powerfolio

Residential Flexibility

Market Vision on Protocols and Architecture for Smart Energy Management

Colophon

This report was prepared by Powerfolio on behalf of the ElaadNL Foundation and Flexiblepower Alliance Network (FAN).

In cooperation with:

BAM MEC	Marco Thijssen
Beebop	Sandra Trittin
BeNext	Edwin van Kessel
Consumentenbond	Yvo Verschoor
ENGIE	Pim Buiting
Fronius	Tobias Hofer
Holland Solar	Jasper Ensing/Maaike Beenes
Itho Daalderop	Pieter Lagerwerf
Itility	Dennis van Goch
Milieu Centraal	Frans Sengers
Peblar (Prodrive)	Martijn van den Bekerom/Koen Elands
Productized	Corné van Bunnik
Sessy	Twan Vooijs
Stiebel Eltron	Nick van der Hoff
Tibber	Anton Westra
Vereniging Eigen Huis	Helen Visser/Richard Snijders

Authors

Jan Pellis
Bart Smakman

Commissioned by

ElaadNL
Flexiblepower Alliance Network (FAN)

Expert group

ElaadNL	Arjan Wargers
ElaadNL	Frank Geerts
FAN	Adriaan van Eck
TNO	Mente Konsman

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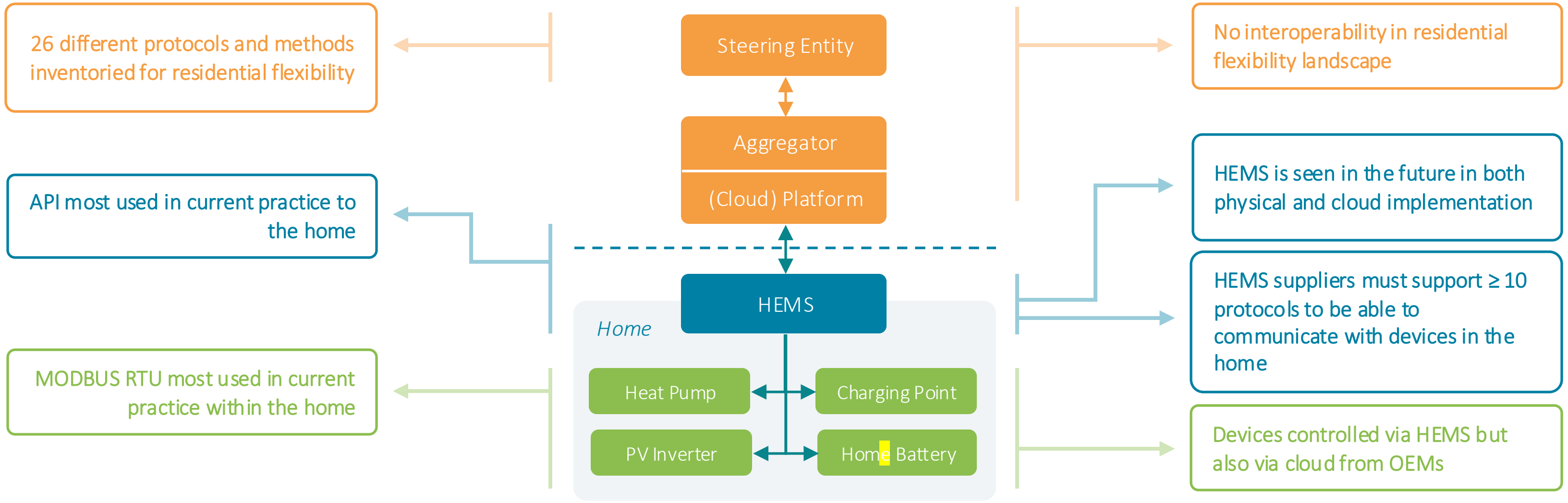
Summary (1/2)

Residential flexibility is one of the building blocks to reduce congestion in low-voltage networks and enable consumers to respond to dynamic energy prices and the abolition of the PV generation netting scheme (in Dutch: salderings-regeling).

This report presents the market's vision on protocols and architecture for residential flexibility. The report is based on 16 interviews with market players and industry associations, as well as discussions with an expert group.



Key Findings:

1. No interoperability in residential flexibility.

The MODBUS RTU communication protocol is the most widely used within homes but does not offer interoperability. Communication to homes primarily occurs through APIs from cloud platforms.

2. A hybrid architecture with both cloud-based and local physical solutions exists now and will exist in the future.

The current practice includes both cloud-based and physical HEMS (Home Energy Management System) architectures, often in hybrid forms, in which OEMs (manufacturers) play a role.

3. Interoperability is necessary to prevent lock-ins and reduce costs for consumers.

Devices within homes must be able to work together for optimal flexibility integration. This enhances consumer freedom when selecting suppliers and lowers acquisition costs. Additionally, it is important that aggregators can communicate with consumer devices in a standardized manner. The choice of specific protocols ensures clarity for both suppliers and service providers.

Summary (2/2)

4. Scaling up residential flexibility can be accelerated, but this depends on decisions.

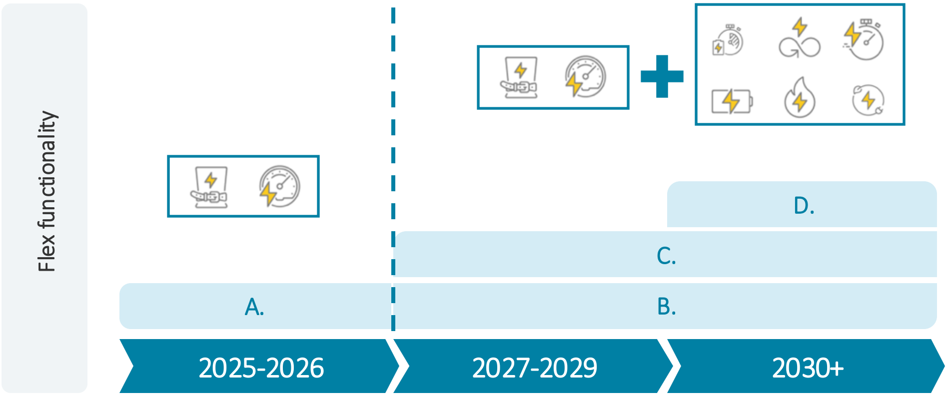
Decisions need to be made regarding the market model for the protocols to be used in the Netherlands, with incentives that promote the use of residential flexibility. There are sufficient flexibility protocols known and ready for broad application. Multiple options for the next steps have been identified and included in a phased growth path for scaling up residential flexibility.

5. Beyond interoperability, functionality growth is needed to unlock the full flexibility potential.

In the initial phase of the growth plan, we need to assume an installed base of home appliances with limited flexibility functionality. These devices can be controlled by limiting production or consumption, or by power modulation using generic communication protocols.

With the increase in (hybrid) heat pumps, home batteries, and charging stations, the number of devices with more sophisticated flexibility functionality will grow. New devices must be equipped with flexibility protocols to realize the full potential of residential flexibility.

Growth path for residential flexibility with flex functionalities



Phasing of growth in interoperability.

A. Installed base with generic protocols
B. Installed base <2027 flexible with generic protocols
C. New devices with flex protocol, or interoperable improved generic protocol
D. New devices with flex protocol

Flex functionality

- Limitation of production or consumption
- Power modulation

- Shifting of production or consumption in time
- Alternative energy profiles
- Interrupting a task
- Energy storage
- Energy buffering
- Switching to another energy type

Contents:

Reading Guide

The report is divided into four sections.

The first section (A) covers the introduction of this report.

The second section (B) describes the background that forms the starting point for the market research.

Section C presents the results of the market research and an overview of the perspectives of market participants. The research includes an inventory of which protocols are used for controlling devices for residential flexibility, and the assumptions from section B have been validated with the market.

The final section (D) describes the synthesis of insights from the market research and discussions with the expert group. This is summarized in the conclusion.

A. Introduction

This section describes the rationale and scope of this report, as well as the methodology used to obtain the research results.

1. Introduction

1.1 Flexible Energy Landscape

Flexiblepower Alliance Network (FAN) and Stichting ElaadNL have been advocating for a flexible energy landscape for years, where electricity consumption, storage, and generation are intelligently controlled. Their goal is to enable and accelerate the energy transition by optimizing the energy system while ensuring a level playing field for all participants.

1.2 Urgency

Due to congestion in electricity grids and the abolishment of the netting scheme for residential PV systems (in Dutch: salderingsregeling), the urgency to smartly control devices in and around homes has increased. The growing number of consumers with dynamic energy tariffs also contributes to this. Smart control allows for better utilization of scarce grid capacity and enables consumers to maximize the use of their self-generated electricity and take advantage of low-price periods. The vision of FAN and ElaadNL is that devices such as heat pumps, home batteries, solar inverters, and charging stations should be connected and coordinated using a Home Energy Management System (HEMS) to respond to signals from the electricity grid and the market.

1.3 Residential Flexibility Through Interoperability

This report examines the standards and protocols currently applied in the Dutch market and those considered promising for the future. It investigates how these protocols contribute to an interoperable system and the necessary steps and architectures to utilize residential flexibility on a large scale by 2027.

1.4 Scope

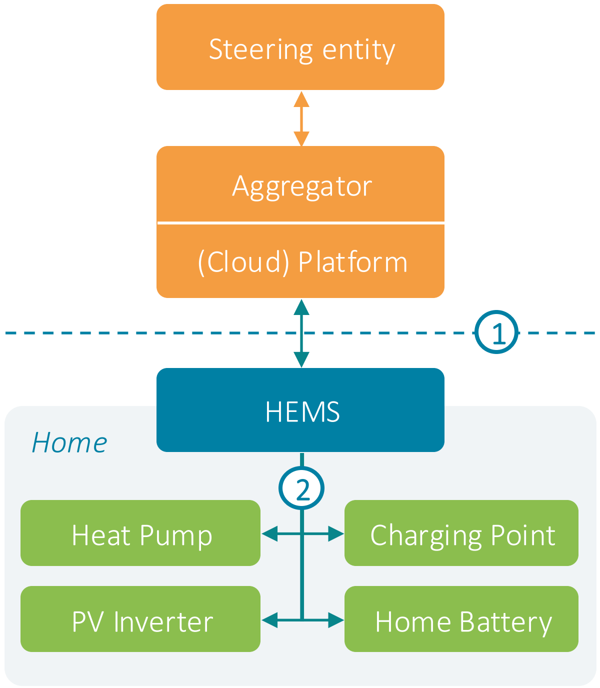
The study focused on interoperability:

1. The reception of control signals at the home level.
2. The interoperability between HEMS and household devices.

Residential flexibility is assumed to originate from the "big four" home devices:

- Heat pumps
- Solar inverters
- Home batteries
- EV chargers

The assumption is that using residential flexibility will be market-driven.



2. Methodology

2.1 Approach

To identify market preferences regarding protocols and architecture for unlocking residential flexibility, 16 interviews were conducted with various market participants and industry or consumer associations. Among those interviewed, 10 parties made their own choice of protocols used for communication with devices providing energy services. The remaining six maintain a more distant role as industry associations, interest groups, or purchasers of third-party services and do not directly choose protocols themselves. However, they have contributed their insights regarding architecture, implementation, and the application of protocols.

2.2 Market

- Providers of HEMS (Home Energy Management System) equipment and services.
- OEMs and suppliers of heat pumps, EV charging stations, solar panel inverters, and home batteries.
- Representatives/consumer advocacy groups.
- Others: energy suppliers, contractors, and software developers

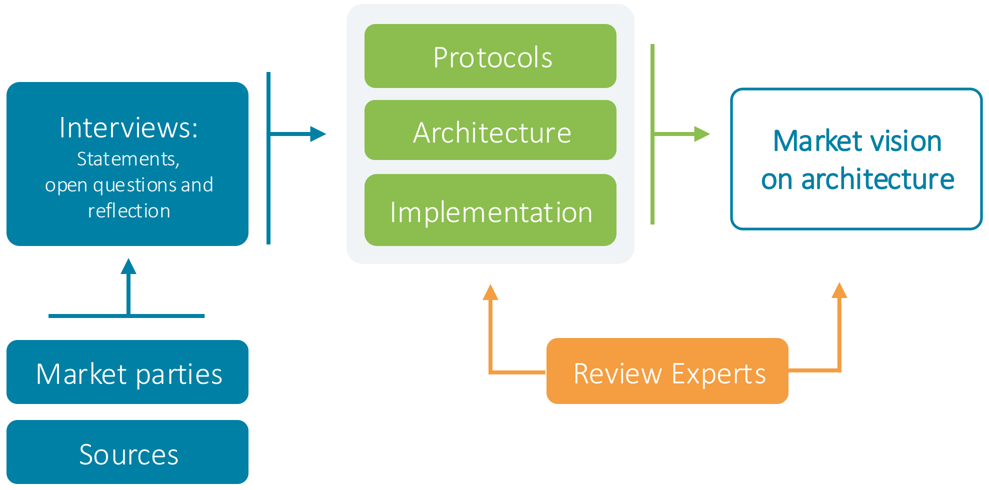
2.3 Experts

The results have been shared and refined with the expert/client group, which includes representatives from TNO, ElaadNL, and FAN.

2.4 Sources

Various sources were consulted (see Appendix V). Important foundational documents include:

1. Energy Management Opportunities for the Home, ElaadNL, FAN, TKI Urban Energy, 2022
2. Flexmonitor: Connected Heat Pumps in the Netherlands, FAN, TKI Urban Energy, 2023



B. Background

This section describes the background and developments that have formed the starting point for the market research. The basic architecture of the market in which residential flexibility is deployed is part of this.

3. Residential Flexibility

The energy transition is significantly reshaping the Dutch electricity system. Historically, demand dictated supply, as with traditional power plants, but this dynamic has now reversed. Increasingly, supply fluctuations from rapidly growing renewable sources like solar and wind lead to peak loads. Additionally, electricity demand is also growing due to the electrification of transport and heating, among other things. This requires not only an expansion of the electricity grid but also smarter ways to align supply and demand. Residential flexibility—the ability of households to adjust their energy consumption and generation—plays a crucial role in this.

3.1 The Changing Energy Landscape

The abolishment of the netting scheme from January 1, 2027, represents a key milestone in this transition. Households with solar panels will see a significant reduction in compensation for electricity returned to the grid, affecting the financial benefits of solar panels. This change encourages households to maximize direct use of self-generated electricity, where a Home Energy Management System (HEMS) can be instrumental.

A HEMS, or smart software integrated into devices such as charging stations or batteries, optimizes the matching of energy supply and demand within a household. It can achieve this by utilizing electricity when locally available or by automatically adapting the operation of devices like heat pumps and batteries to energy price fluctuations, thus minimizing energy costs and relieving grid congestion.

An overview of (Home) Energy Management Systems in the Dutch market can be found on the *Uptempo website* by TKI Urban Energy.

3.2 What is Residential Flexibility?

Residential flexibility includes all actions households can take to modify their energy consumption or production. This ranges from shifting electricity usage in time to store solar energy in electric vehicles and home batteries. It encompasses technical solutions as well as behavioral changes and awareness, though this report's scope is limited to technical solutions.

The benefits are clear:

- Lower energy costs: Flexibility enables households to take advantage of dynamic energy pricing and maximize their self-consumption.
- More efficient grid usage: Flexibility reduces peak loads on the electricity network, which is critical given the increasing congestion issues.
- Acceleration of the energy transition: Utilizing flexibility facilitates further integration of renewable energy and electrification of fossil-fuel-based energy demands for heating and mobility.

3.3 The Importance of Interoperability

To fully utilize the flexibility potential of a home, a well-coordinated control of all flexibly deployable devices is essential. The biggest challenge in this regard is interoperability: the ability of different systems or devices to work together seamlessly, regardless of manufacturer or technology. This involves not only connectivity but also speaking the right language to apply energy flexibility. This fosters innovation and prevents vendor lock-ins, ensuring consumers retain more choice and making the market more dynamic and accessible.

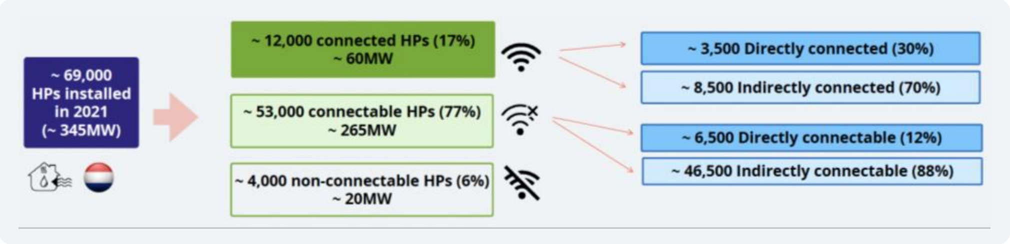
Lock-in

A lock-in is a situation in which consumers become dependent on a specific product, service, or supplier, making switching difficult, costly, or unattractive.

Two adverse lock-ins are relevant for residential flexibility:

1. *Within the home: Devices do not interact effectively with products from other suppliers, forcing consumers to remain with the same supplier or incur additional compatibility costs.*
2. *To the home: Aggregator services are sometimes tied to specific suppliers' devices (such as Home Energy Management Systems, HEMS), complicating switching providers. Compare this to energy contracts, where consumers can easily switch providers without technical adjustments. To offer similar freedom of choice, HEMS must be interoperable with all aggregators.*

It is therefore essential that manufacturers, service providers, grid operators, and policymakers collectively agree on the use of standardized protocols. Only in this way can a widely supported ecosystem emerge where devices and systems communicate and work together seamlessly.



Source: Flexmonitor, Connected heat pumps in the Netherlands, FAN, TKI Urban Energy, 2023

The opposite scenario—where this collaboration is lacking—results in consumers purchasing devices that later turn out to be unsuitable for participating in flexible energy solutions, either independently or in combination with other systems. This is not only a missed opportunity for the consumer but also for the energy system as a whole.

Research by FAN (see illustration) shows, for example, that a large proportion of heat pumps in homes currently cannot be controlled flexibly, even when they have the potential to be connected. By focusing on interoperability and collaboration, this barrier can be removed, making the energy infrastructure future-proof.

3.4 Residential Flexibility and the Consumer

The role of the consumer within the energy system is shifting from passive to active. Whereas households previously only consumed energy, they now have the opportunity to manage their consumption and generation flexibly. This presents opportunities but also requires a new way of thinking and acting.

Awareness and education play a crucial role in this transition. Many households are not yet fully aware of the benefits and possibilities of residential flexibility. By providing clear information and accessible education, consumers can better understand how to optimize their energy consumption, reduce costs, and contribute to the stability of the electricity grid.

Additionally, transparency about energy prices and savings opportunities is essential to encourage consumers to make informed choices. By providing real-time insights into energy rates, personal consumption, and generation, households can respond flexibly to price fluctuations and maximize their self-consumption. Smart meters and energy management systems (such as Home Energy Management Systems, HEMS) can support this process by automatically making the most cost-effective and efficient decisions.

A key consideration when promoting residential flexibility is household comfort. Technological solutions such as smart thermostats, EV chargers, and home batteries should simplify energy management without requiring constant manual intervention. Automation plays a key role here: systems can operate in the background, controlling devices based on real-time grid load and energy prices while consumers benefit from lower energy bills and more sustainable energy use.

Through a combination of education, transparency, and smart technologies, households can gradually transition into active participants in the energy system without being burdened with complex technical decisions. This makes residential flexibility not only more accessible but also more attractive to a broad group of consumers.

The Consumer

In the coming years, I will purchase various devices such as solar panels, an EV charger, a heat pump, and a battery—if I haven't already done so. Electrification continues to progress.

With the abolition of the netting scheme, changes in subsidies, legislation, and network tariffs, it is becoming increasingly attractive to use my devices flexibly.

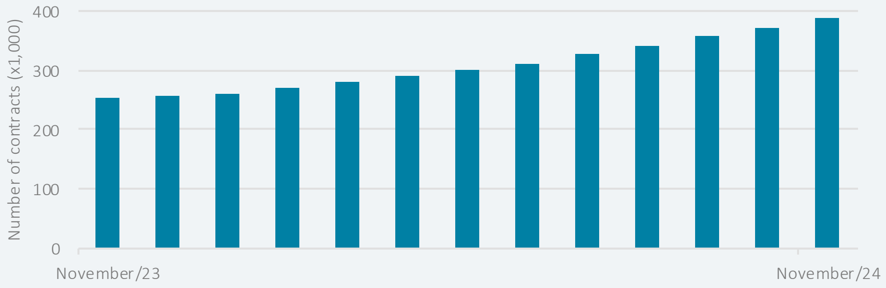
I want this to remain simple, I want to decide which devices participate and who can control them. It should also not be too expensive; in recent years, I have already invested significantly in energy and a new heat pump.

I hope my preferences are considered when drafting new regulations for energy in my home.

4. Market Developments

By describing four key developments, we obtain a clear picture of the significance, growth opportunities, and market conditions surrounding residential flexibility.

Dynamic energy contracts households



Source: Consumer Market Energy Monitor, ACM, January 2025

4.1 Changing Market Conditions

The introduction of dynamic energy contracts has changed the rules of the game. By linking rates to hourly prices on the energy market, households are encouraged to use their energy consumption flexibly. These contracts reward consumers who adjust their consumption to times of low demand or high generation of renewable energy.

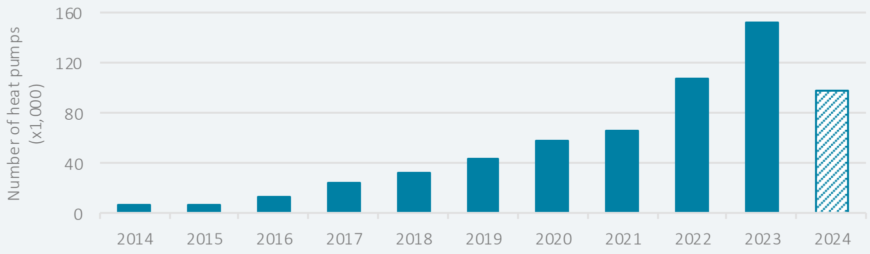
More and more consumers are switching to dynamic rates. In November 2024, around 5% of households had a dynamic energy contract.

4.2 Changing Policies and Regulatory Adjustments

Three developments demonstrate that residential flexibility is significantly influenced by governmental policy decisions:

- The netting scheme will stop by 2027. Owners of solar panels will then have an incentive to find ways to maximize their use of self-generated electricity.
- The recently adopted new Energy Law provides various opportunities for new forms of collaboration within the energy system, such as energy communities where flexibility is used to balance supply and demand.
- The planned obligation to install at least a hybrid heat pump when replacing a gas boiler from 2026 has been scrapped. This may relieve pressure on the electricity grid but also slows the growth of flexibility that hybrid heat pumps could provide.

Forecast of annual number of residential heat pumps put into operation (excl. air-to-air)

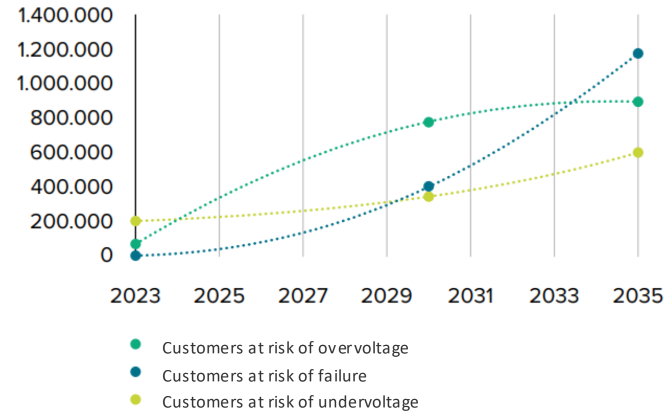


Source: National Heat Pump Trend Report 24-25, Dutch New Energy Research.

4.3 Urgency of Grid Congestion Issues and LAN

In January 2024, the Action Agenda for Grid Congestion in Low-Voltage Networks was published. Its underlying analysis highlights that by 2030, one million low-voltage customers will experience issues due to grid congestion. The action agenda outlines various measures aimed at making devices smartly controllable and improving interoperability..

Number of consumers experiencing issues due to congestion in the low-voltage grid



Source: Problem analysis congestion in the low-voltage network, January 2024

4.4 Research, Pilots, and Initiatives

Various multi-year research projects and numerous pilot programs are responding to and preparing for the market developments described above. The building blocks for scaling up residential flexibility are taking shape in both large and small projects. Examples include:

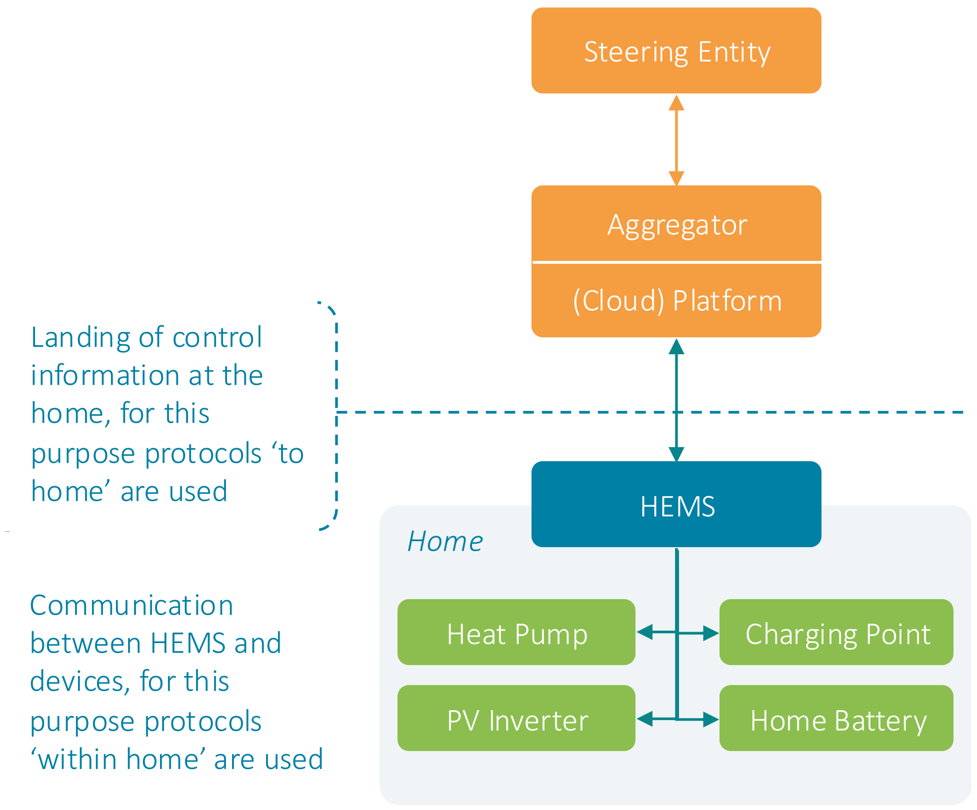
- TNO's 2024 research report, 'The Role of Smart Devices in Resolving Grid Congestion on Low-Voltage Networks,' provides an overview of the role flexibility can play in addressing congestion on low-voltage grids, upcoming developments, and available interoperability protocols.
- Under the Action Agenda for Grid Congestion in Low-Voltage Networks, NEN is working on standardizing protocols for residential flexibility.
- Berenschot conducted a study for Netbeheer Nederland exploring alternative grid tariff systems designed to incentivize consumers to adjust their electricity consumption.
- The GO-e project involved developing the S2 flex protocol and conducting an integrated test with a heat pump.
- Alliander hosted a HEMS Demo Day in 2024, demonstrating how Home Energy Management Systems can manage energy within communities to prevent congestion and voltage issues.
- The EU's 'Code of Conduct for Smart Appliances' provides voluntary guidelines assisting manufacturers in creating energy-efficient, interoperable, and user-friendly smart appliances, promoting energy savings and sustainability.
- At Flexcon 2024, ECOS (European Environmental Citizens' Organisation for Standardisation) presented its vision for establishing a universal energy flexibility standard.

5. Architecture

This architecture diagram presents the basic architecture that served as the starting point for the research. Discussions with market participants have made it clear that various alternatives to this architecture are possible. This is explained in Section C.

Principles of this layered architecture:

- There is a Steering entity responsible for managing capacity and/or balancing the grid through information/signals. The Steering entity could be a regional grid operator, the national grid operator, or a balance responsible party.
- Flexibility is utilized in a market-driven manner, where an aggregator (or another market entity) receives these signals and translates them into control actions directed towards households. Examples include adjusted grid tariffs (such as time-based tariffs) or standardized signals to temporarily lower a household's capacity limits.
- Within the household, the response to these control actions is coordinated among various flexible devices using a Home Energy Management System (HEMS). If a household only has one single controllable device, installing a HEMS may not immediately be logical for the consumer. However, interoperability between devices that communicate with each other and/or with a HEMS will be critical in the future. Currently, several different methods and protocols are in use to facilitate this interoperability.



C. Market Insights

This section describes the results of the market research based on interviews. After an overview of protocols for connecting and controlling devices, the vision of market participants on various topics related to the deployment and scaling of residential flexibility follows.

6. Protocols for Residential Flexibility

6.1 Communication Methods and Protocols

In all interviews, it was asked which protocols are used to connect and control devices for residential flexibility.

- The inquiry into the protocols used by market parties to connect and control devices resulted in identifying 26 diverse protocols and methods (see Appendix I for protocol descriptions).
- These have been categorized into communication protocols and methods* to distinguish between protocols describing functionalities and containing data definitions, and methods limited to message transmission.
- Communication protocols are further classified into:
  - Protocols specifically designed for energy flexibility.
  - Generic communication protocols and/or protocols customizable for energy flexibility control.
- Almost all mentioned protocols and methods can be used for communication between devices within the home, while some are also, or exclusively, suitable for outside communication to the home.
- The remainder of this report largely excludes communication methods, as they are less distinctive in controlling flexibility.. Appendix II contains a comprehensive overview of the protocols, methods, and market responses.

	Generic or specific	Protocol	Within home**	To home**
Communication Protocol	Generic and/or Proprietary customization for flex control	MODBUS RTU	•	
		MODBUS TCP	•	
		OpenTherm	•	
		Proprietary (wired) protocol	•	
		P1 (DSMR)	•	
		Wireless M-bus	•	
		Z-Wave	•	
		EPS-NOW	•	
		Matter	•	
		Proprietary RF protocol	•	
	Specific for flex control	SG-ready (hardwired)	•	
		OCPP	•	
		Sunspec Modbus	•	•
		S2	•	
		IEEE 2030.5	•	•
		EEBus	•	
		OpenADR	•	•
Communication Method		API	•	•
		LTE		•
		MQTT	•	•
		RS485	•	
		WIFI	•	•
		Dig. I/Os / wire	•	
		Ethernet	•	
		Internet	•	•
		TF / Ripplecontrol		•

* The following definitions have been drawn up for this report in order to be able to distinguish between communication protocols and methods in the context of residential flexibility:

- Communication methods are the underlying techniques or transmission mechanisms that enable communication.
- Communication protocols (also) define the content and structure of messages and how devices or systems should respond.

** A dot has been placed in these columns if the protocol or method is generally applied within or to the home.

6.2 Insights on Protocol Application within Homes

The table on the following page summarizes the frequency of applications of different protocols, leading to the insights below.

Insights on current protocol usage:

- Protocols specifically intended for flexibility control are used to a limited extent, often originating from pilot projects, e-charging scenarios, or international applications. "SG-ready" is frequently mentioned but receives limited enthusiasm due to perceived incompleteness for flexible control.
- MODBUS RTU has the highest adoption in current practice and is frequently mentioned as relevant for the (near) future; MODBUS TCP follows closely.
- MODBUS RTU/TCP implementations vary significantly by company, brand, and project in terms of registers and data tables, limiting interoperability for residential flexibility.
- HEMS parties must implement 10 or more protocols to communicate with most other devices
- API usage scores high, especially for communication between homes and cloud platforms and occasionally within homes. However, the lack of standardized practices severely limits interoperability. In other words, there is connectivity but no shared language enabling true interoperability.
- P1 and OpenTherm are not considered flexibility control protocols but play roles in smart meter readings and thermostat-to-heat pump communication, respectively.

Insights for future adoption and broad applicability:

- Significantly fewer protocols are explicitly mentioned.
- MODBUS RTU leads alongside Matter. Matter is highlighted as an interesting development with potential broad market adoption but currently lacks dedicated energy-domain functionality.
- Although market parties provide limited input on the question of future protocols, they emphasize the importance of a central standard. They indicate that this standard can encompass multiple protocols and must align with existing standards. At the same time, they adopt a wait-and-see approach. This is due to a lack of urgency, the absence of a clear market or revenue model, legal obligations, and the expectation that ultimately one or more protocols, just like in other countries, will be imposed.
- Some drawbacks of MODBUS are mentioned regarding its future application. MODBUS TCP has no authentication or encryption for data traffic. This makes it vulnerable to hacks, as once someone gains access to the network, they have control over all devices that can be managed via MODBUS TCP. For MODBUS RTU, it applies that two wires must always be drawn to each device, which leads to additional costs.

Protocols specifically tailored for flexibility control are unpopular, and interoperability remains elusive.

	Generic or specific	Protocol	Within home	To home	Number Currently Used*	Number in the future**
Communication Protocol	Generic and/or Proprietary customization for flex control	MODBUS RTU	•		7	4
		MODBUS TCP	•		5	1
		OpenTherm	•		4	1
		Proprietary (wired) protocol	•		3	0
		P1 (DSMR)	•		3	3
		Wireless M-bus	•		2	0
		Z-Wave	•		1	0
		EPS-NOW	•		1	0
		Matter	•		1	4
		Proprietary RF protocol	•		1	0
	Specific for flex control	SG-ready (**hardwired**)	•		5	1
		OCPP	•		3	3
		Sunspec Modbus	•	•	2	1
		S2	•		1	3
		IEEE 2030.5	•	•	1	1
		EEBus	•		0	4
		OpenADR	•	•	0	1
Method		API	•	•	8	5

* This column indicates how many of the 10 parties, who make independent choices in the application of protocols, currently use this protocol in their practice.
** This column indicates how many of the 10 parties, who make independent choices in the application of protocols, consider this protocol promising for flexibility control in the future.

6.3 Insights on Protocol Application and Communication to Homes

Insights into protocols for home integration:

- Receiving and sending signals to homes typically involve cloud-based control with API connections.
- Several market participants expressed concerns about insufficient attention given to this area, especially given uncertainties regarding upcoming control signals.
- An associated concern is the potential for differing capacity management approaches across various regions in the Netherlands.
- An identified opportunity is to start simply, analogous to the current distribution of market information (EPEX, imbalance prices, and KNMI weather data) already used for residential flexibility control.

Current home communication predominantly utilizes cloud-based API solutions.

7. Interoperability

7.1 The Importance of Residential Flexibility and Interoperability

Three-quarters of interviewed market parties see flexibility as a crucial element in the residential environment for advancing the energy transition. They emphasize that interoperability is essential for scaling residential flexibility. Interoperability extends far beyond mere connectivity ("is the device online?"); it also involves communicating effectively using the correct language for exchanging energy flexibility.

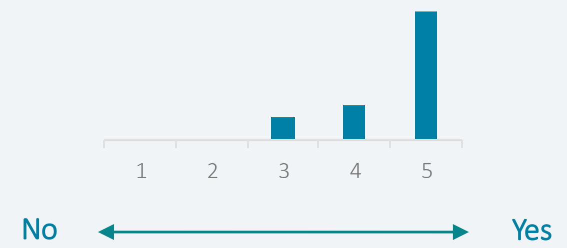
7.2 Business Model

Opinions are divided on whether flexibility for households can become a viable business model. While the sentiment is predominantly positive, there is also some hesitation regarding the business case. Firstly, this is because the current business case is still considered weak: the costs of a HEMS unit in the home are not yet easily recoverable. Additionally, there is concern that an 'ineffective' financial incentive for residential flexibility may drive scaling up, but that the deployment of flexibility will not automatically occur in the right place.

7.3 Organizing Interoperability

Interoperability involves organizing both communication from the market and electricity grid towards households, as well as connecting and managing devices within homes. Interoperability encompasses much more than connectivity ("can the device go online?"); it also involves devices speaking the appropriate language to effectively exchange energy flexibility information.

Statement: The use of residential flexibility is necessary to accelerate the energy transition



Explanation:
This graph and similar graphs in this report show the opinions of market parties on statements that were discussed during the interviews. The horizontal axis shows the scale of answers from 1 to 5. The height of the bars reflects the number of parties that chose a certain value on the scale.

While there is consensus about the importance of interoperability, opinions vary on how to implement it effectively for the installed base.

7.4 Accelerating Interoperability

Accelerating interoperability could involve prescribing detailed standards or defining only functional requirements, with divided opinions on which approach is optimal. Considerations for selecting one or more standards include alignment with the current market situation and consistency with existing standards. Manufacturers, especially those operating internationally, call for a certain degree of uniformity.

About half of the market parties advocate greater central regulation, referencing ongoing international developments and urging alignment where feasible. The other half prefer a market-driven approach supported by effective incentives.

7.5 Developing Interoperability

Nearly all market parties recognize the importance of interoperability. More than half express the need for a robust market standard, while a smaller group prefers to observe market trends before committing.

The majority supports the development of an open system accessible to third parties, occasionally supplemented by proprietary software and protocols.

Statement: Leave it to the market: more interoperability will come naturally if the incentives are big enough

Accelerate interoperability by making clear decisions regarding both market incentive models and protocol adoption

8. Vision on Architecture of Control

This chapter discusses the views of the interviewed parties on the architecture in which household devices can be optimally controlled.

Interviews revealed diverse opinions about the role and structure of a Home Energy Management System (HEMS): a physical device in the home or a cloud-based solution. Additionally, the extent to which a central or decentralized control architecture is desirable is discussed.

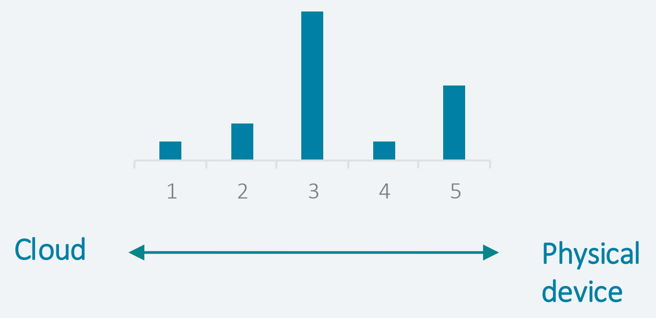
8.1 The Role of a HEMS

Most respondents recognize that a HEMS can play an important role in managing residential flexibility, especially when multiple devices are being controlled. This prevents conflicting scenarios within the household and creates opportunities for a more efficient energy supply.

At the same time, concerns exist regarding implementation and technical limitations, such as the dependence on Wi-Fi connections. There is consensus that a hybrid model, in which local control is combined with cloud-based management, is currently the most practical and scalable. This model provides robustness in case of internet outages and leverages the benefits of cloud scalability.

Additionally, some respondents emphasize that alternatives, such as device control without a HEMS, are also possible but seem less suitable for complex situations involving multiple devices.

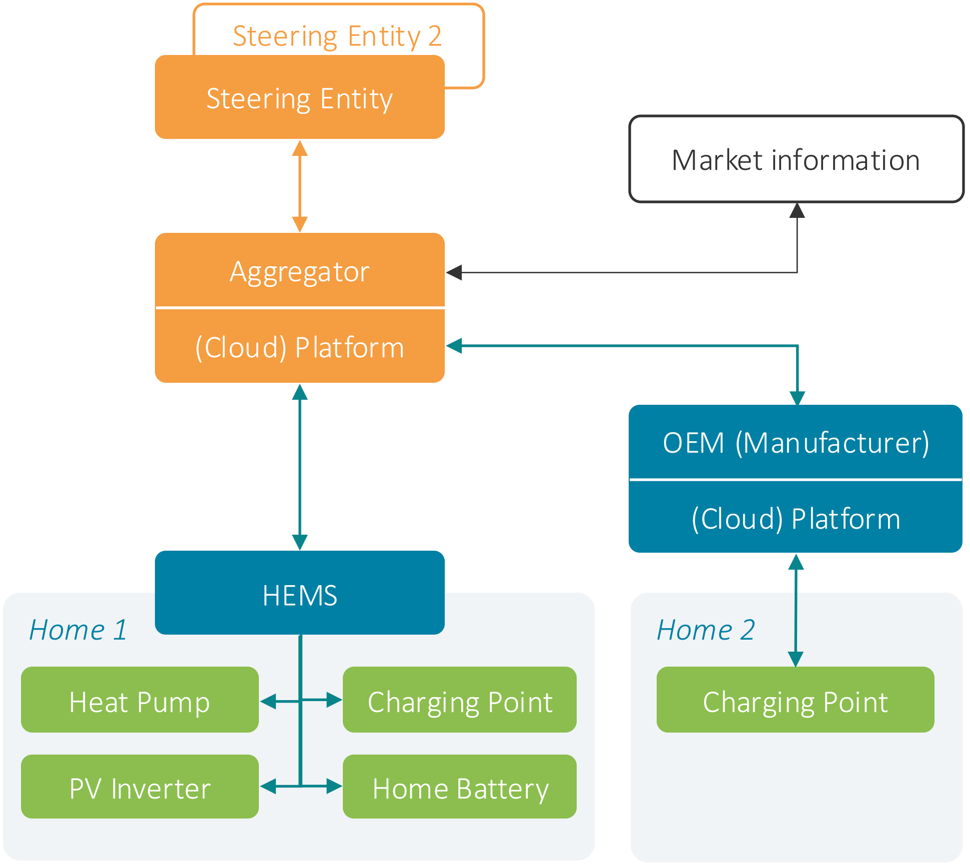
Statement: A HEMS is a physical device in the house or is it a cloud solution



The reality is that architectures with cloud-based and physical HEMS exist side by side, also in combination (hybrid).

8.2 Hybrid Architecture

Feedback from market participants has led to an expanded view of the architecture for enabling residential flexibility. Parties acknowledge the foundational architecture but recognize several variations currently and in the future.



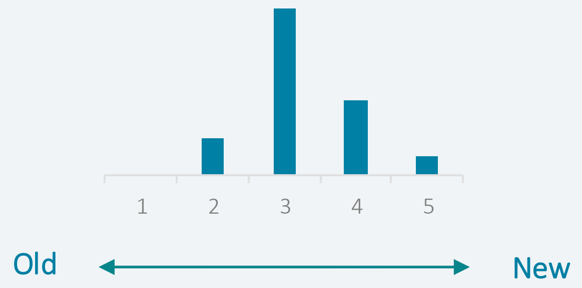
These variations have resulted in an expanded basic architecture, illustrated in the accompanying detailed architecture diagram. Key points include:

- Aggregators typically receive signals from one or multiple controlling entities, combining these signals with market information (e.g., pricing, weather data, forecasts).
- Interoperability between devices within the household is consistently emphasized as important. Interoperability between the home and external parties is mentioned less frequently.
- The need for HEMS functionality is acknowledged, with the caveat that there may be a growth path. A home with just one single flexible device can be controlled directly without the intervention of a HEMS.
- HEMS functionality can be implemented through a physical device in the home or via the cloud (where each device has a separate connection to the cloud, often that of the OEM).
- In reality, both situations exist, sometimes even in combination (hybrid). In practice, this means that a device has built-in functionality from the OEM for control, and the aggregator can coordinate control based on market incentives via the OEM's platform.

9. Vision on Implementation and Scaling

Scaling residential flexibility requires a clear implementation strategy focused on practical feasibility and the integration of existing and new devices. This topic highlights the technical challenges and opportunities for large-scale adoption, as well as the roles of market parties and standards.

Statement: Improving interoperability should focus on existing and new devices



9.1 Old Versus New Devices

Most respondents agree that new devices represent the "low-hanging fruit" for interoperability. They are more energy-efficient, easier to implement, and typically already equipped with modern communication protocols.

However, existing devices such as PV inverters should not be overlooked due to their widespread presence in households. Activating the current installed base is viewed as important, particularly given the urgent need for short-term flexibility at low voltage levels. Retrofitting older devices is anticipated to be necessary, though relatively high retrofit costs could present a barrier. Retrofits of older devices are perceived as expensive and complex.

A suggested approach is to assess the lifespan of existing devices, focusing particularly on recently installed and connected devices. For these devices, retrofitting is more about offering updates, adding protocols, and opening communication channels.

9.2 To and Within the Home

Market parties were asked whether priority should be given to improving interoperability of communication to the home or within the home. The outcome indicates that implementation should focus on both interoperability to the home and within the home.

Interoperability within the home is important to enable devices from different manufacturers to work together and to lower the barrier for deploying residential flexibility.

Regarding interoperability to the home, it was noted that this allows for freedom of choice in selecting a service provider (such as an aggregator). Preventing lock-ins is therefore relevant both to and within the home. Additionally, some parties indicated that interoperability to the home is important for optimization at the neighborhood level.

9.3 Criteria for Scaling

Market parties indicate that the absence of clear decisions on protocols and incentives is the primary factor delaying scaling.

They call on network operators and governments to make these decisions, providing several criteria, including:

- Considering desired functionality in flexibility control, differentiating between new and older devices (installed base) and the associated retrofit costs.
- Ensuring freedom of choice and avoiding lock-ins.
- Aligning with existing (international) practices.

Industry parties highlighted several consumer-specific points:

- Maintain affordability and comprehensibility, offering room and a framework for market innovation.
- Consider long-term maintainability; devices typically have long lifespans, thus maintenance (such as software updates) should ideally be minimal and guaranteed for extended periods.
- Evaluate choices within a broader future vision for the "Dutch home."
- Make realistic promises and ensure incentives are easy to understand.

Choices in implementation pathways should be evaluated based on multiple criteria, including impacts on the installed base and new devices, freedom of choice and avoidance of lock-ins, cybersecurity, and long-term maintainability.

10. Vision on Standards and Protocols

Methods and protocols form the backbone of interoperability and large-scale adoption of residential flexibility. In discussions with market parties, they were asked about their vision on developing and maintaining proprietary closed ecosystems versus using more open systems that facilitate collaboration with devices from other manufacturers and developers.

This chapter discusses the role of open systems, the need for standardization, and the challenges of implementing uniform protocols.

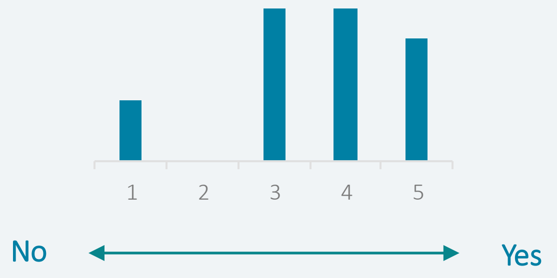
10.1 Open versus Closed Systems

Respondents emphasize the necessity of open systems to prevent vendor lock-ins and encourage collaboration among stakeholders. At the same time, an open system must provide sufficient security and be user-friendly. Some stakeholders still use closed systems but recognize the necessity of transitioning toward greater openness.

10.2 Standardization

Most stakeholders express a strong need for robust standards. Interviews clearly revealed the perceived benefits and essential role of strong standards in promoting interoperability. The current use of protocols and market outlook suggest that standardization does not have to be limited to one single protocol but can accommodate multiple protocols. Additionally, it is emphasized that standards should remain flexible and align with European developments. Forcing national standards is viewed as risky due to potential resistance and high implementation costs.

Statement: My company needs a strong standard that is used by the market



Choosing one or multiple standards is better than making no choice at all

D. Synthesis

This section contains a synthesis of insights from the market research and discussions with the expert group. After an analysis of the complementarity of protocols, a growth path towards greater residential flexibility is presented. Finally, all insights are summarized in the conclusion.

11. Complementarity of Protocols

So far, this report has not addressed the relationship between communication protocols and methods. By mapping the operation of various protocols and methods onto the TCP/IP model for data communication, differences become visible, making it clear how protocols can complement each other. For the application of a protocol for flexibility control, a full stack is ultimately needed to cover all layers. For example, protocols such as S2 and EEBUS can work with different solutions for physical data communication.

Table explanation: The colors correspond to whether a protocol/method is present (blue) or not present (white) in a specific layer of the TCP/IP model. If a protocol is not present, it means that this layer relies on solutions from other protocols or methods.

Given the widespread use and preference for MODBUS, a first step toward increased interoperability could involve establishing agreements achievable within the existing MODBUS infrastructure.

Application layer: Provides communication with user applications (e.g. HTTP, FTP)

Transport layer: Provides end-to-end data transfer and error checking (e.g. TCP for reliable, UDP for fast).

Network layer: Provides logical addressing and routing so that packets reach their destination.

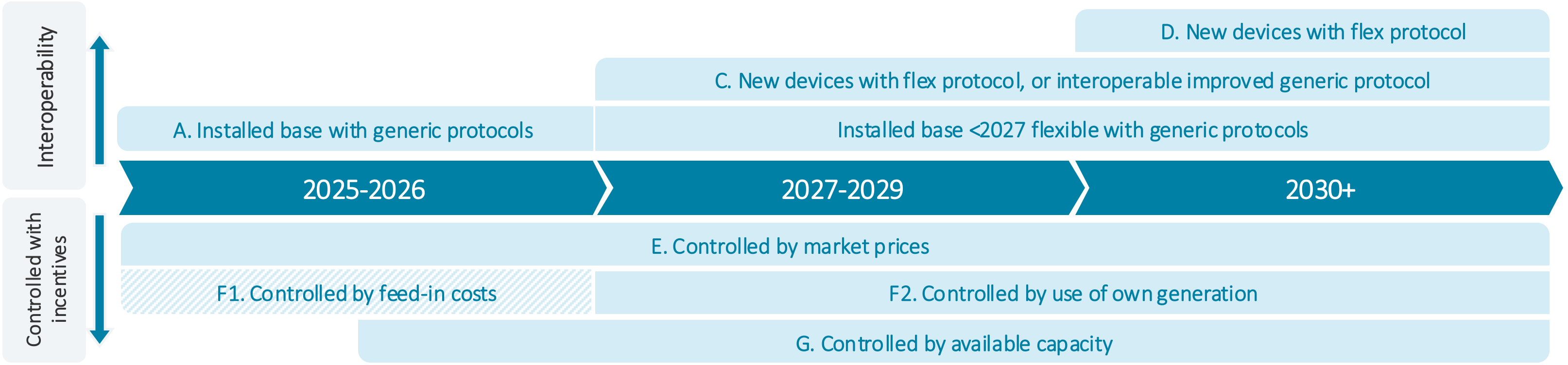
Network interface: Manages the physical transfer of data over the network medium (such as Ethernet or Wi-Fi).

	Protocol generic and/or custom for flex control				Protocol specific for flex control					Communication method			
Protocol/Method*	MODBUS RTU	MODBUS TCP	Wireless M-bus	Matter	SG-ready	OCPP	Sunspec Modbus	S2	EEBus	API	LTE	MQTT	RS485
Application layer		●		●	●	●	●	●	●	●	●	●	
Transport layer		●		●		●		●	●	●	●	●	
Network layer		●		●		●		●	●	●	●	●	
Network interface	●		●	●	●		●				●		●

* For readability, the number of protocols shown has been limited by omitting P1 and OpenTherm and only making the protocols that are mentioned most frequently visible here.

12. Growth Path Towards Increased Residential Flexibility

Interviews with market parties and discussions with the expert group have generated recommendations for the next steps towards greater interoperability and acceleration of residential flexibility. Potential actions are outlined below and linked to timelines within which they could be implemented. These actions will enhance interoperability and enable scalable growth in both scope and functionality.



Possible actions

2025-2026:

- Choose which flex protocols within and to the home in the Netherlands will form the standard.
- Improve interoperability for generic protocols by making specifications publicly available, so that HEMS parties can add integrations more easily.*
- Accept reduced functionality in flex control, see next page.*
- Introduce capacity control with local capacity profiles available via APIs.

2027-2029:

- Improve interoperability with generic protocols through sector-wide agreements on the use of MODBUS registers and APIs.
- With these agreements, compatibility to higher flex protocols such as S2 or EEBUS can be achieved more efficiently.*
- Introduce time-based grid tariffs for small consumers.

2030+:

- Adjust residential flexibility management to the increased number of devices with flex protocols and the resulting increased functionality, taking into account compatibility with devices with 'old' generic protocols that are still in circulation.*

* Suggestions based on discussions with the expert group.

Phasing in the growth towards more residential flexibility by making more and more devices suitable through improved interoperability and by applying control:

A. An installed base has been built up with generic protocols that are not or only partially interoperable.
B. This is used flexibly as smartly as possible.
C. And supplemented with new devices that have a full-fledged flex protocol or an improved interoperable generic protocol.
D. All new devices work with a full-fledged flex protocol.
E. Control on EPEX (dynamic energy prices) and imbalance prices is already taking place and is becoming increasingly widespread in homes.
F. The introduction of feed-in costs and the end of the netting scheme as of 1-1-2027 increase the incentive to use your own generation as much as possible in the home.
G. Control on available capacity in the grid is added to this with time-bound grid rates and (location-specific) capacity profiles.

Criteria to be considered in growth path developments:

- Prevent choices that will lead to lock-ins.
- Consumers remain owners of their energy data.
- Compliance with cybersecurity requirements.
- The consumer retains control over their own devices.
- Choose alignment with existing protocols and compatibility with generic protocols.
- Maintainability in the future.

12.1 Protocols and Functionalities for Flexibility Control*

The growth path anticipates an increase in home devices equipped with interoperable protocols. At the same time, it shows that there is an installed base that is either not controllable or not equipped with the most advanced protocols. This leads to both poor interoperability and reduced functionality in flexibility control.

In current practice, mostly generic protocols are used, which are not inherently designed to fully utilize all flexibility functionalities of a device. To illustrate this, a connection has been made between protocols and eight flexibility functionalities as described in the S2 protocol (further explanation in Appendix IV). The result is presented in the table below, indicating the extent to which different types of protocols (generic or specific) support flexibility functionalities.

Table Explanation: The colors in the table indicate how well the protocols within the generic and specific categories support flexibility functionalities. *Green* means full coverage. *Yellow* indicates that most protocols support this flexibility functionality. *Light blue* means only a few protocols support this functionality.

However, this does not mean that generic protocols cannot control, for example, a home battery or a hybrid heat pump. In such cases, customization is often required to achieve the desired functionalities.

	Flex functionality → / Generic or specific ↓	Limitation of production or consumption	Power modulation	Shift of production or consumption in time	Alternative energy profiles	Interrupting a task	Energy storage	Energy buffering	Switching to another energy source
Communication Protocol	Generic and/or own customization for flex control								
	Specific for flex control								

A generic protocol used for managing flexibility is not only less interoperable but also inadequately prepared to leverage all available flexibility functionalities.

* Information and structure of this section are based on sources and discussions with the expert group.

12.2 Impact Flexibility Functionalities on Utilization of Residential Flexibility*

Residential appliances contain varying flexibility functionalities. The availability or lack of control options directly impacts the utilization of this flexibility. A PV inverter has limited flexibility functionality, and a generic protocol that regulates production limitations is sufficient to make use of this capability. However, for other devices, flexibility is lost if certain control options are not accessible. For example, a hybrid heat pump can significantly contribute to flexibility by switching from electricity to gas without cooling down the home.

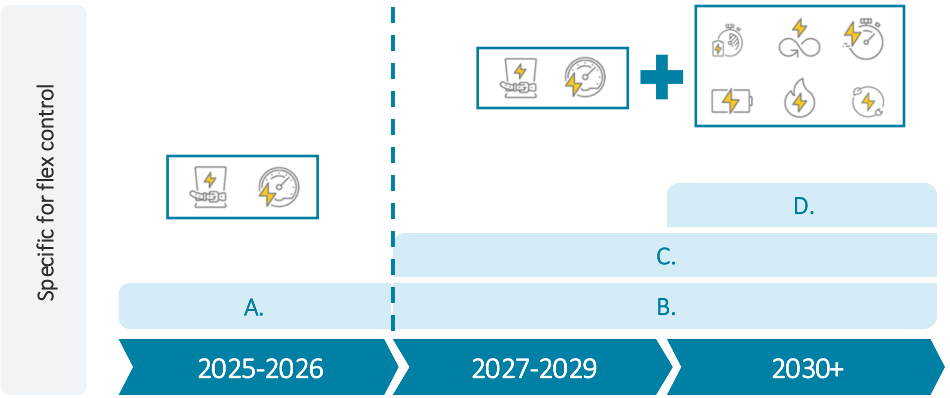
Advanced flexibility protocols include bi-directional communication between the device and the system, where information about flexibility potential is shared. This contributes to the maximum utilization of residential flexibility.

12.3 Developing Functionalities within the Growth Path*

In the coming years, a limited set of functionalities for residential flexibility control must be assumed. If functionality is linked to the previously described growth path, by 2027, it will be possible to fully unlock all flexibility features of home devices through the use of specific flexibility protocols. The necessity for this will increase, as the number of home batteries, (bi-directional) home chargers, and heat pumps (both hybrid and fully electric) is expected to grow significantly in the coming years. These specific devices require dedicated flexibility protocols to maximize their potential.

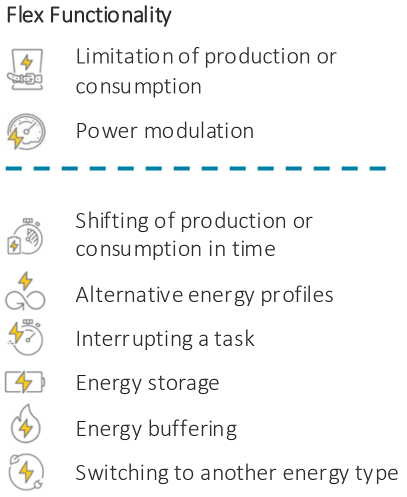
In practice, this means that grid operators, when implementing capacity control, for example, must consider the existing installed base, which can only be controlled to a limited extent through production or consumption restrictions, while newer devices will increasingly offer more flexibility options.

Growth path for residential flexibility with flex functionalities



Phasing of growth in interoperability. (See also page 29)

A. Installed base with generic protocols
B. Installed base <2027 flexible with generic protocols
C. New devices with flex protocol, or interoperable improved generic protocol
D. New devices with flex protocol



* Information and structure of this section are based on sources and discussions with the expert group.

13. Conclusion

1. Current practices are not interoperable

In the current market for controlling residential devices, the MODBUS RTU protocol is dominant. Although widely used, this protocol does not offer interoperability between different systems and devices. Besides MODBUS RTU, many other protocols are in use, forcing providers of Home Energy Management Systems (HEMS) to support around ten different protocols to communicate effectively with all residential devices. Often, cloud integrations with OEMs (manufacturers) are also necessary. In general, the protocols currently in use are fairly generic; specific flexibility protocols are still rarely applied.

2. A hybrid architecture for residential flexibility control

Communication to homes largely takes place via APIs within cloud-based architectures. In some cases, this happens via a HEMS, but often also directly to devices in the home. While the absence of a physical HEMS in the home can have drawbacks, the reality is that in the coming years, there will be a hybrid architecture. This means that homes with and without a HEMS will coexist, and control will be carried out via a combination of connections with different cloud platforms.

3. Interoperability ensures consumer choice

Improvements in interoperability are needed both within the home and for external communication. This is essential to reduce costs and provide consumers with more choices. As part of ensuring interoperability for home connectivity, it is important that capacity control is organized in a uniform manner across the Netherlands.

4. Accelerating residential flexibility is feasible but awaits decisions

The path toward increased residential flexibility primarily requires decisive choices regarding market models, suitable incentives, and flexibility protocols both within and towards homes. The necessary flexibility protocols are already well-developed and available for broad application. Making a decision will provide clarity for suppliers and service providers. However, stakeholders currently take a wait-and-see approach and indicate that choices in the implementation path should be weighed against multiple criteria, such as desired functionality, focus on new and/or existing devices, consumer choice, avoiding lock-ins, and alignment with existing (international) practices.

5. Recommendations for next steps

Several suggestions have been made for quick wins and a phased growth path for scaling residential flexibility:

- Make a decision as soon as possible on flexibility protocols for the future.
- Take an initial step toward greater interoperability by establishing agreements that align with the existing infrastructure (including MODBUS and APIs).
- Further research is recommended to ensure adequate cybersecurity measures when using this existing infrastructure.
- Make documentation publicly available and accept reduced flexibility functionality for the installed base.
- Market participants have indicated their willingness to contribute to scaling residential flexibility—engage these parties as advisors and ambassadors in the next steps.

Appendices

The next section describes the definitions used, the sources consulted, and a more detailed explanation of flexibility functionalities.

I. Communication Protocol and Method Descriptions

API: An interface allowing different software applications and systems to exchange data and invoke functionalities.

Digital I/Os / Wire: Simple digital inputs and outputs used for direct switching and basic power control.

EEBus: A use-case-driven interoperability protocol allowing household devices and energy systems to communicate through a standardized semantic data layer.

EPS-NOW: A protocol for energy management and control of energy facilities.

Ethernet: A wired networking protocol enabling fast and reliable data transmission within and between systems.

IEEE 2030.5: A standard for integrating distributed energy resources into a smart grid via secure IP-based communication.

Internet: A global network connecting devices and systems for communication and data exchange.

LTE: Long-Term Evolution, a wireless broadband communication standard used primarily for mobile devices.

Matter: A universal connectivity protocol designed to help manufacturers create interoperable devices within the smart home ecosystem.

MODBUS RTU: A serial communication protocol widely used for monitoring and controlling energy devices in buildings.

MODBUS TCP: A variant of the MODBUS protocol using TCP/IP networks for communication.

MQTT: Message Queuing Telemetry Transport, a lightweight messaging protocol popular in IoT applications.

OCPP: Open Charge Point Protocol; an open standard for communication between charging stations and backend systems.

OpenADR: Open Automated Demand Response, a client-server-based demand response protocol allowing energy suppliers and grid operators to remotely manage flexibility through standardized messaging.

OpenTherm: A communication protocol for heating and cooling systems.

P1 (DSMR): A serial port interface from smart meters enabling household energy management systems to read real-time consumption data.

Proprietary RF Protocol: A non-standardized radio frequency protocol used by specific manufacturers to control energy devices.

Proprietary (wired) protocol: A custom-designed (wired) communication solution specifically tailored to control energy devices within a closed system.

RS485: A standard for serial communication suitable for long-distance and robust industrial applications.

S2: A flexibility protocol operating with a resource manager abstracting the communication between devices and the Home Energy Management System (HEMS), enabling devices to collaborate independently of their communication language.

SG-ready (hardwired): Devices like heat pumps and boilers receive signals from an energy management system via relay connection to switch on/off or between operating modes.

Sunspec Modbus: A standardized application of the Modbus protocol specifically targeted at solar energy and energy storage components.

TF / Ripple Control: A demand response mechanism transmitting tone-frequency signals over the electricity network to control loads such as boilers or heat pumps.

Wi-Fi: A wireless networking protocol enabling devices to transmit and receive data via radio waves within a local network.

Wireless M-bus: A wireless variant of the M-bus protocol designed for energy meters and other smart grid applications.

Z-Wave: A wireless protocol designed for home automation, focusing on low energy consumption and secure connections.

II. Market Party Responses

This table shows the responses from the interviews per protocol/method.

	Generic or specific	Protocol	Within home	To Home	Number currently used	Number in the future
Communication Protocol	Generic and/or proprietary for flex control	MODBUS RTU	•		7	4
		MODBUS TCP	•		5	1
		OpenTherm	•		4	1
		Proprietary (wired) protocol	•		3	0
		P1 (DSMR)	•		3	3
		Wireless M-bus	•		2	0
		Z-Wave	•		1	0
		EPS-NOW	•		1	0
		Matter	•		1	4
		Proprietary RF protocol	•		1	0
	Specific for flex control	SG-ready (hardwired)	•		5	1
		OCPP	•		3	3
		Sunspec Modbus	•	•	2	1
		S2	•		1	3
		IEEE 2030.5	•	•	1	1
		EEBus	•		0	4
		OpenADR	•	•	0	1
Communication Method		API	•	•	8	5
		LTE		•	4	2
		MQTT	•	•	4	2
		RS485	•		3	0
		WIFI	•	•	2	1
		Dig. I/Os / wire	•		1	0
		Ethernet	•		1	0
		Internet	•	•	2	1
		TF / Ripplecontrol		•	1	0

III. Definitions

Aggregator: A market party translating signals from the market or grid into commands for households. (This document applies a broader definition than the market role definition of aggregator.)

Cloud Platform: A digital platform offering services, data storage, and applications via the internet.

Communication Methods: Underlying techniques and transmission mechanisms enabling communication between devices and systems.

Communication Protocols: Protocols that define the content and structure of messages and how devices or systems should respond.

Controllable Device: A device that can be controlled to manage energy usage, such as heat pumps or charging points.

FAN: Flexiblepower Alliance Network, a foundation promoting energy system flexibility and advocating for an open and fair energy system.

Flex Control: Adjusting energy consumption, storage, or generation based on signals.

HEMS: Home Energy Management System, controlling and aligning devices like heat pumps, home batteries, and charging points with grid and market signals.

Installed Base: The total number of installed and actively used devices or systems within a specific market.

Interconnectivity: The ability of systems and devices to connect and exchange data with each other.

Interoperability: The capability of different systems or devices to work together seamlessly, regardless of manufacturer or technology. This involves not only connectivity but also speaking the correct "language" to exchange energy flexibility.

Lock-in: A situation where consumers become dependent on a specific product, service, or provider, making it difficult or costly to switch.

Market-based Flexibility Deployment: Using price signals and market mechanisms to dynamically adjust energy consumption according to the needs of the electricity grid.

Netting scheme: Policy that allows households with solar panels to offset the electricity they feed into the grid against the electricity they consume annually.

OEM (Original Equipment Manufacturer): A manufacturer that supplies devices (or components used by other companies in their products.)

Residential flexibility: Encompasses all actions households can take to adjust their energy consumption, storage, or generation.

Retrofit: Modifying or upgrading existing devices or systems to provide new functionality or improved performance.

Steering entity: An organization responsible for managing capacity and balance in the electricity grid, such as network operators or balancing responsible parties.

IV. Flexibility Functionalities

Limitation of Production or Consumption

Some devices consume or produce energy that is, in principle, not controllable but can be limited if necessary. Typical examples are solar panels and wind turbines, which only generate energy when sunlight or wind is available, but where production can be reduced (curtailment).

Power modulation

This functionality describes devices capable of adjusting their energy production or consumption without affecting their functionality. Typically, these devices are deployed to balance a microgrid. A diesel generator is a good example, as it can produce electricity on demand. Another example is flaring, where excess energy, usually in the form of heat, is dissipated.

Shifting of Production or Consumption in Time

This pattern describes the ability to shift an entire production or consumption profile in time. A good example is a washing machine with a delayed start function.

Alternative Energy Profiles

This pattern offers multiple ways to perform a task using the same type of energy. For example, a dishwasher can heat water quickly using high power, or slowly using lower power. The resulting energy profiles differ, but in both cases, the water is adequately heated.

Interrupting a Task

Some devices can temporarily stop while performing a task. For example, a washing machine that can pause between phases of a program, such as between the heating and washing cycle. Some devices can pause at random moments, while others only at predefined points in their program. Often, there is a maximum pause duration or a deadline for completing the task.

Energy Storage

When energy is buffered, it is not always possible to retrieve the stored energy in its original form (e.g., hot water cannot be converted back into electricity). In the storage pattern, energy can be recovered in the same form as it was stored. A typical example is battery storage, where electricity is stored and can be used again later.

Energy Buffering

Some devices can temporarily buffer energy. There is one component that places energy into the buffer, converting it into another form, while another component later uses this converted energy. A good example is an electric boiler that stores hot water for later use.

Switching to Another Energy Type

This pattern describes devices capable of switching between different energy forms to achieve the same goal. An example is a hybrid heat pump that can alternate between electricity and gas heating.

Source: S2 Whitepaper, TNO, KNX, ECOS, FAN, 2023.

V. Sources

ACM Consumer Market Energy Monitor (in Dutch)
ACM, 2025.

The opportunities for energy management in the home
ElaadNL, FAN, TKI Urban Energy, 2022.

The role of smart devices in grid congestion on the low-voltage grid (in Dutch)
TNO, 2024

EU Code of Conduct for Smart Appliances
European Union, 2025.

Flexmonitor: Connected heat pumps in the Netherlands
FAN, TKI Urban Energy, 2023.

GO-e WP2: Implementation of HEMS in practice
ElaadNL, 2024.

How to get to one universal standard for energy flexibility: the role of regulation
ECOS, Presentation at Flexcon 2024.

In-home energy flexibility protocols
TKI Urban Energy, 2020.

National Heat Pump Trend Report 24-25 (in Dutch)
Dutch New Energy Research, 2025.

Problem analysis Congestion in the low-voltage network (in Dutch)
Ministry of Economic Affair and Climate, 2024.

S2 Whitepaper
TNO, KNX, ECOS, FAN, 2023.

Uptempo website
TKI Urban Energy, 2025.

Exploration of alternative grid tariff system for small consumption (in Dutch)
Berenschot, 2024.