SEAI Sustainable Energy Authority of Ireland

Rialtas na hÉireann
Government of Ireland

Flexible electric heating technologies:

Potential benefits, barriers and enabling actions

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Report prepared for SEAI by:
Environmental Resources Management

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Sustainable Energy Authority of Ireland
SEAI is Ireland's national energy authority investing in, and delivering, appropriate, effective and sustainable solutions to help Ireland's transition to a clean energy future. We work with the public, businesses, communities and the Government to achieve this, through expertise, funding, educational programmes, policy advice, research and the development of new technologies.

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Flexible electric heating systems: potential benefits, barriers and enabling actions

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Executive Summary

Electrification has been identified as an important pathway to decarbonise heat energy use in all sectors, including the use of heat pumps in residential, commercial and public buildings and low to medium temperature industrial applications, as well as direct electric technologies in high temperature industry applications. When fossil fuels used for heating and transport are replaced by low carbon electricity generated largely from renewable sources, greenhouse gas emissions across the whole energy system fall. However, heat demand can vary more throughout the year than other uses of electricity, such as lighting and appliances, and can spike at times when the electricity grid is already under pressure such as during periods of cold weather. This could make it more challenging to balance electricity supply and demand and manage peak loads on electricity networks with a higher share of electrified heat.

Flexible electric heating systems and thermal energy storage offer solutions. Electric heating technologies that actively communicate with and respond to signals from the grid can shift demand in response to the power system's needs, reducing peak loads and making better use of renewable electricity, while still meeting consumers' heating needs. This is what we mean by flexible electric heating systems. This flexibility can enhance the integration of heat demand into the electricity system and reduce the overall system costs.

Objectives and Scope of the Study

The objective of the analysis is to support policy and system planning by identifying where flexibility can deliver system-level benefits, the conditions required to realise those benefits, and the barriers that currently constrain progress. This study aims to:

- **Understand the requirements** for creating a flexible, integrated electricity and heat system.
- **Assess the potential benefits** for Ireland's electricity system, consumers, and decarbonisation goals.
- **Identify the barriers** to flexible electrified heating across technology, markets, regulation, consumer behaviour, and grid access.
- **Recommend actions** that government and system actors can take now and identify areas that require further investigation.

The study draws on a detailed review of international and Irish literature, engagement with industry organisations in Ireland, and illustrative modelling of thermal energy storage (TES) to show how flexibility can support Ireland's future electricity system.

Key Findings

1. Dynamic interaction between electricity and heat systems requires suitable technologies and supporting infrastructure

Dynamic interaction means operating electric heating technologies in a flexible and responsive way. Electric heating systems, such as heat pumps, electric boilers and resistive heating, can be operated to adjust their electricity use based on the needs of the wider energy system. Thermal energy storage technologies, including hot water tanks and underground thermal energy storage, can further support this. They can store heat which can then be used later, shifting electricity consumption away from times when the grid is under stress. Hybrid systems, where electric heating operates alongside non-electric heating can also provide flexibility by favouring operation of the non-electric component at times of peak electricity demand. The dynamic interaction may also require other enabling infrastructure to enable control and communication between the technologies and energy system actors. Smart metering infrastructure is also essential to measure and verify flexible responses.

2. Flexibility offers major benefits for Ireland

A flexible and integrated electricity and heat system would shift heating demand away from times when the grid is under pressure, and towards times when renewable electricity is plentiful. This offers several benefits:

- **Lower peak electricity demand:** Flexibility can flatten the demand curve, reducing the need for expensive upgrades to the transmission and distribution networks.
- **Reduced reliance on fossil fuelled dispatchable generation:** Aligning heating demand with renewable generation means less need for carbon intensive generation during peak periods and improved security of supply.

- **Lower renewable curtailment:** Flexible heating systems can make use of renewable electricity at times when it would otherwise be wasted (curtailed).
- **Lower system and consumer costs:** Reducing peak demand and using lower cost renewable electricity lowers overall system costs and helps keep consumer bills down.
- **Stronger business case for heat electrification:** Consumers with flexible electric heating can benefit from time-of-use tariffs, flexibility payments, and reduced grid connection costs.

3. Barriers must be addressed to unlock these benefits

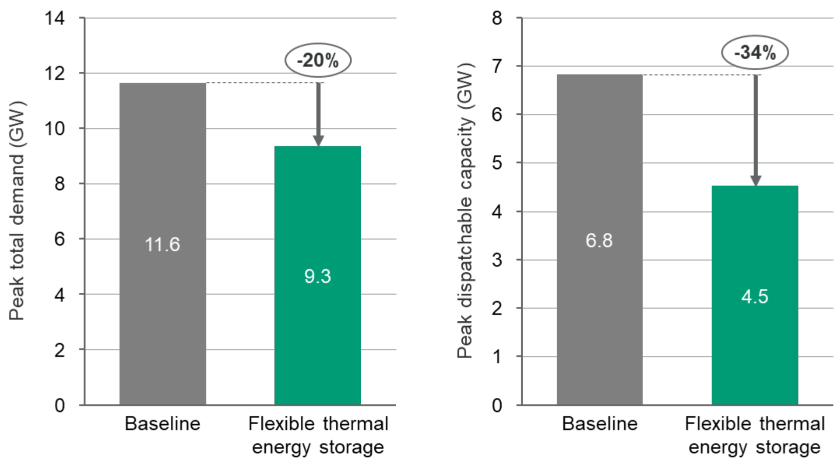
Several challenges currently limit Ireland's ability to fully integrate flexible electric heating:

- **Electricity markets and pricing:** Limited access to electricity markets for small consumers and high, flat non-commodity charges in retail electricity prices reduce incentives for flexible operation.
- **Grid access:** Electrifying a site's heating typically increases the site's maximum import capacity (MIC) from the grid, which is often slow and costly for large and industrial consumers. Existing processes to determine available capacity assume worst-case demand, leading to under-utilised grid infrastructure.
- **Technology and space constraints:** Some thermal energy storage technologies require significant space or have high upfront costs.
- **Consumer behaviour:** Flexibility depends on consumers' willingness to adjust heating schedules and tolerate small temperature changes. In particular, many industrial heat users have limited ability to vary their heating demand.

4. Illustrative modelling shows how thermal energy storage can support Ireland's energy system

A simple illustrative analysis compared a scenario with no thermal energy storage to one with flexible thermal energy storage across residential, commercial, industrial and district heating sectors in Ireland.

Figure 1: Comparison of the peak total demand (GW) (left) and peak dispatchable generation capacity (right) (GW)) under the baseline and flexible thermal energy storage scenarios.



As shown in Figure 1, thermal energy storage was able to shift electricity demand for heating to reduce Ireland's peak total electricity demand by around 20%, and reduce peak dispatchable generation capacity, which is met by non-renewable sources such as gas generation, by around 34%

These results show that combining thermal energy storage with electrification of heat can support the electricity system, reduce peak demand, curtailment of renewables, and the use of dispatchable fossil generation. These factors should act to reduce overall system costs, however, deploying thermal energy storage also involves upfront investment, and future modelling should explore storage sizes, durations, and combinations to identify the most cost-effective options.

Recommendations

Government, regulators, utilities, and system operators can take several actions now to support a flexible integrated electricity and heat system in Ireland:

1. **Strengthen long-term financial signals for flexible heating to improve the business case for flexible electric heating technologies and encourage operation that benefits the electricity system.**
    - Utility companies should develop market mechanisms, such as dynamic time-of-use tariffs, and make them available to all users, including residential households, to incentivise flexibility. The CRU should consider reforming the flat structure of non-commodity charges that are included in retail electricity prices to reward flexible behaviour.
    - The CRU and system and market operators should alleviate unnecessary barriers to demand-side response assets entering existing electricity markets, and system operators should accelerate the development of specific demand-side flexibility products, such as ESB Networks' proposed Demand Flexibility Product and EirGrid's Demand Side Unit tool.
2. **Accelerate access to non-firm import capacities to support sites that must increase their maximum import capacity as they electrify heating.**
    - System operators should accelerate access to non-firm import capacities, considering a site's actual electricity demand profile. This will minimise costs and delays and improve utilisation of existing grid infrastructure. ESB Networks are already piloting Timed Connections in Ireland, and this should be accelerated with the aim of implementing a long-term commercial offering.
3. **Support the adoption of enabling technologies, including thermal energy storage and hybrid systems, particularly for consumers with little opportunity to shift their demand behaviourally.**
    - Government, supported by SEAI, could consider measures to directly encourage the uptake of thermal energy storage, such as grants, where these support the deployment and efficient use of renewable energy.
    - Government could also encourage pilot projects that demonstrate the business case of installing thermal energy storage.
    - Hybrid systems, where electric heating technologies are installed alongside existing non-electric systems can enable flexibility as the system can switch between sources when it is favourable to do so. Government could consider measures to encourage the implementation of these systems as interim solutions for specific use cases in hard to decarbonise sectors, as consumers begin to decarbonise their heat demand.

Further work is also needed to address remaining knowledge gaps and uncertainties:

1. **Improve data on electric heating demand profiles,** through further collection of data from smart meters or consumer trials.
2. **Conduct detailed spatial modelling of electric heating demand and renewables in Ireland** to assess local constraints and the potential for flexibility to resolve them.
3. **Refine integrated electricity and heat system models,** considering other forms of demand flexibility, such as from electric vehicles, to identify benefits and determine the cost optimal generation and energy storage portfolio.
4. **Evaluate the impact of extreme weather on integrated electricity and heat systems**, using detailed modelling.

Flexible electrified heating and thermal energy storage can help Ireland meet its heating and cooling obligations under RED III, reduce energy system costs, improve security of supply, and lower consumer bills. Taking the recommended actions now will ensure Ireland can integrate heating and electricity systems in a way that is fair, cost effective, and aligned with a net zero future.

1 Introduction

Electrification has been identified as an important pathway to decarbonise heat energy use in all sectors, including the use of heat pumps in residential, commercial and public buildings and low to medium temperature industrial applications, and direct electric technologies in high temperature industry applications. When electricity for heating comes from low-carbon sources, emissions across the whole energy system fall.

However, heat demand can vary more throughout the year than other uses of electricity, such as lighting and appliances, and can spike at times when the electricity grid is already under pressure such as during periods of cold weather. This could make it more challenging to balance electricity supply and demand and manage peak loads on electricity networks with a higher share of electrified heat.

Flexible heating systems and thermal energy storage offer solutions. By shifting when and how electricity is used for heating, these technologies help the energy system run more efficiently and can lower costs for everyone.

As Ireland's electricity system decarbonises, the share of variable renewable generation will increase significantly. This will create more frequent periods of both surplus renewable electricity and system stress when renewable output is low. The importance of flexible heating systems and thermal energy storage grows as renewable penetration increases, because they can shift electricity demand for heating to periods of high renewable availability and reduce reliance on dispatchable fossil generation.

1.1 Flexible Electric Heating Systems

Passive electric heating systems describe the operation of electric heating technologies without consideration of the impact on the operation of the electricity grid. Most electric heating systems today operate passively. For example, a heat pump in a house turns on and off according to the household’s needs, without input from the electricity grid. If many people use electric heating at the same time, it may put pressure on the grid, particularly if the peak of the heating demand correlates with the existing peak demand on the electricity network. This could add significant costs to the electricity system, as higher power production and network capacity (at both transmission and distribution network level) may be needed to deal with higher peak demand.

Electric heating technologies that actively communicate with and respond to signals from the grid can shift demand in response to the power system’s needs, reducing peak loads and making better use of renewable electricity, while still meeting consumers’ heating needs. This is what we mean by flexible electric heating systems. This flexibility can enhance the integration of heat into the electricity system and reduce the overall system costs.

1.2 Objective, scope and structure of the report

1.2.1 Scope & Objective

- This report provides a high-level assessment of the potential benefits of, and enabling actions for, the flexible integration of electricity and heat systems in Ireland, with a particular focus on the role thermal energy storage can play in this flexible integration. The objective of the analysis is to support policy and system planning by identifying where flexibility can deliver system-level benefits, the conditions required to realise those benefits, and the barriers that currently constrain progress.
- This assessment draws on a review of literature, engagement with key stakeholders, and high-level modelling of the potential system benefits. The modelling is illustrative, and points to the need for further research and model development in this area.
- This report builds on previous studies that have identified the electrification of heat as a key decarbonisation pathway, including SEAI’s National Heat Study and the 2025 National Comprehensive Heating and Cooling Assessment.

1.2.2 Policy drivers

- The analysis is informed by Ireland’s obligations under the EU Renewable Energy Directive (RED III), in particular Article 23, which requires Member States to increase the share of renewable energy in heating and cooling. Article 23(4) also identifies measures to support this objective, including (j) promoting the integration of thermal energy storage technology. In addition, Article 20a of RED III on energy system integration supports the operational framework for flexible electricity-heat integration. It requires system operators to provide near

real-time information on the renewable energy share of electricity supplied, enabling flexible heating systems to align consumption with periods of high renewable generation. Article 20a also promotes demand response and market access for flexibility assets, which are prerequisites for realising the benefits described in this report.
- At a national level, Ireland's Climate Action Plan sets out the pathway for decarbonising heat, including the large-scale deployment of heat pumps, which implies significant growth in electrified heating demand and reinforces the need to understand the associated electricity system impacts.

1.2.3 Structure of this report

- Section 2 sets out the **key technologies and enabling infrastructure needed t**o enable dynamic interaction between electricity and heat systems.
- Section 3 summarises the **key system and consumer benefits of flexible electric heating**, drawing primarily on literature and stakeholder engagement, and supported by illustrative modelling of thermal energy storage.
- Section 4 identifies **the barriers that limit the realisation of these benefits** and outlines the enabling actions required to address them.
- Section 5 **draws the findings together**, presenting the overall conclusions and recommended actions, and highlighting areas where further analysis would be beneficial.

1.2.4 Acknowledgements

The following organisations contributed their views on the benefits of flexible electrified heating, barriers to the implementation in Ireland, and actions that could help address these barriers:

- Irish Energy Storage Association (IESA)
- Demand Response Association of Ireland (DRAI)
- eHeat Ireland
- Ireland Electrified

2 Flexible Electric Heating Technologies

The following sections summarise the electric heating and cooling technologies (Section 2.2), and thermal energy storage (TES) technologies (Section 2.3) that enable the dynamic interaction of electricity and heat systems. In addition to heating, cooling, and TES technologies, the dynamic interaction may require other enabling infrastructure for control and metering, which is discussed in Section 2.4. These findings are based on a review of literature and discussion with stakeholders.

As discussed in Section 1.1, dynamic interaction means operating electric heating technologies in flexible and responsive ways. Electric heating systems, such as heat pumps, electric boilers and resistive heating, can adjust their electricity use in real-time based on the needs of the wider energy system. This coordinated approach helps to balance supply and demand across the electricity system.

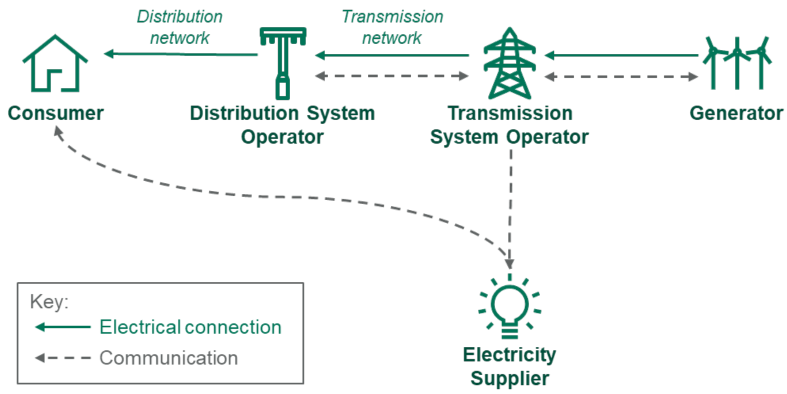
- TES technologies can store heat when electricity is plentiful and inexpensive, often in periods of high renewable energy generation. Stored heat can then be used later, shifting electricity consumption away from times when the grid is under stress.
- Another way to achieve flexibility in electricity demand for heating is through the use of hybrid or parallel systems, where electric heating works alongside non-electric heat technologies. This may be particularly suited to large heating loads such as industry or district heat systems. The non-electric technology could be an existing fossil fuel system that is retained alongside, or a hybrid renewable system using combustible renewables such as biomethane, biomass or bioliquids. Electricity demand flexibility can be achieved by switching between these technologies to meet heating needs. Although this approach may not fully remove fossil fuel use immediately, it can serve as an important interim step towards full electrification of heating that supports dynamic interaction between heat and electricity systems.

2.1 Ireland's Electricity System

Ireland's electricity system has two main parts:
- The **transmission network** is managed and owned by Eirgrid, the Transmission System Operator (TSO), and moves electricity over long distances at high voltages.
- The **distribution network** is managed and owned by ESB Networks, the Distribution System Operator (DSO), and delivers electricity from the transmission system to homes and businesses.

The Commission for Regulation of Utilities (CRU) oversees both EirGrid and ESB Networks.

Figure 2: Diagram of typical electricity system architecture



Recent forecasts from EirGrid and Soni's Tomorrow's Energy Scenarios 2023 [2] show that under a high electrification scenario[1], annual electricity demand across Ireland could more than double between 2023 and 2035, increasing from 33 TWh/year in 2023 to 70 TWh/year in 2035. Annual electricity demand is expected to further increase, reaching 81 TWh/year by 2040 (increase of 48 TWh from 2023). Meeting this demand will require significant investment in the electricity network. For example, SEAI estimated that annual network costs will

[1] Tomorrow's Energy Scenarios' 'Self-Sustaining' scenario considered [2]

increase by €255 million per year by 2030 and by €344 million per year by 2040, compared to 2020. [3] ESB Networks estimated that a total investment of €13.4 billion will be required over the 2026-2030 (Price Review 6 period), including €2.6 billion of distribution network reinforcement and €5.9 billion investment in the transmission network. [4]

In addition to meeting the increased total electricity demand, installed generating capacity must also be able to meet the peak electricity demand. Under the same high electrification scenario [2] , peak electricity demand in Ireland is expected to approximately double between 2023 and 2035, from 5.9 GW to 11.6 GW, and reach 13.2 GW by 2040. Meeting these peaks may require investment in generation that can be turned on and off on demand, referred to as dispatchable capacity. This is likely to include energy storage or fossil fuelled plants. However, fossil fueled plants increase the grid's CO_2 emissions intensity and both technologies can increase average electricity prices.

2.2 Heating and Cooling Technologies

Many electric heating and cooling technologies are available, and the choice of technology depends on several factors. These include technical suitability, economics, space constraints, and customer preferences, amongst others.

A range of heating and cooling technologies that support dynamic integration of electricity and heat systems are summarised in Table 1. Technologies may be used at the building level for residential, commercial & public, and industrial sectors, as well as in district heating networks[2].

Table 1: Summary table showing the suitability of each electric heating and cooling technology for each building sector, as identified in literature. [5, 6, 7, 8, 9, 10, 11, 12, 13, 14]

Category	Technology	Building-level			District heating network
		Residential	Commercial & Public	Industrial	
Heating	Ground-source heat pump (GSHP)	✓	✓	✓	✓)
	Air-source heat pump (ASHP)	✓	✓	✓	✓
	Electric boiler (resistive and electrode)	✓	✓	✓	✓
	Direct electric heating (resistive and storage)	✓	✓	✓	
	Hybrid heat pump (alongside non-electric system)	✓(bioenergy, natural gas as interim[3])	✓(bioenergy, natural gas as interim[3])	✓(H_2, bioenergy, natural gas as interim[3])	✓(H_2, bioenergy, waste heat, natural gas as interim[3])
	Other process heating technology (e.g. kilns, dryers, ovens, furnaces)			✓	
Cooling	Heat pump	✓	✓	✓	✓🗐

[2] This analysis focuses on electric heating and cooling technologies. Other low-carbon heat sources such as biomass boilers, solar thermal systems, and their associated storage are outside the scope of this study, though they may also contribute to system flexibility in different ways.

[3] Hybrid heat pump system using natural gas boiler is not net zero compatible, and is therefore considered an interim solution

[4] Heat pumps can be operated in reverse, providing chilled water for district cooling in district networks

2.2.1 Residential, Commercial and Public Technologies

Ground-source heat pumps (GSHP), air-source heat pumps (ASHP), electric resistance heating (direct heating) and electric boilers are suitable technologies for heating in the residential and commercial and public sectors. The suitability of a technology depends on factors including heating requirements of the consumer, the technology readiness, costs, technology efficiencies and expected lifetime.

For cooling, air conditioning units and heat pumps are the most common electric technologies, [5, 7, 15] with heat pumps offering an opportunity for electricity system flexibility. In Ireland, overall cooling demand is generally low due to the country's low number of cooling degree days (CDD)[5]. [16, 17] However, unlike other commercial buildings, cooling demand from data centres is expected to be significant. Cooling demand may account for between 10% and 40% of the total data centre electricity demand outside cold climates, with cooling technologies including air-cooling (via air conditioning or air handling units served by centralised chillers), liquid cooling (such as direct-to-chip, real-door heat exchanger or immersion cooling) and free cooling using ambient air [18, 19]. There is some potential for flexibility in the cooling demand for data centres through controlled overheating or overcooling, however, this flexibility is limited unless TES is installed. [18]

2.2.2 Industrial Technologies

Industrial heating demand mainly comes from process heating, which typically requires high temperatures, high pressures, and large scales. The choice of heating technology depends on the industrial process requirements and conditions. Suitable electric technologies may include electric kilns, electric boilers, medium- and high-temperature heat pumps, electric ovens, electric furnaces, and electric dryers. Wherever technically feasible, heat pumps are the preferred solution for the electrification of heat as they allow both the end user and the electricity system to benefit from the higher achievable efficiencies. Industrial heat pumps can also capture and upgrade industrial waste heat. However, heat pumps are not currently technically feasible in all use cases, such as very high temperature applications. For these cases, direct electric technologies, such as boilers, ovens, and furnaces, are possible alternatives. [20]

As industrial processes transition to low carbon technologies, they may install hybrid technology systems, such as electric boilers alongside gas boilers. This allows the site to make their demand more flexible. For example, the typical annual hours and load pattern for an electric boiler depends on the production site's operational strategy. [10] If an electric boiler is operated as a substitute for an existing fossil fuel boiler, then it will have the same operation hours as the production site, while if the electric boiler is installed to supplement an existing boiler, it will operate at reduced hours, only when the electricity price is favourable. For example, a study by the Danish Energy Agency suggested that these operational strategies could lead to variations in operational hours of a low carbon technology between >8000 hours or <500 hours per year, if the electric boiler is used as a substitute or supplement to an existing fossil fuel boiler respectively. [10] Hybrid systems enable more flexibility potential in the industrial demand, as it can switch between sources when it is favourable to do so. However, this strategy does not fully electrify a site's heating and may not be net-zero compliant.

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[5] Cooling degree days (CDD) is a measure to estimate the cooling demand for buildings and is represented by how many days the outside temperature is above a certain baseline temperature. For Ireland and many countries, this baseline temperature is typically 18°C. This is relevant for Ireland because it has the lowest CDD in Europe of 0.03 (note: Spain has a CDD of 384, the highest in Europe. [17, 18, 14] The National Heat Study suggested that residential air-cooling technologies will only need to start being installed when the annual cooling degree days surpasses ~20. Ireland's CDD is expected to rise over time with an associated increase in total cooling demand. A CDD of 20, however, is only expected to be reached by 2090 in Ireland. [36]

Case study: Aughinish Alumina make use of an electrode steam boiler alongside a combined heat and power plant

Stakeholder engagement highlighted Aughinish Alumina as an example of a hybrid industrial heating process, where a 25 MW high-pressure electrode steam boiler has been installed. Aughinish Alumina also have a combined heat and power (CHP) plant on-site, which allows the facility to access wholesale electricity prices. The CHP plant continuously generates electricity for on-site use, with any excess exported to the grid and sold at the wholesale rate. When there is excess electricity on the grid and wholesale prices are low, Aughinish turn on their electric boiler and reduce the export of electricity from the CHP plant to the grid. The boiler meets approximately 10% of the site's current steam demand. Installing an additional electric boiler would exceed the generation capacity of the current CHP plant. As a result, it would require importing electricity from the grid, which would not present a viable business case.

Cooling demand in industrial processes was not well documented and was uncertain in the literature reviewed. While many pieces of equipment are cooled, this is largely through heat loss of equipment, or heat extraction for other purposes, such as with a heat exchanger. For industrial applications, the scope of this report is focused on heating demand rather than cooling.

2.2.3 District Heating Network Technologies

District heating networks generate heat at a central location and distribute it to multiple buildings through a network of insulated pipes. Electrified district heating networks typically use heat sources similar to building level heating: air-source heat pumps (ASHPs) and ground-source heat pumps (GSHPs), but at large scale. [6, 21] Water-source heat pumps (WSHPs) can also be used at scale to transfer heat from water to heat the district network. [22] These systems benefit from having fewer and larger heat generation units, which can reduce costs through economies of scale.

District heating networks can also connect to multiple energy sources, including waste heat sources, at a given time. As a result, the network can switch between sources when it is favourable to do so. [21] This builds energy resilience and flexibility into the network.

The high heat capacity and insulation of pipework associated with the district heating network can also be used as a form of thermal storage to offer some supply flexibility. [21] Further storage could be achieved in a district heating network through control of the network temperature, allowing thermal energy to be stored in the network itself. [23] This is achieved through the thermal inertia of the water mass in the district heating network. By actively controlling the network temperature, operators can use this inertia to temporarily store or release thermal energy. For example, increasing network temperature stores excess heat in the water and pipes, while decreasing network temperature releases stored heat to meet demand.

Further analysis is required to understand the potential of district heat networks in Ireland to enable the dynamic interaction of electricity and heat systems in Ireland.

2.3 Thermal Energy Storage Technologies

Thermal energy storage (TES) is a proven method for balancing supply and demand for heating and cooling. TES enables flexibility and supports the dynamic interaction of electricity and heat systems. TES technologies are commonly grouped into three categories:

- **Sensible heat storage (SHS)** involves storing heat by heating solid or liquid mediums.
- **Latent heat storage (LTS)** uses a phase-change material to store and release energy.
- **Thermochemical heat storage (THS)** uses thermochemical materials to store and release heat through endothermic/exothermic reactions.

Table 2 sets out the suitability of TES technology categories for each heating demand segment.

Table 2 Summary table showing the suitability of each thermal energy storage technology for each building sector, as identified in literature. [5, 6, 7, 8, 9, 10, 11, 12, 13, 14]

Category	Technology	Building-level			District heating network
		Residential	Commercial & Public	Industrial	
Thermal energy storage	Sensible heat storage	✓	✓	✓	✓
	Latent heat storage	✓	✓	✓	✓
	Thermochemical heat storage[6]			✓	✓

2.3.1 Sensible Heat Storage

Sensible heat storage (SHS) is the most common form of TES. SHS technologies store heat by heating solid or liquid mediums, such as water, concrete, or rock. SHS technologies are mature, with technology readiness level (TRL) of 9, and are widely used for thermal storage. [14]

[6] The technology readiness level for thermochemical heat storage is currently 4 making this technology not extensive deployed or mentioned in the reviewed literature. However, we assume that this technology would be suitable across industrial sectors and for district heating networks.

Table 3: Summary of sensible heat storage technologies

Technology	Storage medium	Advantages, disadvantages, and case studies
Tank thermal energy storage (TTES)	Water	TTES is a mature technology where heat is stored in water in a large tank above ground. While this technology offers key advantages such as scalability potential, high efficiencies, high heat capacities and long lifetimes (40-50 years [21]), it also has demanding space requirements. The storage temperature for TTES is approximately 60°C making it a common choice for thermal storage in the residential, commercial and public sectors. [14]
Solid-state thermal storage (SSTS)	Concrete, rocks, ceramics	SSTS is technology where heat is stored in a solid, typically concrete, rocks or ceramics. A key advantage for this technology is its high storage temperatures making it a suitable choice for industry where higher processing temperatures are typically required. [5, 10, 24, 25] While this technology has a TRL of 9, a broad range of efficiencies has been reported. Loviisan Lämpö, a Finish heating network operator, recently launched its "Sand Battery" which, using 2 tonnes of crushed soapstone as its thermal storage medium, is being used to heat nearby municipal buildings and for industrial use. The system offers a capacity of 100 MWh and charging/ discharging rate of 1MW (i.e. discharge over 100h/several days). [26]
Underground thermal energy storage (UTES)	Pit: Gravel and water mix	Pit storage is a popular choice for TES because of its high heat capacity, lifetime and efficiency. It also offers seasonal storage capabilities. However, it has a very large space requirement of 5-15 m^2/MWh. [21] Several PTES sites have been deployed in Denmark of varying size. [27] An early site in Ottrupgård in 1995 was installed with a 43.5 MWh capacity and charging/ discharging rate of 0.39 MW (i.e. discharge over ca. 100h/several days). To contrast, a large site in Høte Tasstrup was installed in 2022 with a capacity of 3,300 MWh and charging/ discharging rate of 30.0 MW (i.e. discharge over ca. 100h/several days).
	Borehole: Ground rock/soil	Borehole UTES varies from pit UTES in its underground configuration. Borehole UTES requires minimal space requirements with an additional advantage of providing both heating and cooling storage capabilities. In Brædstrup in Denmark a BTES system was installed in 2012 with storage capacity of 400 MWh and discharge rate of 0.3-0.6 MW (i.e. discharge over ca. 1 month). [27, 28]
	Aquifer: Groundwater and ground material	Aquifer UTES similarly can provide heating and cooling storage capabilities with storage occurring in groundwater and ground materials underground. However, compared to other UTES technologies, aquifer UTES has relatively low heat capacities and faces additional challenges regarding the need for specific geological conditions which can limit its deployment. [27]

2.3.2 Latent and Thermochemical Heat Storage

Latent heat storage uses a phase-change material to store and release energy as the material changes phase (for example, from solid to liquid). These storage technologies can be separated into high and low temperature phase-change material and differentiated by their phase-change material. [29] Their TRL is dependent on the type, with some commercialised low-temperature technologies and high-temperature technologies at a lower TRL of 4.

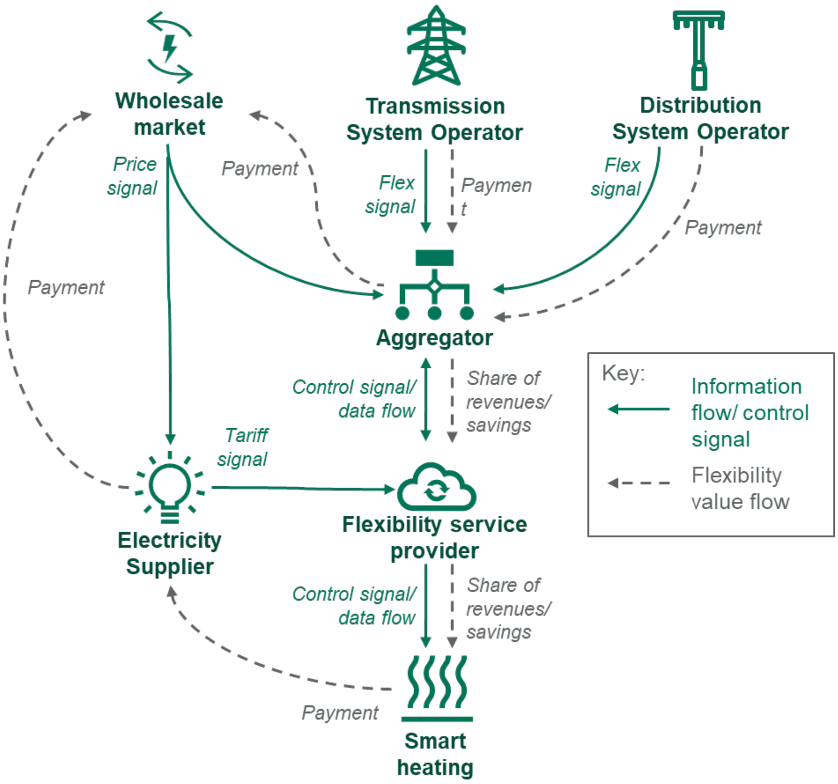
Thermochemical heat storage uses thermochemical materials to store heat through reversible chemical reactions. Heat is absorbed or released during endothermic or exothermic reactions. Thermochemical heat storage offers high energy densities and high storage temperatures, making it suitable for high-temperature industrial applications. [30] Thermochemical heat storage technologies are less mature, with a TRL of 4. [14]

2.4 Supporting Technologies

As discussed in Section 1.1, an integrated electricity and heat system would involve electric heating technologies that operate flexibly in response to the needs of the power system, while still meeting consumers' heating needs. Supporting technologies, such as automated, smart heating controls and smart metering infrastructure, are often needed. [7, 31]

To enable electrified heating to respond dynamically to the grid, a control signal may be required from a flexibility service provider, such as a supplier or an aggregator. Aggregators are particularly important for smaller-scale assets at domestic, commercial and public buildings, as they bring together these assets to control and dispatch them to maximise flexibility. [7]

Figure 3: Diagram showing the flow of control signals and value from flexibility between key players in a flexible electric heating system. Note: flexibility service provider, electricity supplier, and aggregator may be the same actor.



The dynamic interaction between electricity and heat systems requires several components: [7, 31]

- A controller that receives signals from a flexibility service provider and adjusts the operation of the flexible asset, such as heating, cooling, or TES accordingly. The controller may be integrated into the asset or could be an external piece of hardware.
- A reliable and rapid communication system to send control instructions from actors in the energy system (such as the TSO, DSO, supplier, third-party aggregator or flexibility service provider) to the flexible asset. The system also sends data back to verify the action was taken as instructed and to support billing.
- Smart metering infrastructure with hourly or half-hourly resolution to measure and verify the flexibility response of the asset and the resulting reward.

The flexibility service provider can send control signals that optimise the operation of the asset according to the needs of the electricity system and the heating and cooling needs of the consumer.

Case study: GC-CyPhySandBox project aims to develop of a real-world simulation tool to test smart grid control architectures [76]

This project, led by the Walton Institute with University College Dublin and NovoGrid, and funded by SEAI, aims to develop a real-time simulation tool capable of replicating real-world operational scenarios to evaluate smart grid control architectures. The tool will help to assess how data and communication protocols perform, how smart devices perform under dynamic conditions, and investigate the challenges of integrating many small-scale renewable energy sources, such as rooftop solar photovoltaic systems, into the electricity grid. The overarching objective is to support DSOs in developing advanced control systems for distributed energy resources that improve grid flexibility while meeting network and regulatory requirements. This allows DSOs to explore how flexible energy resources can respond to grid events and help avoid costly infrastructure upgrades.

3 Electricity System Benefits of Flexible Electric Heating

This section describes the key system-level and consumer benefits that can be realised through the flexible integration of electricity and heat systems. The analysis draws primarily on published literature and stakeholder engagement. To illustrate the potential benefits of TES for the electricity system, we carried out a simple analysis comparing two modelled scenarios, with and without TES. These results are presented in Section 3.4.

Section 4 identifies the barriers that currently limit the realisation of these benefits in Ireland, and the enabling actions required to address them.

The benefits can be grouped into two categories:

- **System-level benefits:** reduced peak demand on electricity networks, lower system costs (generation and network investment), increased consumption of renewable electricity, and reduced curtailment.
- **Consumer benefits:** lower energy bills through time-of-use optimisation, potential revenue from participating in flexibility markets, and improved security of supply.

Each is discussed in the following subsections.

3.1 Reduced Peak Demand

As set out in Section 1.1, passive electric heating increases the peak electricity demand on the network. This may reduce headroom on the electricity network and require investment in network reinforcement. The smart operation of electric heating and cooling systems can shift electricity use away from peak times to flatten the overall demand profile. [13, 8, 12]. Lower peak demand reduces the need for upgrades to grid infrastructure at both distribution and transmission level, lowering system costs. [7, 31, 12] [31, 32]

Reducing peak demand on the electricity system means that the total required capacity of electricity generation can be lower, limiting the requirement for dispatchable generation and typically carbon intensive peaking plants. [7, 13, 33, 8]

The system cost savings from reducing peak demand lower electricity costs for all consumers. Therefore, increasing flexibility is expected to lower electricity prices for all consumers. This is because the cost of network reinforcement at the distribution and transmission level is passed onto consumers in Ireland as use of system or network charges in their retail electricity price. [34] Demand shifting that reduces peak electricity demand also lowers the need for network reinforcements, resulting in overall reduced electricity costs for consumers. [13, 12, 33, 8] Furthermore, lower peak electricity demand reduces generation costs and therefore lowers the overall wholesale cost of electricity. This further contributes to lowering the retail electricity prices faced by consumers. [12, 33, 13]

Case studies: Several studies quantify the system cost savings from heat flexibility reducing system peak demand across different geographies, including Great Britain, Spain, Italy, Czechia, Poland, and Turkey

A Kensa Group study found that flexibility of heating could reduce the network cost in Great Britain – flexible operation of heat pumps alone led to network savings of savings of £6.5 billion per year (14% reduction) across Great Britain. The modelled flexibility from domestic heat pumps in Great Britain could also reduce curtailment of renewable electricity by 34%. [33]

BEUC's study on the consumer cost of decarbonised heat stated that demand shifting can lead to "savings in the network reinforcement costs" which lead to reductions in retail electricity prices of ca. 3% in Italy, 4% in Czechia, and 2% Poland. It also found that the flexible operation of heat pumps reduced the generation component of retail electricity prices by ca. 2% in Italy, ca. 1% in Czechia, and ca. 1% in Poland. BEUC also found that the flexible deployment of heat pumps across Spain, Italy, Czechia, and Poland reduced use of system network costs in modelled retail electricity prices in 2040 by between 5 – 15% compared to the passive operation of heat pumps, due to reductions in the cost of network reinforcement, generation, and taxes. [14]

SHURA's study found that demand side response from flexible heating in the residential and commercial sectors in Turkey, can lead to savings of ca. €30 million per year due to reduced fuel use in thermal peaking plants, ca. €85 million per year by reducing the redispatch of thermal power plants, although the largest system savings come from avoiding additional capacity investments in generation and distribution grids. [8]

3.2 Avoided Curtailment of Renewables

Passive electric heating demand may not align well with renewable electricity generation. The flexible operation of electric heating, cooling, and TES technologies can shift demand to match periods of high renewable generation. This helps reduce the curtailment of renewables, where renewable electricity generation is deliberately limited because demand is too low. Curtailment undermines the financial viability of renewable energy generation and is a barrier to the transition to a net zero energy system in Ireland. Implementing load shifting and demand flexibility strategies helps to minimise curtailment and supports a more efficient, decarbonised energy system. [7, 12, 33, 14]

Reducing renewable curtailment is expected to lead to lower electricity prices for all consumers. Minimising curtailment reduces system generation cost, as more demand can be met by low-cost renewables rather than dispatchable fossil-fuelled generation. [7, 33] The lower system generation cost leads to lower wholesale electricity prices for consumers.

3.3 Improved Business Case for Heat Electrification

From the perspective of the consumer, dynamically integrating electricity and heat systems benefits consumers by improving the business case for heat electrification.

As discussed in the previous sections, the flexible operation of electric heating reduces the total cost of the energy system, and therefore the energy costs to consumers. Consumers with flexible electric heating may also be specifically rewarded for their flexibility, for example through time-of-use electricity tariffs or payments for participation in flexibility events. [12, 13, 31] Cost-reflective time-varying electricity pricing options can incentivise consumers. [31] Customers can be highly cost-sensitive and therefore reducing the cost of running an electric heating system may improve the business case for consumers and encourage uptake.

The transition to low-carbon electric heating is also expected to increase electricity demand, which may require increasing on-site grid connection capacities. Flexibility from electric heating enables sites to reduce their peak grid import through demand shifting or energy storage, minimising the required grid connection capacity. As consumers are charged for the Maximum Import Capacity (MIC) they require from the network, reducing MIC leads to cost savings. Customers are unlikely to upgrade their existing MIC unless there are clear financial benefits or strong market incentives to do so. Managing a site's MIC requirements can also result in reduced installation costs and accelerated deployment timelines.

3.4 Illustrative Modelling of System Benefits from Thermal Energy Storage

To illustrate the potential benefits of TES for the electricity system, we carried out an analysis comparing two modelled scenarios: a baseline scenario and a flexible TES scenario. The following sections provide a high-level description of the modelling approach and the results. Further detail on the methodology is provided in Appendix 6.2.

3.4.1 Modelled Scenarios

Baseline Scenario

The starting point for this analysis was to take the detailed results for electricity supply and demand from a scenario run on SEAI's National Energy Modelling Framework (NEMF) energy system model[7]. This analysis was carried out for a single year and the year chosen was 2035. Data was taken for electricity demand by sector and electricity generation by technology at hourly resolution for the year.

This scenario assumed:

- A strong commitment to decarbonising Ireland's electricity system through continued deployment of variable renewable generation technologies such as onshore and offshore wind and solar;
- Increased deployment of grid-scale electric battery storage and increased interconnection to other countries;
- Strong support for low carbon heating and cooling technologies including heat pumps, industrial heating technologies, and district heating; and
- Growth in electricity demand in other sectors including from electric vehicles (EVs) and data centres.

Flexible Thermal Energy Storage Scenario

The alternative scenario examined the impact of employing TES on the electricity system (focusing on heating-related electricity demand), across four segments: residential, commercial and public, industrial, and district heating. Although we discuss elsewhere in the report flexibility in electricity demand using hybrid heating systems, where electric heating works alongside non-electric heat technologies, the illustrative modelling is restricted to the analysis of TES. This analysis also did not consider flexibility for datacentre cooling demand.
This analysis was carried out using ERM's Integrated System Dispatch Model (ISDM).

The TES enhances the flexible integration of the electricity and heating sectors by facilitating the effective alignment of electricity consumption with heating demand (known as the electric heating demand profile), while ensuring that consumer heat demand is met when required. TES differs fundamentally from electrical battery storage. TES stores heat rather than electricity, is constrained by heat demand patterns and thermal losses, and can only discharge when heat is required by the end user. These characteristics limit TES flexibility compared to batteries, but also mean TES directly serves heating loads rather than competing with other electricity uses.

Note that for this high-level analysis we did not fully rerun the electricity system dispatch model within the NEMF. Instead, a simplified approach was taken where gas is assumed to be the marginal generation plant, and only gas generation is assumed to vary in response to the changing demand from TES. The generation profile of all other generators including interconnectors and battery storage was kept constant from the baseline run. All non-heating demand and non-heating storage technology behaviour was also kept constant, and only the electric heating demand was allowed to shift, e.g. demand response from EVs was not considered. This was assumed in order to simplify the modelling and to focus on the potential benefits of TES. The assumptions and modelling method can be found in the Appendix 6.2.

3.4.2 Results

This analysis showed that the introduction of TES was able to reduce peak total electricity demand by 20% and lower the required dispatchable generation capacity by 34%. It also reduced renewable electricity curtailment by 0.9 TWh. This was achieved through shifting demand using TES, with total annual electricity demand unchanged.

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[7] See Appendix 6.1 for further details on the NEMF

Illustrative Demand Profile

The demand profile optimisation is illustrated in Figure 4, which shows the total system demand profiles in the baseline and flexible TES scenarios over two high-demand days (late February). In the flexible TES scenario, the electricity demand for each segment has been shifted using TES. The electric heating demand for each segment has been optimised over the full year, shifting into periods of lower total electricity demand or high renewable curtailment.

Figure 5 shows the state of charge (SOC) profile of the system's total TES capacity over the same high-demand period. The TES SOC is the amount of usable thermal energy stored in the system as a proportion of its maximum, fully charged capacity. The TES SOC profile therefore shows how the TES is charged and discharged over a period of time. The weighted total TES SOC profile is dominated by the district heating TES, due to its large capacity. Also, due to its large capacity and duration, the district heating TES charges and discharges over a long period of time and therefore the weighted profile remains at low levels of SOC over the high demand period. This demonstrates how the TES charges and discharges to optimise the electric heating demand profile. The individual demand segment profiles over the same period are shown in Appendix 6.1, alongside the assumptions.

Figure 4: Comparison of electricity demand by segment and resulting curtailment under the baseline and flexible thermal energy storage scenarios over a high demand period.

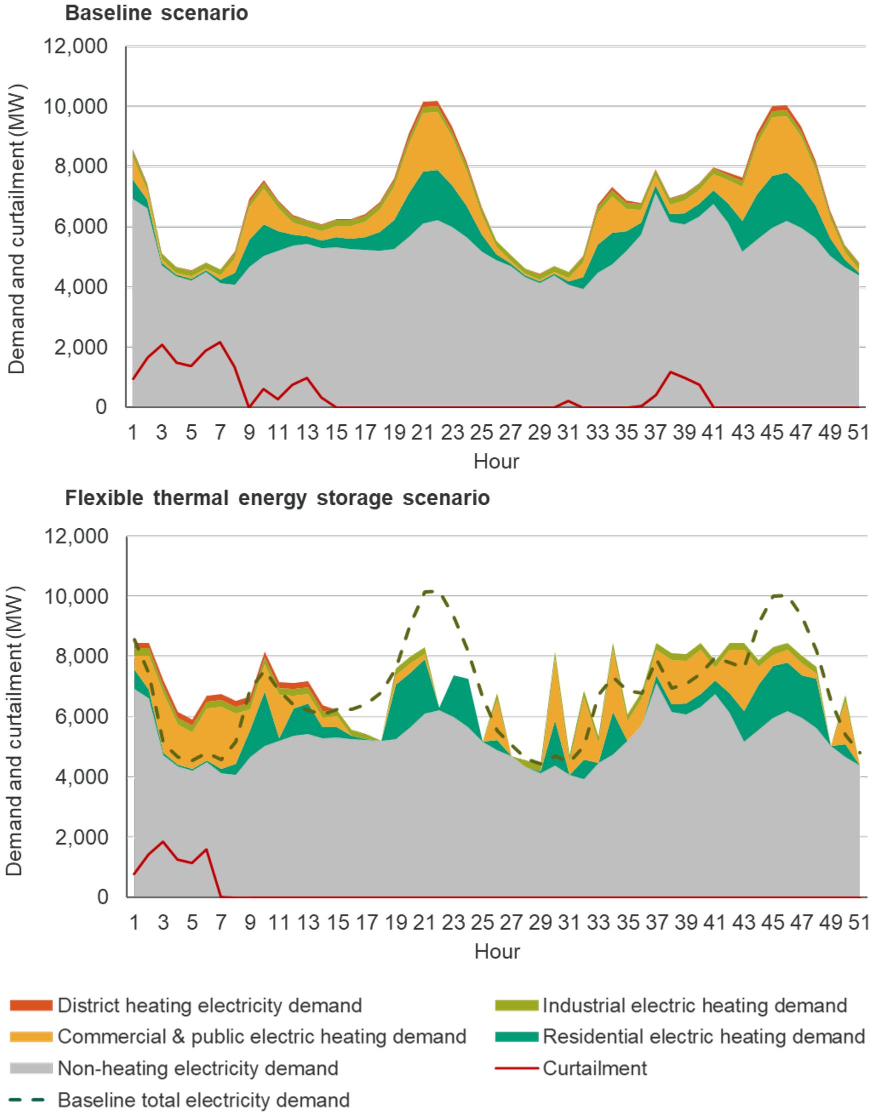
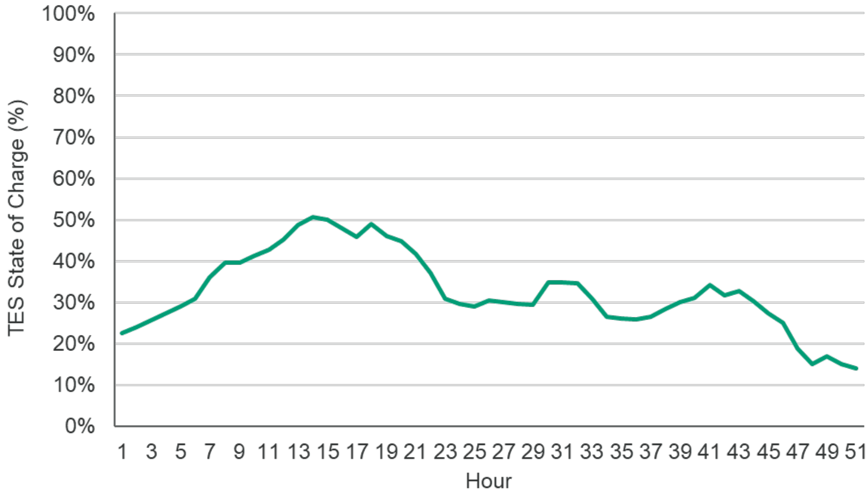


Figure 5: Weighted total thermal energy storage state of charge (SOC, %) under the flexible thermal energy storage scenario over a high demand period.

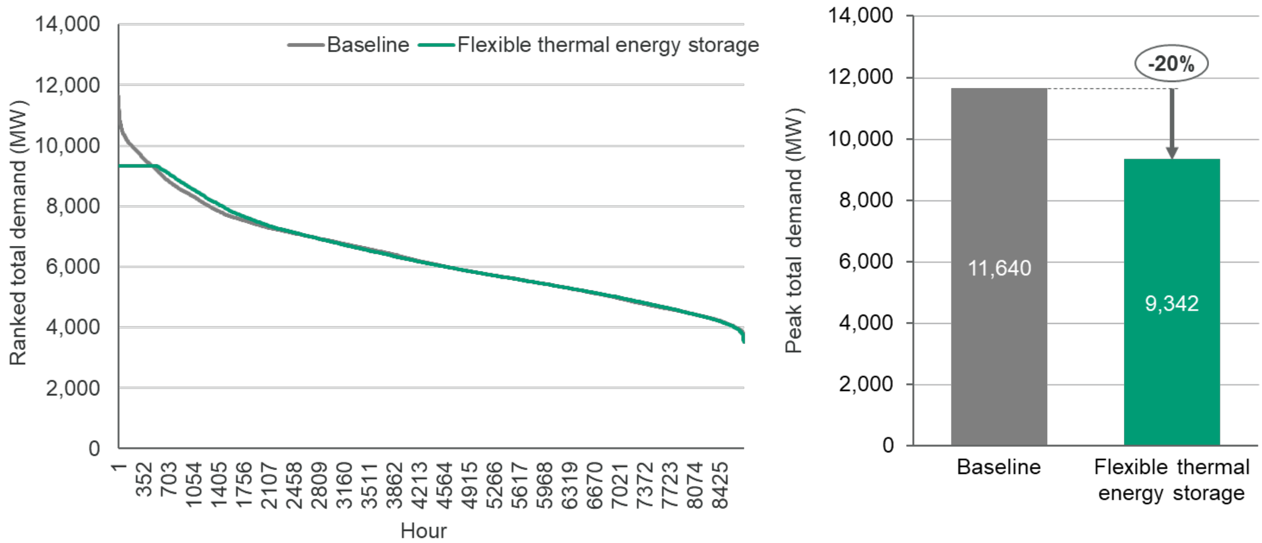


Total Peak Demand

Figure 6 ranks the total electricity demand in each hour of the year[8] and compares the peak overall electricity demand between the two modelled scenarios. The total electricity demand includes both electric heating and other electricity demand (not for heating) but, as described above, only the electric heating demand is shifted.

The peak total demand is 20% lower in the flexible thermal energy storage scenario compared to the baseline. However, the total demand over the year, shown by the area under the curve of the ranked demand graph, remains unchanged. This demonstrates that the peak reduction is due to demand shifting.

Figure 6: Ranked hourly total electricity demand (MW) under the baseline and flexible thermal energy storage scenarios (left), and comparison of the peak total demand (MW) under the baseline and flexible thermal energy scenarios (right).



[8] Graph showing the total demand in each hour of the year, ranked by magnitude of the demand. For example, Hour 1 shows the total demand in the hour of the year with the largest total demand. Hour 8760 shows the total demand in the hour of the year with the lowest total demand.

Net Demand, Dispatchable Generation, and Renewable Curtailment

The impact of introducing TES can also be shown by looking at the impact on dispatchable generation and curtailment of renewables.

The system's net demand is defined as the total demand minus the variable renewable electricity generation. This represents the share of demand that needs to be supplied by dispatchable generation. Dispatchable generating capacities, including gas generation, battery storage, and system imports, meets the net demand.

Figure 7 ranks the hourly positive net demand across the year, under the baseline and flexible thermal energy storage scenarios. The peak net demand is the largest magnitude of demand met by dispatchable generation over the year. The peak net demand is 34% lower under the flexible thermal energy storage scenario than in the baseline scenario (hour 1 of the ranked net demand graph). The area of the ranked net electricity demand graph above zero represents the net electricity demand met by dispatchable generation over the year. The area under the flexible thermal energy storage scenario curve is lower than that of the baseline scenario. This indicates that the TES reduces the need for dispatchable generation to meet electricity demand by 0.9 TWh (22% of positive net demand).

The reduction in total dispatchable generation is achieved by shifting electricity demand to periods of high renewable electricity that would otherwise be curtailed. As a result, the reduction in dispatchable generation is equivalent to the reduction in curtailment (0.9 TWh).

Figure 7: Ranked hourly positive net electricity demand (all sources, not just heating) (MW) under the baseline and flexible thermal energy storage scenarios.

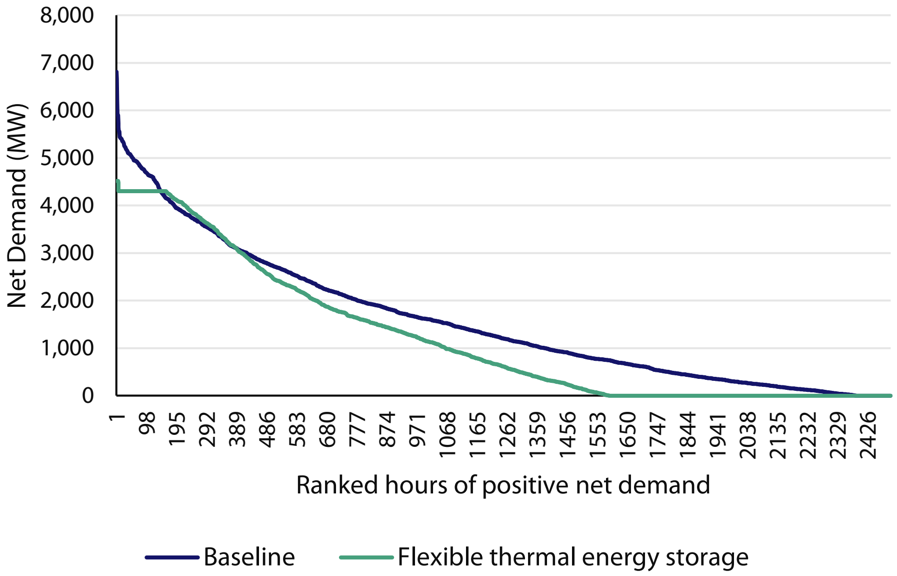
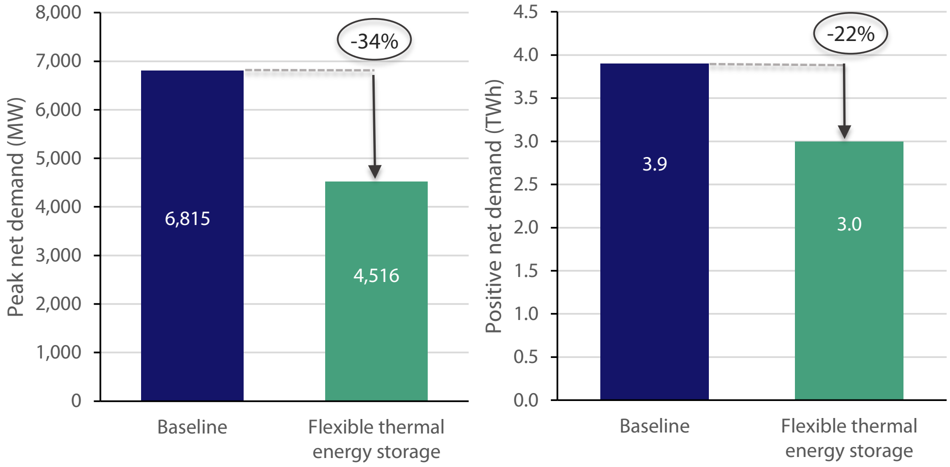


Figure 8: Peak net electricity demand (MW) (left) and total positive net demand (right) (TWh) under the baseline and flexible thermal energy storage scenarios.



Cost Implications

This high-level modelling illustrates that TES allows for electric heating demand to be shifted to maximise system cost savings. As described in the previous sections, cost savings can be achieved because:

1. Lower total peak demand on the network reduces network reinforcement needs and associated costs (see Section 3.1 for further details).
2. Lower dispatchable generation requirements reduce investment in construction and operation of dispatchable generation, such as gas peaking plants (see Section 3.1 for further details).

However, these savings must be balanced with the cost of installing TES. Installed TES capacity should be optimised to maximise total systems savings.

3.4.3 Limitations and Further Work

TES remains an emerging area within whole-system modelling. Better representation of TES operational characteristics and interactions with other flexible components is needed. As decarbonisation scenarios increasingly rely on sector coupling, enhanced modelling of the interactions between heat and electricity systems will be critical. Modelling can be further improved through the development of high temporal resolution demand profiles that better represent consumer behaviour with electric heating. Limited data on electric heating demand profiles limits the understanding of the potential impact of electric heating on the electricity system and the technical flexibility potential. This can be achieved through further collection of data from smart meters or consumer trials.

More detailed electricity system modelling could additionally consider other forms of demand flexibility alongside electric heating, such as the smart charging of EVs. This would improve understanding of the overall technical potential of flexibility from consumers and how the benefits can be shared across sectors. The detailed system modelling can also determine the cost optimal generation and energy storage portfolio, considering renewables, energy storage, and low carbon dispatchable generation alongside consumer flexibility.

Future modelling of the integrated electricity and heat systems could also evaluate the impact of extreme weather events. This would take into account the impact of low temperatures on heat pump efficiency and security of electricity supply, alongside the impact on renewables generation. Evaluating the impact of these low probability events will provide an understanding of how technology deployment and flexibility from electric heating and TES can be configured to manage risks.

In this analysis, TES contributes to decarbonisation by enabling greater utilisation of renewable electricity and reducing the use of dispatchable fossil generation. However, this analysis does not quantify CO_2 emission reductions directly.

4 Barriers and Enabling Actions for Flexible Electric Heating Systems

Barriers hinder the realisation of the benefits set out in Section 3. This section identifies the key barriers and enabling actions for the integration of electricity and heat systems. These are based on a review of published literature and engagement with key stakeholders in Ireland (see Acknowledgements). Where barriers relate to findings from Section 3, this is noted.

These findings are summarised in Table 4 below, which pairs each identified barrier with the enabling actions that could help address it. These actions inform the conclusions and recommendations presented in Section 5.

Table 4: Summary of identified barriers to realising the system benefits of an integrated electricity and heat system in Ireland, and associated actions.

Barrier	Related enabling actions
Limited long-term financial signals to offset the operating costs of electrified heating	• Develop clear, consistent policies with long-term support for flexible electric heating • Reform wholesale electricity market to better reflect renewable costs
Restricted market access for demand-side flexibility assets and consumers	• Remove barriers for demand side flexibility access to existing markets and encourage development of demand side flexibility specific market products • Ensure all suppliers offer dynamic tariffs to consumers
High and flat non-commodity charges in electricity bills	• Adjust taxes and levies in electricity prices to make electric heating more competitive with gas • Reform charges to reward flexibility (e.g., exemptions, time-of-use structure)
Slow grid access and high costs for increased Maximum Import Capacity (MIC)	• Introduce flexible/non-firm grid connections and expand existing pilot projects • Use real-time monitoring for dynamic capacity allocation
Affordability and space constraints for TES, especially at small scale or high temperature	• Provide financial incentives or grants for TES adoption • Develop communal or district heating network scale TES solutions
Limited flexibility in industrial heating demand	• Promote hybrid systems as an interim solution for hard to decarbonise use cases • Demonstrate business case for flexible electric heating, ensuring operability and output quality
Consumer behaviour and building characteristics limit flexibility	• Educate consumers on benefits of load shifting and temperature tolerance, to encourage pre-heating and use of building thermal mass for flexibility • Improve insulation and air-tightness of buildings

4.1 Electricity Market Design and Pricing

4.1.1 Electricity Markets

Long-term financial signals, such as ongoing revenue streams or operating cost savings, are important for providing the needed incentives for customers and industries to make the necessary investments towards the low-carbon heating transition and the integration of electricity and heating systems. These signals also help reduce investment risks by providing greater certainty and stability. Although grants are available to support the upfront costs of electrified heating, there are currently limited long-term financial signals to support the operating costs of these systems. Clear and consistent policies with long-term support and timelines enable the deployment of low-carbon heating technologies. Stable and reliable policies help build robust supply chains and give businesses the confidence to invest. [35]

Ireland's electricity markets offer an opportunity to provide long-term financial signals for flexible electric heating by enabling increased participation of flexible assets and passing on value to consumers. There was some discussion with stakeholders on the design of electricity markets in Ireland, which they believe currently does not provide sufficient financial signals for enabling flexible electrified heating. Existing electricity markets are structured around fossil fuel generation, making it difficult for renewables and flexible technologies, like electrified heating, to participate effectively. For example, stakeholders highlighted the need to reform the wholesale electricity market by decoupling prices from gas costs, which would help reduce electricity prices and improve the economic feasibility of heat electrification. There are currently limited clear policy measures in Ireland to address excess or wasted renewables in the electricity system. [21]

4.1.1.1 Improved Market Access

Improving access to electricity markets, such as wholesale, balancing or capacity markets, can unlock the benefits of flexibility from smaller or aggregated assets. Consumers who can offer demand-side flexibility by shifting their consumption currently have limited access to electricity markets in Ireland, especially wholesale markets. This makes it difficult for those with electric heating to benefit from shifting demand to times of lower electricity prices. Market access is often limited by system complexity. Industrial and commercial companies must rely on intermediaries such as aggregators, while domestic customers need utility companies to offer dynamic tariffs.

Removing barriers to entry for demand-side response assets, including aggregated small-scale assets, is a priority in electricity systems across Europe, including the UK (see case study below). For example, the capacity mechanism in France is open to aggregated demand side response assets, [36] and Belgium has taken steps to open its ancillary services to demand response and independent aggregators. [7] Enabling market access to demand side response assets allows the electricity system to make best use of their flexibility potential and provides a revenue stream to these assets. This revenue stream can offer savings to consumers with flexible electric heating, providing a long-term financial signal that lowers operating costs and improves the business case for adopting electric heating.

Case study: UK's National Energy System Operator (NESO) has programs to alleviate barriers for demand side flexibility participation in its markets.

The **Power Responsive trial** in 2023 entered a fleet of aggregated EVs into the Balancing Mechanism (BM), NESO's tool to balance supply and demand in real time. As a result of the trial, NESO announced up to 300 MW of small-scale aggregated assets can participate in the BM under more relaxed operational metering standards. The Power Responsive programme is now monitoring the accuracies of physical notification, operational parameters, and responses to bid/offer instructions. [77]

The **Enabling Demand Side Flexibility in NESO Markets** program over 2024 – 2025 identified barriers to enabling demand side flexibility participation in selected priority services. This included high barriers to entry, such as minimum aggregated unit sizes and stringent metering requirements. These barriers are being addressed as part of an ongoing programme over 2025 – 2027. [72]

Utility companies in Ireland could develop market mechanisms to support customer flexibility. For example, smart or dynamic tariffs can support demand shifting of low-carbon technologies like electric heating and storage. [7, 33] Under EU legislation introduced in 2022, the CRU has mandated that all suppliers with over 200,000 electricity customers must offer the option of a dynamic electricity tariff to their customers before 1st June 2026[9]. This dynamic tariff must include a standing charge, a base unit rate charge, and a dynamic unit rate charge that matches the half-hourly wholesale prices in Ireland's Day Ahead Market. [37] Although some suppliers currently offer fixed time-of-use tariffs, as of July 2025 no suppliers in Ireland offer a half-hourly dynamic tariff. [38]

[9] The deadline of 1st June 2026 was announced in April 2025 as an extension of the original deadline of 1st October 2025.

Case study: Smart electricity tariffs in Ireland

Most major suppliers including Bord Gáis, Electric Ireland, Energia, and SSE Airtricity offer tariffs with day, night, and peak rates, to encourage consumption during lower cost periods. These tariffs require consumers to have a smart meter, and simpler day/night tariffs are offered to customers with NightSaver meters. [64, 65, 66, 67]

Although several suppliers offer tariffs that target electric vehicle (EV) charging, including Bord Gáis' Smart EV tariff, Energia's EV Smart Drive tariff, Yuno's EV Variable tariff, and SSE Airtricity's Smart EV Charge tariff, **tariffs specifically targeting electric heating** are not offered. However, consumers with electric heating such as heat pumps or storage heaters, are likely to be able to benefit from the time-of-use tariffs on offer. [64, 65, 66, 67, 68]

In contrast, major UK electricity suppliers, Octopus and OVO, offer tariffs that target heat pumps. For example, Cosy Octopus is a 3 rate tariff offered to consumers with a heat pump or electric boiler. [63] OVO offer a reduced rate for the electricity consumed by their customers' heat pumps. This is only available to customers with compatible heat pumps. [75]

4.1.1.2 Demand Side Flexibility Products

In addition to removing barriers to participation in existing electricity markets, there is potential for specific services and tools designed to enable consumers to support the electricity system through demand shifting (demand side flexibility). EirGrid and ESB Networks are developing products to incentivise demand side flexibility, including EirGrid's Demand Side Unit tool and ESB Networks' proposed Demand Flexibility Product, expected to be operational next year. [39, 40, 41, 42, 43] These products could provide a dedicated revenue stream to flexible assets, which may include aggregated electric heating demand from consumers. This financial signal may improve the business case for flexible electric heating, encourage uptake of these technologies, and enable the electricity system to benefit from the flexibility potential of heat.

Case study: Demand Flexibility Product and Demand Side Unit tool

ESB Networks' proposed **Demand Flexibility Product** will involve the procurement of demand flexibility in network locations identified as requiring flexibility to actively manage congestion and energy flows on the distribution network. ESB Networks define demand flexibility as the ability for flexible assets to deliver demand reduction, demand shifting or inject power. The procurement model aims to adopt daily or near-daily demand shifting from high demand periods to periods of low demand and/or high renewable generation output. The proposed contracts will award availability payments with a floor and share structure and negative incentives for negative or late delivery. The floor and share structure guarantee contract holders a minimum level of revenues, with a fixed proportion of net revenues above this floor being shared with consumers. [45, 44] The product underwent a second consultation run by CRU on arrangements over October – December 2024 and established a qualification system for the procurement of services in December 2024. [42, 43]

EirGrid's **Demand Side Unit (DSU)** tool is designed to manage electricity consumption during periods of low generation or peak consumption. The **DSU tool** allows EirGrid to instruct consumers to reduce electricity demand. This requires a minimum unit response of 4 MW and must always be available. Although the DSUs allow aggregation of Individual Demand Sites, EirGrid specify these are typically medium to large industrial premises. The tool currently does not include the ability to instruct consumers to increase demand. DSUs are financially incentivised through a DSU capacity scheme. [41, 69]

4.1.1.3 Locational constraint markets

The stakeholder engagement also revealed diverging views on locational constraints in Ireland. Locational constraints refer to challenges that arise due to the physical location of power generation and consumption, including limited transmission capacities, grid congestion, and geography. It was argued that locational market signals, such as in the Local Constraint Market (LCM) in Scotland, [44] are not as important as temporal market signals in Ireland because, despite a geographical mismatch between electricity supply and demand, locational constraints are not significant. There were differing views on if electrifying heat at industrial and commercial sites in Ireland could constrain the grid. Some argued that these sites are typically spread out, while others raised concerns about potential locational constraints and called for further investigation.

Ireland's Capacity Market includes procurement of capacity across Locational Capacity Constraint Areas (LCCAs) to meet security of supply requirements across the island, despite constraints on the transmission network. [45] Further locational market signals could encourage co-location of industry with areas of high renewable output and curtailment. Further analysis could be carried out to understand the impact of locational constraints in Ireland, and if locational market signals could be beneficial to the system.

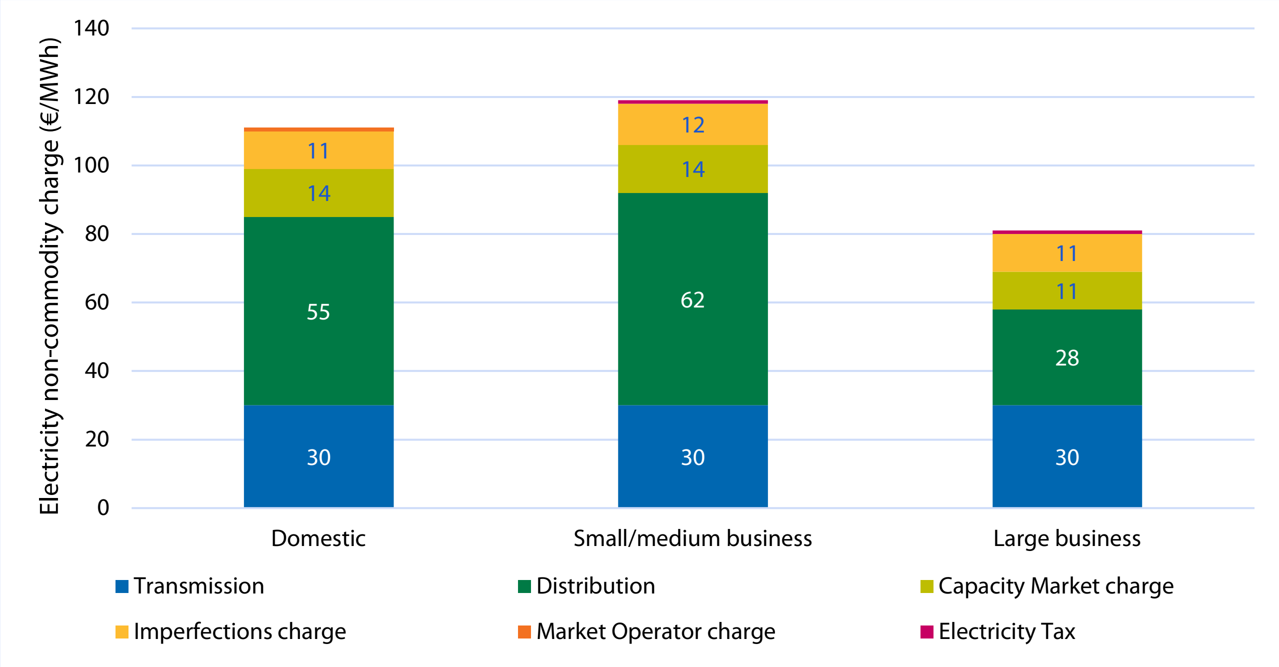
4.1.2 Electricity Prices and Non-Commodity Charges

Stakeholders identified high electricity prices and the high ratio of electricity to oil and gas prices (spark gap) as an important barrier to electrification of heat in Ireland[10]. A significant driver of this is the high non-commodity charges included in retail electricity prices.

Consumer electricity prices in Ireland include the wholesale cost of electricity and several non-commodity charges. These non-commodity charges include Transmission Network Use of System (TNUoS) charges, Distribution Use of System (DUoS) charges, PSO levy, Capacity Market charge, Market Operator charge, and imperfection charges, as shown in Figure 9. [34]

[10] The latest data and analysis of gas and electricity price issued by SEAI for the first half of 2025 confirms Irelands high ranking compared to other EU members states for electricity price to businesses, and the high ratio between electricity and gas prices. Available from https://www.seai.ie/sites/default/files/publications/EPR-Electricity-Gas-Prices.pdf

Figure 9: Modelled breakdown of non-commodity electricity charges for domestic, small/medium business, and large business customers in Ireland over October 2023 – October 2024. Note: PSO levy was set at zero over this period. Source: Cornwall Insight [34]



Analysis shows that although Irish consumers also pay non-commodity charges on gas bills to cover the cost of owning and operating gas networks, these charges are much lower than those for electricity. On average over the 2018 – 2024 delivery years (October – September), non-commodity charges for electricity were found to be 4 – 5 times higher than those for gas across domestic, small business, and large business owners. This cost imbalance discourages consumers from switching from gas to electric heating. [34]

Further analysis found that non-commodity charges make up between 50 – 55% of the total electricity bill for consumers in Ireland. [46] Because these charges form such a large part of the overall cost, consumers have less incentive to benefit from wholesale price fluctuations, as the absolute cost for electricity remains high. The flat structure of non-commodity charges also does not encourage energy use during periods that would benefit the grid. Most non-commodity charges on consumer electricity bills are not time-of-use, meaning they apply to consumption at all times of the day. As a result, variable wholesale prices have less impact on the total bill, reducing the incentive to use electricity flexibly. [46]

Reforming these charges could reward flexibility from electrified heating, for example by providing exemptions to certain charges or moving to a time-of-use structure. Recent progress in Ireland includes the reform of DUoS charges, which introduced a peak rate for customers with a smart meter. However, the impact on consumers is dependent on how suppliers choose to reflect these tariffs in retail prices. [47, 48] International examples show alternative non-commodity pricing strategies: Denmark and Sweden apply time-of-use tariffs to their DUoS charge structure, and Sweden's TNUoS charges include a time-differentiated energy-based component based on actual hourly market prices per bidding zone. [49]

Customers connected to both electricity and gas networks face double non-commodity charges, regardless of usage. Consumers may pay daily standing charges per meter to be connected to the electricity and gas networks, and these charges do not depend on the actual consumption. This weakens the financial case for adopting low-carbon technologies. In particular, this is likely to be a barrier to the development of hybrid solutions that use electric heating technologies alongside traditional gas boilers to optimise the use of low carbon and cheap electricity.

Additionally, as Ireland's energy becomes more electrified and renewable penetration increases, system operators (EirGrid and ESB Networks) may need to become more dynamic in monitoring grid congestion and engaging with demand side flexibility. Coordinated incentives and dynamic pricing systems can encourage flexible energy use.

4.2 Grid Access and Flexibility

When demand consumers connect to the electricity grid in Ireland, they receive a firm maximum import capacity (MIC). They are always able to access their agreed MIC, irrespective of their pattern of electricity demand. [50] Electrifying a site's heating system usually increases the MIC required on-site. The network operator must determine if there is enough headroom on the local network to approve an application for increased MIC or if reinforcement works are needed. This process can lead to high costs and long delays for site owners, which discourages heat electrification.

Current processes to determine if a site's MIC can be increased typically use 'worst-case scenarios' to assess the impact on the grid. In practice, flexible electrified heating systems typically do not need to always import at their peak demand. This approach can result in underutilisation of existing grid infrastructure. A potential solution is to introduce flexible connections or non-firm grid capacity. With flexible connections, the network operator limits the time when the consumer can access their maximum capacity. For example, non-firm capacity could be offered during set time windows when excess renewable generation or low demand is expected. Alternatively, the system operator could use real-time monitoring to provide non-firm capacity dynamically, based on available grid capacity. Allowing a site to access a higher MIC during periods of low network demand avoids the need for network reinforcement and enables on-site heat electrification. Flexible connections could also be offered considering both the time and location of the energy system needs, for example projects could be prioritised based on proximity to renewable generation. [51] Flexible connections help optimise the use of the existing transmission and distribution grid infrastructure and reduce the immediate need for new grid capacity, lowering system costs.

Flexible grid connections for both import and export capacity are already offered in the UK. For example, UK Power Networks allow customers to connect to the distribution network ahead of network reinforcement if they accept that their output may be curtailed during network congestion. They also offer customers a Profiled Connection, where the import capacity is available according to a predefined fixed profile. [52] Flexible connections are currently being piloted in Ireland and Northern Ireland, as summarised in Table 5. CRU has also highlighted the importance of flexible connections in its National Energy Demand Strategy. [53] More real-time monitoring and analysis of the system's available capacity will support flexible connection offers and therefore enable the flexible integration of electricity and heat systems in Ireland.

Table 5: Summary of projects piloting flexible grid connections in Ireland and Northern Ireland.

Network Operator	Pilot project
ESB Networks	ESB Networks are piloting Timed Connections over 2024 – 2025. This allows a customer to use their entire MIC during specific, predetermined hours, but a lower MIC at other times. In principle, this would continue until the full MIC could be granted, for example following network reinforcement. Alternatively, it could be established that either the connection customer or other customers in the locality can provide the flexibility on a longer-term basis more economically than the cost of reinforcement. The pilot aims to test and inform some of the key principles of future flexibility offerings for customers. ESB Networks could decide to introduce this as an enduring solution or could develop more advanced flexibility solutions. [54, 55]
NIE (Northern Ireland Electricity) Networks	NIE Networks announced in September 2024 that they plan to trial a static, timed connection on their HV network, which would enable a customer to draw increased demand overnight. They plan in parallel to develop policies to facilitate and manage flexible connections more widely and expect to be able to introduce such connections from 2026. [56]

4.3 Technical and Behavioural Challenges

In addition to system barriers that may not sufficiently incentivise or enable the flexible integration of electricity and heat systems, there are technical limitations and opportunities to maximise the flexibility potential of consumers' electric heating and cooling. This includes the adoption of storage technologies and consumer behaviour limitations.

4.3.1 Adoption of Thermal Energy Storage Technologies

As discussed in Section 2.3, TES is a proven method for balancing supply and demand for heating and cooling. [14] TES allows electricity to be drawn from the grid at flexible times, without changing the heat demand profile of the consumer. However, several barriers can limit the adoption of TES alongside electric heating.

A wide variety of TES technologies are currently available or under commercial development. This diversity means TES can be used across many industries and building types. However, the range of electric heat sources and storage technologies makes it important to identify the most cost-effective combination for each application. [31] Better understanding of the optimum technology configurations across applications will reduce uncertainty and increase confidence in investing in such technologies. While many TES technologies are mature (see Section 2.3), high-temperature TES (as might be required for industrial processes, for example over 150ºC) may not be as widely commercially available or may face prohibitively high costs.

Case study: Codema's Heat NEWS project aims to accelerate the deployment of thermal energy storage in Ireland [75]

Codema argues that TES has underutilised potential to support decarbonisation in Ireland and suggests that it is cost-effective and more resource efficient than other energy storage technologies such as electrical batteries. The Heat NEWS project is running over 2024 – 2025 and aims to provide a comparative review and suitability analysis of TES across sectors and a business model analysis of TES applied to flexibility services. It will additionally develop a roadmap and 'how-to guide' for incorporating thermal storage into heating systems to enable greater flexible operation to support the electricity grid.

Space requirements can also be a barrier. [31] Some TES technologies are bulky or have large land requirements, making installation difficult where space is limited. Shared or community-based energy storage may be a more space-efficient solution in these cases. [31] Large-scale TES with district heating networks can provide other advantages, as they can store and supply more heat for long periods, offering greater flexibility. [14]

The affordability of TES is additionally a potential barrier for consumer adoption. [31] TES adds another upfront cost on top of the installation of electric heating technologies. Table 6 provides indicative cost and performance ranges from published literature[11]. Costs vary widely depending on the technology and temperature required. Costs may be prohibitive for some consumers, particularly for high temperature applications. Hot water tanks are already common in residential buildings, but other types of TES may be particularly expensive at smaller scales. Policy to support consumers with the upfront cost of TES may be necessary to encourage uptake of these technologies. [31] For example, the UK government has expanded the Boiler Upgrade Scheme to offer a £2,500 discount off the price of heat batteries, which can store heat overnight for use during the day, alongside grants for the installation of heat pumps. [57]

[11] These figures are for reference only; a technology-specific payback analysis was not undertaken in this study and would be required to support investment decisions

Table 6: Cost and performance for various thermal energy storage technologies. [21, 27, 58, 59, 60, 24, 25, 30]

Category	Technology	Storage medium	Storage duration	Heat capacity (kWh/m³)	Cost (€/ kWh)	Storage temperature (°C)
Sensible heat storage	Tank thermal energy storage (TTES)	Water	~ Days	60-80	Small-scale: 100 - 500 Large-scale: 0.8 – 20	~60
	Solid-state thermal storage (SSTS)	Concrete, rocks, ceramics	~ Days	70-150	15-40	250-1,000
	Underground thermal energy storage (UTES) – pit, borehole, aquifer	Gravel and water mix, ground rock/soil, groundwater and ground material	~ Months (seasonal)	30-80	0.1-5	5-95
Latent and thermochemical heat storage	Low temperature phase change material	Paraffin wax or inorganic salt hydrates	~ Days	100-250	10-50	60-80
	High temperature phase change material	Inorganic salts	~ Days	100-250	10-50	150-250
	Thermochemical heat storage	Thermochemical materials	~ Months	100-600	8-100	-20-700

4.3.1.1 Comparison of Thermal Energy Storage and Battery Storage

As an alternative to TES technologies storing heat, battery energy storage systems (BESS) can also be used in a flexible electric heating system to store electricity before it is converted to heat. For example, heat pumps can draw stored electricity from a BESS when needed, avoiding grid use during peak hours. [31] BESS can offer higher efficiency and, for some TES technologies, energy density, and can support other on-site electricity consumption. BESS is particularly well suited to enabling flexibility from heat pumps. The storage of electricity before powering a heat pump rather than the heat produced means that the quantity of energy storage required would be reduced by a factor equal to the heat pump's coefficient of performance (COP). [31]

However, BESS may have shorter lifespans than TES technologies and have greater embodied energy in manufacture. [31] BESS are typically less suited to long-duration storage, while TES can be used to store heat seasonally. Analysis suggests that TES is more cost-effective and has longer lifetimes than BESS in district heat systems and actually requires less land. For example, analysis of a district heating system in the Poolbeg area of Dublin found that the use of tank thermal energy storage cost approximately 1% and used less than 10% of the land area compared to BESS of the same energy capacity. [21]

The suitability of BESS and TES technologies should be assessed on a case-by-case basis, depending on the specific sector, building, and heating technology. This study did not consider BESS in detail.

4.3.2 Consumer Behaviour

In addition to the storage of electricity or heat, flexibility in consumers' heating demand profile enables dynamic interaction between electricity and heat systems. For example, consumers can shift load by pre-heating buildings.

The temperature tolerance of a consumer indicates their willingness to vary the temperature of a building, which can provide a form of demand flexibility. Greater tolerance allows for longer flexibility windows, where buildings can be pre-heated and their temperature allowed to drop for longer before heating is required. [12]

Building thermal mass also impacts the flexibility potential of buildings. Buildings with higher heat inertia enable more intermittent heating and can more effectively pre-heat. [7, 12] A building's heat loss rate is a measure of how quickly a building loses heat under given external temperature conditions and depends on a building's insulation and air-tightness level. Buildings with low heat loss rates retain heat for longer. The ability for a building to shift demand without dedicated TES other than the fabric of the building can be determined through consideration of a building's thermal mass, its heat loss rate, and the occupant's temperature tolerance. [9]

Industrial consumers face further barriers to heating demand flexibility than other types of consumers. Industrial processes typically require continuous, steady heating, leaving little opportunity for flexibility in the demand profile. [10]. Industrial consumers are sensitive to risks that could affect process output and therefore have limited ability to flex the process heat demand. Although there is limited flexibility in the heat delivered to the end use, industrial consumers can provide flexibility to the electricity system through the use of TES, as described in Section 4.3.1. Industrial consumers are generally motivated by business case and therefore are likely to adopt flexible electrified heating systems if they save money without impacting output quality. The adoption of flexible electrified heating systems in the industrial sector requires a favourable business case and confidence that operability will not be compromised.

5 Conclusions and Recommended Actions

Heat electrification using increasingly low-carbon electricity is one of Ireland's most important decarbonisation pathways, as highlighted in the National Heat Study and the 2025 Comprehensive Heating and Cooling Assessment. However, its effective implementation requires careful assessment of the associated impacts on the electricity grid to avoid placing excessive strain on network infrastructure. The flexible integration of the electricity and heat sectors offers a significant opportunity to mitigate grid-overload risks while facilitating higher shares of renewable energy in the national energy mix. TES technologies play a central role in enabling this flexibility.

In this report, we examined the benefits of integrated heat–electricity operation and identified the key barriers and required actions, drawing on a review of existing literature and engagement with key stakeholders. We also carried out high-level illustrative modelling of TES to demonstrate its potential benefits by comparing baseline and flexible scenarios.

The following sections summarise the main findings of this analysis. The benefits, barriers, and enabling actions identified in this report are interdependent. Several barriers, such as high and flat non-commodity charges, constrain multiple benefits simultaneously, affecting both consumer incentives and the overall business case for electric heating. As well, enabling actions often address more than one barrier: for example, reforming non-commodity charges to a time-of-use structure would both strengthen price signals and improve the competitiveness of electric heating relative to gas. The summaries that follow should be read with these interdependencies in mind; Sections 3 and 4 provide the detailed discussion.

5.1 Summary of Benefits

The dynamic interaction between electricity and heat systems in Ireland, involving the flexible operation of electric heating technologies, is expected to provide significant benefits to the system and to consumers. Flexible electric heating can:

- **Lower the peak total electricity demand:** Shifting demand away from peak periods flattens the overall electricity demand curve. This reduces strain on the grid and the need for costly grid upgrades.
- **Reduce reliance on fossil-fuelled dispatchable generation:** By aligning demand with periods of high renewable generation, the reliance on conventional dispatchable sources can be reduced. As these are typically fossil-fuelled, this can reduce the emissions intensity of the grid.
- **Minimise renewable energy curtailment:** Aligning demand with periods of high renewable generation also maximises the utilisation of renewable electricity generated. This also enables the same level of decarbonisation to be achieved with a smaller installed RES capacity, making the energy transition more cost-effective.
- **Lower overall system costs:** All of the above benefits lead to system cost savings, which will be passed onto all electricity consumers in the form of lower electricity costs.
- **Improve the business case for electric heating:** Consumers with flexible electric heating systems can further benefit from time-of-use electricity tariffs, payments for participating in flexibility events, and lower payments for grid connection. This can improve the business case for electric heating systems, encouraging adoption of these low carbon technologies.

5.2 Summary of Barriers

However, several barriers must be addressed to realise these benefits:

- There are **limited long-term financial signals** to offset the operating costs of electric heating.
- **Electricity market design** currently limits access for flexible demand-side assets, such as electric heating technologies.
- **High and flat non-commodity charges** make up a significant proportion of overall consumer electricity prices and reduce incentives for flexible electricity consumption.
- **Increasing a site's MIC** to meet higher electricity demand is often slow and costly, and the structure of firm MIC agreements can lead to underutilisation of existing grid infrastructure.
- **High upfront costs and space constraints** limit the adoption of TES, especially at small scales or high temperatures.
- There is typically **limited flexibility in consumer behaviour**. For residential, commercial and public buildings, this may be due to consumers' low willingness to vary buildings' temperature and the building's physical

characteristics, such as its heat loss rate. Industrial consumers generally face even lower flexibility in heat demand, as industrial processes need to run on an optimised schedule.

5.3 Summary of Enabling Actions

Review of literature and engagement with key stakeholders identified actions that can be taken to overcome these barriers and unlock the full potential of flexible electric heating in Ireland. Actions can be taken now by government and electricity system actors, including utility companies, system and market operators and regulatory bodies, to support a flexible integrated electricity and heat system in Ireland:

Provide long-term financial signals through improved consumer access to electricity markets and establishment of demand side flexibility products to improve the business case of flexible electric heating technologies and encourage operation that benefits the electricity system.

- Utility companies can develop market mechanisms, such as dynamic time-of-use electricity tariffs, to support consumer access to electricity markets and incentivise flexibility.
- The CRU, the system and market operators (including EirGrid and the Single Electricity Market Operator) may want to consider review access requirements of existing electricity markets, to identify and alleviate unnecessary barriers to entry for demand-side response assets, including electric heating.
- System operators ESB Networks and EirGrid are already developing specific products to compensate demand side flexibility in response to system needs on the transmission and distribution networks. The establishment of this financial signal should be accelerated to improve the business case for flexible electric heating assets.

Review the level and structure of the non-commodity charges that are included in retail electricity prices to better incentivise flexibility from electric heating.

- The CRU may want to consider reforming the flat structure of these charges, for example moving to a time-of-use structure, to allow consumers to benefit from wholesale price fluctuations and incentivise demand shifting. Government and utilities should ensure all consumers can benefit from flexibility, and those that are unable to flex their heating demand are not unfairly penalised.

Accelerate access to non-firm import capacities to minimise the costs and delays associated with increasing a site's grid connection and to improve utilisation of existing grid infrastructure.

- System operators should accelerate access to flexible or non-firm import and export capacities for customers, taking into account their electricity demand profile. Non-firm capacity could be offered during set time windows when excess renewable generation or low demand is expected, or dynamically in response to the real-time needs of the grid.
- ESB Networks are already piloting Timed Connections in Ireland. These pilots should be accelerated and ESB Networks should aim to implement a long-term commercial offering.

Encouragement and support of the adoption of TES technologies and hybrid systems can enable flexibility from electric heating systems, particularly for consumers with little opportunity for flexibility in the demand profile for heating delivered to consumers.

- Government, supported by SEAI, could consider measures to directly encourage the uptake of TES technologies, such as grants to overcome the high upfront cost of installing TES, subject to cost-benefit assessment, where these support the deployment and efficient use of renewable energy.
- Government could also encourage pilot projects that demonstrate the business case of installing TES across different applications and demand segments. These measures could target consumers that are highly sensitive to changes in the heat delivery profile, such as consumers with low temperature tolerance or industrial processes.
- Hybrid systems, where electric heating technologies are installed alongside existing fossil-fuelled systems can enable flexibility as the system can switch between sources when it is favourable to do so. Government could consider measures to encourage the implementation of these systems as interim solutions for specific use cases in hard to decarbonise sectors, as consumers begin to decarbonise their heat demand.

5.3.1 Areas for further research

Further research is recommended because this study relies on literature review, stakeholder input, and illustrative high-level modelling. Significant uncertainties remain around consumer behaviour, TES performance across different applications, and high-resolution heat demand profiling. The following areas would benefit from more detailed analysis:

Improve data on electric heating demand profiles.

- Further collection of data from smart meters or consumer trials with electric heating technologies could develop demand profiles that better represent consumer behaviour with electric heating.
- This can improve understanding of the potential impact of electric heating on the electricity system and the technical flexibility potential.

Carry out detailed spatial modelling of electric heating demand and renewables in Ireland to assess local constraints and the potential for flexibility to resolve them.

- The extent of local constraints from the locational mismatch of renewable electricity generation and high electricity demand, and the potential for flexibility from electric heating to resolve these constraints is unclear. Modelling with increased spatial resolution can be used to assess this.
- This assessment can be used to further incentivise the uptake of flexible electrified heating and to develop mechanisms to realise the local flexibility potential, such as Local Constraint Markets. The modelling could also distinguish the impact on the network at the transmission and distribution levels, to enable targeted efforts to reduce network costs.
- Modelling at higher spatial resolution can also be used to analyse the additional network benefits of district heating. District heating networks would be expected to act as point loads on the high voltage network, rather than distributed loads on the low voltage network as for building-level heating systems.

Refine electricity system modelling with integrated electricity and heat systems, considering other forms of demand flexibility alongside electric heating, to identify benefits and to determine cost optimal generation and energy storage portfolio.

- Detailed optimisation modelling of an integrated electricity and heat system would include other forms of demand flexibility alongside electric heating flexibility, such as from smart charging of EVs. This is necessary to improve understanding of the overall technical potential of flexibility from consumers and of how the benefits can be shared across sectors.
- The detailed system modelling can also determine the optimal energy supply portfolio of renewables, energy storage, and low carbon dispatchable generation to minimise the cost of electricity supply.

Evaluate the impact of low probability but high impact events, such as extreme weather, and the opportunity for flexibility to combat related risks.

- Modelling of the integrated electricity and heat systems should consider the potential impact of extreme weather events. For example, in a highly electrified scenario, prolonged periods of low temperatures could cause security of supply challenges. Low temperatures can reduce heat pump efficiency when they are working hardest to maintain internal temperatures. Wind speeds are often below average during these freezing spells.
- More work is needed to understand how technology deployment and flexibility from electric heating and TES can be configured to manage the risk of power cuts and deliver backup heating options if they occur.

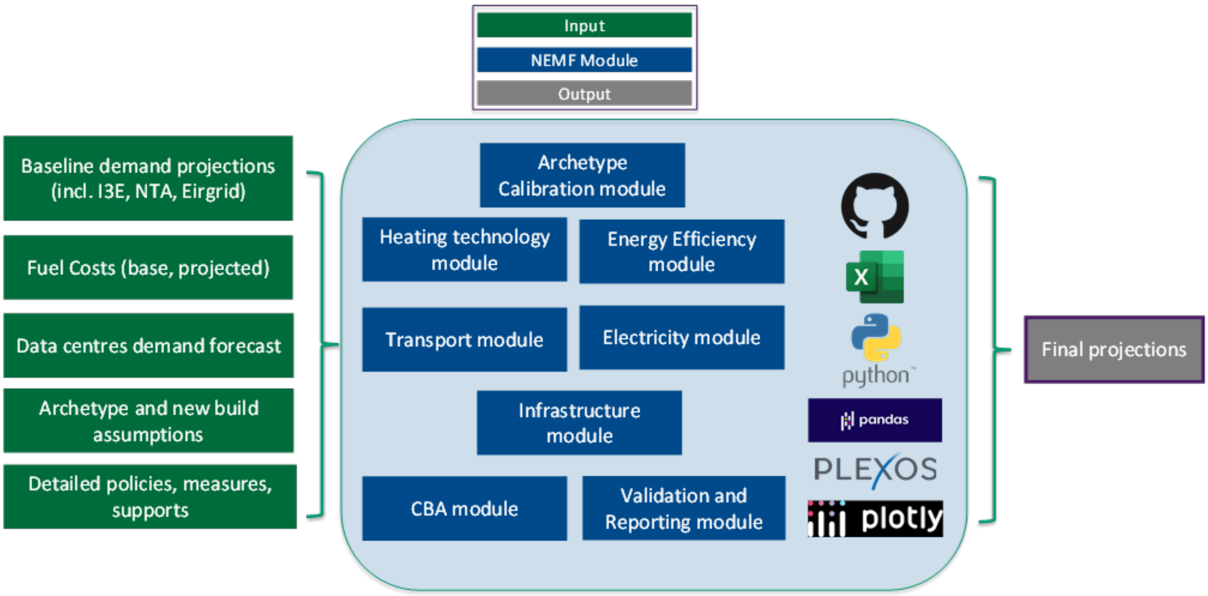
The implementation of the identified enabling actions will allow Ireland to make significant progress towards a cleaner, more flexible, and cost-effective energy system. These actions support Ireland in meeting its RED III obligations under Article 23 to increase the share of renewable energy in heating and cooling, in particular through the measures encouraged under Article 23(4)(j) promoting TES integration. They also align with the energy system integration objectives of RED Article 20a, which enable flexible electricity demand to respond to grid conditions and maximise renewable electricity use. [1] Ongoing research and policy support will be essential to ensure the electrification of heating and cooling remains aligned with Ireland's decarbonisation goals and the evolving needs of the energy system.

6 Appendices

6.1 National Energy Modelling Framework

The National Energy Modelling Framework (NEMF), developed and maintained by SEAI, is a national energy system model that assesses the impacts of packages of energy policies and measures on future energy supply and demand. It combines several SEAI sectoral models to produce policy-rich outlooks for the whole energy system.
The NEMF couples modules focussed on modelling of the heat, transport and electricity sectors. It examines aspects such as the variation in technology readiness, technical suitability, cost data and performance data, to assess various scenarios (including potential decarbonisation paths) in Ireland. A high-level outline of NEMF inputs and modules is shown in Figure 10.

Figure 10: NEMF outline



A key feature of the NEMF is its focus on the end consumer, providing insight into the challenges faced by consumers considering actions and where policy can help. The heat sector module contains a detailed set of archetypes representing all buildings and industries in Ireland. The NEMF contains 650 individual heat demand archetypes, representing a combination of physical and consumer attributes, which in turn provide a detailed description of demand in residential, services and industry sectors, as well as agricultural energy use. Technology suitability and performance are mapped to each archetype, along with costs consumers face when deciding on switching to a lower carbon heating alternative.

The model uses techno-economic data to generate payback and lifetime cost estimates for the various technology options available, accounting for policy incentives, taxes and regulations. This payback and lifetime cost information is used with other data on consumer decision-making behaviour to simulate how much uptake may result in various scenarios and in response to policy measures.

The model also contains representations of bioenergy and hydrogen resources and fuel supply chains as well as an infrastructure module that calculates the costs of infrastructure deployment linked to technology uptake. Where technology deployment is based on centralised decisions, these are accounted for outside of the consumer decision-making framework; district heating and industrial Carbon Capture, Utilisation and Storage (CCUS) are dealt with in this way.

A detailed description of the methodology, data-sources and assumptions used to generate the archetypes within the NEMF is provided in the National Heat Study report "Heating and Cooling in Ireland Today".[12]

[12] SEAI, "National Heat Study: Heating and Cooling in Ireland Today", Feb. 2022. [Online]. Available at: https://www.seai.ie/data-and-insights/national-heat-study/heating-and-cooling-in-ir/

Examples of some of the key questions the NEMF is regularly used to answer are:

- Given a potential set of energy-related policies and measures that could be implemented over a given time horizon, what is the projected future energy supply and demand by sector for each year?
- Is the current set of planned policies and measures likely to meet domestic and European targets for primary / final energy, energy-related emissions and renewable energy shares (RES)?
- What is the size of the possible gap to targets if there is a delay in implementation?
- Which combinations of measures are likely to have the most impact on uptake of schemes and technologies to accelerate decarbonisation and improve energy efficiency across sectors?

More information on the model strengths and links to recent outputs can be found in the National Modelling Assets for Energy and Climate Change Mitigation.[13]

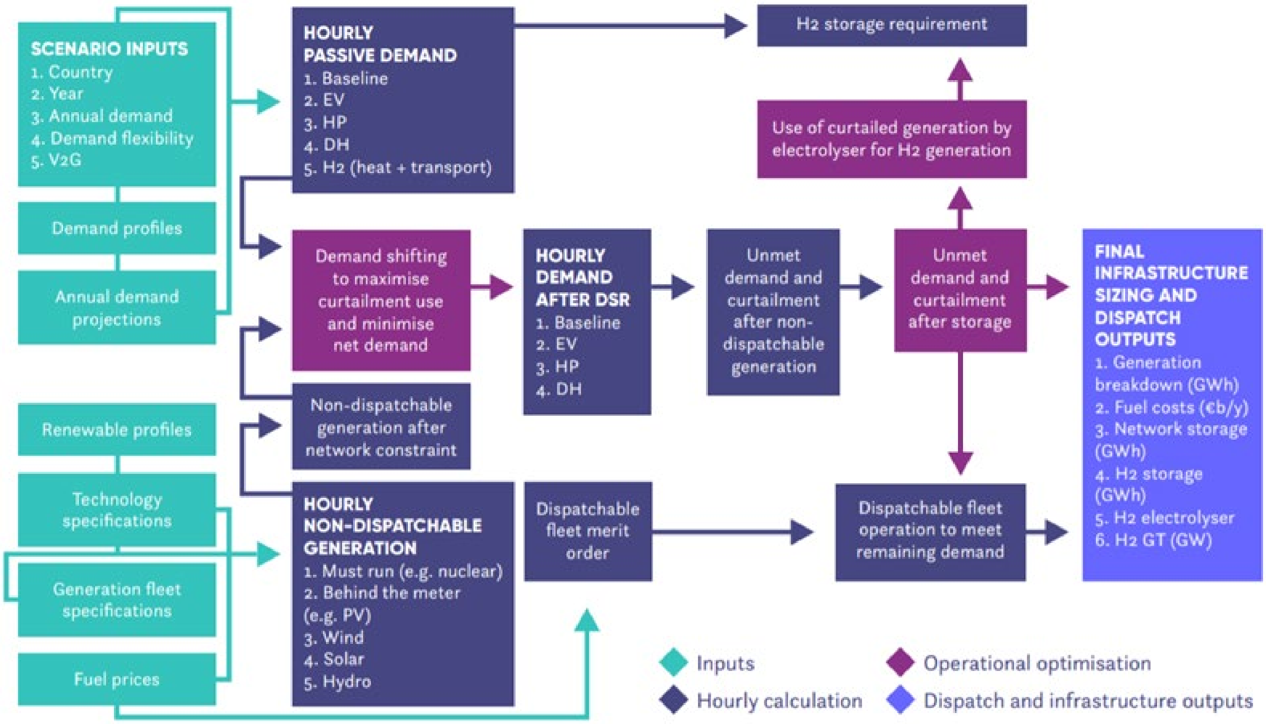
[13] Department of the Taoiseach, "National Modelling Assets for Energy and Climate Change Mitigation", June 2025. [Online]. Available at: https://www.gov.ie/en/department-of-the-taoiseach/publications/research-and-modelling-group/

6.2 Illustrative modelling method, assumptions, and detailed findings by demand segment

6.2.1 Method and assumptions

The illustrative modelling described in Section 3.4 uses ERM's Integrated System Dispatch Model (ISDM). A schematic showing the operation of the ISDM is shown in Figure 11. The ISDM directly integrates electricity demand flexibility with electricity supply variability and network constraints. It takes as inputs hourly demand profiles and renewable generation profiles. The model calculates how demand can be shifted to maximise the use of renewable electricity and minimise the peak total demand (for network infrastructure sizing) as well as peak net demand after use of renewable electricity (for dispatchable capacity sizing). The model meets the remaining demand after use of renewable electricity with dispatchable generation, calculating the final dispatchable infrastructure sizing and costs.

Figure 11: Schematic of ERM's ISDM



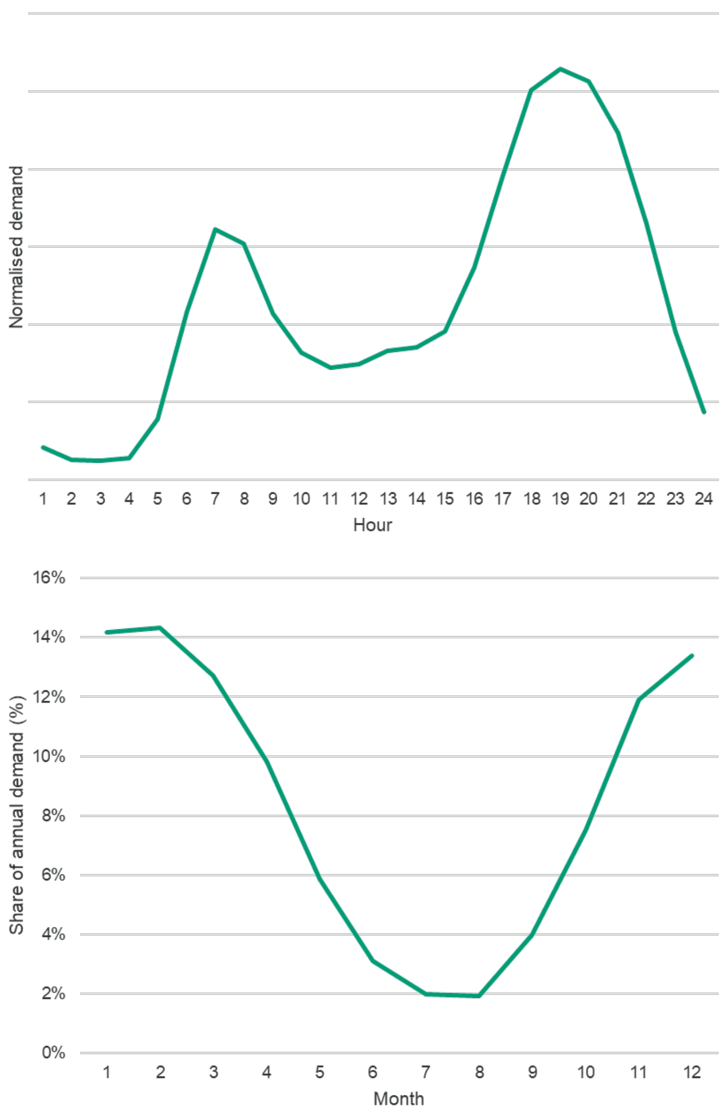
6.2.1.1 Demand and thermal energy storage

The ISDM modelled a simplified version of Ireland's electricity system, considering fixed demand profiles for each sector, including heating and all other demand. The source of this is shown in Table 7 and profiles for the heating demand segments, excluding industrial, is shown in Figure 12.

Table 7: Sources of input data used in the illustrative modelling (SEAI NEMF inputs vs ERM-processed profiles)

Demand sector	Profile used	Source
Commercial and public heating	Custom profile shown in Figure 12	ERM
Residential heating	Custom profile shown in Figure 12	ERM
District heating	Custom profile shown in Figure 12	ERM
Industrial heating	Flat profile	N/A
All other electricity demand	NEMF demand profile	SEAI

Figure 12: Normalised diurnal heating demand profile and seasonal demand variations used for residential, commercial and public, and district heating demand in the ISDM



The total annual heating demand of each demand segment and the assumptions behind the modelled TES capacity are summarised in Table 8. The modelling of the resulting electricity demand profile involves consideration of their heating demand profiles, their electrified heating technology selection, and their technical flexibility potential. We calculated the assumed TES capacity for residential and commercial & public buildings from the proportion of building stock with TES and the installation size per building. The industrial and district heating TES capacity was calculated considering the segments' peak electricity demand and a fixed TES duration.

Table 8: Summary of total annual heating demand and assumed TES adoption in the ISDM

Assumption [source]	Residential	Commercial and public	Industrial	District heating
Annual heating demand (TWh) [14]	3.58	4.09	1.68	0.38
Assumed TES technologies	Low temp. phase change material		Large-scale tank TES	
TES installation size (kWh) [1]	6.3 [15]	70	Dependent on site demand – total system capacity calculated based on 191.6 MW peak demand [16]	Dependent on scheme size – total system capacity calculated based on average peak demand of 3.2 kW per household connected to district heating [17]
Electric heating COP [14]	2.56	1.18	1.2	3
Building stock [14]	651,443	291,910	N/A - based on peak demand.	58,172 (stock of buildings connected to district heating)
Assumed adoption level	25% building stock has TES	25% building stock has TES	75% building stock has TES, 10h duration [18]	100h duration TES [18]
Total TES capacity (GWh)	1.03	5.11	1.72	55.68

6.2.1.2 Generation

The ISDM used electricity generation profiles from SEAI's NEMF. For the flexible thermal energy storage scenario, the ISDM analysis did not carry out a full re-run of an hourly dispatch model for all generators throughout the year. Instead, a simplified approach was taken where gas is assumed to be the marginal generation plant, and only gas generation is assumed to vary in response to the changing demand from TES. The generation profile of all other generators including interconnectors and battery storage was kept constant from the baseline run. The generation assumptions are summarised in Table 9.

[14] Inputs from NEMF
[15] A typical Sunamp heat battery has been used as the basis of the assumed installation size and CAPEX of a building-level TES. Note: Volume shown also to give indication of size. https://www.ecosmartheat.co.uk/heat-pumps.html , commercial uses a larger sized product.
[16] Calculated based on assumed flat industrial demand profile and total annual demand from NEMF of 1.68 TWh
[17] Calculated considering the assumed diurnal demand profile for district heating and the total annual demand from NEMF of 0.38 TWh
[18] Duration of storage for district heating based on case studies of installed district heating TES (for example: https://www.energy-storage.news/100mwh-sand-battery-goes-into-commercial-operation-in-finland/). For industry, daily storage assumed as interim value between building level and district heating.

Table 9: Summary of modelled generation sources and ISDM modelling

Generator	ISDM modelling
Onshore wind	Fixed profile from NEMF
Offshore wind	Fixed profile from NEMF
Solar	Fixed profile from NEMF
Hydro	Fixed profile from NEMF
Gas	Dispatchable to meet demand
Biogas	Must run – constant hourly output
Biomass	Must run – constant hourly output
Renewable waste	Must run – constant hourly output
Non-renewable waste	Must run – constant hourly output
Storage charge/discharge	Fixed profile from NEMF
Import	Fixed profile from NEMF

6.2.2 Demand segment illustrative high demand profiles

6.2.2.1 Residential

Figure 13 shows the residential electric heating demand profile, the TES charge and discharge, and state of charge (SOC) in the flexible thermal energy storage scenario over two high-demand days (late February). This demonstrates how the TES charges and discharges to support heating demand. For example, the residential TES discharges to support the high demand during hour 23 in the figure. However, the charge and discharge profile is optimised across the whole system, taking into account curtailment levels and other system demand. The charge and discharge profile shown in Figure 13 also depends on the operating profile before and after the 2-day period shown. As a result, the residential TES charge and discharge profile does not always align with the residential heating demand. For example, the residential TES charges in hours 20 - 22, despite relatively high residential heating demand.

Figure 14 shows the state of charge (SOC) profile of the residential TES over a full year of operation. This demonstrates that the TES is used throughout the year, although cycling is more frequent in the colder months at the start and end of the year.

Figure 13: Residential electric heating demand, thermal storage charge, discharge, (MW) and state of charge (%) over the high demand period.

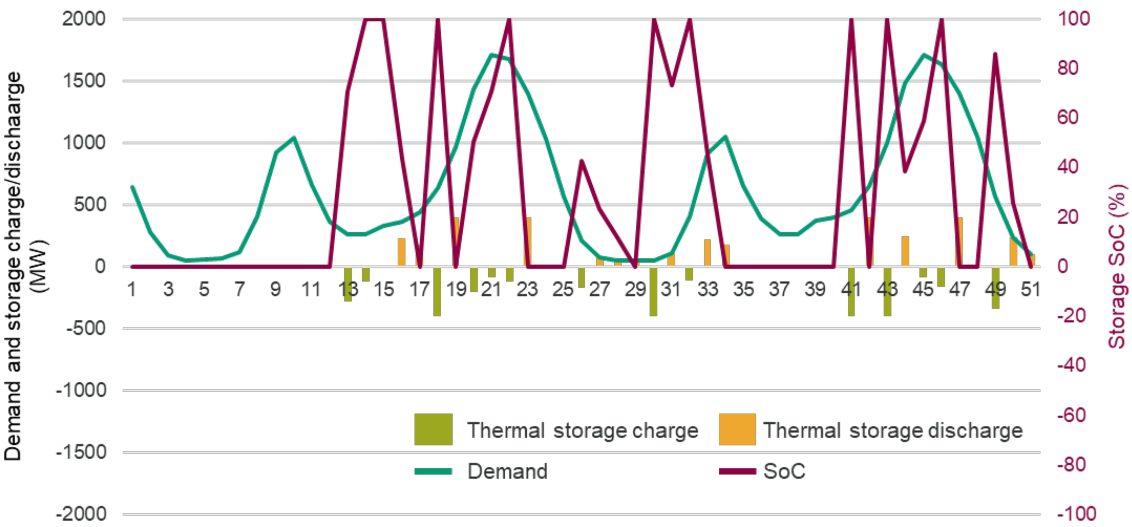
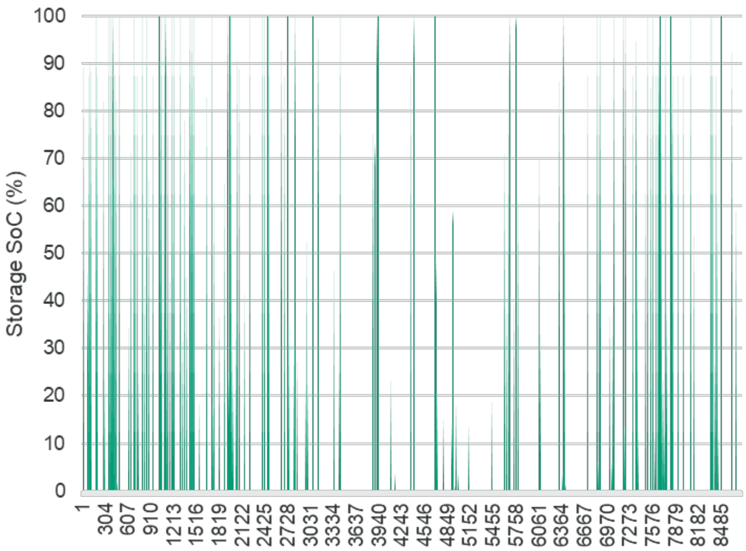


Figure 14: Residential thermal storage state of charge (%) over a year of operation



6.2.2.2 Commercial and public

Figure 15 shows the commercial and public electric heating demand profile, the TES charge and discharge, and state of charge (SOC) in the flexible thermal energy storage scenario over two high demand days (late February). This demonstrates how the TES charges and discharges to support heating demand. For example, the TES discharges to support the high commercial and public heating demand between hours 20 – 23 and 45 - 48 in the figure. However, the charge and discharge profile is optimised across the whole system, taking into account curtailment levels and other system demand. The charge and discharge profile shown in Figure 15 also depends on the operating profile before and after the 2-day period shown. As a result, the commercial and public TES charge and discharge profile does not always align with the commercial and public heating demand. For example, the TES discharges in hour 9 and not in hour 10, despite demand appearing to increase.

Figure 16 shows the SOC profile of the commercial and public TES over a full year of operation. This demonstrates that the TES is used throughout the year, although cycling is more frequent in the colder months at the start and end of the year.

Figure 15: Commercial and public electric heating demand, thermal storage charge, discharge, (MW) and state of charge (%) over high demand period.

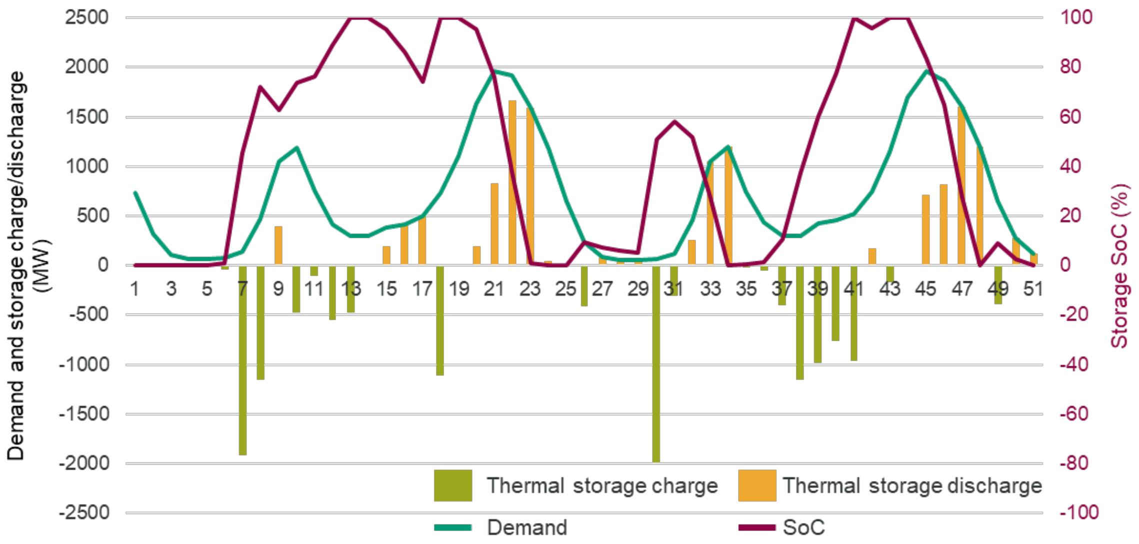
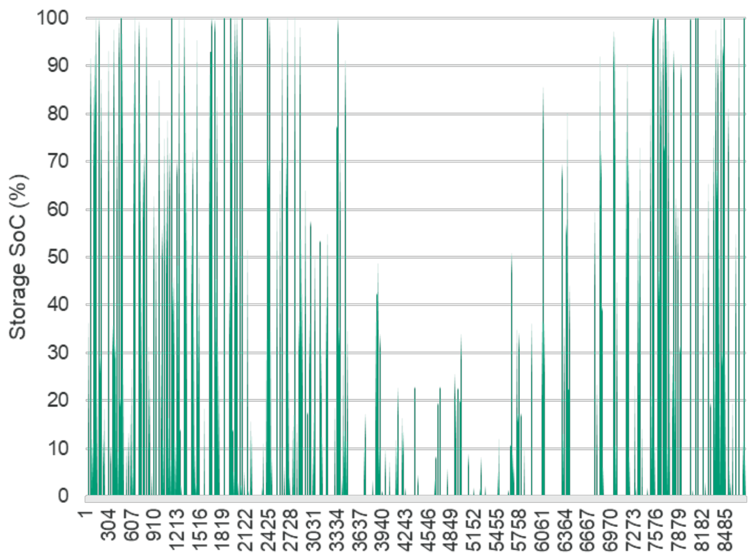


Figure 16: Commercial and public thermal storage state of charge (%) over a year of operation



6.2.2.3 Industrial

Figure 17 shows the industrial electric heating demand profile, the TES charge and discharge, and SOC in the flexible thermal energy storage scenario over two high demand days (late February). This demonstrates how the TES charges and discharges to support heating demand. As the industrial heating demand is assumed to be flat, the charge and discharge profile is largely optimised by taking into account curtailment levels and other system demand. The charge and discharge profile shown in Figure 17 also depends on the operating profile before and after the 2-day period shown.

Figure 18 shows the SOC profile of the industrial TES over a full year of operation. This demonstrates that the TES is used throughout the year - although cycling is more frequent in the colder months at the start and end of the year, this is less pronounced than for residential and commercial and public segments due to the flat industrial demand profile. There is some reduced cycling during the summer months, likely to be due largely to lower overall electricity system demand as the industrial heating demand remains flat.

Figure 17: Industrial electric heating demand, thermal storage charge, discharge, (MW) and state of charge (%) over high demand period.

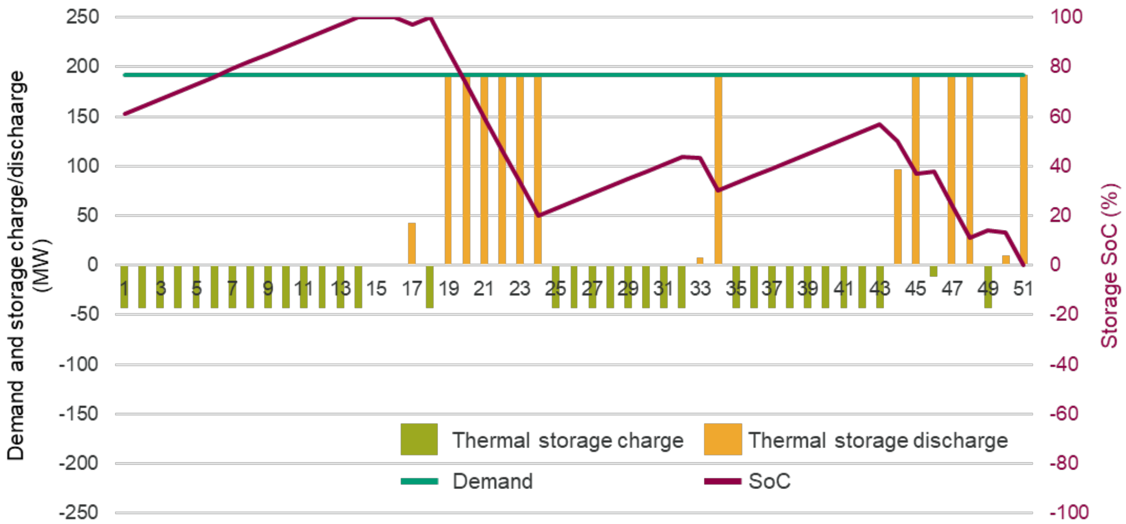
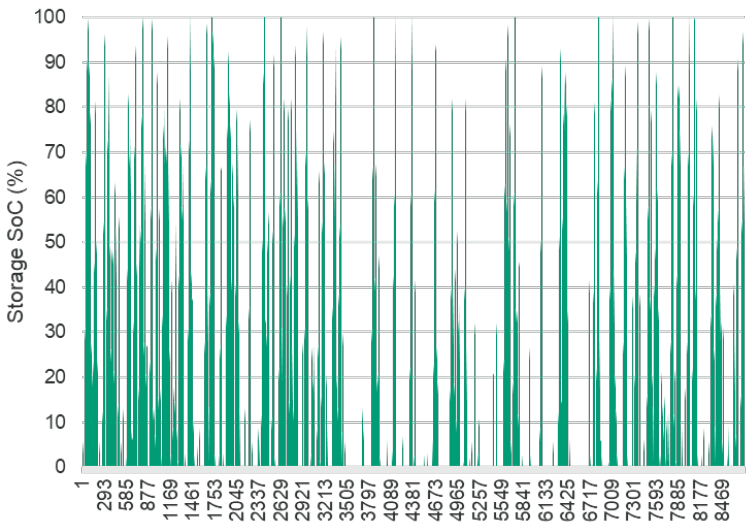


Figure 18: Industrial thermal storage state of charge (%) over a year of operation



6.2.2.4 District heating

Figure 19 shows the district electric heating demand profile, the TES charge and discharge, and SOC in the flexible thermal energy storage scenario over two high demand days (late February). This demonstrates how the TES charges and discharges to support heating demand. For example, the TES discharges to support the high district heating demand following hour 15 in the figure. However, the charge and discharge profile is optimised across the whole system, taking into account curtailment levels and other system demand. The charge and discharge profile shown in Figure 19 also depends on the operating profile before and after the 2-day period shown. As a result, the district heating TES charge and discharge profile does not always align with the commercial and public heating demand. For example, the TES remains charging over hours 8 – 11, despite relatively high heating demand. Due to its long duration, the district heating TES can discharge over a long period, meeting heating demand over at least a full day, as demonstrated in Figure 19.

Figure 20 shows the state of charge (SOC) profile of the district heating TES over a full year of operation. This demonstrates that the TES is used throughout the year, although cycling is more frequent in the colder months at the start and end of the year. Due to the high capacity and duration of the district heating TES, cycling is less frequent than for the building-level TES. [21]

Figure 19: District electric heating demand, thermal storage charge, discharge, (MW) and state of charge (%) over high demand period.

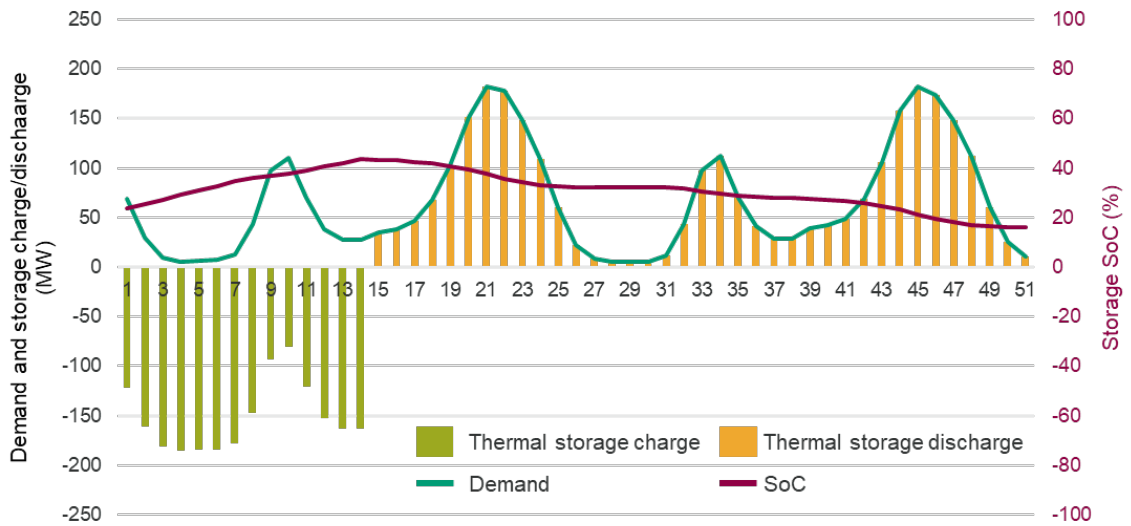
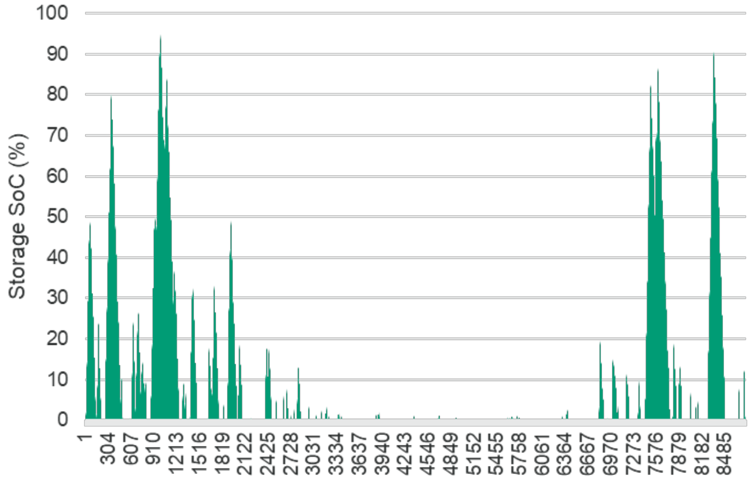


Figure 20: District heating thermal storage state of charge (%) over a year of operation



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