

Onderzoeksrapport

Participatief modelleren duurzame doelgedragingen

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Samenvatting

Doel

Ondanks uitgebreide subsidieregelingen en ruime financiële draagkracht onder huiseigenaren, verloopt de voortgang bij het isoleren van woningen naar de standaard die vereist is voor aardgasvrije verwarming te langzaam om de beleidsdoelen te halen. Evenzo blijft de elektriciteitsvraag van huishoudens sterk geconcentreerd tijdens de avondspits, wat druk legt op het elektriciteitssysteem en het netwerk.

Om beter te begrijpen waarom de voortgang traag verloopt en hoe beleid verandering kan versnellen, heeft het Ministerie van Klimaat en Groene Groei opdracht gegeven aan SEVEN (Universiteit van Amsterdam) om twee prioritaire gedragingen te analyseren: woningen isoleren naar de standaard en het verminderen van de piekbelasting van elektriciteit in huishoudens. Beide maken deel uit van het "Duurzaam Leven"-programma van het ministerie en vereisen gecoördineerde beleidsmaatregelen om op te schalen.

Dit rapport beantwoordt de vraag: **hoe kan beleid huishoudens het meest effectief ondersteunen bij het isoleren naar de standaard en het verschuiven van elektriciteitsgebruik buiten de piekuren, gegeven de complexe systemen waarin deze beslissingen worden genomen?**

Methodologie

Het rapport hanteert een systeemdenken-benadering, gebaseerd op participatieve modelleersessies met belanghebbenden vanuit beleid, wetenschap, maatschappelijke organisaties en praktijk. In plaats van enkel barrières op te sommen, richt deze aanpak zich op hoe verschillende factoren op elkaar inwerken en waar beleid het grootste verschil kan maken.

Gedurende drie sessies hebben deelnemers gezamenlijk de belangrijkste factoren en relaties in kaart gebracht die het gedrag van huishoudens vormgeven. Deze zijn vastgelegd in causale lus-diagrammen (CLDs) die laten zien hoe factoren elkaar versterken of tegenwerken. De gedetailleerde diagrammen zijn vervolgens vereenvoudigd om de belangrijkste relaties voor beleid te benadrukken.

De CLDs zijn geen voorspellende modellen. Ze zijn bedoeld als instrumenten die beleidsmakers helpen zien waar interventies het systeem als geheel kunnen beïnvloeden. Tevens synthetiseert het kennis uit verschillende domeinen en ondersteunen traceerbaarheid en transparantie in besluitvorming.

Beleidsaanbevelingen met hoge hefboomwerking

Hieronder presenteren we de beleidsaanbevelingen met het hoogste hefboompotentieel: interventies die ingrijpen op onderliggende structuren die gedrag vormgeven, in plaats van geïsoleerde of eenmalige maatregelen. Dergelijke interventies kunnen meerdere delen van het systeem tegelijk beïnvloeden.

De aanbevelingen zijn direct gebaseerd op de systeemkaarten en richten zich op waar beleid het meest effectief belangrijke knelpunten kan verminderen of positieve interacties kan ondersteunen. Verdere uitleg wordt gegeven in het hoofdrapport.

Isoleren naar de Standaard

1. **Zorg voor beleidsstabiliteit en voorspelbaarheid voor isolatie naar de standaard.** Vermijd frequente, onvoorspelbare wijzigingen in isolatie gerelateerde subsidies, normen en regelgeving. Bied een duidelijke routekaart voor de lange termijn m.b.t. de isolatiestandaard, zodat huishoudens, professionals en financiers kunnen plannen. Faseer noodzakelijke veranderingen transparant in met voldoende vooraankondiging.
2. **Bouw een sterke, onafhankelijke adviesinfrastructuur voor isolatie.** Investeer in hoogwaardige, onafhankelijke en lokaal toegankelijke isolatieadviesdiensten (bijv. loketten, gemeentelijke of regionale adviseurs) die huishoudens helpen begrijpen wat haalbaar is in hun woning, praktische en procedurele barrières verlagen, en hen begeleiden van eerste interesse tot het isoleren naar de standaard.
3. **Breid de professionele capaciteit voor isolatie naar de standaard uit en coördineer deze.** Vergroot de beschikbaarheid van gekwalificeerde isolatieprofessionals door uitgebreide opleidings- en certificeringstrajecten, en verbeter het behoud, de coördinatie en de matching tussen huishoudens en installateurs.
4. **Stuur sociale ervaringen actief aan door slechte gevallen te minimaliseren en goede te versterken.** Versterk kwaliteitsnormen, garanties en klachtenmechanismen om negatieve isolatie-ervaringen te verminderen, en investeer in communicatie- en peer-to-peer initiatieven die positieve ervaringen zichtbaar maken, zoals buurtambassadeurs, voorbeeldwoningen en duidelijke voor-en-na voorbeelden.

Verminderen van Piek Elektriciteitsvraag

1. **Maak slimme automatisering mogelijk door technische, organisatorische en governance-condities.** Verwijder structurele barrières voor de adoptie van slimme technologie door interoperabiliteit tussen apparaten te waarborgen, voldoende beschikbaarheid van installateurs en toegankelijke investeringsopties, terwijl duidelijke governance-condities worden vastgesteld die vertrouwen beschermen door transparantie, gegevensbescherming, verantwoording voor beslissingen en uitkomsten, en betekenisvolle gebruikerscontrole en opt-out opties.
2. **Bouw gestructureerde leer- en monitoringprogramma's voor huishoudelijke elektriciteitsflexibiliteit.** Investeer in duidelijke en lokaal toegankelijke leer- en monitoringprogramma's die huishoudens helpen piekgebruik van elektriciteit, tarieven en hun eigen verbruikspatronen te begrijpen, en duurzame betrokkenheid in de tijd ondersteunen. Voorbeelden zijn het begrijpelijk maken van tariefstructuren en het inbedden van

monitoringstools en -vaardigheden in alledaagse huishoudpraktijken, met name op momenten waarop huishoudens al energie gerelateerde beslissingen nemen.

3. **Behoud en versterk vertrouwen in instituties en slimme energiesystemen.** Onderhoud en versterk actief vertrouwen in publieke instituties, energieleveranciers en slimme energietechnologieën door transparantie, duidelijke toewijzing van verantwoordelijkheden, robuuste gegevensbescherming en consistente communicatie te waarborgen. Dit omvat duidelijke uitleg over hoe flexibele elektriciteitssystemen werken, hoe huishoudgegevens worden gebruikt, wie verantwoordelijk is voor beslissingen en uitkomsten, en welke waarborgen en opties huishoudens hebben als systemen niet presteren zoals verwacht.

Kanttekening

De systeemkaarten weerspiegelen gedeelde inzichten van belanghebbenden, geen empirisch gevalideerde modellen van het energiesysteem. Hoewel variabelen en causale verbindingen kritisch zijn beoordeeld op plausibiliteit en interne coherentie, zijn de CLDs niet formeel gevalideerd tegen empirische data, noch bevatten ze kwantitatieve effectgroottes, tijdsdynamiek of vertragingen. Ze moeten worden gelezen als weergaven van plausibele relaties, niet als voorspellingstools. De kaarten abstraheren ook van verschillen tussen huishoudens, gebouwen en regio's, en van bredere politieke of systeem brede dynamiek. Ze kunnen het beste worden gebruikt ter ondersteuning van strategisch denken en coördinatie tussen beleidsmaatregelen, in plaats van als blauwdrukken voor enkelvoudige oplossingen.

Deze samenvatting is het Nederlands, de volledige rapportage is in het Engels.

Executive Summary

Purpose

Despite extensive subsidy schemes and widespread financial capacity among homeowners, progress in insulating homes to the standard required for gas-free heating remains too slow to meet policy targets. Similarly, household electricity demand remains highly concentrated during evening peak hours, putting pressure on the electricity system and the grid.

To better understand why progress is slow and how policy can help accelerate change, the Ministry of Climate Policy and Green Growth commissioned SEVEN (University of Amsterdam) to analyse two priority behaviours: insulating homes to the standard and reducing household peak electricity demand. Both are part of the Ministry's "Sustainable Living" programme and require coordinated policy action to scale up.

This report asks: **how can policy most effectively support households in insulating to the standard and shifting electricity use away from peak hours, given the complex systems in which these decisions are made?**

Methodology

The report uses a systems-thinking approach, based on participatory modelling workshops with stakeholders from policy, science, civil society, and practice. Rather than merely listing barriers, this approach focuses on how different factors interact and where policy can make the biggest difference.

Across three sessions, participants jointly mapped key factors and relationships shaping household behaviour. These were captured in causal loop diagrams (CLDs) that show how factors reinforce or counteract one another. The detailed diagrams were then simplified to highlight the most important relationships for policy.

The CLDs are not predictive models. They are intended as sensemaking tools that help policymakers see where interventions can influence multiple parts of the system. They also synthesise knowledge across different domains and support traceability and transparency in decision-making.

High-leverage Policy Recommendations

Below we present the policy recommendations with the highest potential leverage: interventions that address underlying structures shaping behaviour, rather than isolated or one-off measures. Such interventions can influence several parts of the system at once.

The recommendations are directly informed by the system maps and focus on where policy can most effectively reduce key constraints or support positive interactions. Further explanation is provided in the main report.

Insulation to the Standard

- (1) Ensure policy stability and predictability for insulation to the standard.** Avoid frequent, unpredictable changes in insulation-related subsidies, standards, and regulations. Provide a clear, long-term roadmap toward the insulation standard so households, professionals, and financiers can plan, and phase in necessary changes transparently and with sufficient notice.
- (2) Build a strong, independent insulation advice infrastructure.** Invest in high-quality, independent, and locally accessible insulation advice services (e.g. one-stop shops, municipal or regional advisers) that help households understand what is feasible in their home, reduce practical and procedural barriers, and guide them from initial interest through to insulating to the standard.
- (3) Expand and coordinate professional capacity for insulation to the standard.** Increase the availability of qualified insulation professionals through expanded training and certification pathways, and improve retention, coordination, and matching between households and installers.
- (4) Actively manage social experiences by minimising bad cases and amplifying good ones.** Strengthen quality standards, warranties, and complaints mechanisms to reduce negative insulation experiences, and invest in communication and peer-to-peer initiatives that make positive experiences visible, such as neighbourhood ambassadors, showcase homes, and clear before-and-after examples.

Reducing Peak Electricity Demand

- (1) Enable smart automation through technical, organisational, and governance conditions.** Remove structural barriers to smart technology adoption by ensuring interoperability between appliances, sufficient availability of contractors, and accessible investment options, while establishing clear governance conditions that protect trust through transparency, data protection, accountability for decisions and outcomes, and meaningful user control and opt-out options.
- (2) Build structured learning and monitoring programmes for household electricity flexibility.** Invest in clear and locally accessible learning and monitoring programmes that help households understand peak electricity use, tariffs, and their own consumption patterns, and support sustained engagement over time. Examples include making tariff structures comprehensible and embedding monitoring tools and skills into everyday household practices, particularly at moments when households are already making energy-related decisions.
- (3) Maintain and strengthen trust in institutions and smart energy systems.** Actively maintain and strengthen trust in public institutions, energy providers, and smart energy technologies by ensuring transparency, clear allocation of responsibilities, robust data protection, and consistent communication. This includes clear explanations of how flexible electricity systems

operate, how household data are used, who is accountable for decisions and outcomes, and what safeguards and options households have if systems do not perform as expected.

Caveat

The system maps reflect shared insights from stakeholders, not empirically validated models of the energy system. While variables and causal connections were critically reviewed for plausibility and internal coherence, the CLDs were not formally validated against empirical data, nor do they include quantitative effect sizes, time dynamics, or delays. They should be read as showing plausible relationships, not as forecasting tools. The maps also abstract from differences between households, buildings, and regions, and from broader political or system-wide dynamics. They are best used to support strategic thinking and coordination across policy measures, rather than as blueprints for single solutions.

1. Introduction

A rapidly closing window

Humanity is transgressing multiple planetary boundaries, pushing the Earth system beyond the safe operating space for human societies (Richardson et al., 2023). Climate change represents a particularly urgent risk: under current policies, global average temperatures are projected to increase beyond levels to which societies cannot reasonably adapt. It is therefore critical to limit global heating to below 2°C, which requires rapid and sustained reductions in greenhouse gas emissions across all sectors (Pörtner et al., 2023).

Demand-side solutions are critical

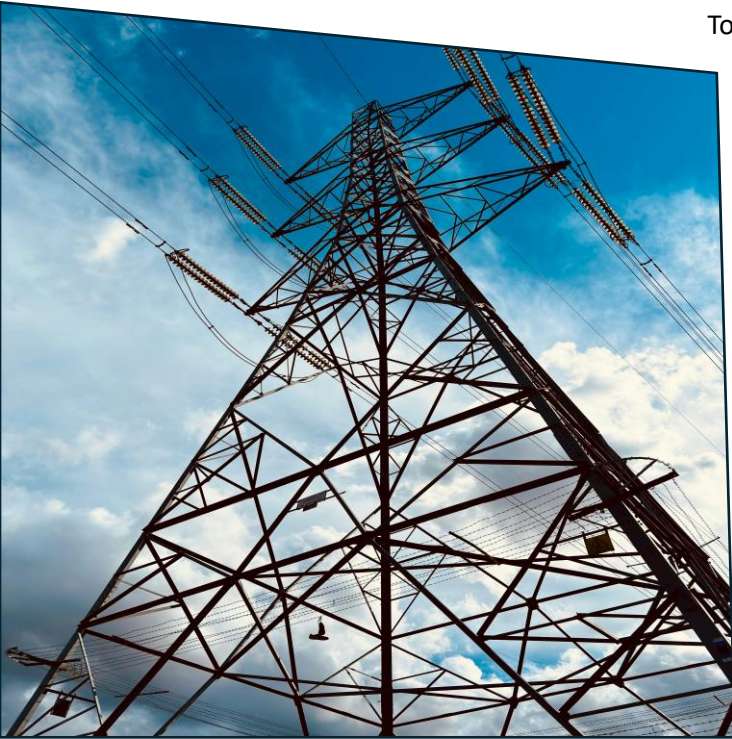
A growing body of evidence shows that supply-side technological solutions alone are insufficient to meet climate targets. The IPCC Sixth Assessment Report concludes that demand-side solutions, which include changes in consumption patterns and lifestyles, could reduce global greenhouse gas emissions by 40–70% by mid-century compared to business-as-usual scenarios (Creutzig et al., 2022). Crucially, these changes can maintain or even improve well-being when supported by appropriate infrastructures and policies.

For Europe specifically, modelling studies indicate that low-demand pathways could reduce final energy demand by up to 50%, substantially lowering the need for new energy infrastructure, easing pressure on electricity grids, improving energy security, and reducing total system costs (Dablander et al., 2025; Wiese et al., 2024). Such pathways are particularly relevant for densely populated, highly electrified countries like the Netherlands, where grid congestion and peak demand are already binding constraints. For such pathways, household behaviour adjustment is critical.



Systems lens necessary to understand behaviour change

Household behaviour does not occur in a vacuum. Decisions about insulation, heating, appliance use, or electricity consumption are shaped by a complex interplay of personal, social, and structural factors (Kastner & Stern, 2015; Michie et al., 2011). As emphasized in both behavioural science and public policy research, focusing narrowly on individual motivation or information provision risks overlooking the structural conditions that enable or constrain behaviour (Dupoux et al., 2025; Hallsworth, 2023).



To address these challenges, this report applies methods from systems thinking, in particular *Group Model Building* (GMB). GMB is a participatory modelling approach that brings together diverse stakeholders to jointly map the causal structures underlying complex policy problems (Vennix, 2001), yielding a *Causal Loop Diagram* (CLD). By identifying key variables, feedback loops, reinforcing and balancing dynamics, and potential tipping points, GMB helps uncover where interventions can have the greatest systemic leverage.

We used GMB to develop shared system representations (CLDs) of two critical demand-side challenges in the Dutch energy transition: increasing home insulation and reducing electricity demand during peak hours. The resulting insights form the basis for the policy-relevant system analysis and recommendations presented in this report.

Structure of this report

After briefly describing the background behind the two case studies on insulation and peak-electricity demand, we describe our Methodology in Section 2. We then discuss simplified CLDs and their feedback loops, distilled from the underlying (session-derived) CLDs, for the two case studies in Section 3. This simplified CLD forms the basis of policy recommendations discussed in Section 4. We conclude with a discussion, limitations, and future avenues in Section 5.

Background on case study insulation

In the Netherlands, the built environment is responsible for about 12% of national greenhouse gas emissions, with homes contributing the majority share since more than 80% of households still rely on natural gas for space heating (CBS, 2025b). Cutting these emissions depends crucially on large-scale insulation, which reduces heating demand and makes low-temperature systems like heat pumps both technically and economically viable.

To drive this transition, the Dutch government has committed to a gas-free housing stock by 2050, with intermediate milestones such as insulating 2.5 million homes by 2030 and ensuring all new builds comply with the EU's revised Energy Performance of Buildings Directive and are *Zero Emissions Buildings*. A central concept is "isolatie naar de standaard", that is, bringing homes to an insulation

level compatible with being heated without natural gas (RVO, 2024). This requires upgrading floors, walls, and roofs to RC-values of 3.5–8.0 m²K/W and installing HR++ or triple glazing.

Over the years, the government has deployed a mix of subsidies, loans, and regulatory measures to accelerate insulation. The Sustainable energy investment subsidy scheme (ISDE) covers insulation, glazing, and heating systems, and was recently expanded to provide higher subsidy levels, bonuses for combining measures, and lower eligibility thresholds for homeowners (RVO, 2026). The Nationaal Warmtefonds provides low- and zero-interest loans to homeowners, particularly those with limited means. For the rental sector, programs such as SAH (*Stiumuleringsregeling aardgasvrije huurwoningen*) support landlords by subsidizing district heating and SVOH (*Subsidieregeling Verduurzaming en Onderhoud Huurwoningen*) support private landlords with insulation, glazing and heat pumps. For homeowners' associations, which can also be a mix between landlords and homeowners, there is the SVVE. Despite these subsidy schemes, progress is lagging. A survey by the Dutch Central Bank found that more than 95% of homeowners have the financial means to invest in insulation and heat pumps, yet uptake remains slow due to perceptions of high costs, long payback times, and a lack of awareness (DBN, 2024). At current renovation rates, the government's targets may not be met (ABN AMRO, 2024).



These challenges are compounded by the composition of the Dutch housing stock. With just over 8 million dwellings, about 57% are owner-occupied, 27% are social rental housing, and 16% are private rental dwellings (CBS, 2025a). In terms of dwelling types, 42% are terraced houses, 36% are apartments, 13% are detached dwellings, and 9% are semi-detached dwellings (CBS, 2023a). Retrofit potential and difficulty vary considerably: terraced and semi-detached houses, often built in the post-war decades, are relatively straightforward to insulate, whereas detached homes present large surface areas and higher costs. Apartments, by contrast, face governance hurdles, as insulation upgrades require agreement among multiple owners or landlords.

Ownership status also shapes opportunities. Homeowners can decide autonomously but bear the full financial and organizational burden. Homeowners' associations cannot decide autonomously, and are often subject to long decision taking processes. Private renters face the classic “split incentive” problem: landlords carry the costs, while tenants reap the benefits. Social housing tenants benefit from coordinated renovation programs led by housing associations, though funding remains uneven (Boelhouwer, 2020). For the purposes of this research, we will focus solely on homeowners.

While new housing is on track, the vast majority of the existing stock requires significant retrofitting. The scale of this challenge highlights not only the technical tasks ahead, but also, among others, the

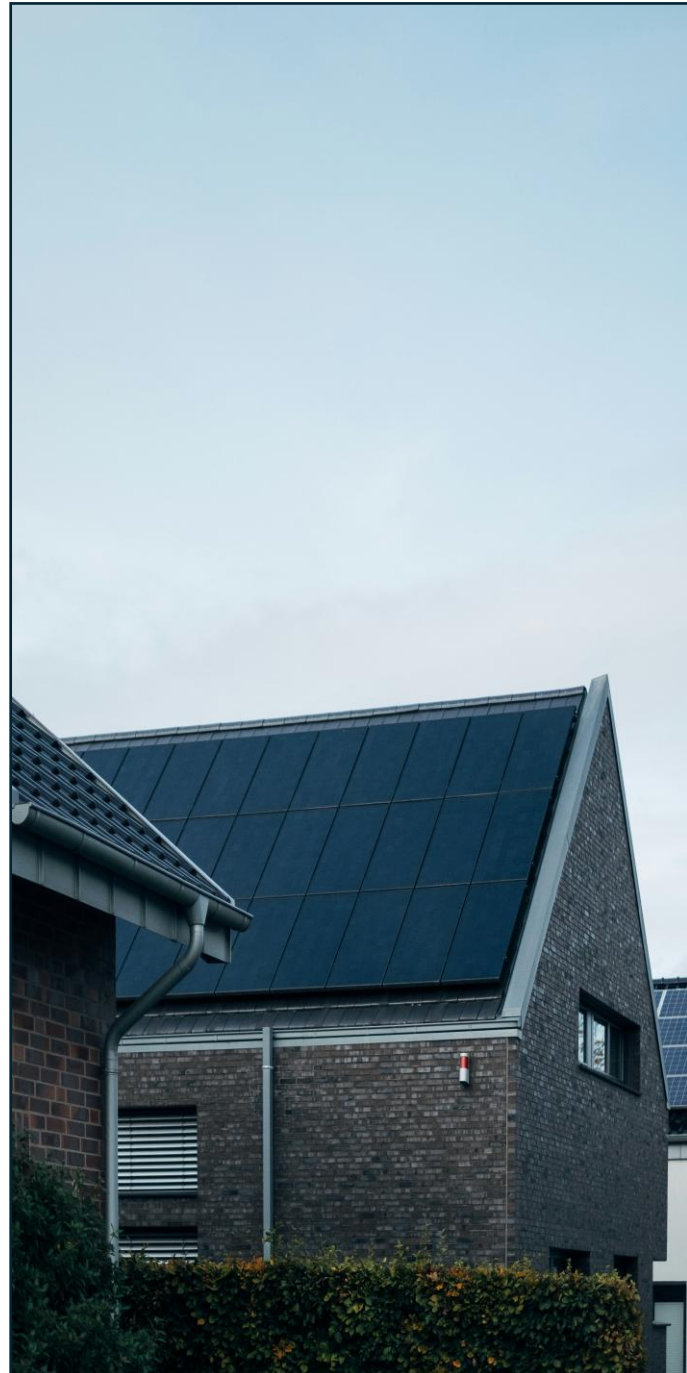
economic, administrative, and psychological barriers that determine whether households actually insulate their homes (Klemm et al., 2025; McGinley et al., 2025; Wilson et al., 2015). The systemic perspective developed in this report aims to integrate those into a holistic understanding of insulation uptake.

Background on case study peak-electricity demand

Electricity demand in the Netherlands is highly concentrated during evening hours (16:00-21:00). At these times, households return home and engage in energy-intensive activities, such as cooking, laundry, dishwashing, and lighting, alongside newer demands from electric vehicles and heat pumps. This clustering coincides with the decline in solar production, increasing grid stress (Sahin & Rau, 2025).

The consequences of peak energy demand in the evenings are multiple. First, it contributes directly to grid congestion, which is now one of the most pressing bottlenecks in the Dutch energy transition (Rijksoverheid, 2025; TNO, 2024). Grid congestion can delay or prevent new connections and capacity upgrades, with reported impacts including new housing developments that cannot be connected and longer waiting times for businesses and households (Motivaction, 2024). Furthermore, high peaks require costly redispatch and investments in grid reinforcement, increasing system costs that are ultimately borne by consumers (Sundt et al., 2020). Peak energy demand also presents a key barrier to renewable energy transitions, undermining the effective use of renewable electricity (Hansen et al., 2019; Stram, 2016). When solar PV production is curtailed in the afternoon due to overgeneration, and fossil sources must be ramped up a few hours later, the climate benefits of renewable expansion are reduced (Hubert et al., 2024).

International studies show that even modest reductions of 3–6% in peak demand can offset the need for a mid-sized fossil-fuel power plant, avoiding both emissions and system costs (Sundt et al., 2020). In the Netherlands, where one-third of households now own solar panels (CBS, 2023b), shifting demand from evening peaks to midday would allow greater self-consumption of solar generation and reduce dependence on polluting backup capacity. Reducing peaks is therefore not only a technical necessity but also an environmental and policy priority, helping the government meet its renewable targets while containing costs and preventing further gridlock.



While 51% of Dutch citizens indicated that they have never heard of grid congestion (Motivaction, 2025), the Dutch government, regulators, and system operators have taken steps to address the evening peak. For example, the Ministry of Climate Policy and Green Growth launched the “*Zet ook de knop om*” campaign, urging citizens to reduce consumption between 16:00 and 21:00. These campaigns explicitly link household behaviour to congestion relief and frame peak shifting as a collective responsibility (Rijksoverheid, 2025). Moreover, energy suppliers increasingly offer dynamic or time-of-use (TOU) contracts in which electricity is cheaper during midday or late at night and more expensive in the evening. These contracts create financial incentives to run appliances or charge EVs outside peak times. The Dutch Authority for Consumers and Markets (Authority for Consumers and Markets, 2025) reports that adoption is growing slowly, with 7% of Dutch households having dynamic contracts as of September 2025.

National and local system operators are increasingly using flexibility measures to reduce peak congestion. At the system level, TenneT, the national transmission operator, has introduced capacity contracts that reward large consumers and businesses for avoiding evening peaks. In 2025, it allocated nearly 9 GW of off-peak usage contracts, showing how adjusting demand can complement physical grid reinforcement (TenneT, 2025). At the distribution level, pilots such as the Flex-E project demonstrate how local flexibility and smart charging can help reduce congestion in residential areas (Netbeheer Nederland, 2025). Similarly, Dutch smart grid initiatives have tested the aggregation of household flexibility through EV chargers, smart appliances, and automated load-shifting. These programmes show that household participation can support grid balancing, although engagement remains highest among more technically capable and environmentally motivated users (Smale et al., 2017). Finally, regional distribution system operators, such as Stedin and Liander, encourage households to align electricity use with solar generation. Their communication highlights both household benefits (cost savings, efficiency) and systemic benefits (less congestion, fewer outages) (Rijksoverheid, 2025).

Overall, Dutch initiatives reflect a policy mix of informational measures, financial incentives, and infrastructure pilots. Yet, household behaviour regarding electricity use during peak/off-peak hours is shaped by various social (Abrahamse & Steg, 2013; Lavin & Julienne, 2025; Sahin & Rau, 2025; Wolske et al., 2020), economic (Kacha et al., 2024; TNO, 2024), informational and psychological (de Vries, 2023; Hubert et al., 2024; Siitonen et al., 2024; Weck et al., 2017), and policy and structural (Rijksoverheid, 2025; von Loessl, 2023) barriers and drivers. The systemic perspective developed in this report aims to integrate those into a holistic understanding of reducing peak electricity consumption.

2. Methods

2.1. Participants

The sessions about increasing homeowners' uptake of insulation to the standard were attended by 24 participants across sessions, varying from 7 to 9 participants per session. The sessions about reducing households' peak-electricity demand included 24 total participants, varying from 10 to 7 participants per session.

The sessions about insulation were attended by civil servants from various ministries, scientists (both from universities and applied scientists), NGOs active in the energy transition, interest groups, and a private company advising households on their energy situation. The sessions about peak-electricity demand were attended by civil servants from various ministries, scientists (both from universities and applied scientists), a private advisory organization, NGOs active in the energy transition, interest groups, a local energy cooperation, and net providers. Due to privacy considerations, we cannot disclose their names nor organizations.

2.2. Structure of each GMB session

The Group Model Building process was structured across three sessions, two half-day and one full-day session, attended by 7 to 12 participants, facilitated by a team comprising a facilitator, modeler and note-taker. The methodology adapted established GMB scripts including the [Nominal Group Technique](#), [causal mapping in large groups](#), and [initiating and elaborating a casual loop diagram](#). Each session followed a structured progression combining individual reflection, small group work (typically 2 to 3 participants), and plenary discussions to ensure balanced participation and build consensus around model elements.

Session 1 focused on variable identification and establishing initial connections to the central variable. Participants individually brainstormed and ranked influential variables before collectively positioning them on screen relative to the central variable (influencing, influenced by, or bidirectional). The session progressed from identifying direct connections with the central variable to mapping relationships between all variables. Session 2 deepened the model by systematically identifying gaps, expanding the model with missing elements, analyzing critical connection mechanisms, and identifying and classifying feedback loops (reinforcing and balancing). Session 3 continued model refinement and briefly discussed the strength of selected connections, concluding with an intervention identification exercise (only for insulation, where time allowed it).

Throughout all sessions, the team maintained careful documentation practices including regular model backups, workbooks for participant reflection between sessions, and structured consensus-building protocols to handle disagreements.

For the modelling, the team opted for using Kumu (kumu.io), an online tool for live modelling. Kumu is a relatively simple tool for modelling, yet has most functionalities that are needed for creating CLDs. The tool allowed us to share a link of the current model with participants, so that they could view the model on their own device whilst working on individual or group assignments. Moreover, it also

provides an interactive interface that allows participants to isolate elements of the CLD and view their connections, facilitating understanding.

2.3. Analytical approach

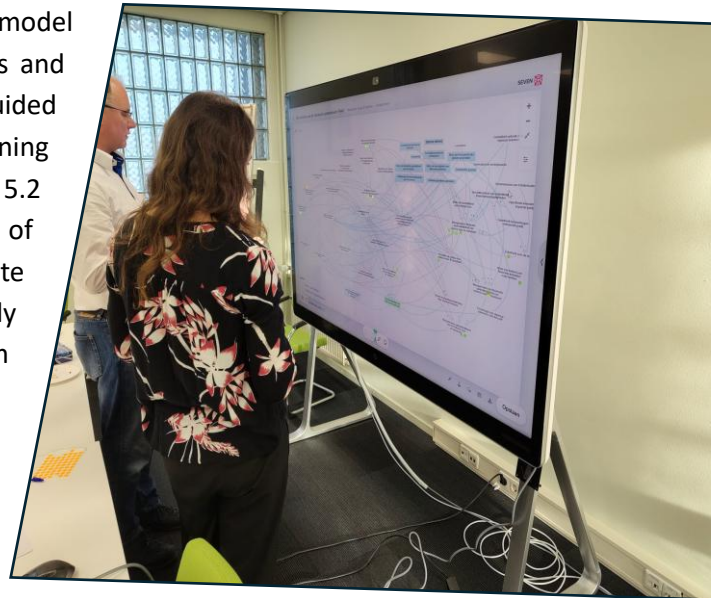
To support analysis and policy interpretation, we reduced the detailed CLDs produced through group model building to simplified CLDs that capture the core dynamics of the two systems under study. Such abstraction is standard practice in systems modelling, as highly detailed CLDs are often difficult to interpret, communicate, and use for leverage-point analysis, while carefully simplified diagrams can make dominant feedback loops and intervention points more visible. The goal of the simplification was therefore not to remove complexity per se, but to retain the key structures driving system behaviour while improving clarity and analytical tractability.

To move from the detailed CLDs produced in the group model building sessions to simplified CLDs suitable for analysis and policy discussion, we followed an iterative, expert-guided aggregation process. As a first step, we used the reasoning capabilities of OpenAI's frontier large language model GPT 5.2 (hereafter "AI") (OpenAI, 2025) to propose clusters of conceptually related variables and to suggest candidate composite variables. All proposed groupings were carefully inspected, revised, or rejected by the modelling team based on substantive expertise and close reference to the original CLDs.

In a second step, the AI was used to propose links between these composite variables, explicitly constrained by the structure of the underlying, fine-grained CLDs. These proposed links needed to remain faithful to the original causal directions and signs wherever possible. Because aggregation can mask or distort dynamics, particular attention was paid to preserving key feedback loops and distinguishing reinforcing from balancing mechanisms. Where aggregation introduced ambiguity or heterogeneity, links were explicitly marked as mixed (+/-, gray colour).

All AI-generated suggestions were subjected to repeated human review and iterative refinement, with links, signs, and composite variables revised through close inspection and discussion among the team. The use of AI should therefore be understood as a supporting analytical tool that facilitated systematic exploration and consistency checking, embedded within a predominantly human-led modelling and validation process. Existing literature demonstrates that augmenting human capabilities with AI can significantly improve performance on a large variety of tasks (Vaccaro et al., 2024).

Feedback loops were identified through structured analysis of the simplified CLDs, involving systematic inspection of causal pathways, identification of closed causal chains, and classification as reinforcing or balancing based on the direction of effects. Policy recommendations were developed in a subsequent interpretive step, by analysing which interventions would effectively strengthen reinforcing dynamics or weaken the primary constraints revealed by the respective CLDs. As in the simplification process, AI was used in a supporting role to help identify and organise both feedback



loops and potential intervention points implied by the CLDs, which were subsequently discussed, filtered, and refined by the author team. Lastly, the policy recommendations were put into context with existing scientific and policy literatures.

The methodology, results, and implications were discussed with an academic council consisting of Prof. Jan-Willem Bolderdijk, Prof. John Grin, Prof. Frenk Harreveld, Prof. André Nollkaemper, and Dr. Vítor V. Vasconcelos, all from the University of Amsterdam.

3. Results

We first describe how we integrated the variables of the CLDs with psychological theory in Section 3.1. We then describe the CLDs or system maps for the specific case studies, starting with insulation to the standard in Section 3.2 and peak electricity demand in Section 3.3.

3.1. Integration with psychological theory

To ease interpretation and structure the variables, we map them onto the COM-B framework, a well-established and widely used framework in behaviour change analysis (Mitchie et al., 2011). COM-B conceptualizes behaviour as arising from the interaction between Capability, Opportunity, and Motivation. *Capability* refers to individuals' psychological and physical ability to perform a behaviour, including knowledge, skills, and cognitive capacity. *Opportunity* captures external factors that enable or constrain behaviour, encompassing both the physical environment (e.g. infrastructure, time, resources, availability of services) and the social environment (e.g. social norms, expectations, institutional arrangements). *Motivation* includes the mental processes that energize and direct behaviour, ranging from reflective processes such as intentions, goals, and beliefs to automatic processes such as habits, routines, and emotional responses. The variables in the following figures are coloured according to their type (with the central variable being grey).

3.2. System map: Insulating to the standard

The simplified CLD visualised in Figure 1 describes insulating to the standard as the result of interacting behavioural, psychological, social, and structural influences. The simplified CLD represents the core system using a small set of composite variables that integrate the many drivers identified in the detailed CLD (see Appendix A).

Blue arrows indicate positive relationships: if one variable goes up (or down), the other one goes up (or down) as well. Red arrows indicate negative relationships: if one variable goes up (or down), the other one goes down (or up). Grey arrows can indicate two things, namely either that the relationship is positive or negative depending on the underlying variables: for example social experiences—if they are positive—can increase the perceived attractiveness of insulation, but if they are negative, they can decrease it. Or grey arrows can indicate that we do not know whether a relationship is positive or negative.

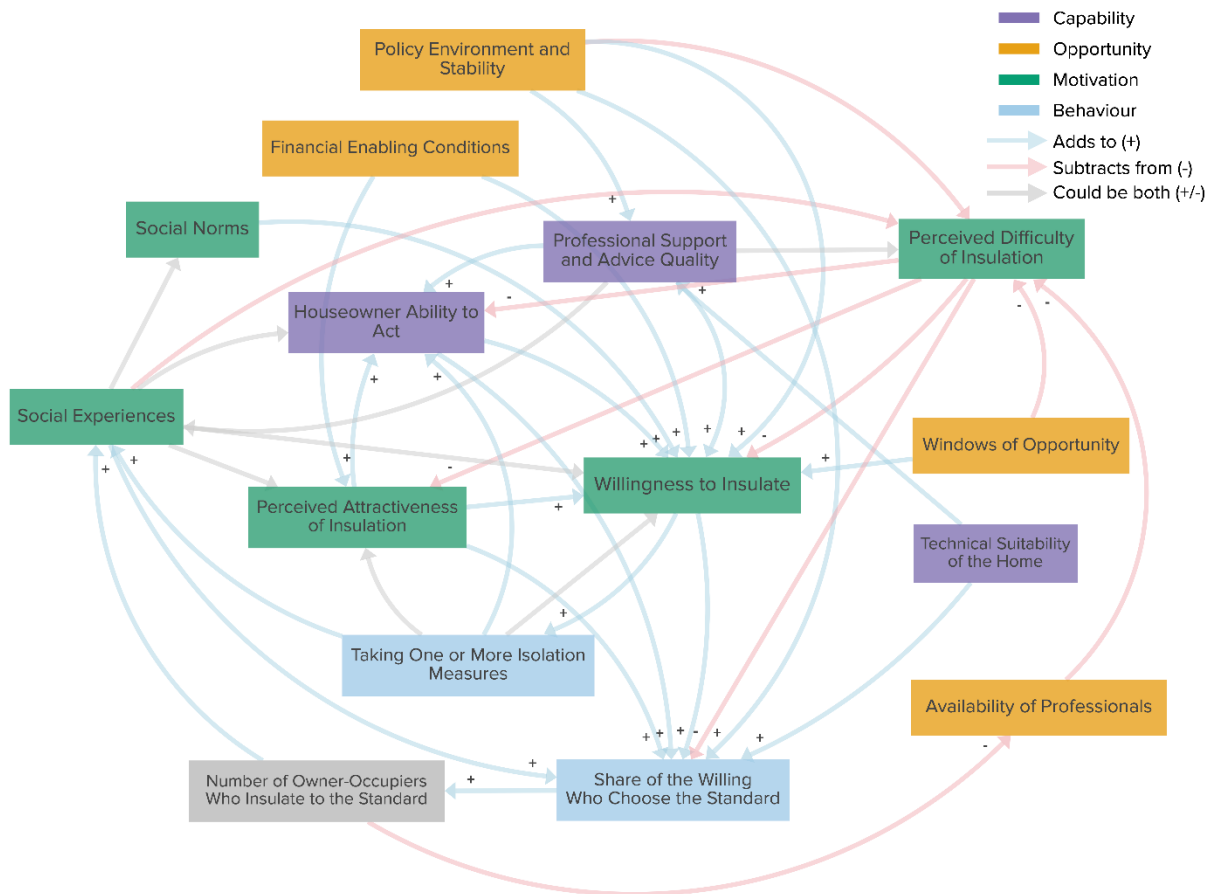


Figure 1. Simplified CLD. The detailed CLD was provided to the ministry and is available upon request. Colours indicate the type of the variable based on the COM-B model.

The central variable is the **Number of Owner-Occupiers Who Insulate to the Standard**. Households move from willingness to insulate to actually taking measures and, for some, to insulating up to the standard (encoded in the variable **Share of the Willing Who Choose the Standard**).

At the core of the system lies **Willingness to Insulate**, which functions as the main motivational junction. This composite variable integrates urgency, perceived obligation, social support, loan aversion, concern about climate change and geopolitics, and baseline energy use (see Appendix A). Willingness determines whether households engage with insulation at all but is analytically distinguished from the conditional decision to proceed to the standard.

Several composite variables shape how willingness translates into action. **Perceived Attractiveness of Insulation** integrates financial and non-financial benefits, perceived home value, and experienced benefits from prior measures, influencing both willingness and the likelihood that willing households choose the standard. **Houseowner Ability to Act** (“doenvermogen”) captures practical and cognitive capacity, including knowledge of what is technically feasible and do-it-yourself capability, and determines whether motivated households can proceed. **Perceived Difficulty of Insulation** aggregates perceived hassle, complexity, overestimation of difficulty, and feasibility, acting as a key gatekeeper that reduces willingness, ability to act, and standard uptake when high.

Several enabling and contextual variables connect household decision-making to broader structures. **Financial Enabling Conditions** shape perceived attractiveness and willingness through borrowing

capacity, financing options, costs, energy prices, and financial institutions. **Professional Support and Advice Quality**, which also includes advice consistency, links institutional conditions to household trajectories by influencing ability to act, willingness, perceived difficulty, and social experiences.

Behavioural aspects are captured by **Taking One or More Insulation Measures**, which marks the transition from intention to action and generates both reinforcing feedback (through capability building and positive experiences) and potential balancing effects (such as diminishing returns or perceptions of having “done enough”). **Social Experiences** and **Social Norms** transmit individual outcomes into collective patterns, shaping attractiveness, difficulty, and willingness through diffusion and observation.

On the structural side, **Availability of Professionals** represents a key capacity constraint that can counteract reinforcing demand-side dynamics as uptake grows. **Technical Suitability of the Home, Policy Environment and Stability**, and **Windows of Opportunity** shape feasibility, willingness, and perceived difficulty, providing important contextual conditions without being endogenously affected in the simplified CLD.

We move beyond a qualitative analysis of the importance of variables in Appendix B, where we provide an exploratory quantitative analysis based on (strong) assumptions about the timescales of the different variables and the strength and functional form of their relationships.

3.2.1. Feedback loops

The simplified CLD contains 65 formally identifiable feedback loops. Rather than interpreting each loop individually, we follow standard practice in the system dynamics literature by focusing on a small number of important and policy-relevant feedback mechanisms. These loops represent families of structurally similar feedbacks and capture dominant dynamics shaping insulation uptake.

The system is characterized by three important reinforcing feedback loops that can accelerate insulation uptake once momentum builds, alongside a single dominant balancing loop related to professional capacity constraints. Accordingly, we describe the feedback loops and then turn to variables that constitute enabling conditions and constraints.

R1. Good experiences spread and fuel further uptake

Social Learning & Norm Reinforcement Loop (R1): *Social Experiences* → *Social Norms* → *Willingness to Insulate* → *Taking one or more isolation measures* → *Social Experiences*

When homeowners observe or hear about insulation experiences in their social environment, these social experiences strengthen social norms around insulating homes. Stronger norms increase willingness to insulate, which leads to more households taking one or more insulation measures. As more measures are taken, social experiences become more visible, discussed, and widespread, further reinforcing norms and willingness (Figure 2).

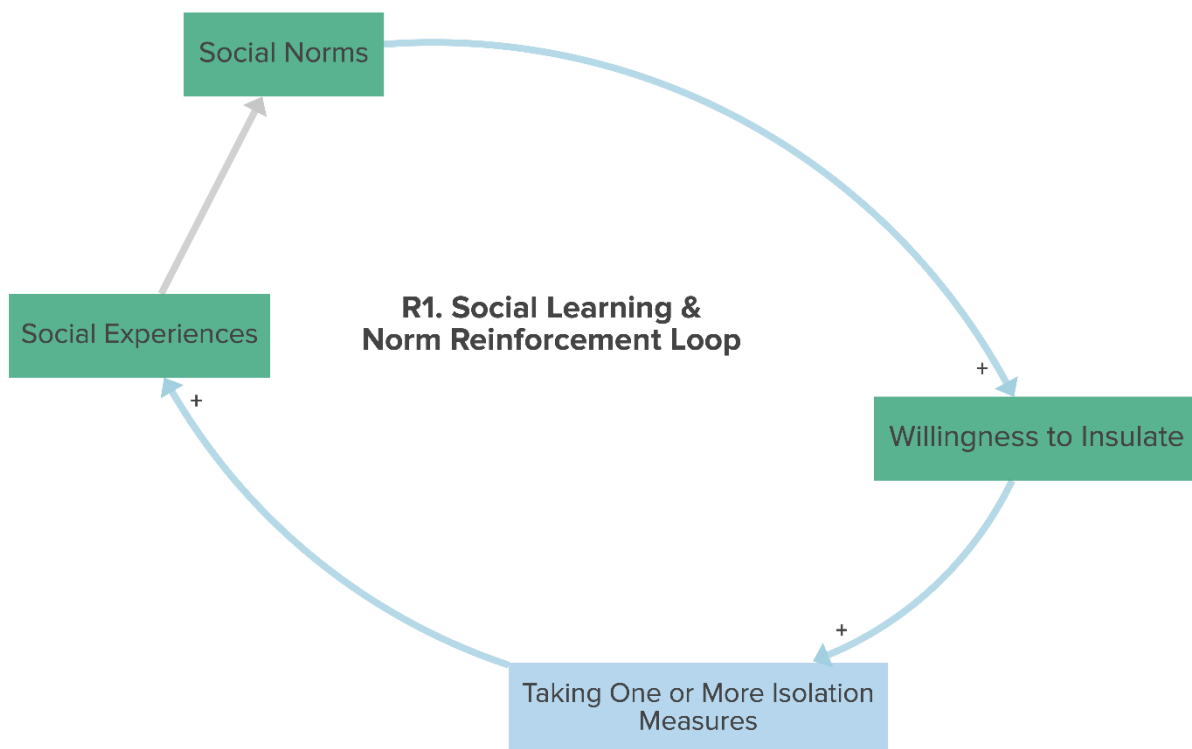


Figure 2. Social Learning & Norm Reinforcement Loop.

A closely related reinforcing mechanism (not shown) operates through adoption of the standard: a higher share of willing households choosing the standard increases the number of owner-occupiers insulating to the standard, which in turn increases social experiences and further raises the likelihood that willing households choose the standard. Together, these dynamics describe a self-reinforcing process in which visible uptake and shared experiences normalize insulation and accelerate further adoption.

Importantly, the reinforcing effect of social learning and norm formation depends on the valence of social experiences. While positive experiences strengthen norms and willingness to insulate, the simplified CLD explicitly allows social experiences to increase or decrease willingness, perceived attractiveness, and perceived difficulty. When experiences are predominantly negative, for example due to hassle, delays, or poor outcomes, social learning can weaken or even counteract the reinforcing dynamics described above by increasing perceived difficulty and reducing willingness. In such cases, the same social channels that normally accelerate uptake may slow progress instead.

R2. Taking action builds confidence and enables more action

Capability Building Loop (R2): *Willingness to insulate* → *Taking one or more isolation measures* → *Houseowner Ability to Act* → *Willingness to insulate*

In this reinforcing loop, higher willingness to insulate leads homeowners to take one or more insulation measures, and taking measures increases houseowner ability to act. Greater ability—through increased familiarity, skills, or practical knowledge—feeds back into higher willingness to insulate, which in turn promotes further action. This loop captures how initial engagement with insulation can build capability over time, making additional or more ambitious measures increasingly feasible for homeowners (Figure 3).

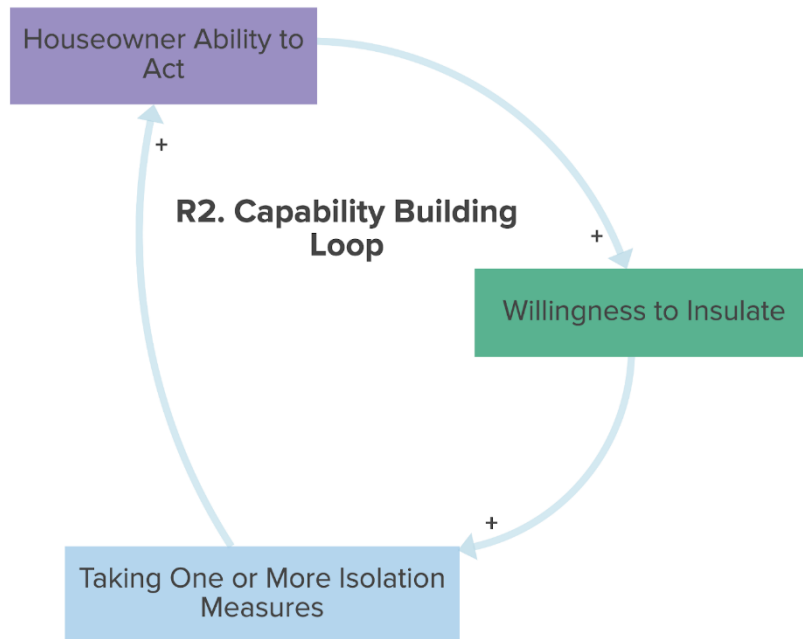


Figure 3. Capability Building Loop.

R3. Positive experiences make insulation more attractive

Attractiveness & Benefit Reinforcement Loop (R3): *Social Experiences (positive) → Perceived Attractiveness of Insulation → Willingness to Insulate → Taking one or more isolation measures → Social Experiences (positive)*

This reinforcing loop operates when social experiences with insulation are positive. Positive experiences increase the perceived attractiveness of insulation, which raises willingness to insulate. Higher willingness leads to more households taking one or more insulation measures, and taking measures generates additional social experiences. When these experiences are positive, they further enhance perceived attractiveness, reinforcing the cycle. This loop highlights how positive outcomes and benefits, once experienced or observed, can make insulation increasingly appealing and sustain momentum in uptake.

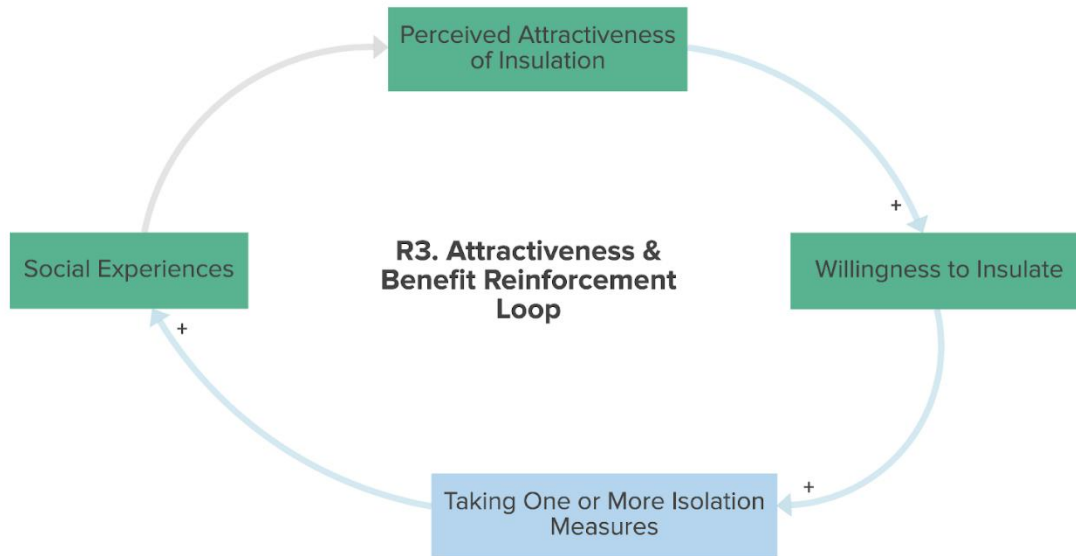


Figure 4. Attractiveness & Benefit Reinforcement Loop.

A closely related reinforcing mechanism (not shown) operates through adoption of the standard: higher perceived attractiveness of insulating leads to a higher share of willing households choosing the standard, which increases the number of owner-occupiers insulating to the standard, which in turn increases social experiences, (potentially) raising the perceived attractiveness and hence the likelihood that households choose the standard.

At the same time, the simplified CLD allows for a counteracting dynamic within willingness itself. As households take insulation measures, the perceived obligation of effort (part of *Willingness to Insulate*) can decline, reducing willingness to take further measures. Moreover, the last insulation measures towards the standard are also typically more complex, which can similarly reduce willingness. This short, intra-household balancing mechanism can weaken or reverse the reinforcing attractiveness loop once households feel they have “done enough.” This counteracting dynamic is also relevant for the feedback loops R1 and R2 discussed above.

B1. Success can strain capacity and slow further progress

Professional Capacity Constraint Loop (B1): *The number of owner-occupiers who insulate to the standard → Availability of Professionals → Perceived Difficulty of Insulation → Houseowner Ability to Act → Willingness to insulate → Share of the willing who choose the standard → The number of owner-occupiers who insulate to the standard*

As the number of owner-occupiers who insulate to the standard increases, the availability of professionals declines. Reduced availability increases the perceived difficulty of insulation, which lowers houseowner ability to act and, in turn, reduces willingness to insulate. Lower willingness decreases the share of the willing who choose the standard, slowing the growth in the number of owner-occupiers insulating to the standard. This balancing loop describes how rapid uptake can create capacity bottlenecks that counteract further progress if professional supply does not keep pace with demand.

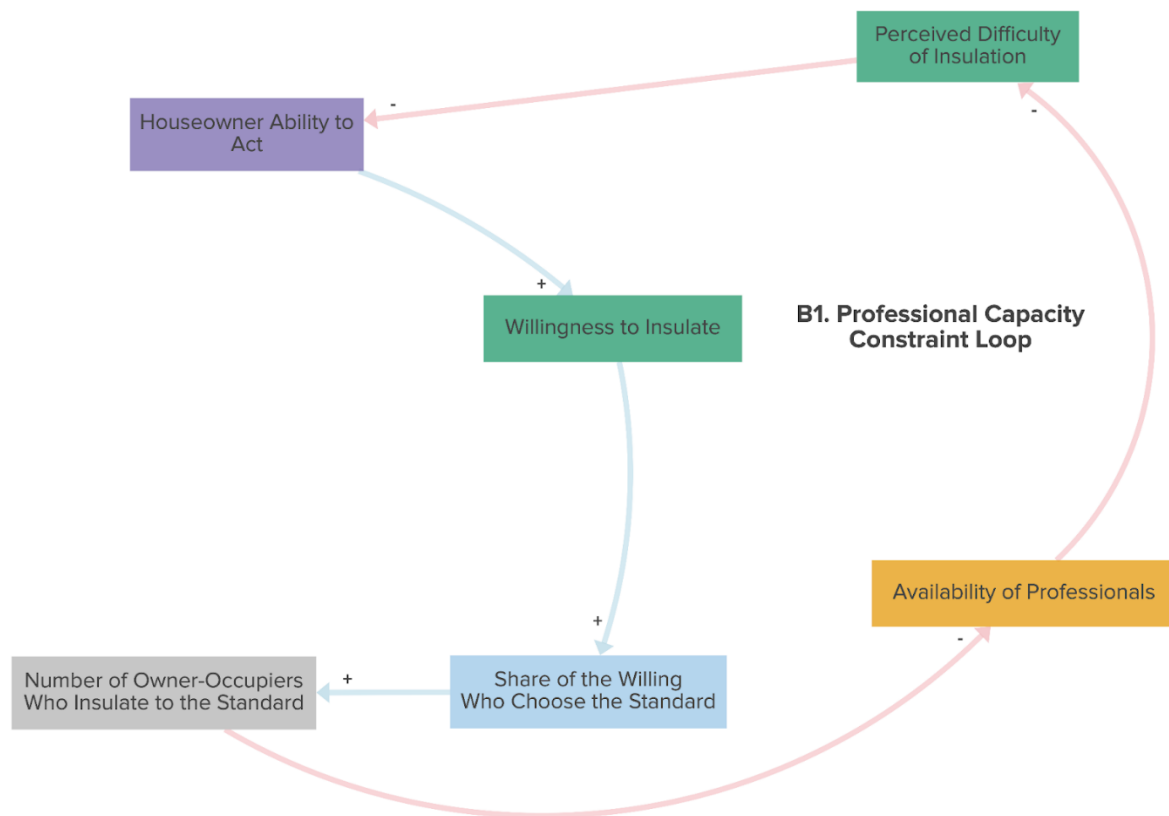


Figure 5. Professional Capacity Constraint Loop.

3.2.2. Enabling conditions and constraints

The simplified CLD identifies a small number of dominant reinforcing and balancing feedback loops that shape insulation uptake. However, not all influential variables form feedback loops themselves. Several factors enter the system primarily as contextual or enabling conditions: they affect multiple variables within the dominant loops, shaping key decision points in the insulation process without themselves being reinforced or counteracted. As such, these variables help determine whether reinforcing processes can plausibly take hold and whether the main capacity-related constraint becomes salient, without implying quantitative claims about the strength or timing of these effects.

Five such variables appear particularly important. **Policy Environment and Stability** affects willingness, perceived difficulty, professional support and advice quality, and the share of willing households choosing the standard, thereby shaping both household expectations and the operating conditions for intermediaries. **Financial Enabling Conditions** influence perceived attractiveness of insulation and willingness, affecting whether motivation is likely to translate into action. **Windows of Opportunity** are represented as contextual factors that increase willingness and reduce perceived difficulty at specific moments, without generating self-reinforcing dynamics. **Technical Suitability of the Home** shapes feasibility by affecting professional support and advice quality and the likelihood that willing households proceed to the standard. While **Professional Support and Advice Quality** is influenced by policy stability and technical suitability of the home, it influences houseowner ability to act, willingness to insulate, perceived difficulty, and social experiences, linking institutional and professional conditions to household decision-making and thus functioning as a key enabling factor.

In summary, while the CLD indicates that insulation uptake is not limited by multiple structural balancing loops, but by a single dominant capacity constraint, the absence of strong balancing forces does not imply automatic uptake. Reinforcing feedback loops require sufficient initial activation, which depends on enabling conditions such as policy stability, financial accessibility, professional support and advice quality, and timing. Policy therefore plays a dual role: enabling the activation of reinforcing dynamics at early stages, and alleviating capacity constraints as uptake accelerates.

3.3. System map: Peak-electricity demand

The simplified CLD visualised in Figure 6 describes peak-hour electricity demand as the outcome of interacting behavioural, social, technical, and structural influences. It represents the core system using a limited set of composite variables that integrate the many drivers identified in the detailed CLD (see Appendix).

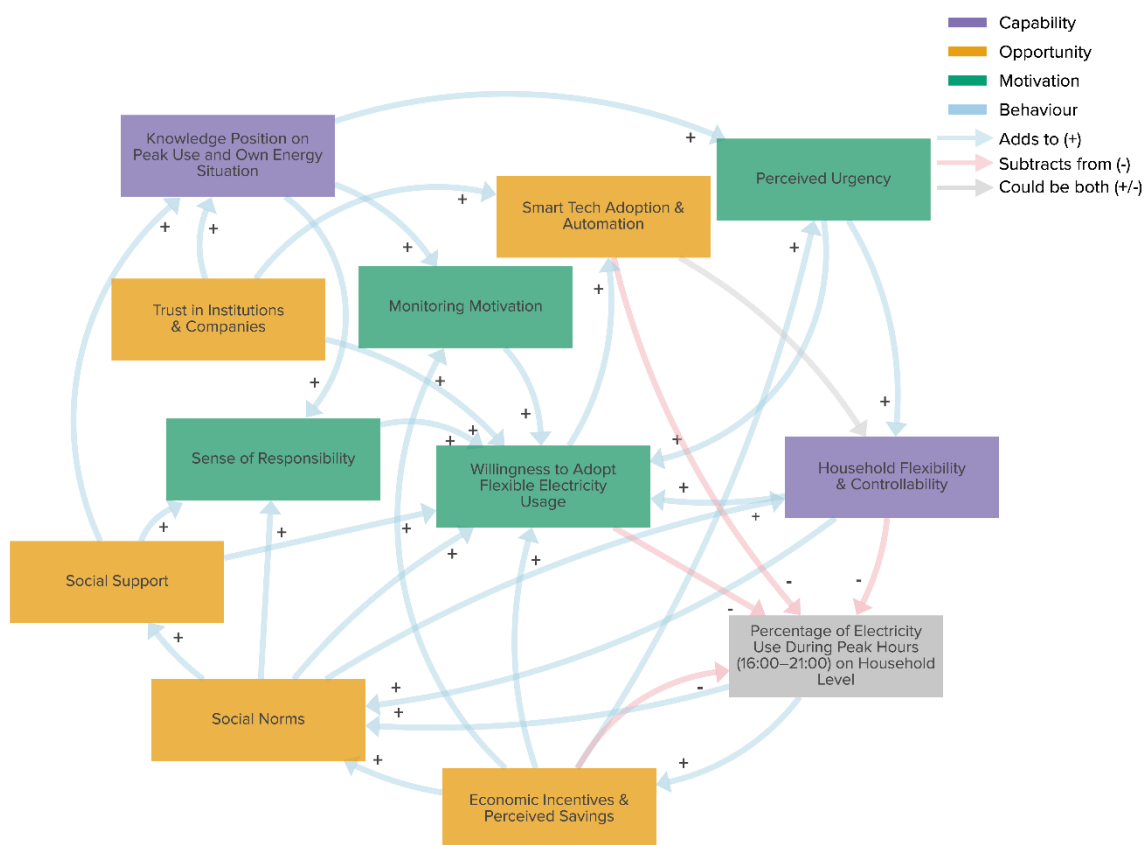


Figure 6. Simplified CLD. The detailed CLD was provided to the ministry and is available upon request. Colours indicate the type of the variable based on the COM-B model. Note: The grey arrow indicates a mixed relationship: Smart Tech Adoption & Automation tends to increase most sub-variables included in Household Flexibility & Controllability but may decrease the visibility of electricity usage, producing both positive and negative sub-variable relationships.

The central variable of interest is the **Percentage of Electricity Use During Peak Hours (16:00–21:00) on Household Level**, which reflects how electricity demand is distributed across the day at the household level and shapes economic incentives and social norms related to peak demand. **Willingness to Adopt Flexible Electricity Usage** functions as the main motivational junction in the system. It integrates signals from economic incentives and perceived savings, perceived urgency, social norms

and support, trust in institutions and companies, and personal and collective sense of responsibility. Changes in willingness determine whether households engage with flexibility at all and whether they are open to delegating control to automated systems.

Several composite variables shape how this willingness emerges and translates into outcomes. **Knowledge Position on Peak Use and Own Energy Situation** captures households' understanding of peak demand, grid congestion, tariffs, and their own electricity use, as well as the availability and integrality of advice and monitoring skills and tools. This knowledge increases **Monitoring Motivation**, reflecting the extent to which households are willing to actively track their electricity use, and contributes to higher perceived urgency and responsibility within the system.

Economic Incentives and Perceived Savings represent the financial context in which flexibility decisions are made, including price incentives, peak–off-peak price differences, electricity prices, and access to own generation and storage. These incentives influence both willingness to adopt flexible electricity use and percentage of peak-hour electricity use directly, while changes in peak demand feed back into perceived savings and incentives.

Household Flexibility & Controllability reflects the practical capacity to shift electricity use in time, which comes from both automated systems and conscious manual decisions. It encompasses the controllability of electricity use in and out of peak hours, flexibility in routines, appliance-related feasibility, user abilities, storage options, perceived agency, comfort and ease, the degree of manual control, and the visibility of electricity use. This variable influences peak-hour electricity use and also feeds back into social norms and willingness to adopt flexible electricity usage.

On the structural side, **Smart Tech Adoption & Automation** captures the extent to which households are willing and able to use smart appliances, energy management systems, and automated control, and whether the necessary technical, financial, and institutional conditions are in place. **Trust in Institutions and Companies**, which also includes the degree of household susceptibility, and willingness to adopt flexible electricity usage shape smart tech adoption & automation. Smart tech adoption & automation generally increases household flexibility and controllability by, for example, increasing comfort and ease, and directly reduces peak-hour electricity use. At the same time, smart tech adoption & automation can have an opposing effect on one specific aspect of household flexibility & controllability, namely the visibility of electricity use. As electricity use is increasingly shifted automatically rather than through conscious, manual actions, flexible behaviour can become less salient to households and less observable in their social environment. This reduction in visibility does not undermine the technical effectiveness of automation, but it can weaken social reinforcement mechanisms.

Social norms and social support transmit individual outcomes into collective patterns. **Social Norms** capture descriptive and injunctive norms around flexible electricity use and media and policy attention to peak use, as well as processes of calling out norm deviation. Social norms influence the sense of responsibility and willingness to adopt flexible electricity usage as well as **Social Support**, which reflects the degree to which households receive encouragement, information, and reassurance from their social environment, including exposure to positive experiences in social networks. Social support, in turn, increases knowledge position, sense of responsibility, and willingness. Through these pathways, individual household behaviour feeds back into the social context that shapes future behaviour.

3.3.1. Feedback loops

The simplified CLD contains 89 formally identifiable feedback loops. Rather than interpreting each loop individually, we follow standard practice in the system dynamics literature by focusing on a small number of important and policy-relevant feedback mechanisms. These loops represent families of structurally similar feedbacks and capture the dominant dynamics shaping peak electricity demand.

The system is characterized by three important reinforcing feedback loops that can reduce percentage of electricity use during peak hours on household level, alongside a single dominant balancing loop. For the reinforcing feedback loops, we focus on the positive relationship between Smart Tech Adoption & Automation and Household Flexibility & Controllability whereas for the balancing feedback loop, we focus on the negative relationship, induced by automation reducing visibility. Accordingly, we describe the feedback loops and then turn to variables that constitute enabling conditions and constraints.

R1. Knowledge enables monitoring, which supports flexibility and further reinforces knowledge

Knowledge, Monitoring & Learning Loop (R1): Knowledge position on peak use and own energy situation → Monitoring motivation → Willingness to adopt flexible electricity usage → Smart tech adoption & automation → Household flexibility & controllability → Social norms → Social support → Knowledge position on peak use and own energy situation

When households have more knowledge about peak electricity use, tariffs, and their own energy situation, they are more likely to monitor their electricity consumption. Monitoring increases awareness of when and how electricity can be shifted, which strengthens willingness to adopt flexible electricity use. Higher willingness translates into greater adoption of smart technologies and automation, such as smart charging or home energy management systems. These technologies increase household flexibility and controllability, making flexible behaviour easier and more reliable. In absence of automation, willing households can also exercise flexibility manually (e.g. running appliances at off-peak hours), which is represented in the model as part of household flexibility and controllability. As flexible behaviour becomes more visible and shared within social networks, social norms and social support strengthen, feeding back into higher collective knowledge and understanding. Together, these dynamics form a reinforcing learning loop in which knowledge, monitoring, and experience mutually reinforce one another and accelerate the uptake of flexible electricity use (Figure 7).

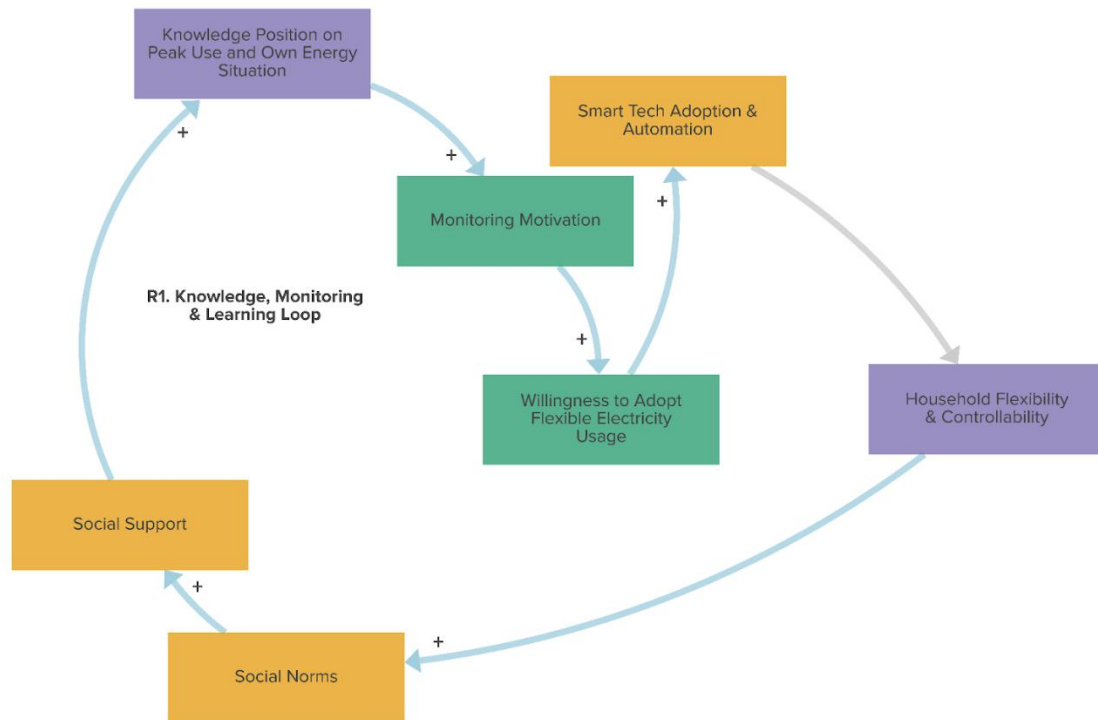


Figure 7. Knowledge, Monitoring & Learning Loop.

A closely related reinforcing mechanism (not shown) operates through perceived urgency: knowledge position increases perceived urgency, which strengthens household flexibility and feeds back into social norms and support, and ultimately, knowledge.

At the same time, the simplified CLD allows for a counteracting dynamic: perceived urgency increases household flexibility and willingness to adopt flexible use, both of which reduce the percentage of electricity use during peak hours. This reduction can dampen social norms via reduced policy and media attention to flexible electricity use.

R2. Social norms and support normalise flexible electricity use

Social Norms, Support & Responsibility Loop (R2): *Social norms* → *Social support* → *Sense of responsibility* → *Willingness to adopt flexible electricity usage* → *Smart tech adoption & automation* → *Household flexibility & controllability* → *Social norms*

In this reinforcing loop, stronger social norms around flexible electricity use, shaped by what others do, expect, and discuss, increase social support through information exchange, encouragement, and shared experiences. Social support strengthens both personal and collective senses of responsibility for reducing peak electricity demand. A stronger sense of responsibility increases willingness to adopt flexible electricity use, which leads households to adopt smart technologies and automation that enable flexible behaviour. As automation increases household flexibility and controllability, flexible electricity use becomes more visible and easier to sustain, reinforcing social norms. This loop captures how flexible electricity use can spread socially: once flexibility becomes normal and socially expected, it is increasingly adopted and reinforced within communities (Figure 8).

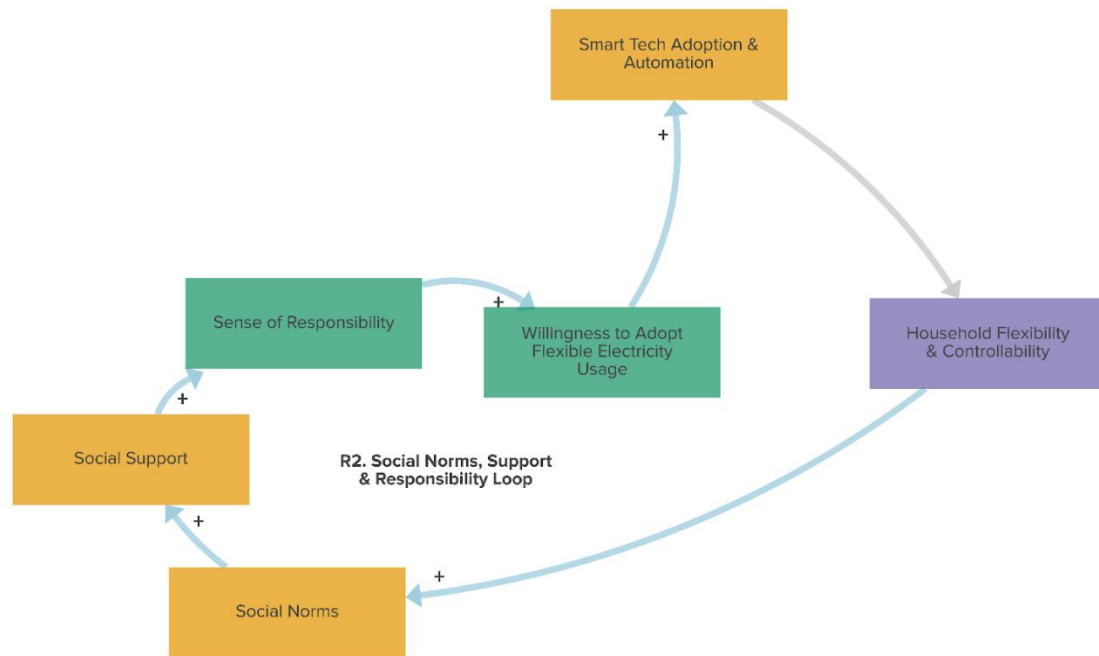


Figure 8. Social Norms, Support & Responsibility Loop.

Importantly, the reinforcing influence of social norms and support depends on continued visibility and positive social interpretation of flexible electricity use. If flexibility becomes less observable and less discussed, social reinforcement may weaken. In such cases, the same social mechanisms that normally normalise flexible use may lose their motivating force, slowing further diffusion rather than accelerating it.

R3. Automation lowers effort and builds capacity, encouraging further adoption

Smart-Tech–Enabled Capability Loop (R3): *Smart tech adoption & automation* → *Household flexibility & controllability* → *Willingness to adopt flexible electricity usage* → *Smart tech adoption & automation*

This reinforcing loop describes how smart technologies themselves help sustain further adoption. When households adopt smart technologies and automation, their ability to control and shift electricity use increases. Greater flexibility and controllability reduce inconvenience and preserve comfort, which strengthens willingness to adopt flexible electricity use. Higher willingness, in turn, supports further adoption of smart technologies and automation. This loop highlights how automation can transform flexibility from an effortful behaviour into a routine, low-friction practice, thereby reinforcing its own uptake over time (Figure 9).

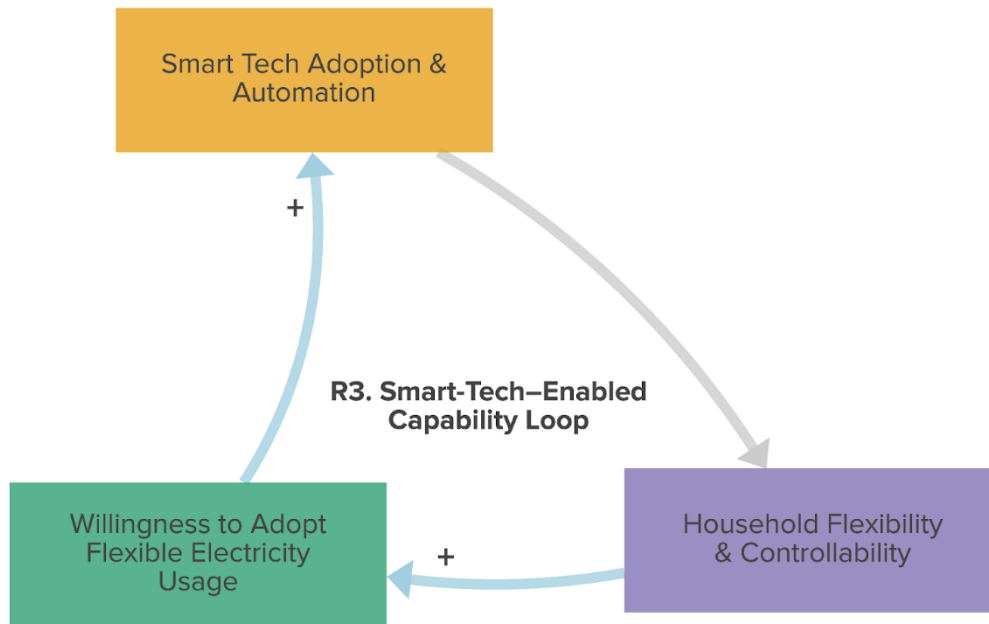


Figure 9. Smart-Tech-Enabled Capability Loop.

A closely related counteracting mechanism (not shown) operates through economic incentives and perceived savings. As household flexibility increases, the percentage of electricity use during peak hours declines. This decline can reduce the perceived savings opportunity from further shifting, which can dampen monitoring motivation and willingness to adopt flexible use.

B1. Automation can reduce visibility, weakening social reinforcement

Automation-Visibility-Norm Dampening Loop (B1): *Smart tech adoption & automation* → *Visibility of electricity use (within household flexibility & controllability)* → *Social norms* → *Willingness to adopt flexible electricity usage* → *Smart tech adoption & automation*

This balancing loop captures a potential counteracting dynamic associated with automation. As a larger share of electricity use becomes smart-controlled, electricity consumption patterns become less visible to households and their social environment. Reduced visibility weakens social norms around flexible electricity use, as there is less observable behaviour to discuss, compare, or emulate. Weaker social norms reduce willingness to adopt flexible electricity use, which slows further adoption of smart technologies and automation. This loop does not imply that automation is undesirable; rather, it highlights a potential unintended consequence whereby highly automated systems reduce the social salience of flexibility, dampening the social reinforcement that otherwise accelerates adoption (Figure 10).

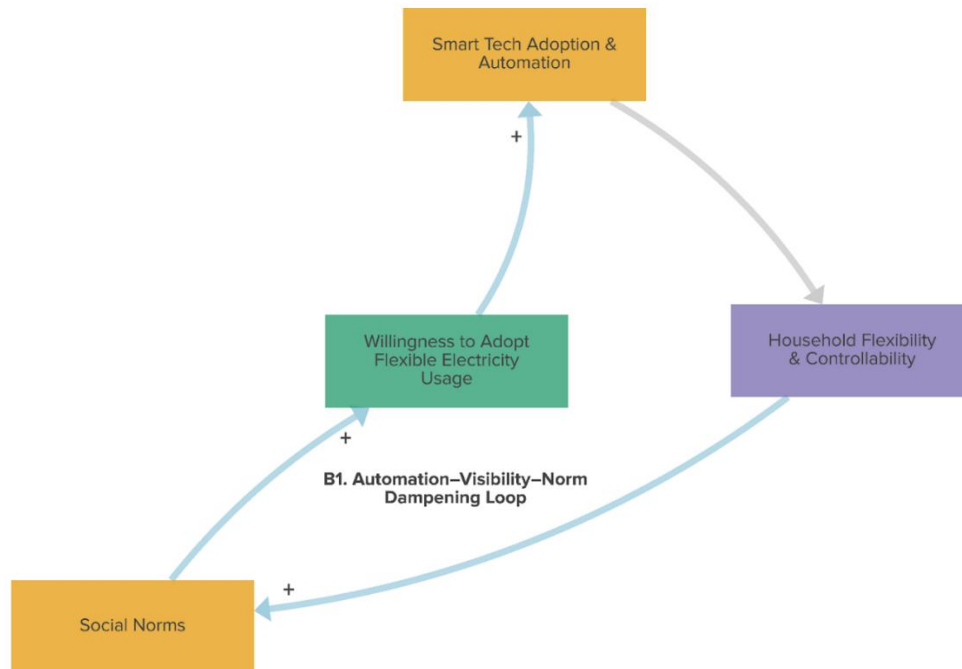


Figure 10. Automation–Visibility–Norm Dampening Loop.

3.3.2. Enabling conditions and constraints

The simplified CLD identifies several reinforcing and balancing feedback loops that shape household peak-electricity use. However, not all influential variables form feedback loops themselves. Some factors enter the system primarily as contextual or enabling conditions: they affect multiple variables within the dominant loops, shaping key decision points without being endogenously reinforced or counteracted. These variables therefore influence whether reinforcing dynamics can plausibly emerge, without implying claims about the magnitude or timing of their effects.

Two such variables are particularly salient. **Trust in Institutions and Companies** conditions whether households accept information, adopt smart technologies, and are willing to adopt flexible electricity usage, influencing multiple pathways simultaneously. Low trust can limit engagement across several parts of the system, while sustained trust supports participation in learning and automation processes. In the CLD, trust influences multiple variables but is not itself reinforced or counteracted through feedback loops. Unlike trust, **Economic Incentives and Perceived Savings** both influence and are influenced by the central variable. In the CLD, economic incentives directly reduce the percentage of electricity used during peak hours and also affect social norms, perceived urgency, monitoring motivation, and willingness to adopt flexible electricity use. At the same time, reductions in the percentage of peak electricity use can decrease perceived savings, potentially weakening their motivational force. This means that economic incentives can trigger behavioural change but may also generate balancing dynamics as their salience declines. They do not, on their own, create reinforcing feedback processes that sustain change. For this reason, economic incentives are treated as an influential but potentially self-limiting driver within the system, rather than as a primary source of reinforcing dynamics.

In summary, while the CLD indicates that peak electricity demand is not limited by multiple structural balancing loops, but by a single dominant capacity constraint, the absence of strong balancing forces does not imply automatic reduction of peak electricity demand. Reinforcing feedback loops require sufficient initial activation, which depends on enabling conditions such as trust in institutions and companies. Policy therefore plays a role in enabling the activation of reinforcing dynamics at early stages.

4. Policy recommendations

In this section, we discuss policy recommendations derived from the system maps. To structure the policy recommendations, we draw on the Intervention Level Framework and ultimately on Donella Meadows’ seminal work on leverage points in complex systems (Meadows, 2008, Chapter 9). Table 1 provides a comparative overview of Meadows’ twelve leverage points and the Intervention Level Framework. Together, these frameworks provide a systematic way to assess how much leverage different types of policy interventions are likely to have.

A central insight from systems thinking is that not all interventions are equally powerful. Complex systems offer multiple “places to intervene,” ranging from relatively shallow to deep leverage points, each associated with different types of change. At the lower end of the leverage spectrum are interventions that adjust structural elements of the system, such as constants, parameters, or buffer sizes—for example, changing tax rates, subsidy levels, or technical standards. While such measures can be effective in the short term, their impact often depends on continued enforcement and may be limited if underlying system dynamics remain unchanged.

Table 1. Overview of and mapping between Meadows’ 12 points to intervene and the Intervention Level Framework.

	Meadows 12 points to intervene	Intervention level framework
Degree of leverage (high to low)	1. Power to transcend paradigms	Paradigm
	2. Paradigm that the system arises out of	
	3. Goals of the system	Goals
	4. Power to add, change, evolve, or self-organise system structure	System structures
	5. Rules of the system	
	6. Structure of information flow	
	7. Gain around driving positive feedback loops	Patterns
	8. Strength of negative feedback loops	
	9. Length of delays	
	10. Structure of material stocks and flows	Structural elements
	11. Size of buffers and other stabilising stocks	
	12. Constants, parameters and numbers	

Moving up the leverage hierarchy are interventions that alter feedback loops and delays, such as mechanisms that strengthen reinforcing dynamics (e.g. social diffusion of insulation uptake) or dampen balancing forces (e.g. administrative bottlenecks that slow adoption). Higher still are interventions that reshape the structure of the system itself, including information flows (what

information is available to whom and when), institutional rules, responsibilities, and incentive structures. These interventions can fundamentally change how actors interact and how decisions are made over time.

At the highest leverage points are interventions that affect the goals of the system and, ultimately, the paradigms or underlying assumptions from which the system arises, for example dominant norms about comfort, energy use, responsibility, or the role of government. Although such interventions are often the most difficult to implement directly, they can enable deep and durable change by reorienting the system as a whole.

The policy recommendations presented below are distilled directly from the simplified causal loop diagram, with a focus on the dominant reinforcing and balancing feedbacks identified in the system. Rather than being formulated to target specific leverage points a priori, the recommendations emerge from asking where policy intervention can most effectively strengthen reinforcing dynamics or weaken the primary constraints revealed by the respective CLDs. The Intervention Level Framework and Meadows' leverage points are then used analytically to characterise the nature and depth of these interventions.

4.1. Insulation to the Standard

We discuss the policy recommendations, their rationale, leverage point level, and relation to existing scientific literature below. Table 1 summarises this analysis by showing how each recommendation relates to the dominant feedback loops and where it sits within the leverage hierarchy.

Table 2. Summary of policy interventions and leverage point depth for insulating to the standard.

Policy intervention	Loops touched	Primary leverage depth	Intervention Level Framework (ILF)	Meadows leverage points
Ensure policy stability and predictability with a long-term roadmap	R1, R2, R3	High	System goals System structures	3. Goals of the system 4. Power to change system structure
Build a strong, independent insulation advice infrastructure	R2, R3, B1	High	System structures	4. Power to change system structure 6. Structure of information flow
Expand and coordinate professional capacity for insulation to the standard	B1, R2	High	System structures	4. Power to change system structure 8. Strength of negative feedback loops
Actively manage social experiences: minimise bad cases and amplify good ones	R1, R3	Medium–High	System structures	6. Structure of information flow 7/8. Feedback loops
Use targeted policies to push households from “some insulation” to “insulate to the standard”	R2, R3	Medium	System structures Structural elements	5. Rules of the system 12. Constants, parameters, and buffers
Use financial instruments strategically along the entire insulation journey	R2, R3	Medium	System structures Structural elements	5. Rules of the system 12. Constants, parameters, and buffers
Exploit life-event windows as moments of lower hassle and higher urgency	R2, R3	Medium–Low	System structures Structural elements	6. Structure of information flow 9. Length of delays

4.1.1. Ensure policy stability and predictability with a long-term roadmap

Recommendation. Avoid frequent, unpredictable changes in insulation-related subsidies, standards, and regulations. Provide a clear, long-term roadmap toward the insulation standard so households, professionals, and financiers can plan, and phase in necessary changes transparently and with sufficient notice. Additionally, aim to simplify the current system of regulations, which is perceived as being too complex (Milieu Centraal, personal communication).

Rationale. In the simplified CLD, Policy Environment and Stability influences Willingness to Insulate, Perceived Difficulty of Insulation, and Professional Support and Advice Quality, all of which shape the activation and strength of reinforcing dynamics. Policy instability can raise urgency in the short term but simultaneously undermine trust, feasibility, and advisory capacity, weakening overall system performance. By providing a stable environment in which uptake can accumulate, learning can compound, and benefits can be perceived as durable, this recommendation also supports the **Social Learning & Norm Reinforcement Loop (R1)**, the **Capability Building Loop (R2)**, and the **Attractiveness & Benefit Reinforcement Loop (R3)**, preventing reinforcing dynamics from being disrupted by policy uncertainty. This recommendation is also consistent with the detailed CLD, where policy instability reduces feasibility, advice quality, and willingness.

Leverage point level. This intervention primarily targets system goals, and secondarily system structures, by stabilising expectations and coordination conditions across actors and over time. In Meadows's framework, this corresponds most directly to Leverage Point 3 (goals of the system) and partially to Leverage Point 4 (power to change system structure), as long-term direction enables reinforcing dynamics to develop rather than being disrupted by policy uncertainty.

Scientific literature. The scientific literature consistently identifies policy stability and predictability as a central condition for scaling up home insulation and retrofit activity. Cross-country reviews and policy-mix analyses show that frequent stop-start changes in subsidies, standards, or programme design undermine household trust, increase perceived difficulty, and discourage investment by installers, advisers, and financiers, whereas stable, long-term frameworks enable learning, capacity building, and market maturation (Hanna et al., 2025; Kerr & Winskel, 2020).

4.1.2. Build a strong, independent insulation advice infrastructure

Recommendation. Invest in high-quality, independent, and locally accessible insulation advice services (e.g. one-stop shops, municipal or regional advisers) with a clear mandate to help households understand what is feasible in their home, reduce practical and procedural barriers, and guide them from initial interest to choosing and implementing the insulation standard. Developing a unified, independent advice framework through collaboration between Milieu Centraal and RVO, as well as establishing physical "Energy Houses" at the municipal level that support homeowners in their sustainability journey, were mentioned as potential high leverage intervention points by participants. Simultaneously, educate and train contractors, installers, and other parties with direct access to homeowners to provide high-quality advice.

Rationale. In the simplified CLD, Professional Support and Advice Quality is a key enabling condition that directly increases Houseowner Ability to Act and Willingness to Insulate, while shaping Perceived Difficulty of Insulation, which negatively affects both willingness and the Share of the Willing Who

Choose the Standard. By increasing ability and reducing perceived difficulty, high-quality advice strengthens the **Capability Building Loop (R2)** and helps activate reinforcing dynamics at early stages, when uptake would otherwise remain low. By (indirectly) increasing the likelihood that insulation experiences are positive and perceived as beneficial, it also strengthens the **Attractiveness & Benefit Reinforcement Loop (R3)**. At the same time, lower perceived difficulty improves the conversion of willingness into realised uptake, thereby partially mitigating the **Professional Capacity Constraint Loop (B1)**. This recommendation is also consistent with the detailed CLD, where high-quality advice shapes multiple psychological and practical determinants simultaneously, reinforcing its role as a foundational condition for activating positive feedback dynamics rather than a narrow informational intervention. Good advice also helps counteract moral licensing (“this was only the first step, here’s what’s left to do”).

Leverage point level. This intervention targets system structures, by reshaping information flows, intermediary roles, and coordination mechanisms that govern feasibility, perceived difficulty, and households’ ability to act. In Meadows’s framework, this aligns mainly with Leverage Point 6 (structure of information flows) and Leverage Point 4 (power to change system structure), as improved advice reorganises how knowledge, trust, and guidance circulate through the system and lowers activation thresholds for reinforcing feedback loops.

Scientific literature. The scientific literature consistently shows that high-quality, trusted advice and intermediary support is a key enabling condition for increasing home insulation uptake, especially for deeper retrofits. Reviews and cross-country studies find that stand-alone information campaigns have limited effects, whereas personalised advice delivered through one-stop-shop or similar intermediary models reduces perceived difficulty, coordination burdens, and uncertainty, thereby improving the conversion of willingness into action (Hanna et al., 2025; Kerr & Winskel, 2020; Owen et al., 2014). Evidence from European one-stop-shop initiatives indicates that such models are especially effective at guiding households through complex decisions, coordinating contractors and finance, and encouraging bundled or staged measures, helping to avoid lock-in to shallow retrofits (Bertoldi, Boza-Kiss, et al., 2021).

4.1.3. Expand and coordinate professional capacity for insulation to the standard

Recommendation. Increase the availability of qualified insulation professionals, for example through expanded training and certification pathways and measures that improve retention and matching between households and installers.

Rationale. In the simplified CLD, increasing uptake reduces the availability of professionals, which raises perceived difficulty and lowers both willingness to insulate and the share of willing households who choose the standard. This creates the main balancing dynamic in the system, the **Professional Capacity Constraint Loop (B1)**, which can slow or stall further uptake even when willingness is high. Expanding professional capacity directly weakens this loop by preventing perceived difficulty from escalating as uptake grows. It also supports the **Capability Building Loop (R2)** by ensuring that households can translate ability and willingness into action and accumulate positive learning over time. This recommendation is also consistent with the detailed CLD, where higher uptake reduces professional availability and professional availability increases feasibility and households’ ability to act.

Leverage point level. This intervention targets system structures, as it directly reshapes supply-side capacity, coordination, and organisational arrangements that otherwise generate the dominant balancing constraint in the system. In Meadows’s framework, this corresponds primarily to Leverage Point 4 (power to change system structure) and indirectly to Leverage Point 8 (strength of feedback loops), by weakening the professional capacity constraint that limits uptake as demand grows.

Scientific literature. The scientific literature identifies professional and workforce capacity as a binding constraint on scaling up home insulation and deep retrofits. International reviews and policy evaluations show that shortages of trained installers, retrofit coordinators, and energy advisers raise costs, increase waiting times, and elevate perceived difficulty, thereby slowing uptake even when household willingness and financial support are high (Hanna et al., 2025; Kerr & Winskel, 2020). This is particularly salient in the Netherlands, which has a tight labour market and shortages limiting the pace of the energy transition (van Tuijl et al., 2025).

4.1.4. Actively manage social experiences: minimise bad cases and amplify good ones

Recommendation. Implement strong quality standards, warranties, and complaints mechanisms to reduce the likelihood of negative insulation experiences, and invest in communication and peer-to-peer programmes that make positive experiences visible, such as neighbourhood ambassadors, showcase homes, and transparent before-and-after cases.

Rationale. In the simplified CLD, Social Experiences influence Social Norms, Willingness to Insulate, Perceived Attractiveness of Insulation, and Perceived Difficulty of Insulation, placing them at the core of key reinforcing dynamics. Because these links can operate in both positive and negative directions, negative experiences can undermine reinforcing loops by reducing willingness and increasing perceived difficulty beyond the households directly affected. Conversely, positive experiences strengthen norms, attractiveness, and willingness. This recommendation thus directly targets both the **Social Learning & Norm Reinforcement Loop (R1)** and the **Attractiveness & Benefit Reinforcement Loop (R3)** by shaping both the valence and the visibility of insulation experiences. This recommendation is also consistent with the detailed CLD, where exposure to negative insulation outcomes reduces attractiveness, ability, and willingness, while positive exposure strengthens norms and motivation.

Leverage point level. This intervention targets system structures, as it reshapes information flows, quality assurance mechanisms, and social feedback channels that determine how insulation experiences propagate through the system. In Meadows’s framework, this corresponds primarily to Leverage Point 6 (structure of information flows) and, indirectly, Leverage Point 8 (strength of feedback loops), since preventing negative experiences and amplifying positive ones alters how strongly reinforcing and counteracting social feedbacks operate.

Scientific literature. The scientific literature shows that social experiences matter for home insulation uptake and can be shaped by policy design. For example, empirical evidence from community-led retrofit programmes demonstrates positive peer spillovers when retrofit experiences are actively communicated through local intermediaries: households living near designated “block leaders” are significantly more likely to adopt retrofit measures, with effects operating through social interaction rather than passive visibility (van Casteren et al., 2024).

4.1.5. Use targeted policies to push households from “some insulation” to “insulate to the standard”

Recommendation. Use differentiated incentives and regulatory instruments that explicitly encourage completion to the standard rather than only “doing something.” Examples include higher subsidy rates or bonus payments for reaching the standard, top-up grants that convert partial measures into standard-level packages, and default advisory pathways in which the standard is consistently presented as the reference option.

Rationale. The simplified CLD explicitly distinguishes between Willingness to Insulate and the Share of the Willing Who Choose the Standard, which then determines the Number of Owner-Occupiers Who Insulate to the Standard. Many determinants increase general willingness, but conversion to the standard depends more strongly on factors such as houseowner ability to act, perceived difficulty, technical suitability, and professional support and advice quality. Policies that focus only on stimulating “any insulation” primarily increase willingness and initial action, but can leave a substantial drop-off before the standard. The CLD therefore justifies a second, targeted layer of policy aimed specifically at the conditional decision to proceed to the standard. By structuring early actions as steps toward completion and increasing the likelihood that insulation delivers salient benefits, this recommendation also supports the **Capability Building Loop (R2)** and the **Attractiveness & Benefit Reinforcement Loop (R3)**, reducing the risk that partial measures stall learning or undermine perceived value. This recommendation is also consistent with the detailed CLD, which shows distinct feasibility-related determinants for standard-level uptake compared to initial measures.

Leverage point level. This intervention primarily targets structural elements when implemented through differentiated subsidy levels and bonus payments, and system structures when designed through staged pathways, top-up mechanisms, or default routes that govern how households move from partial measures to standard-level insulation. In Meadows’s framework, this corresponds mainly to Leverage Point 12 (constants and parameters, such as subsidy levels) and, where pathway design and conditionality are central, to Leverage Point 5 (rules of the system), as the intervention reshapes eligibility criteria, defaults, and decision rules that structure the conversion from willingness into completed insulation to the standard.

Scientific literature. Recent research on residential retrofit policy consistently distinguishes between initial uptake and retrofit depth, showing that policies aimed at encouraging “any action” tend to deliver predominantly single, shallow measures unless explicitly designed otherwise. Reviews of European retrofit programmes and incentive schemes find that undifferentiated subsidies and tax credits rarely result in comprehensive retrofits, while performance-based or package-oriented designs (e.g. higher support conditional on reaching defined efficiency levels) are more effective at increasing the share of deeper renovations (Bertoldi, Economidou, et al., 2021; Hanna et al., 2025). Complementary policy analyses emphasise the risk of lock-in from partial measures and argue for staged pathways, top-up mechanisms, or standard-referenced designs that explicitly target the completion decision rather than initial participation (Bertoldi, Boza-Kiss, et al., 2021; Kerr & Winskel, 2020).

4.1.6. Use financial instruments strategically along the entire insulation journey

Recommendation. Deploy financial instruments that lower upfront barriers for initial measures while maintaining or improving the business case for progressing from partial measures to the standard. This can include progressive subsidies that increase with depth, tailored loan products for constrained households, and standardised “all-in” packages for reaching the standard. Financial institutions should be engaged not only as financiers but also as trusted intermediaries that actively promote standard-level upgrades.

Rationale. In the simplified CLD, Financial Enabling Conditions and Perceived Attractiveness of Insulation are key inputs into Willingness to Insulate. Financial conditions therefore shape whether reinforcing dynamics related to motivation and attractiveness activate at all. The CLD also implies that after initial measures are taken, marginal financial attractiveness can decline, increasing the risk that households stop short of the standard. Financial instruments designed with this dynamic in mind can support both initiation and completion. This recommendation thus supports the **Capability Building Loop (R2)** and the **Attractiveness & Benefit Reinforcement Loop (R3)**, reducing the risk that financial barriers interrupt reinforcing dynamics over time. This recommendation is also consistent with the detailed CLD, where financial institutions influence perceived attractiveness and homeowner support.

Leverage point level. This intervention primarily targets structural elements by adjusting affordability conditions and incentive gradients, and secondarily system structures when financial instruments are designed to reshape the staged progression from initial measures to the standard. In Meadows’s framework, this corresponds mainly to Leverage Point 12 (constants and parameters) and, where progression is explicitly structured, to Leverage Point 5 (rules of the system).

Scientific literature. The scientific literature on retrofit finance highlights that financial barriers and incentives operate differently at different stages of the insulation journey, and that instruments optimised for initial uptake do not automatically support progression to deeper or standard-level outcomes. Reviews of renovation finance show that upfront grants are effective for triggering first measures, while progressive incentives, tailored loan products, and bundled “all-in” financing are more relevant for sustaining attractiveness and affordability as projects become more complex and capital-intensive (Bertoldi, Economidou, et al., 2021).

4.1.7. Exploit life-event windows as moments of lower hassle and higher urgency

Recommendation. Align insulation-to-standard programmes with moments when perceived hassle is naturally lower and urgency is higher, such as house moves, major renovations, or mortgage refinancing. This can include integrating insulation standard assessments into mortgage advice, requiring or strongly incentivising standard-level insulation when major works are undertaken, and providing additional support precisely at these moments.

Rationale. In the simplified CLD, Windows of Opportunity increase Willingness to Insulate and reduce Perceived Difficulty of Insulation, increasing the likelihood that households take measures and choose the standard. These effects help activate reinforcing dynamics that otherwise remain weak when perceived difficulty is high and willingness is low, supporting the **Capability Building Loop (R2)** and the **Attractiveness & Benefit Reinforcement Loop (R3)**. Targeting moments of heightened responsiveness increases the effectiveness of interventions. This recommendation is also consistent with the detailed

CLD, where facilitating life-changing events simultaneously reduce perceived hassle and increase urgency.

Leverage point level. This intervention primarily targets structural elements by acting on the timing of decisions and lowering barriers at specific moments, and secondarily system structures when these moments are embedded into institutional processes such as mortgage advice or renovation permitting. In Meadows’s framework, this aligns mainly with Leverage Point 6 (structure of information flows) and Leverage Point 9 (delays), as the intervention exploits periods of heightened responsiveness and makes information and support available when the system is most receptive.

Scientific literature. The scientific literature shows that home insulation and retrofit decisions cluster around specific “trigger points”, particularly house moves and major renovation or repair activities, rather than occurring as stand-alone energy decisions. Reviews and qualitative studies consistently find that most energy efficiency measures are implemented alongside broader renovations, when disruption and coordination costs are already incurred and perceived hassle is lower (Wilson et al., 2015; Kerr & Winskel, 2020). Recent policy-oriented research therefore recommends aligning retrofit and insulation-to-standard interventions with these moments, for example through renovation processes or property transactions, to increase effectiveness and reduce the risk of lock-in to sub-optimal outcomes (Brown et al., 2014; Bertoldi et al., 2021).

4.2 Peak electricity demand

We discuss the policy recommendations, their rationale, leverage point level, and relation to existing scientific literature below. Table 3 summarises this analysis by showing how each recommendation relates to the dominant feedback loops and where it sits within the leverage hierarchy.

Table 3. Summary of policy interventions and leverage point depth for peak-electricity demand.

Policy intervention	Loops touched	Primary leverage depth	Intervention Level Framework (ILF)	Meadows leverage points
Enable smart automation through technical, organisational, and governance conditions	R3, R1	High	System structures	4. Power to change system structure
Build structured learning and monitoring pathways for household electricity flexibility	R1, R2	Medium–High	System structures	6. Structure of information flow
Strengthen and maintain trust in smart energy institutions and technologies	R3 (primary), R1 (secondary)	Medium–High	System structures	6. Structure of information flow
Preserve visibility of flexible electricity use under automation	B1 (primary), R2 (secondary)	Medium	System structures	6. Structure of information flow
Support social diffusion of flexible electricity use through local networks	R2, R1	Medium	System structures	6. Structure of information flow

4.2.1 Enable smart automation through technical, organisational, and governance conditions

Recommendation. Reduce structural barriers to smart technology adoption by ensuring interoperability between appliances, sufficient availability of contractors, accessible investment options, and policy agreements governing smart appliance use. This includes establishing common technical standards and communication protocols (e.g. for smart EV chargers, home energy management systems, and heat pumps) for devices to work together reliably, and organisational arrangements that can manage automation across households (e.g., an aggregator that automatically schedules EV charging within user-set limits in response to time-of-use prices or local congestion signals). At the same time, establish governance conditions that protect trust, including transparency, data protection, clear accountability for decisions and outcomes, and meaningful options for user control and opt-out.

Rationale. The simplified CLD identifies Smart Tech Adoption & Automation as a key driver of the **Smart-Tech-Enabled Capability Loop (R3)**. Automation increases Household Flexibility & Controllability by lowering effort and preserving comfort, which strengthens Willingness to Adopt Flexible Electricity Use and supports further adoption of smart technologies. This loop illustrates how automation can transform flexibility from an effortful activity into a routine, low-friction practice. Greater automation and flexibility can also support the **Knowledge, Monitoring & Learning Loop (R1)**, insofar as increased flexibility strengthens Social Norms and Social Support, which feed back into knowledge and engagement. Economic Incentives and Perceived Savings also feed into Willingness to Adopt Flexible Electricity Use, meaning they can support smart tech uptake via willingness.

Leverage point level. This intervention targets system structures, as it focuses on the technical, organisational, and institutional conditions that govern smart technology adoption. In Meadows's framework, it aligns primarily with Leverage Point 4 (power to change system structure). By addressing interoperability, contractor availability, investment conditions, and governance arrangements that protect trust and accountability, the intervention reshapes the structural environment in which households decide whether and how to adopt automated flexibility.

Scientific literature. Empirical evidence from the Netherlands shows that smart appliances and dynamic tariffs can support peak shifting when supported by reliable technology, interoperability, and appropriate organisational conditions (Klaassen et al., 2016). Evidence also indicates that enabling services, such as appliance control, flexibility rewards, and meaningful bill savings can increase acceptance of time-of-use tariffs and automation, for example via smart EV charging that shifts load to cheaper, off-peak periods (Sarda et al., 2024; Sundt et al., 2020). At the same time, reviews of smart grid and demand response projects identify persistent structural barriers, including lack of unified standards, interoperability issues, limited contractor capacity, and concerns about control and accountability (Sarda et al., 2024; Smale et al., 2017; Weck et al., 2017). National studies further indicate that households' willingness to engage with automated flexibility depends not only on economic incentives, but also on usability, comfort, and institutional trust (TNO, 2024).

4.2.2 Build structured learning and monitoring programmes for household electricity flexibility

Recommendation. Invest in clear, coherent, and locally accessible learning programmes that help households understand peak electricity use, tariffs, and their own consumption patterns, and that

support sustained monitoring over time. This includes investing in user-friendly feedback apps and peak alerts to support households in manually adjusting usage until automation becomes more widespread. Improving the availability, quality, and integrality of information; making electricity tariff structures comprehensible; and embedding monitoring tools and skills into everyday household practices, particularly at moments when households are already engaging with energy-related decisions can also be helpful. These could include independent advice (municipal/regional), simple “what to do in my situation” guidance, and support that reduces confusion around tariffs (including what households can realistically save, and under what conditions) and peak-use impacts.

Rationale. In the simplified CLD, Knowledge Position on Peak Use and Own Energy Situation plays a foundational role in the **Knowledge, Monitoring & Learning Loop (R1)**. Higher knowledge increases Monitoring Motivation, Perceived Urgency, and Sense of Responsibility, each of which supports Willingness to Adopt Flexible Electricity Use and encourages engagement with smart technologies and automation. This recommendation also supports the **Social Norms, Support & Responsibility Loop (R2)**. As households gain experience with flexibility, increased Household Flexibility & Controllability feed back into Social Norms and Social Support, reinforcing knowledge and learning.

Leverage point level. This intervention primarily targets system structures by reshaping information flows between institutions, tariffs, technologies, and households. In Meadows’s framework, it aligns most closely with Leverage Point 6 (structure of information flows).

Scientific literature. Reviews and field experiments indicate that feedback can reduce consumption and support load shifting when households understand when and why peak use occurs (Darby, 2006; Faruqui et al., 2010). Furthermore, practical knowledge and monitoring skills are especially relevant for load shifting (Hubert et al., 2024). Research shows that information on household energy use is most effective when it is delivered by trusted entities in a simple, clear, and personally relevant way (Frederiks et al., 2015). However, effects are often limited or short-lived when information is provided in isolation or without ongoing engagement (Cellina et al., 2024). Dutch policy reviews similarly emphasise that awareness-raising should be paired with clear, consumer relevant guidance and tools that provide insight and control, rather than relying on awareness campaigns alone (TNO, 2024).

4.2.3 Strengthen and maintain trust in institutions and smart energy technologies

Recommendation. Actively strengthen and maintain trust in public institutions, energy providers, and smart energy technologies by ensuring transparency, clarity of responsibilities, data protection, and consistent communication. This might include transparency about how dynamic tariffs, rebates, or automated control actions translate into household bills and clear explanations of how flexible electricity systems work, who is responsible for decisions and outcomes, how household data are used, and what safeguards and options households have if systems fail or produce unwanted outcomes.

Rationale. In the simplified CLD, Trust in Institutions and Companies plays a foundational role in shaping both Willingness to Adopt Flexible Electricity Use and Smart Tech Adoption & Automation. Trust also affects whether households accept information and advice, influencing their knowledge position and engagement with monitoring and learning. When trust is low, households are less willing to delegate control to automated systems, less likely to engage with information, and more hesitant to change behaviour, potentially weakening multiple reinforcing feedback loops simultaneously. Conversely, sustained trust enables learning, automation, and flexibility to reinforce one another. Accordingly, this

recommendation directly supports the **Knowledge, Monitoring & Learning Loop (R1)** and **Smart-Tech-Enabled Capability Loop (R3)**.

Leverage point level. This intervention primarily targets system structures by shaping institutional credibility, accountability, and information legitimacy. In Meadows's framework, it aligns most closely with Leverage Point 6 (structure of information flows).

Scientific literature. Empirical studies show that trust in both institutional competence and integrity significantly influences willingness to adopt smart grid technologies, often through perceived benefits (Siitonen et al., 2024). Research on dynamic tariffs and smart metering further indicates that privacy concerns and uncertainty about data use can reduce participation (von Loessl, 2023). Reviews of Dutch smart grid and demand response projects similarly highlight trust and transparency as recurring enablers or barriers to household participation (Weck et al., 2017).

4.2.4 Preserve the visibility of flexible electricity use under automation

Recommendation. Design automated flexibility systems in ways that maintain or recreate the visibility of flexible electricity use for households and their social environment. This may include feedback on automated actions (e.g. cost and reward visibility, such as showing when automation avoided peak priced periods or earned a rebate), neighbourhood-level peak indicators, or local progress dashboards that make flexible behaviour observable and discussable, even when it is no longer manually enacted.

Rationale. The **Automation-Visibility-Norm Dampening Loop (B1)** captures a potential unintended consequence of automation: as a larger share of electricity use becomes smart-controlled, the Visibility of Electricity Use declines. Reduced visibility weakens Social Norms around flexible electricity use, which lowers Willingness to Adopt Flexible Electricity Use and slows further adoption of automation. This loop highlights a structural tension: the very features that make flexibility effortless can also reduce its social salience. Preserving visibility can help prevent automation from eroding the social reinforcement mechanisms captured in the **Social Norms, Support & Responsibility Loop (R2)** while also supporting the **Knowledge, Monitoring & Learning Loop (R1)** via social support.

Leverage point level. This intervention primarily targets system structures by deliberately reshaping how information about electricity use is generated, surfaced, and shared under conditions of automation. In Meadows's framework, it aligns most closely with Leverage Point 6 (structure of information flows).

Scientific literature. Research shows that feedback and visibility are central to learning and sustained engagement with energy behaviours (Darby, 2006), and that visibility can support the formation of social norms and peer effects in household energy transitions (Abrahamse & Steg, 2013; Wolske et al., 2020). Qualitative evidence suggests that smart technologies can become less salient over time as they become embedded in everyday routines (Hargreaves et al., 2013), which can reduce the visibility of flexible energy use and therefore dampen social norms. Empirical work on peak oriented 'pause hours' used prompts and post event feedback to make outcomes visible, including comparison to neighbours and goal achievement (Mäkivierikko et al., 2023). While visibility measures are important for diffusion among households that have not yet adopted automation, they can also help existing users keep flexibility salient and shareable, which supports wider social normalisation.

4.2.5 Support the social diffusion of flexible electricity use through local networks

Recommendation. Support initiatives that foster social interaction, experience-sharing, and mutual support around flexible electricity use at the local level, such as neighbourhood programmes, peer-to-peer learning, or community-based energy initiatives. Where appropriate, programmes can incorporate small rewards or collective incentives to increase participation and maintain engagement.

Rationale. The **Social Norms, Support & Responsibility Loop (R2)** shows how flexible electricity use can spread through social processes. Stronger Social Norms increase Social Support, which strengthens personal and collective Sense of Responsibility and, in turn, Willingness to Adopt Flexible Electricity Use. As households adopt smart technologies and increase flexibility, behaviour becomes more visible, reinforcing norms and completing the loop. This recommendation leverages the fact that social processes translate individual experiences into collective patterns. Rather than targeting households in isolation, it focuses on enabling environments in which flexible electricity use becomes socially normal. This can also support the **Knowledge, Monitoring & Learning Loop (R1)** by improving practical knowledge and shared understanding of tariffs and peak use through social exchange. Economic Incentives and Perceived Savings are also relevant here as they strengthen social norms.

Leverage point level. This intervention primarily targets system structures by strengthening social information flows within communities. In Meadows's framework, it aligns most closely with Leverage Point 6 (structure of information flows).

Scientific literature. Research shows that social influence interventions can meaningfully affect household electricity use (Abrahamse & Steg, 2013; Wolske et al., 2020). Community-based demand response initiatives provide further evidence that local coordination and interaction can support reductions in peak demand, with incentives strengthening participation (Mäkivierikko et al., 2023). Practice-oriented studies also highlight that flexibility is not equally available to all households due to entrenched daily routines and constraints, suggesting that interventions accounting for social context (e.g. family schedules and shared practices) are likely more effective than those targeting individuals in isolation (Hubert et al., 2024; Nicholls & Strengers, 2015).

5. Discussion

This report applied a participatory systems modelling approach to insulating to the standard and reducing households' peak electricity consumption. The resulting system maps provide a structured way to reason about the reinforcing and balancing feedback loops shaping insulation uptake and peak-electricity demand and to derive policy-relevant insights.

Beyond drawing on existing evidence and integrating the expertise of multiple stakeholders, the CLDs add value by functioning as a synthesis and sensemaking tool that brings together factors that are often studied in isolation across different literatures and levels of analysis. In doing so, it highlights feedback structures that are rarely examined systematically in the scientific literature but are critical for understanding system-wide dynamics of insulation uptake and reducing peak-electricity demand. While not providing definitive answers, the CLDs offer a coherent starting point for further empirical testing, quantitative modelling, and policy experimentation.

At the same time, it is important to be explicit about what the CLDs do and do not capture, and how they should be interpreted in a policy context. The following section below briefly outlines the main limitations of the CLDs and provides guidance on how the results should be used, to avoid over-interpretation and to clarify the scope of the analysis. The report ends with future avenues.

5.1. Limitations of the CLDs and use guidance

First, note that the CLDs reflect the **elicited expertise and shared understanding of the participating stakeholders**, rather than a direct representation of the systems "as they are" in an objective or empirical sense. The system maps should therefore be understood as a structured synthesis of stakeholder knowledge, assumptions, and mental models, developed through facilitated group model building. During the sessions and in subsequent analytical work, we critically assessed whether individual variables and causal connections were internally coherent, plausible, and consistent with existing evidence and theory. However, this form of plausibility checking does not constitute formal validation. A more rigorous validation would require triangulation with empirical data, systematic comparison with findings from the academic literature, targeted empirical testing of key causal links, and potentially quantitative calibration or simulation-based testing to assess whether the implied dynamics reproduce observed patterns. As such, the CLDs are best interpreted as a credible, transparent starting point for analysis and policy reasoning, rather than a definitive or empirically validated model of the insulation system.

Second, the CLDs reflect the **limited breadth and depth** that could be achieved within the available time and structure of the modelling process. Given the number of sessions, the need to converge on a shared understanding, and the partial dropout of participants, the diagrams necessarily emphasise a core set of behavioural and delivery-related mechanisms. As a result, several dimensions that were mentioned in the sessions, such as external drivers (e.g. regional context), are not explicitly included. In the case of peak electricity demand, this constraint may also explain the limited number of balancing loops, since many potentially counteracting mechanisms were either outside the model boundary or not developed into full causal pathways. These structural limitations of the CLDs imply that important

system dynamics may be underrepresented, even when they were recognised by participants. Relatedly, the selection and presentation of feedback loops in the simplified CLDs reflect analytical choices made under these constraints. While the diagrams contain a large number of formally identifiable feedback loops, only some of these are highlighted to maintain analytical clarity. Due to time constraints, feedback loops were not systematically discussed, validated, or prioritised with participants, but only among the author team. While the feedback loops discussed in this report constitute key reinforcing and balancing dynamics, they should not be understood as a complete or definitive mapping.

Third, the CLDs are an **aggregate representation of the system**, which necessarily abstracts from heterogeneity across households, buildings, and local contexts. Households are treated as a homogeneous population, meaning that differences by income, tenure, vulnerability, or access to finance and advice are not explicitly represented, and equity or distributional impacts cannot be assessed within this framework. Similarly, several variables both in the insulation case, such as policy environment and stability, technical suitability of the home, and professional capacity, and in the peak electricity demand case, such as household flexibility, knowledge position, and smart technology adoption, are represented in aggregated form. This implies that important variation across housing and household types, regions, or forms of capacity constraints is averaged out, potentially masking bottlenecks that are highly salient for specific subgroups or locations.

Fourth, the CLDs reflect a **deliberate choice of system boundaries**, which limits the range of dynamics that can be analysed. For example, while the CLD captures key behavioural, social, and delivery-related mechanisms shaping insulation uptake, it does not endogenously represent broader political economy dynamics, institutional power relations, or policy feedbacks, such as how uptake might influence political support, lobbying, or regulatory ambition over time. Likewise, interactions with other parts of the energy system, such as heat pump adoption, grid constraints, or solar PV uptake, are treated as outside the model boundary. Expanding the CLD in future work to include these dimensions would allow analysis of cross-sectoral interactions and governance feedbacks that are increasingly important for system-wide decarbonisation. Relatedly, the problem framing around the peak electricity demand case study introduces a limitation. By focusing on household-level flexibility, the CLD implicitly treats peak demand as a behavioural challenge for households, even though many peak-hour activities are tied to socially shared routines and infrastructural constraints that are only partially adjustable at the household level. This framing reflects the scope of the modelling exercise, but it limits conclusions about whether peak demand is best addressed through household change versus provision-side or systemic solutions.

Lastly, the CLDs do not explicitly model **time dynamics or effect strengths**. Causal relationships indicate direction of influence but not the speed, magnitude, or relative importance of different effects. Delays between policy intervention, behavioural response, and realised uptake are not represented, nor are accumulation processes such as workforce growth or learning-by-doing. As a result, the CLD cannot be used to infer short- versus long-term impacts, tipping points, or sequencing requirements without additional modelling or empirical calibration. Similarly, the absence of effect sizes means the diagram should be read as a map of plausible causal structure rather than a tool for quantitative prioritisation.

When using the CLDs to inform policy, it is important to **treat the system maps as a strategic sensemaking tool, rather than as predictive models** or as evidence that any single intervention will

automatically produce the desired outcome. The CLDs highlight potential reinforcing and balancing dynamics, but whether these dynamics dominate in practice depends on context, timing, and implementation quality, none of which are explicitly modelled. Policymakers should therefore avoid “single-lever” thinking (e.g. assuming that removing one constraint will be sufficient) and instead interpret the CLDs as pointing to combinations of enabling conditions that need to be in place for reinforcing processes to plausibly activate. Likewise, the presence of feedback loops does not imply inevitability: negative experiences, capacity constraints, or policy instability can just as easily weaken reinforcing dynamics if not carefully managed. Used appropriately, the CLDs supports strategic, system-level judgement about where coordination is needed and where unintended consequences may arise, rather than providing a blueprint for mechanical policy optimisation.

5.2. Future Avenues

With additional time and resources, a natural next step would be to extend the current qualitative CLD analysis by introducing explicit time dynamics. While the CLD clarifies which variables interact and where reinforcing or balancing feedbacks may arise, it does not indicate how quickly changes unfold or where delays may be critical. Working with relevant stakeholders, time dynamics could be explored by identifying typical durations for key processes, such as training professionals, completing insulation projects, or observing social diffusion effects. This would enable more realistic reasoning about short-versus long-term policy impacts and potential sequencing challenges.

A second, closely related step would be to develop empirical estimates of the relative strength of key causal relationships and to translate the CLD into a quantitative system dynamics model. The simplified analysis in Appendix B illustrates how this could look like. Using available survey data, administrative records, and targeted expert elicitation, approximate parameter values could be assigned to the most influential links. Implemented as a system dynamics model, this would allow one to explore “what-if” scenarios and policy packages: for example, comparing demand-side incentives with and without simultaneous capacity expansion, or testing the robustness of policies under different assumptions about delays and uptake rates. Such an extension would not replace the CLD’s role as a sensemaking tool, but would complement it by enabling structured exploration of dynamic behaviour over time.



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6. Appendix

Sections A.1 and A.2 show the mapping between the composite variables of the simplified CLD to the variables of the underlying CLD, first for insulation and then for peak electricity demand. The final outcome variables are also listed. Section B presents a computational analysis of the effects of interventions.

A1. Composite Variables: Insulation

COMPOSITE VARIABLE: Perceived Attractiveness of Insulation

- Perceived financial attractiveness of insulating to the standard
- Perceived attractiveness of insulating to the standard
- Perceived non-financial attractiveness of insulating to the standard
- Perceived benefits of insulating
- Perceived home value

COMPOSITE VARIABLE: Financial Enabling Conditions

- Mortgage borrowing capacity
- Availability of attractive financing options
- Average costs of insulation measures
- Average gas price
- Level of influence of financial institutions such as banks

COMPOSITE VARIABLE: Professional Support and Advice Quality

- Average quality of an integral advise to go to the standard
- Degree of trust in companies/institutions of homeowners
- Understanding of building physics and possibilities with the professional
- Degree of negativity in regard to insulating to the standard with professionals
- Synchronicity with other measures to make the house more sustainable

COMPOSITE VARIABLE: Perceived Difficulty of Insulation

- Perceived hassle of insulating to the standard
- Overestimation of difficulty of insulating to the standard
- Perceived complexity of insulating to the standard
- Degree of feasibility of insulating to the standard

STANDALONE VARIABLE: Houseowner Ability to Act

- Houseowner's ability to act
- Percentage of 'do-it-yourself' homeowners
- Knowledge position on insulating to the standard and possibility with the houseowner

COMPOSITE VARIABLE: Social Experiences

- Positive experience with isolation measures taken
- Exposure to positive isolation outcomes in social networks
- Exposure to negative isolation outcomes in social networks

COMPOSITE VARIABLE: Taking one or more isolation measures

- Taking one or more isolation measures

COMPOSITE VARIABLE: Social Norms
Observation that isolation is the norm

COMPOSITE VARIABLE: Willingness to Insulate
Degree of urgency houseowners
Degree of support from houseowners
Loan aversion
Perceived obligation of effort by owner-occupier
Level of concern about climate change
Level of concern about global geopolitics
Average energy usage houseowner

COMPOSITE VARIABLE: Technical Suitability of the Home
Degree of technical suitability of the home
Building specific defects

COMPOSITE VARIABLE: Policy Environment and Stability
Degree of policy instability
Legal responsibilities of municipalities to facilitate their inhabitants

COMPOSITE VARIABLE: Windows of Opportunity
Facilitating life-changing events
Sociodemographic background (context)

STANDALONE VARIABLE: Availability of Professionals
Availability of professionals

FINAL VARIABLES:
Share of the willing who choose the standard
The number of owner-occupiers who insulate to the standard

A2. Composite Variables: Peak Electricity

COMPOSITE VARIABLE: Knowledge position on peak use and own energy situation
Knowledge position with regard to peak usage and net congestion
Availability of information for households
Comprehensibility of tariff structures
Degree of integrality of the advice given to households about their energy situation
Presence of a monitoring tool
Monitoring skills

COMPOSITE VARIABLE: Economic incentives & perceived savings
Price incentive from net provider and energy supplier
Average price difference between peak and non-peak
Average electricity price
Level of availability of own power source
Average cost of energy storage
Perceived cost savings

COMPOSITE VARIABLE: Perceived urgency
Perception of urgency
Psychological distance
Crisis experience

COMPOSITE VARIABLE: Social norms

Descriptive norm

Injunctive norm

Calling out norm deviation

Degree of media and policy attention for peak use

COMPOSITE VARIABLE: Social support

Support from social network

Exposure to positive experiences in social network

COMPOSITE VARIABLE: Sense of responsibility

Personal responsibility

Collective responsibility

COMPOSITE VARIABLE: Trust in institutions & companies

Degree of trust in government institutions

Degree of trust in companies involved in smart appliance use

Degree of susceptibility

COMPOSITE VARIABLE: Smart tech adoption & automation

Willingness to use smart appliances

Degree of HEMS (Home Energy Management Systems) usage

Usage of smart functionality of electric car

Usage of smart functionality of heat pump

Degree of interoperability between appliances

Policy agreement for smart appliances

Availability of contractors in the energy sector

Availability of means to invest in new technology

Percentage of electricity that is smart-controlled

Degree of trust in unsupervised use of appliances

Degree of integrity in the energy situation in households

COMPOSITE VARIABLE: Household flexibility & controllability

Degree of controllability of electricity use (in/out of peak)

Perception of flexibility in daily routines

Feasibility of appliance functionalities

Degree of user abilities

Degree of changed induction cooking use

Presence of neighborhood facilities

Degree of electricity storage

Perceived agency in shifting electricity usage

Degree of comfort and ease

Percentage of electricity usage that is manually directed

Degree of visibility of electricity usage

COMPOSITE VARIABLE: Monitoring motivation

Willingness to monitor electricity usage

FINAL VARIABLES:

Percentage of electricity use during peak hours (16.00–21.00) on household level

Willingness to adopt flexible electricity usage

B. Effects of interventions

The CLDs do not include estimates for the magnitude of the relationships between any variables. If one had these estimates, one could assess the effect that different interventions have on the central variable. Interventions here are operationalised as changes in a particular variable (e.g., increasing homeowners' ability to act by 1 standardized unit).

In this section, we used a number of **strongly simplifying** assumptions to showcase an analysis aimed at identifying the most important variables to intervene on for the insulation case. We describe the methodology in Section B1 and the results in Section B2. We want to stress that this exercise is illustrative, and given the strongly simplifying assumptions the conclusions one can draw are very limited. We add this merely to showcase what future work, which includes a quantification of the link strength between variables, could provide.

B1. Methodology

Following the methodology proposed by Uleman et al. (2025), we converted the CLDs into systems of linear ordinary differential equations. Variables are classified as **stocks** (accumulate over time, 1-10 year timescales), **auxiliaries** (adjust quickly, <1 year timescales), and **constants** (fixed or very slowly changing, >10 year timescales). Auxiliary variables are substituted out to obtain an effective stock-to-stock system matrix that accounts for indirect pathways through auxiliaries.

Because empirical calibration is outside the scope of the current analysis, all causal link strengths are treated as uncertain. For each simulation run, link parameters are sampled independently from bounded uniform distributions. In this analysis, the default upper and lower bounds of effect sizes were used, namely, effects sizes are assumed in the range from 0 to 0.3 standard deviations (and standard deviations per year for the stocks).

Interventions are simulated one-at-a-time by applying a standardized unit change (default strength $\delta = 1.0$ or -1.0 standard unit) to a target variable. The mechanism depends on the variable type: a stock is perturbed via its initial condition, a constant via its fixed value, and an auxiliary via its intercept term. Each intervention is evaluated relative to an implicit counterfactual in which all initial conditions are zero and no intervention is applied.

To identify which assumed causal links most strongly drive intervention effects, the analysis computes Spearman rank correlations between each sampled link parameter and the resulting intervention effect (evaluated at $t = t_{end}$). For each correlation, 95% bootstrap confidence intervals are computed (200 bootstrap samples).

This workflow makes explicit structural, parametric, and temporal assumptions. These enable systematic comparison of leverage points, but they also constrain interpretation:

- Structure-driven analysis: Results depend on the completeness and correctness of the CLD structure and polarities.
- Uniform, independent priors: Link strengths are sampled uniformly and independently within bounds; real systems may be more or less constrained.
- Linearity by default: Saturation, thresholds, and non-monotonic effects per pairwise effect are not represented.

- Zero baseline and unit interventions: Effects are standardized for comparability, not matched to real-world magnitudes or costs.
- Classification of factors as variables assumes responses to input variables much quicker than 1 year; classification of factors as stocks assumes variations of the order of the year for all stocks.
- All factors without incoming links or that are assumed to respond much slower than the maximum time frame (10 years) are assumed to be constant.

B2. Results: Insulation

We simulated 10,000 scenarios over a 10-year time horizon to assess the effect that intervening on the variables of the CLD has on the number of homeowners who insulate to the standard. For each scenario, the link strengths are sampled uniformly and independently. By running so many scenarios, we can estimate the average (or median) effect of the intervention, as well as the uncertainty around it. Figure B1 visualises the intervention strength for each variable in the CLD. The variable with the strongest effect is the share of the willing who choose the standard, but this is trivially so, as this variable is part of who we encoded the number of homeowners who insulate to the standard.

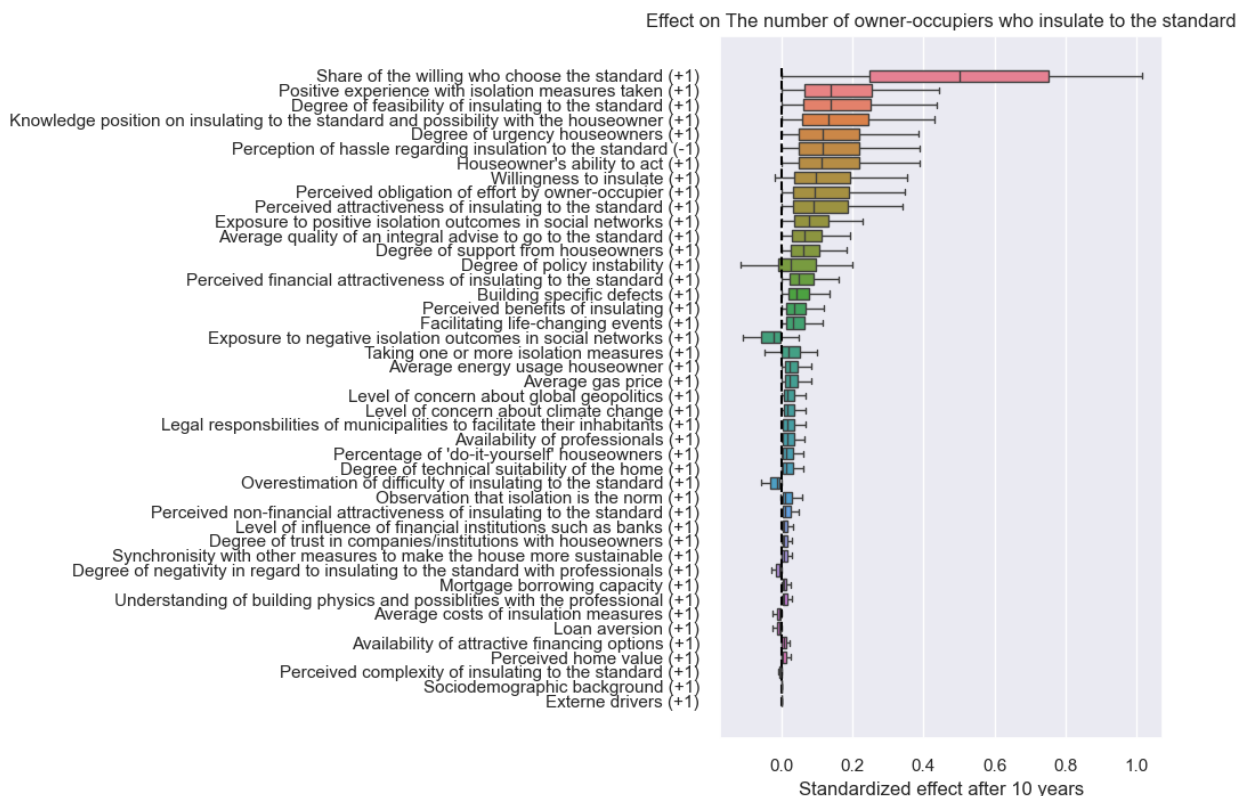


Figure B1. Standardised intervention strength on the number of homeowners insulating to the standard for each variable in the complete CLD after ten years.

Positive experience with insulation measures, degree of feasibility of insulation, and knowledge position were the top three interventions. The prominence of these experience-based, feasibility-related, and knowledge-related variables reflects their position in the causal structure of the CLD. These factors influence multiple downstream determinants of insulation uptake, including willingness,

perceived difficulty, ability to act, and the likelihood that willing households proceed to insulating to the standard. As a result, interventions targeting these variables tend to propagate through more pathways than interventions acting on a single dimension, such as financial attractiveness alone.

By contrast, financial variables such as insulation costs or access to financing primarily affect willingness through a limited set of pathways and do not substantially reduce perceived difficulty or implementation barriers in the model. Under the assumptions of this analysis, this narrower causal reach leads to smaller average effects on standard-level uptake, even when financial interventions are assumed to be strong.

Importantly, these findings do not imply that financial incentives are unimportant in practice. Rather, they indicate that, given the current causal structure encoded in the CLD, financial measures on their own are unlikely to unlock the full potential for standard-level insulation without complementary interventions that improve feasibility, knowledge, and the quality of household experiences.

Again, this analysis should be interpreted as a ranking of structural leverage points under uncertainty and the strong assumptions detailed above, not as an estimate of real-world effect sizes or policy cost-effectiveness.

B3. Results: Peak-electricity

We simulated 10,000 scenarios over a 10-year time horizon to assess the effect of intervening on variables in the peak electricity demand CLD has on the percentage of household electricity use during peak hours on household level. As in the insulation analysis, link strengths were sampled uniformly and independently, allowing us to estimate the average intervention effect implied by the causal structure under uncertainty. Figure B2 visualises the distribution of intervention effects across variables.

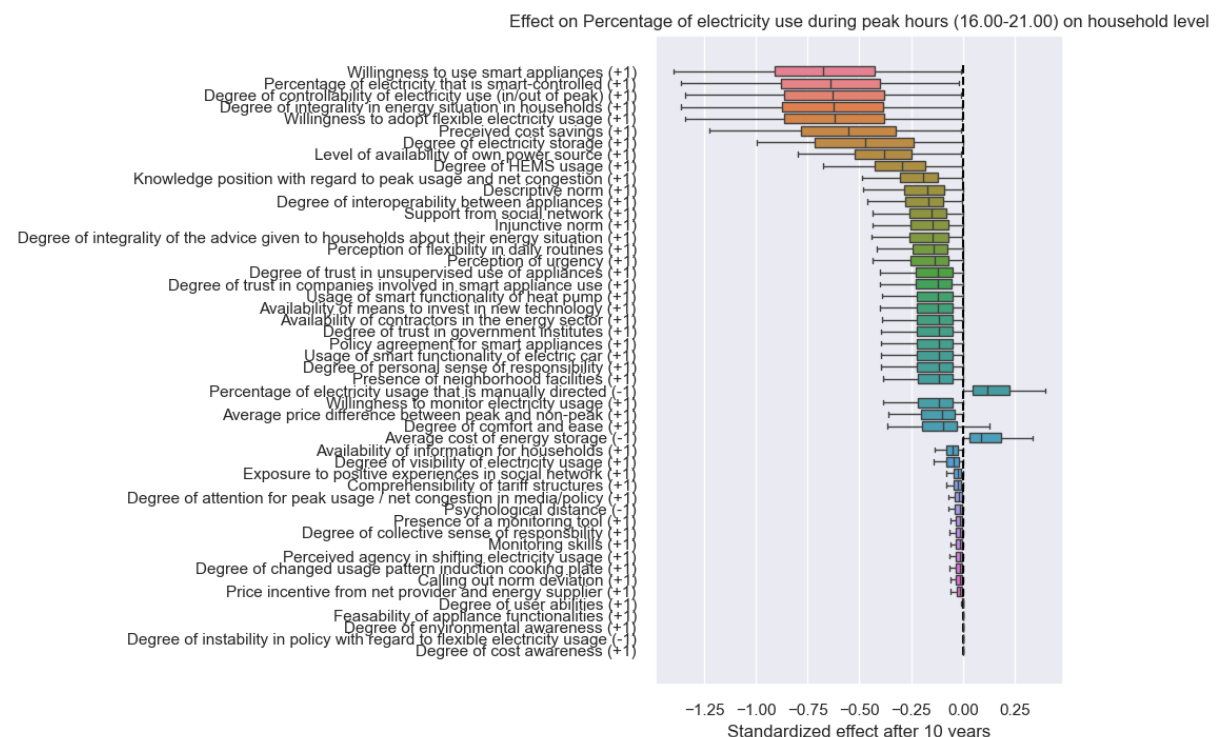


Figure B2. Standardised intervention strength on the percentage of electricity use during peak hours for each variable in the complete CLD after ten years.

The strongest effects are associated with variables related to smart automation and controllability of electricity use, including willingness to use smart appliances, the share of electricity that is smart-controlled, and the degree of controllability of electricity use in and out of peak hours. These variables are structurally closest to the outcome in the CLD and influence peak usage directly, which explains their consistently large effects across simulated scenarios.

Variables related to knowledge, advice, and social context show moderate effects. By contrast, price signals, monitoring, and informational interventions alone tend to have smaller effects, as they affect electricity use primarily through manual behavioural adjustments and are weakly connected to controllability in the model.

As with the insulation case, this analysis should be interpreted as a ranking of structural leverage points under uncertainty and the strong assumptions detailed above, not as an estimate of real-world effect sizes or policy cost-effectiveness.