperable HEMS

Interoperable HEMS has moved beyond concept. The key choices have been made, leading protocol initiatives are engaged, open-source implementation work has started, and interoperability testing is underway. The next phase is to broaden adoption, align market actors and embed interoperability in products, programmes and policy across Europe.

7.1 Build on the momentum

ElaadNL has already started this next phase in practice. Market parties have begun developing reusable open-source software modules for the selected protocols, and the first interoperability test event has already taken place. Follow-up test events are planned. Together, these steps have created a development path in which implementation, testing and market learning already reinforce each other.

The goal is to build on this movement, strengthen it and bring more parties into it. That is how interoperability becomes credible in the market: not only as a technical ambition, but as something that is implemented, tested and used in practice. The next step is broader adoption. Manufacturers, HEMS providers, protocol organisations, standardisation bodies, service providers and public actors all have a role in making interoperable flexibility easier to build, integrate, test and trust. Open implementations can lower barriers, pre-normative testing can create implementation evidence, and clearer procurement, subsidy and policy signals can help move the market faster.

7.2 Next steps per stakeholder

This implementation path will continue, and market parties are actively invited to join by participating in interoperability test events, by contributing to reusable software modules, and by applying the selected protocols in practical implementations.

The next steps below build on that same movement.

- **Protocol and ecosystem organisations** continue joint implementation and testing work, clarify interpretation differences early and provide practical guidance that helps suppliers implement the selected protocols consistently.

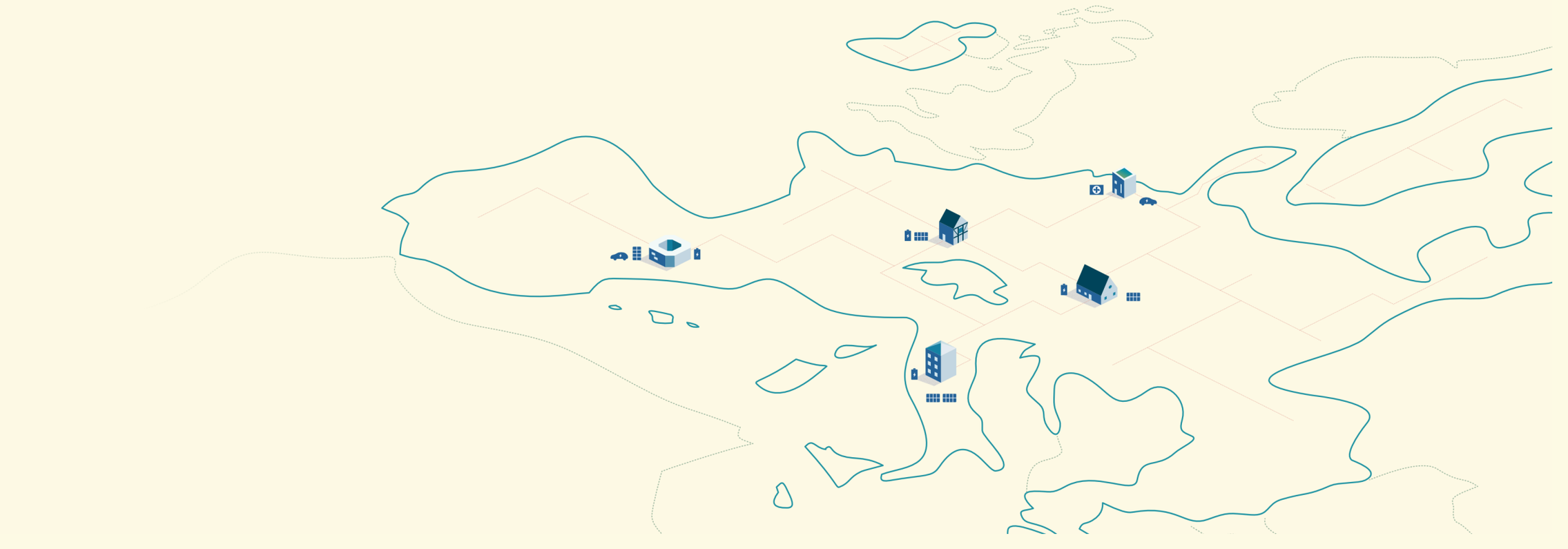
- **Manufacturers** incorporate open-source software modules and/or use them as a reference for their own software development to update products for interoperability. Smart devices support at least one of the selected in-home protocols and are designed for reliable integration into interoperable HEMS environments. Where legacy devices are involved, manufacturers also share Modbus specifications to accelerate converter solutions.

- **HEMS providers and related service parties** integrate and support the selected protocol set across the relevant domains and turn interoperability into reliable, low-threshold services for households and flexibility markets.

- **Standardisation organisations and test initiatives** use implementation evidence from pre-normative testing to strengthen specifications, test protocols and future certification approaches.

- **National policymakers and public programmes** reinforce implementation programmes, test events and practical convergence, and use procurement and subsidy schemes to reward interoperable solutions.

- **The European Union** embeds interoperability in relevant subsidy frameworks, energy market and system codes, and future policy and regulatory instruments. That is how Europe can turn today's progress into a scalable and resilient interoperable HEMS market.



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Credits

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