Heating without the hot air: Principles for smart heat electrification

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Contents

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Abbreviations

CE4All	Clean Energy for All Europeans
EEOs	Energy Efficiency Obligations
EPBD	Energy Performance of Buildings Directive
EPC	Energy Performance Certificate
IEA	International Energy Agency
kW	kilowatt
kWh	kilowatt-hour
LCFS	Low-Carbon Fuel Standard
NZEB	nearly zero-energy buildings
PCMs	phase change materials
p/kWh	pence per kilowatt-hour
RHI	Renewable Heat Incentive
TOU	time-of-use

Tables and Figures

Executive summary

Heat is of critical importance for meeting Europe's climate goals: Heating in buildings is responsible for almost one-third of total EU energy demand and around 75% of heat is met by burning fossil fuels. The European Union is currently reviewing its 2030 climate targets and has put forward a Green Deal for Europe that makes buildings a priority sector, recognising that the decarbonisation of space and hot water heating is of vital importance to achieving the European Union's climate goals in 2030 and beyond.

The transformative challenge of decarbonising heating should not be underestimated and will require strategic and ongoing policy and governance support. Heating decarbonisation requires a well-coordinated approach that cuts across several areas — buildings, heating systems (both at individual and at district level), the power sector and existing heating fuel supply infrastructure.

Neither energy efficiency nor low-carbon heat technologies can achieve decarbonisation on their own — a combination of energy efficiency and low-carbon heat technologies is the most economic and practical approach to heat decarbonisation. Whilst there are uncertainties around the optimal technology mix for heating in the future, it is clear that electrification will have to play a significant role whether through individual heat pumps or renewable electricity used to power district heating networks via large-scale heat pumps. Recognising the increasing interlinkages between different sectors, the European Green Deal announced a strategy for smart sector integration by mid-2020.

This report develops a suite of pragmatic principles for decarbonising heat through smart sector integration and sets out a number of policies that can help deliver on them.

Principle 1: Put Efficiency First. Whichever low-carbon heat technology is adopted, energy efficiency is critical. It reduces heat demand and thereby the investment required to decarbonise heat, it is an enabler of buildings that are electrified to act as a flexible resource, and it is an enabler of low and zero-carbon heating systems to operate at higher performance. By reducing demand for and associated costs of zero-carbon heating, energy efficiency can also support a more socially equitable heat transformation.

Principle 2: Recognise the value of flexible heat load. Using additional electric heat loads flexibly is critical for integrating a growing share of renewables and mitigating avoidable increases in peak load. Luckily, electrified heat can be very flexible and provide demand-side response functions by using the building and district heating networks as a thermal battery.

Principle 3: Understand the emissions effects of changes in load. If a larger share of heat is electrified, the emission intensity of electricity becomes increasingly important. Carbon emissions per unit of electricity consumed differs significantly over the course of a day. Electrified heat can take advantage of this by consuming electricity when there is a lot of zero-carbon electricity on the system and avoiding peak hours when emissions are typically the highest.

Principle 4: Design tariffs to reward flexibility. Electricity tariffs should encourage the use of electricity when most beneficial for the power system and carbon emission reduction. Electricity pricing is an important approach to encourage flexibility and delivers economic benefits to consumers for providing such flexibility.

This report makes a number of policy recommendations to be addressed at EU and national level:

1. **Step up energy efficiency in building upgrades through more ambitious targets and policies.** This will require an increase in the energy efficiency targets set in the Energy Efficiency Directive and more ambitious targeted energy efficiency policies at the national level.
2. **Phase out carbon-intensive heating systems.** Regulatory measures have a track record of success and given the required pace of decarbonisation it will be necessary to rule out inefficient and carbon-intensive heating systems through regulation. This can be achieved at the EU level through the Ecodesign Directive and the Energy Performance of Buildings Directive and at the national level through building codes.
3. **Phase out subsidies for fossil fuel-based heating systems.** Many energy efficiency programmes still support the installation of new fossil-fuel-based heating systems. Given the lifetime of heating technologies, this needs to be discontinued.

4. **Implement well-designed and well-funded financing mechanisms for energy efficiency and low-carbon heat.** Particularly in the context of limited household capital, it is important to offer financial support enabling the investment and compliance with regulation phasing out carbon-intensive heating systems. Member States should scale up existing and implement new financing mechanisms.
5. **Ensure fair distribution of costs between different fuels.** Currently most of the costs of the energy transition are allocated to electricity, resulting in misleading incentives, especially as the power system gets cleaner. The upcoming review of the energy taxation legislation in Europe offers an opportunity to ensure a fairer distribution of costs among the different fuels.
6. **Encourage the flexible use of heat through the introduction of time-varying prices.** Consumers operating their heating system flexibility should be rewarded for the benefits they provide to the power system and in avoided carbon emissions. This can be achieved through the introduction of time-varying prices.

None of these recommendations on its own can deliver accelerated heat decarbonisation at the scale needed to meet the climate targets. Only when combined will we be able to decarbonise heat and unlock the many benefits that smart heat decarbonisation can bring to the energy system and society as a whole.

Introduction

The current EU emission reduction targets[1] are not sufficient to reach the goal of a rapid and nearly complete decarbonisation before 2050, as set out in the Paris Agreement.[2] Recognising this, the new European Commission published the European Green Deal in December 2019 and announced a forthcoming revision to the 2030 greenhouse gas reduction target from 40% to at least 50% and toward 55% based on 1990 levels.[3] This means accelerating the pace of decarbonisation across the entire economy.

Of critical importance in this effort is the decarbonisation of space and water heating; the European Green Deal envisages a "renovation wave" of buildings.[4] In Europe, 31% of the energy consumed is used for space and water heating. This makes it one of the largest elements of consumption in the European energy system[5] — and 75% of this heat is still generated from fossil fuels.[6] Without decarbonising heating, it clearly will be impossible to achieve the reductions in carbon emissions needed to prevent dangerous rises in global temperature. Given the scale of the carbon reduction requirement and the speed of change in the heating sector, rapid and transformational change in how heat is used and generated is needed.

For Europe, it is likely that the decarbonisation of space and water heating will require electrifying significant quantities of existing heat consumption alongside building efficiency upgrades and expansion of the wider electricity system.[7] Heat decarbonisation can happen more rapidly at lower consumer cost and with greater energy system benefits if the transition follows a smart strategy, which takes into consideration all parts of the energy system and maximises system flexibility, that is, the ability of peaks and troughs in energy demand to be minimised and managed. Recognising the increasing interlinkages between different sectors, the European Green Deal announced a strategy for smart sector integration by mid-2020. This paper explores the principles and policies for achieving smart, integrated heat decarbonisation.

Heat is also highly relevant for the power sector because both sectors are expected to converge in many EU decarbonisation scenarios.[8] In other words, if fossil fuels are replaced with electric forms of heating, it will increase the amount of electricity used for heat. Heat pumps are widely seen as a key technology to limit the associated additional capacity requirements, both in the grid as well as in generation. If this electricity is mainly generated from variable, decentralised renewable sources, the demand, or customer, side needs to contribute to a stable electric grid by providing flexibility. Electricity demand will grow even more if green hydrogen becomes a heat energy vector (indirect electrification), unless the production of hydrogen, using methane reformation combined with carbon capture and storage, becomes technically, environmentally and economically viable.

On the demand side, heat decarbonisation will require significant improvements in energy efficiency. These efficiency gains generate direct emissions reductions by lowering heat demand and increasing performance of heating systems,[9] as well as indirect reductions by leveraging

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[1] European Commission. (2019a). *2030 climate & energy framework* [Webpage]. Retrieved from https://ec.europa.eu/clima/policies/strategies/2030_en

[2] Anderson, K., and Broderick, J. (2017). *Natural gas and climate change.* Brussels, Belgium: FOEE. Retrieved from http://www.foeeurope.org/sites/default/files/extractive_industries/2017/natural_gas_and_climate_change_anderson_broderick_october2017.pdf

[3] European Commission. (2019b). *The European Green Deal.* Brussels, Belgium: Author. Retrieved from https://ec.europa.eu/info/sites/info/files/european-green-deal-communication_en.pdf

[4] European Commission, 2019b.

[5] Heat Roadmap Europe. (2017). *Profile of heating and cooling demand in 2015.* Copenhagen, Denmark: Author. Retrieved from https://heatroadmap.eu/wp-content/uploads/2018/11/HRE4_D3.1.pdf

[6] Heat Roadmap Europe, 2017.

[7] Heat Roadmap Europe. (2019). *The legacy of Heat Roadmap Europe 4.* Copenhagen, Denmark: Author. Retrieved from https://heatroadmap.eu/wp-content/uploads/2019/02/HRE_Final-Brochure_web.pdf

[8] Connolly, D., Hansen, K., Drysdale, D., Lund, H., Van Mathiesen, B., Werner, S., et al. (2015). *Enhanced heating and cooling plans to quantify the impact of increased energy efficiency in EU Member States: Translating the Heat Roadmap Europe methodology to Member State level.* (Work package 2. Main report: Executive summary.) Brussels, Belgium: Stratego project. Retrieved from https://www.euroheat.org/wp-content/uploads/2016/04/WP2-Main-Report.pdf

[9] Most heating systems can operate more efficiently at lower flow temperatures. This is the case for both fossil and renewable heating systems.

buildings' thermal storage capacity to increase the flexibility of heating system operations. This demand-side flexibility is critical for integrating new electrical loads into the power system. It is therefore important that policymakers avoid looking at heat in isolation. We can maximise the benefits of heat decarbonisation by considering the interactions among the power sector, heating systems and demand-side flexibility, along with developments in information technology and communications that improve the flexibility of heating system operation. Recognising this, the European Green Deal promised to deliver a "strategy for smart sector integration".[10]

Still, whilst the decarbonisation of heat is technologically possible, it represents a significant institutional and economic challenge. In Europe, most of the buildings that will exist in 2050 have already been built. Therefore, in order to decarbonise space heating, it will be essential to retrofit our existing building stock with low-carbon heating technologies and upgrade their energy performance. This, by default, is disruptive for occupants,[11] is subject to high transaction costs, can be relatively expensive compared to existing fossil fuels[12] and is relatively expensive, thus requiring strong policy support.

The European Commission conducted an assessment of the investments needed to reach the 2030 targets for energy efficiency and renewable energy. It found that about 75% of the required investment will need to be allocated to installing clean energy technologies in buildings, including energy efficiency and renewable heat and generation.[13] As space and hot water heating are the primary energy end uses, most of the investment in buildings must focus on heat.

It is important to note that current heating solutions benefit from decades of optimisation and standardisation. Without dedicated programmes for low-carbon heat, installers and homeowners will tend to stick to business as usual. They will opt for like-for-like replacements of heating systems already familiar to them. The same ease of installation has yet to be achieved for many low-carbon heating solutions. Once delivered at scale, supply chains will innovate and deliver much more seamless offerings.

Whilst heat decarbonisation poses many challenges, it could also offer tremendous opportunities if approached holistically. It can offer significant comfort benefits for households alongside wider socioeconomic benefits, such as the creation of new supply chains, employment, health system savings, improvements in air quality and enhanced energy security.[14] We need integrated policies to exploit those opportunities and capture the many benefits heat decarbonisation can deliver.

This report describes smart heat policy. By "smart", we mean an integrated approach that optimises heat decarbonisation across sectors and maximises the benefits offered by recent technological developments. Heat, as discussed in this report, covers space heating and hot water provision. It does not include industrial heat.

The key questions this report answers include:

- What role should demand-side efficiency and flexibility play?
- How do we align policies intelligently to deliver both decarbonisation and beneficial outcomes from a total energy systems perspective?
- Flexibility offers tremendous value to the energy system. How do we encourage the flexible operation of heating systems, whilst minimising the costs?

The first section of the paper briefly considers the technological options for heat decarbonisation. The next section introduces our principles for smart heat decarbonisation, and the third considers the policy measures that can support our principles.

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[10] European Commission, 2019b.

[11] Through innovation inroads have been made to deliver retrofits more quickly and seamlessly, but there will always be an element of disruption and inconvenience.

[12] As shown in the Netherlands. See CE Delft. (2018). *Kosten voor verwarmer: Analyse van de spreiding bij eindverbruikers* (Heating costs: Analysis of the distribution among end users). Delft, Netherlands: Author. Retrieved from https://www.ce.nl/publicaties/2183/kosten-voor-verwarmen-analyse-van-de-spreiding-bij-eindverbruikers

[13] European Commission. (2019). *United in delivering the Energy Union and Climate Action: Setting the foundations for a successful clean energy transition. (SWD[2019] 212 final}-{SWD[2019] 213 final.)* Brussels, Belgium: Author. Retrieved from https://ec.europa.eu/energy/sites/ener/files/documents/recommondation_en.pdf

[14] The International Energy Agency. (2019a). *The critical role of buildings.* Paris, France: Author. Retrieved from https://www.iea.org/publications/reports/PerspectivesfortheCleanEnergyTransition/

Options for heat decarbonisation

Whilst there are a number of approaches that can be taken to reduce emissions from heating, there are few scalable technologies that can produce zero-carbon heat. This is fundamentally because there are few options to produce zero-carbon energy (e.g., wind, solar, nuclear), and heat technologies must rely on these already limited options.

Heat produced using zero-carbon sources of electricity is a key solution, and heat pumps can be used to maximise system efficiency. Solar thermal technologies may also be able to play an important role, particularly for hot water demand where solar radiation and temperatures are higher at low latitudes. Solar thermal solutions, however, require a second heat generator to provide 100% of end-user demand.

Low-carbon combustion technologies also exist, including bioenergy and waste, which can be combusted as biomass or biogas and hydrogen. In many countries, the potential scale of bioenergy is limited by the availability of the bioresource and remaining questions over land use sustainability and greenhouse reduction potential. Fine particle emissions such as PM2.5 (particulate matter less than 2.5 micrometers in diameter) are another unsolved issue.

Great uncertainty exists on the use of hydrogen in heating, as questions remain around production methods, transmission, its performance as a heating fuel and the cost of production. The more important question is whether a highly valuable resource such as hydrogen[15] should be used for low-grade heat provision when there are other competing uses where alternatives are more constrained. Recent work by the International Energy Agency (IEA)[16] shows the breadth of competing applications, ranging from industry applications, aviation, long-distance vehicle travel and heavy-duty vehicles to power generation, to name just a few.

Whilst we don't discount hydrogen as a potential solution — it may have significant value particularly because it can be used to store large amounts of energy — this paper focuses on the immediate decarbonisation potential of heat electrification and energy efficiency, which can decarbonise heating now and can have wider energy system benefits. It is also worth noting that whilst hydrogen is often presented by incumbent voices as a less disruptive approach than widespread electrification, even ignoring its uncertainty, it cannot be provided at the cost of current fossil energy sources and it will require significant changes. Hydrogen is still likely to require substantial disruption for both consumers and industry with the requirement for hydrogen-suitable appliances, modifications to gas transportation infrastructure and rapid growth in hydrogen production facilities.[17] The costs associated with hydrogen conversion, and the associated uncertainties, mean that electrification is still regarded as a core strategy for heat decarbonisation, even in the UK, where there is a well-developed gas grid.[18]

Given that key scalable low-carbon heating technologies rely at least in part on renewable electricity, it is useful to compare the respective capacity requirements. Previous analysis shows that generating one unit of usable heat through different technologies requires substantially different amounts of renewable electricity.[19] Limiting the number of conversions from one energy vector to another will be important to avoid wasting renewable electricity. Also, the ability to use electricity for converting ambient heat into space and hot water heat provides an option to

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[15] In the future, some hydrogen may not be in this category. If it is the only viable product for electricity that is otherwise constrained off, it is arguably a form of flexibility and not necessarily a premium fuel. This is clearly not a major issue in current systems but in very high renewable systems could play a larger role.

[16] The International Energy Agency. (2019b). *The future of hydrogen.* Paris, France: Author. Retrieved from https://www.iea.org/reports/the-future-of-hydrogen

[17] Ketsopoulou, I., Taylor, P., and Watson, J., eds. (2019). *Disrupting the UK energy system: Causes, impacts and policy implications.* London, UK: UK Energy Research Centre. Retrieved from http://www.ukerc.ac.uk/publications/disrupting-uk-energy-system.html

[18] Committee on Climate Change. (2019a). *Net zero technical report.* London, UK: Author. Retrieved from https://www.theccc.org.uk/wp-content/uploads/2019/05/Net-Zero-Technical-report-CCC.pdf

[19] See Agora Verkehrswende, Agora Energiewende, & Frontier Economics. (2018). *The future cost of electricity-based- synthetic fuels.* Berlin and Cologne, Germany: Authors. Retrieved from https://www.agora-energiewende.de/fileadmin2/Projekte/2017/SynKost_2050/Agora_SynKost_Study_EN_WEB.pdf. There are, of course, other important considerations, such as peak load capacity requirements when comparing different technologies. This particular issue will be discussed in a different section of the paper.

limit the amount of electricity required.

The current potential to use the available green hydrogen for space and hot water heating is very limited. Today, hydrogen production from electrolysis using excess renewable electricity is small — only 2% of global hydrogen production is from electrolysis and this isn't necessarily using renewable electricity.[20] On the future production of hydrogen, the UK's Climate Change Committee concluded for the UK that 'producing hydrogen in bulk from electrolysis would be much more expensive [than producing it from natural gas with carbon capture and storage] and would entail extremely challenging build rates for electricity generation capacity'. The approach of using 'green' renewable hydrogen for heating also appeared significantly more expensive than heat pumps, in part due to the relative conversion efficiencies described previously.[21]

While commentators have suggested that the costs of green hydrogen produced from renewable electricity could fall significantly over the coming decades,[22] this is largely associated with drops in the cost of renewable electricity generation. Reductions in the cost of renewable electricity generation would also lead to cheaper heat electrification. The relative cost differential between green hydrogen and heat pumps would remain, suggesting that heat pumps are always likely to be cheaper than using the combustion of green hydrogen. This section therefore focuses on integrating heating systems that do not rely on gas in a power system with an increasing share of renewables, although it is likely that, for the total decarbonisation of heat, complementary technologies will be needed.

Clearly, there is no one-size-fits-all approach. A study of the Danish energy systems identifies two main options for that country: heat pumps used in buildings in rural locations, and district heating fed by large-scale heat pumps and combined heat and power to serve urban areas.[23] In Sweden, where no large-scale gas grid exists, heat pumps have emerged as the most promising option, with very high penetration, both as building and district heating level solutions.[24] In the United Kingdom, the existence of the extensive gas grid makes change more difficult, not least because fossil-fuel-based solutions are cheaper by comparison. A number of studies suggest that hydrogen could possibly play a supplementary or hybrid role for heating in the UK context.[25]

While this report does not determine what share of the heating load each of those technologies should serve, significant electrification of heat is required for efficient decarbonisation, whatever the balance of technologies. There are uncertainties around many elements that will determine which technologies are most suitable in a particular context, including future technology costs, power system change, further innovation and consumer uptake.

Even though there are significant uncertainties around the technology path, a number of issues are already clear today:

1. **All technological options require substantial improvements in the energy efficiency of the existing building stock in order to be effective at a reasonable cost to consumers.** This report demonstrates why this is the case and why, rather than treating heat demand as an exogenous variable, any pathway needs to place it at the centre of the transition towards a decarbonised heating system.
2. **Decarbonising heat entirely through energy efficiency alone or through sole reliance on low-carbon heat supply is unlikely to be the most economic and feasible option.** The 'right' balance between energy efficiency and flexibility and low-carbon heat supply is highly context-dependent but in most, if not all, cases will

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[20] IEA, 2019b.

[21] Committee on Climate Change. (2018). *Hydrogen in a low-carbon economy.* London, UK: Author. Retrieved from https://www.theccc.org.uk/wp-content/uploads/2018/11/Hydrogen-in-a-low-carbon-economy.pdf

[22] Mathis, W., and Thornhill, J. (2019, 21 August). Hydrogen's plunging price boosts role as climate solution. *Bloomberg News.* Retrieved from https://www.bloomberg.com/news/articles/2019-08-21/cost-of-hydrogen-from-renewables-to-plummet-next-decade-bnef

[23] Lund, H., Möller, B., Mathiesen, B. V., and Dyrelund, A. (2010). The role of district heating in future renewable energy systems. *Energy, 35*(3), 1381-1390.

[24] UK Energy Research Centre. (2016). *Best practice in heat decarbonisation policy.* [Webpage]. London, UK: Author. Retrieved from http://www.ukerc.ac.uk/programmes/technology-and-policy-assessment/best-practice-in-heat-decarbonisation-policy.html

[25] Strbac, G., Pudjianto, D., Sansom, R., Djapic, P., Ameli, H., Shah, N., et al. (2018). *Analysis of Alternative UK Heat Decarbonisation Pathways.* For the Committee on Climate Change. London, UK: Imperial College. Retrieved from https://www.theccc.org.uk/wp-content/uploads/2018/06/Imperial-College-2018-Analysis-of-Alternative-UK-Heat-Decarbonisation-Pathways.pdf

include all three elements in order to avoid unnecessary overinvestment.[26]

3. **Rapid progress needs to be made now.** Waiting another decade or more for technologies to be available at scale is not an option. Policy should focus on known options for heat decarbonisation, such as improving building fabric efficiency, avoiding oil and gas boilers in new buildings, deploying district heating in urban areas and converting fossil-fuel-based heating systems to low-carbon technologies.
4. **Learning how different low-carbon heating technologies perform in different types of buildings, occupied by different occupants, is critical for making informed policy decisions in the future.** This means installing low-carbon heating systems together with energy efficiency improvements in existing buildings, even in building types where there is uncertainty about which option for low-carbon heat will emerge as the dominant one. For example, in dense urban areas, several options might be employed, ranging from district heating systems to hydrogen and heat pumps. This will allow for learning about their performance, potential for flexibility and impact on the energy system.
5. **The embodied carbon emissions of most low-carbon technologies are significantly lower compared to the operational carbon emissions of fossil-fuel heating systems.**[27] It is sometimes argued that switching from a fossil-based heating system to a low carbon solution before the end of its useful life does not result in carbon savings because of the embodied carbon emissions[28] in the low-carbon technology. This has been shown to be inaccurate in many contexts. Hence, early retirement of heating systems can deliver significant carbon savings if the operational emissions of the replacement heating system are close to zero or are very low.

Building on the above, we set out a number of principles and promising strategies for smart heat policies below.

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[26] Hansen, K., Connolly, D., Lund, H., Drysdale, D., and Thellufsen, J. Z. (2016, November). Heat Roadmap Europe: Identifying the balance between saving heat and supplying heat. *Energy, 115*(3), 1663-1671.

[27] Finnegan, S., Jones, C., and Sharples, S. (2018, December). The embodied CO_2e of sustainable energy technologies used in buildings: A review article. *Energy & Buildings, 181,* 50-61.

[28] Embodied carbon emissions are emissions associated with the materials and manufacture of a new system.

Principles for smart, integrated heat decarbonisation

Rather than looking at heat in isolation, there is a strong case for a decarbonisation approach that aligns renewable energy, electrification and energy efficiency. In particular, there are several persuasive arguments why heat decarbonisation requires a significant advance in energy efficiency.

The most obvious reason is that cost-effective energy efficiency reduces overall heat decarbonisation costs by lowering heat demand; it also directly reduces emissions. Furthermore, many heating systems do not operate efficiently and effectively in a poorly insulated building. For example, heat pumps work more efficiently at lower flow temperatures than fossil-fuel systems normally operate, just as fossil-fuel systems can be operated more efficiently at lower flow temperatures. Hence, the deployment of energy efficiency measures opens up buildings to a wider range of low-carbon heat options.

But energy efficiency is also needed for optimising the ability of electric low-carbon heating systems to integrate with variable renewable energy resources through thermal energy storage. The more efficient a building, the more flexible the operation of its heat supply. The building will stay warm longer because it loses less heat.

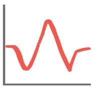
If designed smartly, low-carbon heating systems can offer tremendous value through their diurnal flexibility and their ability to absorb excess renewable electricity and shift load to off-peak periods.

This chapter shows how aligning low-carbon heat with renewable energy and energy efficiency can offer tremendous value: energy efficiency can reduce heat decarbonisation cost, is a technical precondition for the efficient operation of many low-carbon heat technologies and determines the potential for the flexibility of heat demand. The flexible operation of heating systems can deliver substantial value for the energy system, society and consumers. Smart pricing, in turn, can encourage customers to shift their electricity use to capture that value. Each of these integrated heat decarbonisation principles (as seen in Table 1) is discussed below in turn.

Principle 1: Put Efficiency First

Experience shows that environmental, energy and economic goals can be met more reliably and at lower cost if their focus includes both supply-side and demand-side solutions. Taking an efficiency-first approach prioritises investments in customer-side efficiency resources whenever they would cost less or deliver more value than investing in energy infrastructure, fuels and supply

Table 1. Principles for integrated heat decarbonisation

	Principle	Purpose	Policy
	**Principle 1: Put Efficiency First**	Ensure that socially cost-effective energy efficiency opportunities are delivered to avoid unnecessary overinvestment in low-carbon heat supply.	• Building codes, appliance standards and labelling • Financial support schemes • Energy Efficiency Obligations
	**Principle 2: Recognise the value of flexible heat load**	Ensure optimal integration of electric heating loads into the power system to integrate renewables and mitigate avoidable peak load.	• Financial support schemes • Electricity pricing
	**Principle 3: Understand the emissions effects of changes in load**	Operate electric heating systems flexibly to minimise carbon emissions.	• Electricity pricing
€	**Principle 4: Design tariffs to reward flexibility**	Encourage and reward customers for the flexible operation of their heating system.	• Electricity pricing • Carbon intensity standards

alternatives.[29] This approach has been coined “Efficiency First” in Europe and is now an important pillar of European energy and climate policy.

How does this relate to heat? Numerous studies have been conducted on the ideal technology mix for decarbonising heat. Most, if not all, of them agree that, without energy efficiency, the total cost of decarbonising heat will be significantly higher. Energy efficiency reduces heat demand, which in turn ensures a building can be heated at a lower cost through a heating system with a smaller capacity. Reducing heat demand also delivers substantial cost savings for additional generation capacity if all or a large part of heat is electrified.[30]

A report published in 2019 by the IEA[31] on the critical role of buildings for the clean energy transition demonstrates both the significant challenges and potential solutions for decarbonising the built environment, in particular as regards heat. It identifies three key strategies as potential responses. First, create sufficiency by avoiding unnecessary energy demand and technology investment through strategic planning, building design and energy technology measures that address the underlying need for energy use. These measures should at least maintain or even improve service levels in buildings. Second, deliver radical advances in energy efficiency through building fabric improvements and efficient appliances. Third, deliver decarbonisation by replacing carbon intensive technologies with high-performance, low-carbon solutions.

At the EU level, the Union of the Electricity Industry — Eurelectric[32] — recently presented its decarbonisation pathways, showing that energy efficiency must be the main source of emissions reduction in buildings, followed by electrification through heat pumps. Modelling by Heat Roadmap Europe of the optimal balance between heat savings and supply in four EU countries (Czech Republic, Croatia, Italy and Romania) indicates that 30% to 50% of projected heat demand should be avoided through energy savings measures. It also recommends that the residual heat demand be provided through low-carbon sources such as heat pumps and district heating fed by low-carbon heat sources.[33]

These findings are mirrored by national studies. Analysis commissioned by Agora Energiewende[34] shows that a scenario for heat decarbonisation in Germany involving both significant energy efficiency improvements and heat pumps is considerably cheaper to attain compared to all other scenarios. A similar study by the Wuppertal Institute[35] about Germany shows that the emission reductions needed to meet climate goals — especially those from the electrification of heating — are much more easily achievable, from both a technological and economic standpoint, if associated with substantial energy efficiency improvements.

Analysis of UK household energy demand scenarios shows that an approach combining energy efficiency and heat pumps can deliver cost-effective energy savings of around 25%.[36] The UK’s Climate Change Committee recently called on its government to significantly increase the rate of energy efficiency retrofits, saying UK homes were “unfit for the future”.[37] District heating systems can also benefit significantly from improved end-use energy efficiency. Experience from Poland through the Krakow Energy Efficiency Project demonstrates that by investing not only in the network itself, but also improving the efficiency of the

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[29] Cowart, R. (2014). *Unlocking the promise of the Energy Union: “Efficiency first” is key.* Brussels, Belgium: Regulatory Assistance Project. Retrieved from https://www.raponline.org/knowledge-center/unlocking-the-promise-of-the-energy-union-efficiency-first-is-key/

[30] Eyre, N., and Baruah, P. (2015, December). Uncertainties in future energy demand in UK residential heating. *Energy Policy, 87,* 641-653.

[31] IEA, 2019a.

[32] Eurelectric. (2019). *Decarbonisation pathways.* Brussels, Belgium: Author. Retrieved from https://cdn.eurelectric.org/media/3457/decarbonisation-pathways-h-5A25D8D1.pdf

[33] Hansen et al., 2016.

[34] Agora Energiewende. (2018). *Building sector Efficiency: A crucial Component of the Energy Transition. Final report on a study conducted by Institut für Energie- und Umweltforschung Heidelberg (Ifeu), Fraunhofer IEE and Consentec.* Berlin, Germany: Author. Retrieved from: https://www.agora-energiewende.de/en/publications/building-sector-efficiency-a-crucial-component-of-the-energy-transition/

[35] Lechtenböhmer, S., Schneider, C., and Samadi, S. (2017). *Energy efficiency quo vadis?: The role of energy efficiency in a 100% renewable future.* Stockholm, Sweden: Wuppertal Institut. Retrieved from https://epub.wupperinst.org/frontdoor/index/index/docId/6706

[36] Rosenow, J., Guertler, P., Sorrell, S., and Eyre, N. (2018, October). The remaining potential for energy savings in UK households. *Energy Policy, 121,* 542-552.

[37] Committee on Climate Change. (2019b). *UK housing: Fit for the future?* London, UK: Author. Retrieved from https://www.theccc.org.uk/wp-content/uploads/2019/02/UK-housing-Fit-for-the-future-CCC-2019.pdf

buildings that consume the heat, is a highly cost-effective approach that benefits consumers directly whilst improving the efficiency of the district heating system.[38] More efficient buildings enable more efficient operation of the district heating network at lower temperatures, allowing it to integrate lower-grade heat sources such as low temperature geothermal, large-scale heat pumps and waste industrial heat. This approach is called fourth generation district heating.[39]

Principle 2: Recognise the value of flexible heat load

A key challenge of heat decarbonisation through electrification is the increase in both electricity network capacity and the increase in electricity generation capacity needed to support heat electrification. This challenge has been highlighted by incumbents in both the UK[40] and the Netherlands.[41] Whilst the electrification of heating is of course likely to increase the capacity requirements of electricity systems, demand-side flexibility has the potential to limit the increase in capacity requirements and therefore reduce resulting energy system costs.

The value of flexibility

Flexibility of energy systems can reduce system capacity and increase utilisation of assets therefore reducing consumer costs whilst at the same time increasing the potential for the integration of intermittent renewable electricity generation sources. Analysis of the UK's energy system has shown that flexibility provided by an optimal combination of demand-side response (i.e., flexible load), storage, electricity interconnection and dedicated peaking plants (electricity generation only used at times of particularly high demand) could reduce the cost of electricity decarbonisation.[42] Further analysis has highlighted the potential for flexibility in residential sector energy use, including that associated with heat electrification, to reduce decarbonisation costs.[43]

Low-carbon heating technologies may offer potential for integrating an increasing share of variable renewable energy resources (particularly wind) in the power system,[44] and indeed, electrifying heat smartly may be an important approach to encourage investment in a balanced and cost-effective renewable electricity system. For example, the smart operation of heat pumps (either in individual homes or as part of district heating networks) could provide a flexible resource to accommodate larger shares of wind power reducing curtailment.[45]

In the past, most attention has been paid to flexibility in power systems with limited attention given to heat demand. With increasing integration of the power and heat sectors, heat flexibility becomes highly relevant. Operating heating systems using electricity as the main or significant fuel flexibly offers a whole suite of different power system benefits that fall broadly into three different categories — grid benefits, energy cost savings (if time-varying tariffs are present) and renewable energy integration, as depicted in Figure 1). In a system with a high share of variable renewables, district heating networks and heat pumps operated in efficient buildings provide a flexible resource that can follow renewable generation over the course of a day.[46] Thermal storage

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[38] Rosenow, J., Bayer, E., Genard, Q., Toporek, M., and Rososińska, B. (2016). *Efficiency first: From principle to practice; Real world examples from across Europe.* Energy Union Choices. Retrieved from https://www.raponline.org/wp-content/uploads/2016/11/efficiency-first-principle-practice-2016-november.pdf

[39] Lund, H., Østergaard, P. A., Chang, M., Werner, S., Svendsen, S., Sorknæs, P., et al. (2018). The status of 4th generation district heating: Research and results. *Energy, 164,* 147-159.

[40] Lowes, R., Woodman, B., and Clark, M. (2018). *Incumbency in the UK heat sector and implications for the transformation towards low-carbon heating.* (Working paper.) London, UK: UKERC. Retrieved from http://www.ukerc.ac.uk/publications/incumbency-in-the-uk-heat-sector.html

[41] Lowes, R. (2019). *Power and heat transformation policy: Actor influence on the development of the UK 's heat strategy and the GB Renewable Heat Incentive with a comparative Dutch case study.* PhD thesis. University of Exeter. Retrieved from https://ore.exeter.ac.uk/repository/handle/10871/38940

[42] Sanders, D., Hart, A., Ravishankar, M., and Brunert, J. (2016). *An analysis of electricity system flexibility for Great Britain.* London, UK: Carbon Trust and Imperial College London. Retrieved from https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/568982/An_analysis_of_electricity_flexibility_for_Great_Britain.pdf

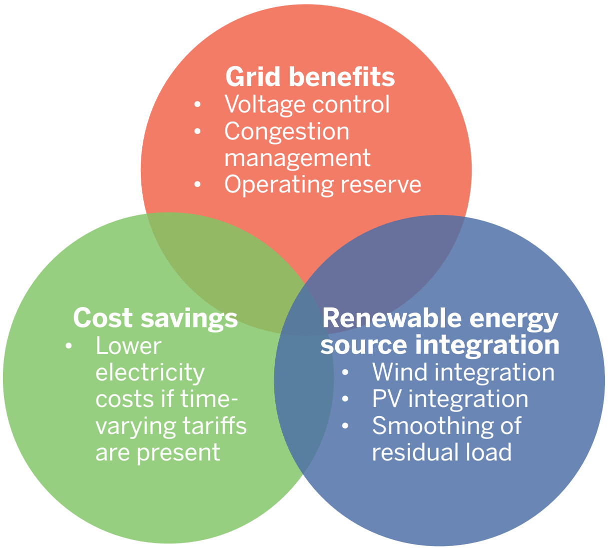
[43] Ovo Energy and Imperial College London. (2018). *Blueprint for a post-carbon society: How residential flexibility is key to decarbonising power, heat and transport.* Bristol and London, UK: Authors. Retrieved from https://www.ovoenergy.com/binaries/content/assets/documents/pdfs/newsroom/blueprint-for-a-post-carbon-society-how-residential-flexibility-is-key-to-decarbonising-power-heat-and-transport/blueprintforapostcarbonsocietypdf-compressed.pdf

[44] Strbac et al., 2018.

[45] Ruhnau, O., Hirth, L., and Praktiknjo, A. (2019). *Heating with wind: Economics of heat pumps and variable renewables.* (Working paper.) Kiel and Hamburg, Germany: ZBW — Leibniz Information Centre for Economics.

[46] Seasonal storage and flexibility are addressed elsewhere in the report.

Figure 1. Benefits of heat flexibility[47]



Source: Fischer, D. and Madani, H. (2017). *On heat pumps and smart grids: A review.*

(especially where effectively increased by energy efficiency) increases the flexibility of the electricity system. Storing heat as hot water, or in the existing thermal mass of buildings, is also considerably cheaper than storing electricity.[48]

There is no reason to assume that heat pump and district heating energy demand will be flat or follow the load profile of conventional fossil fuel heating systems. If that was the case, this would result in increased peak load potentially requiring costly generation capacity expansion and network upgrades. For example, based on standard user practices, data from the UK shows that if 20% of all buildings were fitted with heat pumps this would add 14% to peak load.[49] To avoid such an increase in peak load, load shifting is critical. This provides diurnal flexibility. Given the seasonal variation in heat loads, intraseasonal storage will be required once electrified heating has reached scale. There are uncertainties around the level of storage required and the best ways of delivering this. As the rollout of low-carbon heating technologies continues, a better understanding of the seasonal storage needs and opportunities will emerge. At this point, seasonal storage is not an active barrier to heat decarbonisation in most countries and should not be seen as a reason for stalling progress.

Diurnal flexibility

There are options, however, for substantially reducing the impact of increasing peak demand. Luckily, heat pumps can operate flexibly over the course of a day and, if managed well, can be a valuable resource to the power system. At times of abundant electricity produced from renewable sources, heat generated by a heat pump can be stored in the structure of the building or in a thermal energy storage tank (used for space and/or hot water heating). In Europe, most heat pump systems connect to a water-based system that includes a hot water tank (although some systems are for hot water only).[50] The building envelope and the water tank can be understood as a diurnal battery for heat storage. When combined with energy efficiency enhancements to improve the heat retention characteristics of a building and/or a water tank, heat pumps can operate much more flexibly, minimising on-peak electricity demand. The higher the energy efficiency of a building, the higher its ability to modulate heat demand over time.[51]

The potential for such demand-side flexibility is surprisingly large. Even without a hot water tank used for space heating, heat pumps deployed in energy efficient buildings can be turned off for periods of several hours without affecting thermal comfort.[52] Countries that have reported long off-periods range from Denmark (five to six hours at 5°C outside temperature and two to three hours at -12°C outside temperature), Switzerland (all house types can achieve off-blocks of more than six hours, with the most highly insulated buildings achieving off-blocks of more than 12 hours) and Austria (length of off-blocks at temperatures above -7°C were between five and 10 hours).[53] A UK study

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[47] Fischer, D., and Madani, H. (2017, April). On heat pumps in smart grids: A review. *Renewable and Sustainable Energy Reviews, 70*(C), 342-357.

[48] Zhai, Z., Abarr, M. L. L., Al-Saadi, S. N. J., and Yate, P. (2014). Energy storage technologies for residential buildings. *Journal of Architectural Engineering, 20*(4), B4014004.

[49] In this study, some heat pumps analysed ran on the basis that the house was heated continuously, and others ran so that the house was only heated at certain times as needed. Love, J., Smith, A. Z., Watson, S., Oikonomou, E., Summerfield, A., Gleeson, C., et al. (2017, October). The addition of heat pump electricity load profiles to GB electricity demand: Evidence from a heat pump field trial. *Applied Energy,* 204, 332-342.

[50] Fischer, D., et al. (2017).

[51] Dreau, J. L., and Heiselberg, P. K. (2016, September). Energy flexibility of residential buildings using short term heat storage in the thermal mass. *Energy, 111,* 991-1002.

[52] Arteconi, A., Hewitt, N. J., and Polonara, F. (2013, March). Domestic demand-side management (DSM): Role of heat pumps and thermal energy storage (TES) systems. *Applied Thermal Engineering, 51*(1-2), 155-165.

[53] Arteconi et al., 2013.

shows that a standard building construction with moderate levels of insulation can maintain thermal comfort for a two-hour off-period given sufficient (four hours) notice, with a standard air source heat pump and no additional thermal storage. This comfort is maintained during an average cold winter period.[54] Studies have shown that it is important that buildings offer sufficient heat storage capability to shift load over longer periods. Trials in buildings where this has not been the case highlight insufficient load shifting opportunities.[55]

Similarly, district heating systems can be highly flexible.[56] Heat fed into the district heating network can be stored in (a) the heat carrier fluid, (b) thermal storage devices and (c) the thermal inertia of the buildings where heat is supplied. The water in the district heating network and the thermal storage capabilities of the building envelope are typically used for intraday balancing.[57]

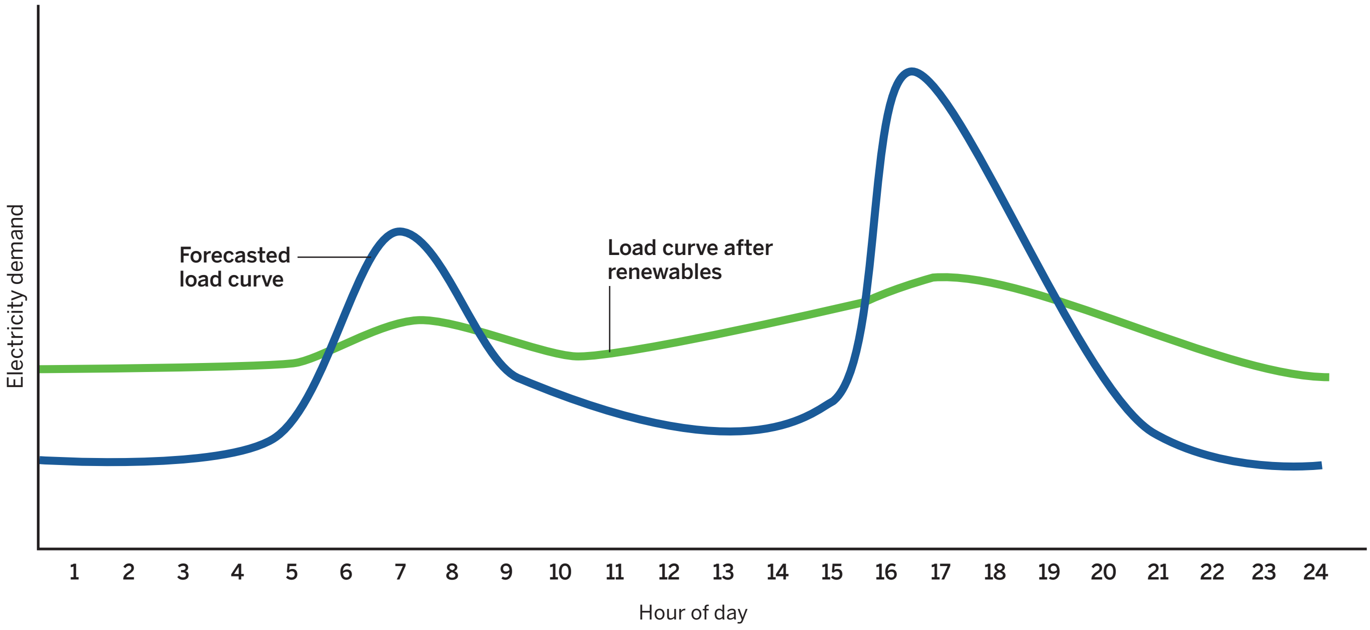
An idealised load curve where heat demand is shifted from on-peak to off-peak periods is sketched below in Figure 2, where the use of wind power reduced morning peak and the use of solar power lowered the evening peak.

The extent to which such flexibility is needed and possible depends on a range of factors, including the daily and seasonal patterns of renewable generation, the energy performance of the building and the availability of a thermal storage tank. It also requires smart controls that operate the heat pumps in response to signals, such as pricing. This will only be possible if the building occupants agree to this kind of heating system operation.

In some locations, the need for flexibility is less profound as renewable energy generation may coincide with uncontrolled heat pump operation. The adoption of controlled heat pumps could take advantage of this surplus. For example, even without adjusted controls, the electricity demand of heat pumps certainly matches the availability of electricity generated by wind power in Denmark.[58]

Solar energy, both photovoltaic and thermal, can provide near zero-carbon energy, and for countries with low space

Figure 2. Heat load flexibility



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[54] Delta Energy & Environment. (2018). *IEA HPT Programme Annex: Heat pumps in smart grids; UK executive summary.* Edinburgh, Scotland: Author. Summary. Retrieved from https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/680514/heat-pumps-smart-grids-executive-summary.pdf

[55] Sweetnam, T., Fell, M., Oikonomou, E., and Oreszczyn, T. (2018, March). Domestic demand-side response with heat pumps: Controls and tariffs. *Buildings Research & Information*, *47*(4), 344-361. 36

[56] Luc, K. M., Heller, A., and Rode, C. (2019). Energy demand flexibility in buildings and district heating systems — a literature review. *Advances in Building Energy Research*, *13*(2), 241-263.

[57] Vandermeulen, A., van der Heijde, B., and Helsen, L. (2018, May). Controlling district heating and cooling networks to unlock flexibility: A review. *Energy, 151*, 103-115.

[58] Hedegaard, K., and Münster, M. (2013, November). Influence of individual heat pumps on wind power integration — energy system investments and operation. *Energy Conversion Management 75*, 673-684. Retrieved from https://www.sciencedirect.com/science/article/pii/S0196890413004743

heating demand and high solar irradiation, solar thermal is an extremely valuable technology. The potential for solar energy to contribute to heat decarbonisation, however, is limited in countries at higher latitudes that are generally colder and receive lower levels of solar irradiation. Analysis suggests that solar thermal could likely provide only minimal primary heat energy supply even in a cost-effective decarbonised energy system across the 14 largest EU member states.[59] While hot water is required all year, solar output peaks in summer at times of lower energy demand and provides its lowest levels of output in winter, when heat demand is highest. Whilst there may be some solar output in winter, there may be days when it is overcast and cold, and output is negligible and demand is high. As a result, building-level heating systems, and the wider energy system, may need to be built to a capacity that sees solar play no role on the highest heat demand day. Whilst the role for high latitude solar may currently appear limited, further drops in generation and storage costs could increase its role.

Batteries could potentially add further flexibility. Whilst it is unlikely that it will be feasible and economic to use electric batteries solely for the purpose of heat decarbonisation, they could provide some value. There are currently ongoing pilots with heat batteries. These batteries are heat storage systems using phase change materials (PCMs) to store a concentrated amount of heat in a relatively small space. They are charged via a heat pump or direct electric heating during off-peak hours and discharged when heat is required during on-peak periods. Heat batteries can therefore enable buildings with limited thermal storage capabilities to operate more flexibly, avoiding peak load periods and utilising cheaper off-peak electricity.[60] The only energy that is used during on-peak times is the central heating pump to circulate water within the heating system, but this is significantly less than the energy required for heating itself.

An evaluation of early trials showed that properties with heat batteries and heat pumps consumed 85% of electricity on average during off-peak periods with only 15% falling into on-peak periods whilst maintaining thermal comfort.[61] It is worth noting that heat batteries are still in the early stages of commercialisation with only a small number of units installed to date. With innovation and increased deployment, it is likely that the costs of heat batteries will come down whilst their capacity will increase. Recently, Scotland has (as the first country in the world) provided dedicated support for financing heat batteries through its Home Energy Scotland Loans.[62]

The importance of seasonal balancing

As the previous section shows, the potential for diurnal flexibility is relatively large and, if operated smartly, can limit peak load consumption. Intraseasonal balancing is, however, more challenging. Prolonged periods of extremely cold weather could result in significant demand for additional capacity. The relatively small number of electric low-carbon heating systems currently installed in most EU countries creates no significant problems and should not be a reason for delaying the rollout of low-carbon heat technologies. With increasing penetration, it will be important to put in place solutions that offer intraseasonal storage and balancing capabilities.

Two primary options exist:

- **Seasonal thermal storage.** When connected to a district heating network, thermal storage devices — such as large storage tanks, pits and groundwater-carrying layers — can also be used for seasonal storage.[63] In Europe, large-scale seasonal thermal energy storage has operated since the 1970s, with the first pilot projects in Sweden.[64] On the heat supply side of the district heating system, large-scale heat pumps can operate in such a way that

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[59] Heat Roadmap Europe, 2019.

[60] Angenendt, G., Zurmühlen, S. Rücker, F., Axelsen, H., and. Sauer, D. (2019, January). Optimization and operation of integrated homes with photovoltaic battery energy storage systems and power-to-heat coupling. *Energy Conversion and Management, 1,* 100005.

[61] Shepherd, T. (2018). *Various heating solutions for social housing in North Lincolnshire: Ongo Homes.* Technical Evaluation Report. NEA Technical Innovation Fund. Newcastle upon Tyne, UK: National Energy Action. Retrieved from https://www.sunamp.com/wp-content/uploads/2019/04/CP780-TIF-REPORT-Aug-18-FINAL-1.pdf

[62] Power Technology. (2018). *Heat batteries to be included in Home Energy Scotland loans. Power Technology: Energy news and market analysis* [Webpage]. Retrieved from https://www.power-technology.com/news/heat-batteries-included-home-energy-scotland-loan-scheme/

[63] Vandermeulen, et al. (2018).

[64] Mangold, D., and Deschaintre, L. (2015). *Seasonal thermal energy storage: Report on state of the art and necessary further R+D.* IEA: Solar Heating & Cooling Programme. Paris, France: International Energy Agency. Retrieved from http://task45.iea-shc.org/data/sites/1/publications/IEA_SHC_Task45_B_Report.pdf

uses excess renewable electricity to avoid curtailment.[65] Solar thermal may also play a greater role if combined with interseasonal storage (possibly alongside district heating).[66] One notably large Danish project, which includes interseasonal thermal storage in a pit, is now fully operational.[67]

- Seasonal storage of hydrogen produced from renewable electricity. During particularly cold days, increased demand through electrified end uses could be met by running thermal power plants using hydrogen. The first industrial-scale hydrogen power plant located in Italy has now been running for almost a decade.[68]

In countries with existing gas distribution infrastructure, hybrid or bivalent systems that combine a heat pump with a combustion boiler may be able to provide a balancing function. In both the UK and the Netherlands, which both have extensive gas distribution networks, it's been suggested that hybrid systems may be able to play a cost-effective role for heat decarbonisation.[69] Hybrid systems generally include a heat pump that is sized to not meet the maximum demand of a building on its highest demand (coldest) day. On cold days, which are likely to coincide with highest electricity demand, combustion heating is used, reducing electricity demand. This, in theory, reduces the electricity system's capacity requirements and utilises existing gas network capacity. However, for these systems to be zero carbon, only zero-carbon gas such as hydrogen or sustainable biogas capacity could be used for this peaking. Interseasonally stored hydrogen could be used in hybrid systems in order to balance the system. Questions, however, remain over the consumer issues associated with requiring two heating appliances. This approach is fundamentally based around electrification with hydrogen backup.

Principle 3: Understand the emissions effects of changes in load

The average emissions from many electricity grids in Europe have decreased in recent decades, reflecting how successful the countries have been in reducing overall power plant emissions.[70] But because electrification will add load, it is important to account for the emissions from the generating resources that will serve that load and to add load in a way that aligns with low- or zero-emitting resources, maximizing the emissions benefits of electrification.

Knowing the electricity generation source used to power devices, like heat pumps, and how this development is likely crucial for determining the overall potential emissions reduction. Electricity supply and demand must be balanced in real time, and the last generating unit added to meet demand is referred to as the marginal unit. Around Europe, marginal units vary over the course of the day and year, depending on fuel availability and operational characteristics, such as the capability to cycle (turn on or off) and ramp (turn up or down) when needed.

Because heat electrification will increase load, managing a system's marginal emissions is especially important as electrification increases and European policymakers seek to determine related emissions effects. A marginal emissions analysis shows, in aggregate, the emissions from the resource on the margin in a system, meaning the emissions that would be added with the use of one more kWh, or that would be deducted if a kWh is avoided, at each time period during the year. CO_2 emissions per kWh generated vary significantly over the course of a single day, as data from the UK shows in Figure 3.

Also important will be a sense of the expected emissions

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[65] Münster, M., Morthorst, P. E., Larsen, H.V., Bregnbæk, L., Werling, J., Lindboe, H. H., and Ravn, H. (2012, December). The role of district heating in the future Danish energy system. *Energy, 48*(1), 47-55.

[66] Eames, P., Loveday, D., Haines, V., and Romanos, P. (2014) *The future role of thermal energy storage in the UK energy system: An assessment of the technical feasibility and factors influencing adoption.* (Research report.) London, UK: (UKERC. Retrieved from http://www.ukerc.ac.uk/asset/82664E2B-6533-4019-BF5140CEB7B9894D/

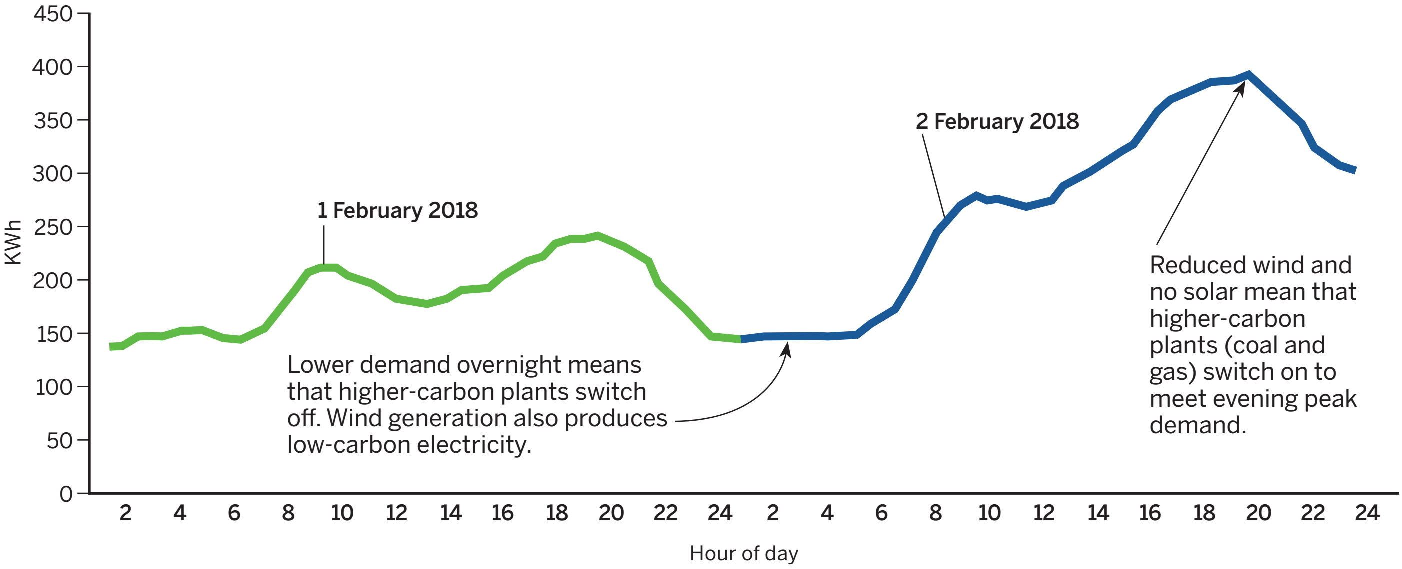
[67] State of Green. (2019). *World's largest thermal storage pit in Vojens* [Webpage]. Retrieved from https://stateofgreen.com/en/partners/ramboll/solutions/world-largest-thermal-pit-storage-in-vojens/

[68] Enel. (2010, 12 July). Enel: At Fusina (Venice), inauguration of first industrial-scale hydrogen plant in the world [Press release]. Retrieved from https://www.enel.com/media/press/d/2010/07/enel-at-fusina-venice-inauguration-of-first-industrial-scale-hydrogen-plant-in-the-world

[69] Strbac et al., 2018; and Government of the Netherlands. (2018). Klimaatakoord (Climate agreement). The Hague, Netherlands., Retrieved from https://www.klimaatakkoord.nl/documenten/publicaties/2019/06/28/klimaatakkoord

[70] European Environment Agency. (2018). Electricity generation — CO2 emission intensity [Table]. Retrieved from https://www.eea.europa.eu/data-and-maps/daviz/co2-emission-intensity-5#tab-googlechartid_chart_11_filters=%7B%22rowFilters%22%3A%7B%7D%3B%22columnFilters%22%3A%7B%22pre_config_ugeo%22%3A%5B%22European%20Union%20(current%20composition)%22%5D%7D%7D

Figure 3. Carbon intensity of generation[71]



Source: National Grid (2018). *Future energy scenarios.*

when significant amounts of electrification load are added to the grid. It will be necessary to understand how much additional low-carbon generation will be needed if one expects there to be hundreds of thousands of heat pumps. This will require an analysis of the emissions impact of heat load by comparing, over the long term, business-as-usual generation and expected generation with electrified heat in place.

The smart operation of heating systems can directly contribute to reducing emissions by shifting demand to those hours where electricity is cleanest. Technology is already available to optimise heating system operation based on the carbon intensity of the grid.[72] If controlled in this way, heating systems can switch on and off depending on the carbon emissions at a given time. Also, high emissions generally occur at the same time as high electricity prices as the marginal plant is often the highest carbon. Algorithms taking into account forecasts of carbon emissions and the required comfort levels allow the smart operation of heating systems. An additional tool is the use of pricing as a signal to guide heating system operation as the following principle demonstrates.

Principle 4: Design tariffs to reward flexibility

Smart pricing encourages customers to shift their electricity use from periods with high electricity prices (and higher marginal emissions) to periods with lower prices (and lower emissions). That is, smart tariffs help ensure that choices consumers make to minimise their own utility bills are consistent with choices that also minimise overall system costs and carbon intensity.[73] Electricity tariffs can be designed in such a way to make optimal use of existing power system infrastructure whilst limiting future system costs. They also empower adopters of low-carbon heating systems to save on the costs of operating them, whilst reducing system costs and thus benefitting all consumers. To the extent existing infrastructure can accommodate additional demand, grid costs can be spread over a larger volume of consumption, thus reducing electricity prices instead of driving unnecessary new investment and higher costs.

We already know that customers are willing to shift their consumption to cheaper hours of the day if the financial

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[71] National Grid. (2018). *Future energy scenarios*, p. 32. Warwick, UK: Author. Retrieved from http://fes.nationalgrid.com/media/1363/fes-interactive-version-final.pdf

[72] See, for example, Delta Energy & Environment. (2014). *IEA HPT Annex 42: Heat pumps in smart grids; Review of smart ready products United Kingdom.* Edinburgh, Scotland: Author. Retrieved from https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/341743/Delta-ee_Smart_Ready_Heat_Pumps_in_UK_22_Jan_14_FINAL.pdf

[73] Farnsworth, D., Shipley, J., Lazar, J., and Seidman, N. (2018). *Beneficial electrification: Ensuring electrification in the public interest.* Montpelier, VT: Regulatory Assistance Project. Retrieved from https://www.raponline.org/wp-content/uploads/2018/06/6-19-2018-RAP-BE-Principles2.pdf

incentive is meaningful. For example, price can dramatically influence when electric vehicle owners charge their vehicles at home.[74] A recent report from the UK testing variable pricing demonstrated that users shift about 70% of charging out of peak hours.[75]

Examples of such pricing range from time-of-use (TOU) tariffs — where the consumer pays a variable, predetermined fee for specific blocks of time based on historical usage patterns (such as a day and night or a weekday and weekend tariff) — to the most granular real-time pricing, where the price is determined by actual conditions on the system from one interval to the next. In between the two, critical peak pricing sets significantly higher prices for a limited number of prenotified critical peak periods. Another emerging tariff form is the peak-time rebate. Consumers on such a tariff receive a partial refund if they avoid using electricity during peak hours but are charged a uniform price for electricity regardless of whether it is consumed during peak periods or any other time of day.

One example of a time-varying tariff is provided below. The Octopus Agile tariff in the UK offers half-hourly prices that are linked to the half-hourly wholesale market prices. More specifically, the supplier determines on a daily basis the rates that apply to the customers based on a formula that is tied to the day-ahead, half-hourly wholesale price. The company then communicates the applicable rates to the final consumers at 4 p.m. every day through its smart phone application, giving them sufficient time to adapt their consumption for the following day. A prerequisite to signing up for this tariff is the possession of a smart meter that can take half-hourly consumption measurements and send them to the supplier for billing purposes. An additional feature of the tariff is that it can inform consumers when wholesale prices drop below zero and pay them if they consume electricity during those times. This information can either be shared via text message alerts, allowing consumers to manually change their consumption, or directly to the consumer's pre-programmed smart appliances. Figure 4 depicts the load profile of a household with a heat pump and the Octopus Agile tariff for a 24-hour period, demonstrating clearly how load-shifting to off-peak hours corresponds well with the tariff structure.

Danish eFlex Project

From 2011 to 2012, DONG Energy Eldistribution carried out a trial project to test responsiveness of consumers to incentives for demand-side response. The aim of the project was to identify the most effective incentives that would mobilise demand-side response in order to defer or avoid grid costs. Most of the participating households had heat pumps installed.

Participating households were provided with a heating automation system with an integrated control unit, which would interrupt the heat pump during peak periods and turn it back on when peak periods had passed. Automation was based on price signals based on the North Pool day-ahead electricity market and minimum comfort levels. The system allowed users to override the automation if they wanted to.[76]

The project showed that there was significant potential for heat pump load management — customers on average overrode turn-down events 1% of the time, or approximately once in three months.[77] This shows that households do respond to pricing incentives and are receptive to automation based on price signals. The project did find that during periods of extraordinarily cold weather, the potential for flexibility was more limited.

To what extent users will be subjected willingly to time-variable pricing and be able (and willing) to shift heat demand is uncertain. Experience from Denmark — testing automated heat pump demand-side response guided by

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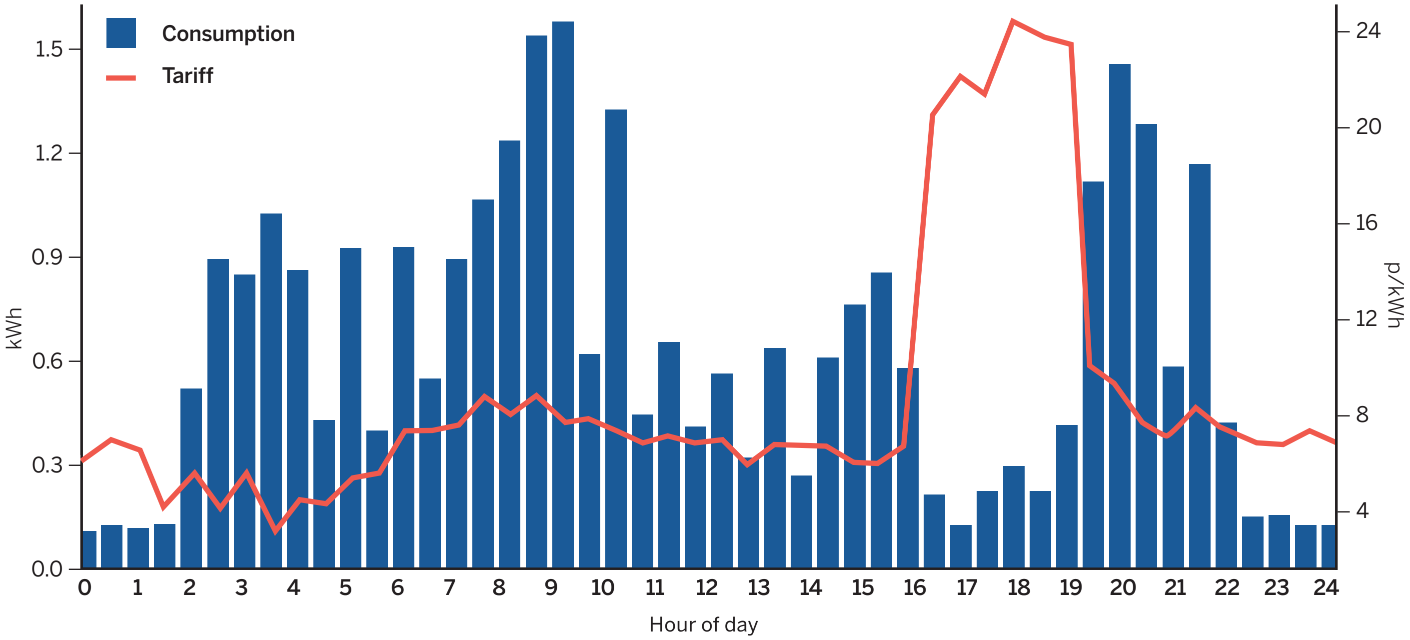
[74] Hildermeier, J., Kolokathis, C., Rosenow, J., Hogan, M., Wiese, C., and Jahn, A. (2019). *Start with smart: Promising practices for integrating electric vehicles into the grid.* Montpelier, VT: Regulatory Assistance Project. Retrieved from https://www.raponline.org/knowledge-center/start-with-smart-promising-practices-integrating-electric-vehicles-grid/

[75] Transport Research Laboratory. (2019). *Project report: Consumers, vehicles and energy integration.* (Project PPR917.) Berkshire, UK: Author. Retrieved from https://trl.co.uk/sites/default/files/CVEI%20D5.3%20-%20Consumer%20Charging%20Trials%20Report.pdf

[76] Dong Energy Eldistribution A/S. (2012). *DONG Energy Eldistribution A/S Department of Grid Strategy.* The eFlex Project. Author. Virum, Denmark.

[77] Sweetnam et al., 2019.

Figure 4. Example of time-varying tariff and load shifting of heat pump consumption



prices — indicates that consumers will respond to price signals if automation is present. The Danish eFlex Project sidebar (on the previous page) provides more information.

Although smart pricing is an essential component of the smart operation of heating systems, its effectiveness will be limited if it is not accompanied by a means for customers to easily and efficiently respond to that pricing.

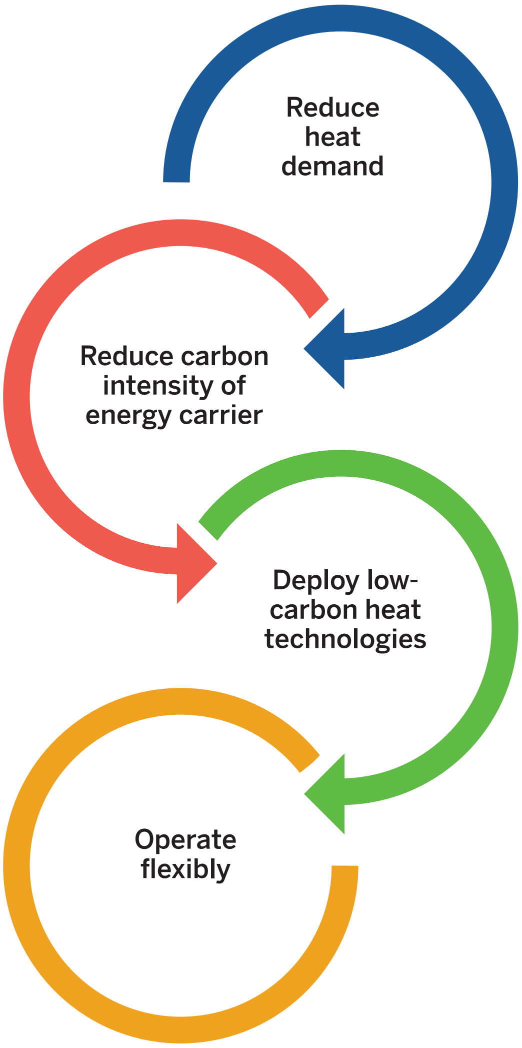
The effectiveness of pricing can be maximised with the use of smart technology, such as automated systems of load control. The reverse is also true: the deployment of smart technologies will have limited benefits without smart tariffs. So far, there is limited real-world experience with time-variable pricing and the responsiveness of low-carbon heating systems.

Designing policies for smart heat

As previously demonstrated, a smart approach can deliver heat decarbonisation not in isolation but as a package that includes energy efficiency, flexibility, pricing and smart operation of heating systems. Considering the principles for integrated heat decarbonisation, this section sets out a number of policies that can deliver on this.

The first step of any heat decarbonisation policy must always cost-effectively reduce heat demand. The remaining heat demand should then be satisfied by energy carriers with low- or zero-carbon emissions supplied by low-carbon heat technologies. Those technologies should operate flexibly (if possible) in such a way that is most beneficial for the energy system, integrating variable renewable resources, lowering carbon emissions and reducing cost for consumers.

Figure 5. Smart heat policy logic[78]



Source: Chaudry, M., Abeysekera, M., Hosseini, S.H.R., Jenkins, N., and Wu, J. (2015). Uncertainties in decarbonising heat in the UK.

Smart heat policy maximises the benefits of heat decarbonisation for the energy system. It encourages flexible operation of electric heating systems through pricing and smart technology. Time-of-use tariffs or more sophisticated pricing strategies, coupled with thermal storage through efficient buildings and hot water tanks, reduce operational cost of heat pumps and incentivise load shifting.[79] Figure 5 demonstrates what smart heat policy logic can look like.

Another consideration is that most heating systems are replaced when they fail; they often fail during cold periods when a new system is needed quickly. When such so-called distress purchases are being made, there is often limited time to assess other (low-carbon) heating solutions, and a like-for-like replacement takes place. Policies need to be designed around such trigger points to ensure that lock-in of fossil-fuel-based heating systems does not occur when replacing heating systems.

Building codes, appliance standards and labelling

Building codes, appliance standards, and labelling are critical for supporting heat decarbonisation to avoid lock-in of new fossil-fuel-based heating systems, to phase out existing heating systems, and to improve energy efficiency.

Building codes require specific levels of energy performance and limit carbon emissions. It is essential that both energy efficiency and clean energy generation technologies can be used in combination to allow homeowners to meet the building code requirements at minimum cost. For new buildings, the Energy Performance of Buildings Directive (EPBD) provides a framework implemented by EU Member States to gradually tighten low-carbon requirements

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[78] Chaudry, M., Abeysekera, M., Hosseini, S. H. R., Jenkins, N., and Wu, J. (2015, December). Uncertainties in decarbonising heat in the UK. *Energy Policy*, *87*, 623-640. Retrieved from https://www.sciencedirect.com/science/article/pii/S0301421515300306.

[79] Renaldi, R., Kiprakis, A., and Friedrich, D. (2017, January). An optimisation framework for thermal energy storage integration in a residential heat pump heating system. *Applied Energy*, *286*(3), 520-529. Retrieved from https://www.sciencedirect.com/science/article/pii/S0306261916302045

for buildings. The EPBD requires all new buildings from 2021 (public buildings from 2019) to be nearly zero-energy buildings (NZEB). This should result in an increasing share of new buildings fitted with low-carbon heating systems. The impact on existing buildings is less significant as the EPBD requirements only apply in case of major renovations (affecting more than 25% of the surface area of a building or its value). There are, however, opportunities to introduce stricter national minimum standards for existing buildings, for example applicable at the point of sale or rental.[80]

Building codes can also phase out the installation of fossil fuel heating systems in new and existing buildings more explicitly. Some European countries have already taken steps in that direction with different levels of ambition:

- Denmark banned the installation of oil-fired boilers and natural gas boilers in new buildings in 2013 and also banned the installation of new oil-fired boilers in existing buildings in areas where district heating or natural gas is available beginning in 2016.[81]
- Norway has banned oil-fired heating systems in all buildings (new and existing) beginning in 2020. Existing oil boilers will need to be replaced.[82]
- The Netherlands has banned the connection of new houses to the gas grid, for which building permits are obtained after 1 July 2018.[83]
- The German government announced a ban for installing oil heating systems in all buildings by 2026, when a low-carbon alternative is technically feasible. [84]
- The UK government has announced that after 2025 gas and oil boilers will no longer be allowed to be installed in new buildings.[85]
- The Austrian National Council voted in favour of banning the installation of oil boilers in new buildings after 2020.[86]
- The Flemish government is planning to ban oil heating boilers by 2021 in new buildings, during deep renovation projects, and in houses where a gas pipeline is available in the street. There is also a plan to ban natural gas connections for new housing developments by 2021.
- The Irish government's Climate Action Plan includes a ban on the installation of oil boilers from 2022 and gas boilers from 2025 in all new dwellings.[87]
- All regions across Poland have ruled to ban the use of coal boilers in new and existing buildings in the next years.[88]

Energy performance requirements could also be placed on social housing providers. For example, the Scottish government has mandated social housing providers to meet certain energy efficiency standards for their buildings by 2020.[89]

Another important policy measure is appliance standards, including standards for heating systems. Such standards have been pivotal in holding back energy demand

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[80] Steuwer, S., Jahn, A., and Rosenow, J. (2019). *Minimum energy efficiency standards for rental buildings in Germany — untapping health benefits.* Proceedings of ECEEE Summer Study 2019. Retrieved from https://www.eceee.org/library/conference_proceedings/eceee_Summer_Studies/2019/7-make-buildings-policies-great-again/minimum-energy-efficiency-standards-for-rental-buildings-in-germany-untapping-health-benefits/

[81] International Energy Agency. (2017). *Danish Energy Agreement for 2012-2020* [Webpage]. Retrieved from https://www.iea.org/policies/606-danish-energy-agreement-for-2012-2020

[82] Solsvik, T. (2017, 15 June). Oil producer Norway bans use of heating oil in buildings. *Reuters.* Retrieved from https://uk.reuters.com/article/us-climatechange-norway/oil-producer-norway-bans-use-of-heating-oil-in-buildings-idUKKBN1961VL

[83] Beckman, K., and van den Beukel, J. (2019). *The great Dutch gas transition.* Oxford, UK: Oxford Institute for Energy Studies, University of Oxford. Retrieved from https://www.oxfordenergy.org/wpcms/wp-content/uploads/2019/07/The-great-Dutch-gas-transition-54.pdf?v=7516fd43adaa

[84] Bundesregierung (Cabinet of Germany). (2019). *Eckpunkte für das Klimaschutzprogramm 2030* (Key points for the 2030 climate protection program). Berlin, Germany: Author. Retrieved from https://www.bundesregierung.de/resource/blob/975202/1673502/768b67ba939c098c994b71c0b7d6e636/2019-09-20-klimaschutzprogramm-data.pdf?download=1

[85] HM Treasury and Hammond, P. (2019). *Spring statement 2019: Philip Hammond's speech.* London, UK: Government of the United Kingdom. Retrieved from https://www.gov.uk/government/speeches/spring-statement-2019-philip-hammonds-speech

[86] Republic of Austria Parliament. (2019). *Nationalrat verbietet Ölkesselanlagen in Neubauten ab 2020 (National Council bans oil boiler systems in new buildings).* (Parliamentary correspondence no. 945.) Retrieved from https://www.parlament.gv.at/PAKT/PR/JAHR_2019/PK0945/index.shtml

[87] Department of Communications, Climate Action & Environment. *Climate action plan.* Dublin, Ireland: Government of Ireland. Retrieved from https://www.dccae.gov.ie/en-ie/climate-action/topics/climate-action-plan/Pages/climate-action.aspx

[88] Rosenow, J. and Cowart, R. (2020). *Polish coal boiler phase-out an inspiration for clean heat.* Brussels, Belgium. Regulatory Assistance Project. Retrieved from https://www.raponline.org/blog/polish-coal-boiler-phase-out-an-inspiration-for-clean-heat/

[89] Scottish Government. (2019). *Home energy: Energy efficiency in social housing* [Webpage]. Glasgow, Scotland. Retrieved from https://www.gov.scot/policies/home-energy-and-fuel-poverty/energy-efficiency-in-social-housing/

according to the IEA. In Europe, appliance standards are set through the Ecodesign Directive. Standards can rule out specific types of heating systems from being sold to consumers and will continue to be a viable tool to phase out the most inefficient heating systems. In principle, appliance standards could also be used to eventually ban fossil fuel-based heating systems through tighter requirements.

Similar to the energy efficiency label for electrical devices, the energy efficiency of buildings is classified on a sliding bar label (sometimes called Energy Performance Certificate, or EPC), with a colour scale ranging from green to red to indicate the energy requirements or consumption. This provides an estimate of costs for heating and hot water. Moreover, the efficiency classes indicate the building's energy efficiency and carbon emissions. Experience from the UK[90] shows that it is important to use realistic carbon emission factors when establishing EPCs for buildings with low-carbon heating systems. In the case of the UK, an outdated carbon emissions factor is used to assess the environmental impact of heat pumps, leading to a lower EPC rating. Recognising this, the methodology for EPCs in the UK will be reformed in such a way that heat pumps are treated more realistically.

Financial support schemes

Financial support schemes have played and will continue to play an important role in supporting heat decarbonisation. Regulatory measures described above need support by well-integrated financial schemes that allow users to make the investments required. Recognising this, the European Investment Bank has recently reviewed its lending guidelines on energy projects making building renovation and energy efficiency a priority.[91]

There is a wide range of potential financing mechanisms that can enable households and businesses to invest in both energy efficiency and low-carbon heat technologies (or a combination of the two). In general, policy mechanisms look to reduce costs of low-carbon measures or increase the costs of alternatives (or both), and this can be done via the provision of grants, low-cost finance or ongoing tariff support — all funded either via tax or socialised across consumer bills. The key types of mechanisms for supporting low-carbon heat and energy efficiency are presented:

- **Low-interest loan programmes**. Loan programmes typically provide loans at a reduced or even 0% interest rate. Probably the most established loan programme for building retrofits is the German KfW programme. Currently, KfW provides loans up to €100,000 per dwelling at an interest rate of 0.75%. Measures financed include both building fabric improvements and low-carbon heating solutions.[92] Similar programmes can be found in many other European countries, for example in France,[93] Scotland,[94] Estonia[95] and Ireland.[96] Loans are most relevant for larger investments, such as a major building retrofit and/or a new heating system. Depending on the funder, they may require a sufficient credit score and income, and therefore, not all energy users may have access to this type of finance. They may be particularly useful for buildings owned by private landlords and wealthier homeowners.
- **Grant programmes**. Grant programmes usually provide a contribution to the investment cost of energy efficiency and low-carbon heating measures. The level of the incentive typically differs by the type of measure and the customer — low-income households often receive higher contributions than the able-to-pay. Grants are more commonly used for supporting smaller investments compared to loan programmes. They exist across a wide range of European countries, including the

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[90] Rosenow, J. (2019, 21 October). Energy performance certificates hold back heat decarbonisation. *Foresight: Climate & Energy*. Retrieved from https://foresightdk.com/energy-performance-certificates-hold-back-heat-decarbonisation/

[91] European Investment Bank. (2019). *EIB energy lending policy: Supporting the energy transformation*. Kirchberg, Luxembourg: Author. Retrieved from https://www.eib.org/attachments/strategies/eib_energy_lending_policy_en.pdf

[92] KfW. (undated). *Energieeffizient sanieren — kredit (Energy efficient renovation — credit)* [Webpage]. Frankfurt, Germany: KfW Development Bank. Retrieved from https://www.kfw.de/inlandsfoerderung/Privatpersonen/Bestandsimmobilien/Finanzierungsangebote/Energieeffizient-Sanieren-Kredit-(151-152)/

[93] French-Property.com. (2018). *Interest free loans for home energy conservation* [Webpage]. French news. Retrieved from https://www.french-property.com/news/build_renovation_france/interest_free_loan_energy_conservation/

[94] Energy Saving Trust. (undated). *Home Energy Scotland loan — Overview* [Webpage]. London, UK: Author. Retrieved from https://www.energysavingtrust.org.uk/scotland/grants-loans/home-energy-scotland-loan-overview

[95] CITYnvest. (undated). *KredEx Revolving Fund for energy efficiency in apartment buildings* [Webpage]. Retrieved from http://citynvest.eu/content/kredex-revolving-fund-energy-efficiency-apartment-buildings

[96] Bank of Ireland. (undated). *Green home improvement loan* [Webpage]. Retrieved from https://personalbanking.bankofireland.com/borrow/loans/green-energy-home-improvement-loan/

countries listed above. In some cases, loans and grants can be blended to maximise the incentive to invest. They may be particularly useful for less wealthy households.

- **Tax rebates.** Tax rebates are essentially an ex-post grant paid through a reduction of tax payments. Well-known programmes offering tax rebates can be found in France[97] and Italy.[98]
- **Energy Efficiency Obligations (EEOs).** EEOs require energy companies (typically suppliers or distribution companies) to deliver a specific amount of energy savings. The obligated parties achieve this by offering households and businesses incentives to invest in energy efficiency and low-carbon heating systems.[99] There are 16 EEOs across Europe driven by the EU's Energy Efficiency Directive.[100]
- **Low-carbon heat and energy efficiency feed-in tariffs.** Similar to renewable electricity generation, low-carbon heat and energy efficiency can be funded through a feed-in tariff rewarding units of heat generated or saved. No feed-in tariffs for energy efficiency exist at this point, but for renewable heat generation, there are dedicated programmes that have similar characteristics to a feed-in tariff (see example of the Renewable Heat Incentive in the UK below).
- **Energy efficiency funds.** Energy efficiency funds are special entities founded and funded by the government for organisation and funding of energy efficiency programmes. They typically provide grants and loans to beneficiaries. An example of such a fund can be found in Bulgaria.[101]
- **Auctions.** Competitive bidding through an auction is used in Portugal,[102] Switzerland[103] and Germany[104] to procure energy efficiency and, in some cases, low-carbon heating systems. International experience shows, however, that auctions only deliver a modest amount of finance and their track record is relatively short.[105]
- **On-bill finance programmes.** On-bill finance programmes allow the repayment of a loan via a surcharge on the energy bill. Such programmes have had some success outside Europe, but experience in Europe with this instrument has been mixed.[106] The most prominent example of an on-bill finance programme, the British Green Deal, has failed to deliver on its expectations.[107]

When considering heat decarbonisation, the design of such financing schemes is not trivial.

For on-site renewable electricity generation, it makes sense to design financial support schemes such as feed-in tariffs in a way that incentivises electricity generation for both self-consumption and export to the grid. This is different for heat. Heat generated on-site cannot be exported (unless connected to a district heating system), and incentives should not encourage the wastage of low-carbon heat. If incentives are solely based on heat generated, there is a risk of wasting valuable low-carbon heat. In an extreme case, this could lead to financing low-carbon heating systems in completely uninsulated buildings with very high heat losses or, worse still, incentivising the generation of heat with no use. Not only would this result in the inefficient operation of heating systems at higher temperatures, it would also provide a disincentive to undertake energy efficiency measures

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[97] French-Property.com. (undated). *Home energy conservation* [Webpage]. Building & renovation. Retrieved from https://www.french-property.com/guides/france/building/renovation/energy-conservation

[98] Odyssee-Mure. (2017). *Fiscal incentives for energy savings in the household sector: Ecobonus 2017* [Webpage]. Retrieved from http://www.measures-odyssee-mure.eu/public/mure_pdf/household/ITA30.PDF

[99] Whether low-carbon heating systems are eligible for support under an EEO depends on the scheme design. In the past, such technologies have been supported in a number of countries through EEOs.

[100] For a review of EEOs across Europe, see Fawcett, T., Rosenow, J., and Bertoldi, P. (2019). Energy efficiency obligation schemes: Their future in the EU? *Energy Efficiency, 12*(1), 57-71.

[101] Naydenova, I. (2019). Loan (Bulgarian Energy Efficient Fund — BGEEF). Res Legal Europe. Retrieved from http://www.res-legal.eu/search-by-country/bulgaria/single/s/res-hc/t/promotion/aid/loan-bulgarian-energy-efficiency-fund-bgeef/lastp/111/

[102] Sousa, J. L., and Martins, A. G. (2018, May). Portuguese plan for promoting efficiency of electricity end-use: Policy, methodology and consumer participation. *Energies*, *11*(5), 1137. Retrieved from https://www.mdpi.com/1996-1073/11/5/1137/htm

[103] ProKilowatt [Website]. Retrieved from https://www.prokw.ch/fr/accueil/

[104] Bundesministerium für Wirtschaft und Energie (Federal Ministry of Economics and Technology). *Federal funding for energy efficiency in the economy — funding competition* [Webpage]. Retrieved from https://www.wettbewerb-energieeffizienz.de

[105] Rosenow, J., Cowart, R., Thomas, S., and Kreuzer, F. (2017). *Market-Based instruments for energy efficiency: Policy choice and design.* IEA/OECD: Paris. Retrieved from https://www.raponline.org/knowledge-center/market-based-instruments-energy-efficiency-policy-choice-design/

[106] Mundaca, L., and Kloke, S. (2018, May). On-bill financing programs to support low-carbon energy technologies: An agent-oriented assessment. *Review of Policy Research*, *35*(4), 502-534.

[107] Rosenow, J., and Eyre, N. (2016, November). A post mortem of the Green Deal: Austerity, energy efficiency, and failure in British energy policy. *Energy Research & Social Science*, *21*, 141-144.

Domestic Renewable Heat Incentive in the UK

The domestic renewable heat incentive (RHI) is the key current policy driving the deployment of low-carbon heating in the UK. It opened in 2014 for domestic applications, following a delay associated with concerns over scheme cost effectiveness.[108] The scheme supports heat pumps, solar thermal and biomass combustion and provides quarterly payments to households for seven years following accreditation.

The payments for renewable heat are based on the deemed (anticipated) heat requirements of a building and vary by technology. Overall, the scheme was designed to provide a small financial return on the additional investment for a renewable heating system compared to a fossil fuel system.

The deemed heat generation depends on the deemed heat loss based on a basic energy survey. In other words, the more inefficient a building, the higher the heat loss and the higher the deemed heat requirements. As the payments are based on the deemed heat requirements, the RHI provides a disincentive to first undertake fabric efficiency works that would lower the overall heat demand and be beneficial for the operation of low-carbon heating systems.

Anecdotal evidence suggests that suppliers of renewable heating technologies discourage consumers to install energy efficiency measures before the installation of the new heating system. This is counterintuitive and violates the Efficiency First principle.

To some extent this is corrected by establishing minimum energy efficiency requirements, but this regulation incentivizes the deployment of minimal energy efficiency measures rather than optimal. The domestic RHI scheme rules state that a beneficiary of the scheme must install loft and/or cavity wall insulation before applying, if those measures are listed as a recommendation on the energy performance certificate (EPC) of a building. There are other energy efficiency measures, however, which could be undertaken.

Deployment of renewable heat under the RHI has been below initially expected levels[109] with the early years of the scheme unexpectedly seeing biomass boilers as the most popular technology. While the domestic scheme continues to see general underdeployment, heat pumps have become the most popular technology.[110]

and manage heat loads, which may be more cost effective. It is important to design any financial support schemes for low-carbon heat in such a way that they incentivise the installation of efficiently sized and operated heating systems. One example of a policy instrument where the incentives are somewhat misplaced is the Renewable Heat Incentive in the UK (see sidebar above).

A smart policy approach would provide premium payments if consumers decide to also invest in energy efficiency at the same time or before installing low-carbon heating systems. This is the case for some renewable electricity programmes such as the feed-in tariff in the UK. In order to benefit from the full feed-in tariff, domestic buildings had to achieve an EPC rating of at least D. Any buildings below that energy efficiency rating received lower payments for the renewable electricity generated.[111] Establishing minimum requirements for energy efficiency is another approach (also employed by the RHI). In Flanders (Belgium), green electricity certificates are only granted if roofs and attic floors comply with a minimum thermal resistance of $3 m^2 K/W$.[112]

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[108] Lowes, R., Woodman, B., and Fitch-Roy, O. (2019, August). Policy change, power and the development of Great Britain's Renewable Heat Incentive. *Energy Policy, 131,* 410-421. Retrieved from https://doi.org/https://doi.org/10.1016/j.enpol.2019.04.041

[109] Comptroller & auditor general. (2018). *Low-carbon heating of homes and businesses and the Renewable Heat Incentive*. Department for Business, Energy & Industrial Strategy. London, UK: National Audit Office. Retrieved from https://www.nao.org.uk/wp-content/uploads/2018/02/Low-carbon-heating-of-homes-and-businesses-and-the-Renewable-Heat-Incentive.pdf

[110] Lowes et al., 2019.

[111] Nolden, C. (2015). *Performance and impact of the feed-in tariff scheme: Review of evidence.* London, UK: Department of Energy and Climate Change. Retrieved from https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/456181/FIT_Evidence_Review.pdf

[112] Eclareon GmbH. (2018). *Report on PVP4Grid concepts and barriers.* Berlin, Germany: PV-Prosumers4Grid. Retrieved from https://www.pvp4grid.eu/wp-content/uploads/2018/08/2.-PVP4Grid_D2.4_Final-Report_BE.pdf

In addition to providing support for low-carbon heating solutions, it is also important to review existing energy efficiency programmes and assess whether they still incentivise the installation of fossil-based heating systems. Given the long lifetime of heating systems (around 20 years), the subsequent lock-in is not compatible with ambitions to deliver on net zero-carbon emission targets.

Carbon intensity standards

The bulk cost of clean energy policies is not applied to or placed on heating fuels such as gas and heating oil.[113] In many EU countries, this results in artificially high electricity prices and comparably lower prices for the other energy carriers, providing a disincentive to electrification.

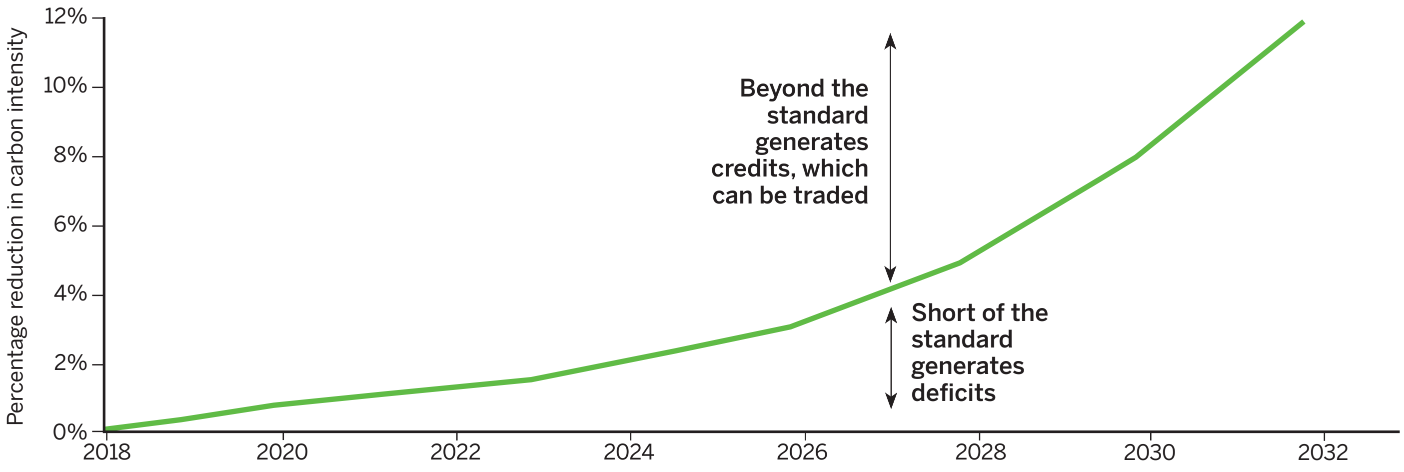
Fundamentally, policymakers should ensure that levies on bills and market structures do not disincentivise low-carbon heat electrification. The EU Emissions Trading Scheme effectively places a carbon price on electricity that is not placed on gas and other fossil fuels used for space and hot water heating. This increases the cost of electricity relative to gas and reduces the financial incentive to use electricity for heating. There have been calls in some countries to rebalance this current imbalance potentially through a levy on gas.[114]

In addition to creating dedicated regulations and incentives that drive heat decarbonisation, an obligation to decarbonise the fuels supplied to generate heat can be placed on consumers, producers or suppliers in the energy sector. This will help meet minimum standards for the carbon content of energy that they respectively consume, produce or sell.[115] Such a carbon intensity standard would, to some extent, reduce the disparity between the costs of electricity and other heating fuels, particularly where electricity is becoming less carbon intensive than gas and heating oil.

A carbon intensity standard could also include a trading element. Obligated parties who overachieve the standard would earn tradeable credits, which could be purchased by those who do not meet the standard (see Figure 6 for an illustration).[116]

Obligated parties would have a variety of options to achieve the standard, which includes reducing the carbon content of their fuels (e.g., electricity decarbonisation or biomethane or hydrogen injection into the gas grid) and fuel

Figure 6. Illustration of tradeable carbon intensity standard[117]



Source: Energy Systems Catapult. (2019). *Rethinking decarbonisation incentives: Future carbon policy for clean growth.*

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113 Grave, K., Breitschopf, B., Ordonez, J., Wachsmuth, J., Boeve, S., Smith, M., et al. (2016). *Prices and costs of EU energy.* (Final report.) Brussels, Belgium: European Commission. Retrieved from https://ec.europa.eu/energy/sites/ener/files/documents/report_ecofys2016.pdf

114 Day, G., and Sturge, D. (2019). *Rethinking decarbonisation incentives: Future carbon policy for clean growth.* Birmingham, UK: Energy Systems Catapult. Retrieved from https://es.catapult.org.uk/wp-content/uploads/2019/07/Rethinking-Decarbonisation-Incentives-Future-Carbon-Policy-for-Clean-Growth.pdf

115 Detailed proposals for carbon intensity standards in the heating sector have been made before. See Energy Systems Catapult. (2019). *Setting carbon standards for energy key to achieving 'Net Zero' economy* [Webpage]. Retrieved from https://es.catapult.org.uk/news/setting-carbon-standards-for-energy-key-to-achieving-net-zero-economy/

116 Frontier Economics. (2019). *Setting standards for carbon intensity. A report for Energy Systems Catapult.* London, UK: Author. Retrieved from https://es.catapult.org.uk/wp-content/uploads/2019/05/2019-03-29-RDI-Setting-Standards-for-Carbon-Intensity-Report-FINAL.pdf

117 Day and Sturge, 2019.

California Low Carbon Fuel Standard

California issued its Low Carbon Fuel Standard (LCFS) in 2007 as a means to drastically reduce greenhouse gas emissions. The LCFS originally mandated that all of California's transportation fuels must reduce carbon emissions by 10% by 2020; the directive has been amended with a new target of 20% by 2030.

Fuel providers must produce and sell a mixture that will accomplish these reductions through all stages, or pathways, of transport fuels — production, distribution and utilisation.

California officially adopted the LCFS in 2009, with the mandate becoming effective in 2011. In recent years, the LCFS has been revised to address implementation deficiencies, with the state readopting an adjusted LCFS in 2016.

The LCFS regulators developed a system of credits specifically geared towards established regulated parties — fuel importers, refiners and retailers. For instance, refineries earned LCFS credits if they updated equipment and processes to reflect more energy efficient standards. Stakeholders have made a practice of trading and/or selling credits to companies that need them to meet standards. Thus, California has a unique system where fuel companies not only buy and sell LCFS credits to one another, but they also work with public utilities, natural gas producers and automakers.[118]

So far, the LCFS has proven successful. The average carbon intensity of fuels sold in California has declined steadily since 2010, with a projected reduction of 6.25% by the end of 2019, or more than 40 million metric tonnes of carbon.[119]

switching (e.g., switching from heating oil to heat pumps). Such a policy would need to be designed in a way to avoid reaping the lowest hanging fruits.

Although not in the heating sector, carbon intensity standards already exist. California introduced the Low Carbon Fuel Standard in 2007. This sets targets for transport fuels and their carbon content (see accompanying sidebar).

An important question is who to obligate. Given the large number of heating fuel consumers, the most obvious parties are the fuel suppliers/retailers of heating fuels who have access to customers and are often involved in providing and maintaining the technology used for heating.

The role of carbon intensity standards needs to be carefully considered. They are unlikely to deliver sufficient deployment of low-carbon heat on their own and will need accompaniment by the other policies presented in this report.

Energy Efficiency Obligations

EEOs require organisations such as utilities to carry out a defined level of activity delivering energy savings but leave it to these obligated parties to find the best delivery routes for doing so.

The design of the savings target within the EEO, however, can disincentivise utilities to support the heat electrification. The increased electricity consumption of low-carbon heating systems resulting from fossil fuel switching can have a negative impact on the ability of utilities to meet targets defined in kWh of electricity savings as a portion of total kWh of electricity supplied.

A better metric would be energy savings across all fuels, allowing fuel switching to electricity as long as the total energy demand is reduced. This could be particularly useful for heat pumps that, through their use or ambient energy, can deliver significant overall demand reductions compared to combustion or resistive technologies. Greater numbers of heat pumps cause increased efficiency compared to combustion or direct electric technologies. A carbon intensity standard could provide a similar incentive to a cross-fuel energy efficiency incentive and may perhaps be more suitable. It could also be useful to apply targets that consider other metrics as well, such as avoided CO_2 emissions (this was the case in the UK EEO from 2008-2012) or peak load reductions

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[118] Energy Systems Catapult & Energy Technologies Institute. (2018). *California Low Carbon Fuel Standard: Rethinking decarbonisation incentives — Policy case studies.* Birmingham and Loughborough, UK: Authors. Retrieved from https://es.catapult.org.uk/wp-content/uploads/2018/10/California-LCFS-Case-Study-FINAL.pdf

[119] California Air Resources Board. (2019). Data dashboard: 2011-2018 performance of low carbon fuel standard [Table]. Retrieved from https://ww3.arb.ca.gov/fuels/lcfs/dashboard/dashboard.htm

(this exists in several EEOs in the U.S.).

Whether EEOs can also be used as a mechanism to provide finance for low-carbon heat depends on the economics of heating technologies in the specific context where EEOs operate. In principle, EEOs can provide a mechanism to finance low-carbon heating systems. But for more capital-intensive solutions, EEOs are unlikely to be the most suitable policy instrument — most EEOs around the world tend to support highly cost-effective measures and only few high cost technologies.[120] If coupled, however, with additional finance provided through tax rebates (an approach established in France[121]) and/or loans (as piloted in Ireland[122]), EEOs may well be able to play a role in delivering low-carbon heating systems.

Electricity pricing

As discussed in Principle 4, electricity pricing is a key element of encouraging heating system flexibility. Low-carbon heat uptake depends on independent actions by energy users. For consumers to benefit from the value produced by their flexible electrification load, the system value or societal value of their actions must be communicated through the electricity prices they pay or avoid.

Recent analysis in the UK has highlighted that current policy structures may exacerbate the cost differential between electricity and gas, and this can be a barrier to heat decarbonisation; specifically, electricity in the UK is subject to a carbon tax and levies whilst gas is not.[123] Policymakers must ensure that there are no existing institutional cost barriers that could actively disincentivize smart gas to electric fuel switching. As well as resolving these basic but fundamental regulatory issues, policymakers must also ensure that electricity pricing allows for smart heat electrification.

The implementation of the Clean Energy for All Europeans (CE4All) package will create an enhanced framework for smart pricing, and Member States should prioritise its timely implementation. Wholesale electricity prices (in other words, the energy component of a consumer's bill) that are driven by the fundamentals of supply and demand for energy and balancing services will better reflect the value of flexibility (for example, as a result of the removal of price caps).[124] These wholesale energy prices could then be reflected in customers' bills through dynamic pricing contracts.[125] In addition, the package supports the establishment of dynamic network tariffs and, more broadly, the use of tariff designs that will lead to cost-efficient grid operation and development in the short and long term.

At the same time, more can be done at the national level to support smart pricing and, by extension, the cost-effective integration of electric heating systems. Given the low levels of low-carbon heat penetration across European countries, simple dynamic tariffs — such as day and night tariffs or TOU tariffs with more periods and seasonal differentiation — can already offer significant benefits. Most importantly, heat-dedicated tariffs should follow as closely as possible the associated costs. As the power system continues to transition and variable renewable energy sources become the predominant form of power generation, it will be crucial that tariffs also evolve to keep pace.

It is important to differentiate between countries with regulated prices and those without.

- **Member States with regulated prices:** A minimum of 11 Member States had some form of price regulation in place as of 2016, with some offering regulated prices in addition to market offers.[126] In those countries,

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[120] Rosenow et al., 2017.

[121] Rohde, C., Rosenow, J., and Eyre, N. (2014, July). *Energy saving obligations: Cutting the Gordian Knot of leverage? Energy Efficiency, 8*(1), 129-140.

[122] Credit Union Development Association. (undated). *Credit unions team up with SEAI & REIL to provide Pro Energy Homes* [Webpage]. Retrieved from https://www.cuda.ie/2019/05/13/nationwide-rollout-planned-for-a-one-stop-shop-home-energy-upgrade-scheme/

[123] Barnes, J., and Mothilal, S. (2019, January). The economics of heat pumps and the (un)intended consequences of government policy. *Energy Policy*, 111198. Retrieved from https://doi.org/10.1016/j.enpol.2019.111198

[124] For more information on the benefits of implementing effective price formation in wholesale electricity markets, see Hogan, M. (2016). *Hitting the mark on missing money: How to ensure reliability at least cost to consumers.* Montpelier, VT: Regulatory Assistance Project. Retrieved from https://www.raponline.org/knowledge-center/hitting-mark-missing-money-ensure-reliability-least-cost-consumers

[125] More specifically, the legislation establishes the right of suppliers to offer dynamic pricing contracts and of consumers with a smart meter in place to request such a contract from any supplier that has more than 200,000 customers.

[126] Council of European Energy Regulators. (2017). *Retail markets monitoring report: CEER report.* (Ref: C17-MMR-83-02.). Brussels, Belgium: Author. Retrieved from https://www.ceer.eu/documents/104400/-/-/56216063-66c8-0469-7aa0-9f321b196f9f

regulated low-carbon heat tariffs could be implemented as a transitional measure until an open and competitive retail market is in place.

- **Member States without regulated prices:** Even in the case of markets where electricity prices are not regulated, there might be a need to establish such tariffs if the markets fail to deliver — for example, due to the lack of competition. Theory suggests that an open, competitive retail market should deliver innovative products that meet consumers' needs (and there is evidence supporting this based on experience from European countries that have had deregulated prices for longer).[127] Several retail markets across Europe, however, are not competitive enough, and market power could strangle any attempts to introduce innovative ideas. Recent data demonstrate that the majority of national markets in Europe exhibit a high concentration of suppliers in the retail market.[128] If the market fails to provide such solutions, then it would be prudent for regulators to introduce smart, low-carbon heat-dedicated tariffs and, more broadly, tariffs for new highly controllable loads (this might be possible to be implemented through the supplier of last resort, which is already regulated to some extent depending on the jurisdiction). Such a solution should be applied as a transitional measure whilst, in parallel, focusing on removing any obstacles to the creation of an open and competitive retail market.

Although dynamic energy prices linked to wholesale markets are important, they send signals only about the cost of electricity production and not about the state of the network or the wider system. Network tariffs should send the right signals to consumers about the use of the network. National regulators should mandate that network companies implement time-varying network tariffs for controllable heat loads, such as heat pumps. In addition, regulators and network companies should develop a monitoring framework for assessing the impact of the tariffs on charging behaviour and grid utilisation.

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[127] European Commission. (2019e). *Energy prices and costs in Europe.* Brussels, Belgium: Author. Retrieved from https://ec.europa.eu/energy/sites/ener/files/documents/swd_-_v5_text_6_-_part_1_of_4.pdf

[128] Only five out of 21 national markets exhibited low concentration levels in 2016. See Council of European Energy Regulators, 2017.

Conclusions and key recommendations

The European Union is currently reviewing its 2030 climate targets and has put forward a Green Deal for Europe that makes buildings a priority sector. The decarbonisation of space and hot water heating is of vital importance to achieving the European Union's climate goals in 2030 and beyond. The transformative challenge of decarbonising heating should not be underestimated and will require strategic and ongoing policy and governance support. Heating decarbonisation requires a well-coordinated approach that cuts across several areas — buildings, heating systems (both at individual and at district level), the power sector and existing heating fuel supply infrastructure.

This report has shown that whichever low-carbon heat technology is adopted, energy efficiency is critical. It reduces heat demand and thereby the investment required to decarbonise heat, it is an enabler of buildings that are electrified to act as a flexible resource, and it is an enabler of low and zero-carbon heating systems to operate at higher performance. By reducing demand for and associated costs of zero-carbon heating, energy efficiency can also support a more socially equitable heat transformation.

Neither energy efficiency nor low-carbon heat technologies can achieve decarbonisation on their own — a combination of energy efficiency and low-carbon heat technologies is the most economic and practical approach to heat decarbonisation. Whilst there are uncertainties around the optimal technology mix for heating in the future, it is clear that electrification will have to play a significant role, whether through individual heat pumps or through renewable electricity used to power district heating networks via large-scale heat pumps.

Efficient electrification will require the flexible operation of heating systems, both diurnally and intraseasonally. Intraseasonal heat balancing remains a key issue for heat decarbonisation, via electrification, at scale. Energy efficient buildings can be very flexible, and there is experience with managing them in such a way to avoid the most carbon-intensive peak hours. Intraseasonal balancing, particularly in colder regions, will need to be addressed in the medium to long term, and thermal storage, such as large storage tanks, pits and groundwater-carrying layers, may be a valuable approach for balancing district heating networks. For an electrified system that includes large numbers of building-level heat pumps, hydrogen is currently expected to be a key vector for interseasonal balancing; however, questions remain over the optimal future use of hydrogen. During the coldest days of the year, hydrogen could be used to provide peaking power generation or provide heat through combustion in hybrid heat appliances. A lack of experience of either approach at scale suggests this issue could be an excellent area for future heat decarbonisation research and development. A growing zero-carbon heating market can be expected to provide technological innovation, learning and innovation, but policymakers must ensure that zero-carbon heat deployment is aligned with wider system integration.

With regard to heat decarbonisation and smart sector integration, this report makes a number of policy recommendations to be addressed at the EU and national level:

1. **Step up energy effficiency building upgrades through more ambitious targets and policies.** This will require an increase in the energy efficiency targets set in the Energy Efficiency Directive and more ambitious targeted energy efficiency policies at the national level.
2. **Phase out carbon-intensive heating systems.** Regulatory measures have a track record of success, and given the required pace of decarbonisation it will be necessary to rule out inefficient and carbon-intensive heating systems through regulation. This can be achieved at the EU level through the Ecodesign Directive and the Energy Performance of Buildings Directive and at the national level through building codes.
3. **Phase out subsidies for fossil fuel-based heating systems.** Many energy efficiency programmes still support the installation of new fossil fuel-based heating systems. Given the lifetime of heating technologies, this needs to be discontinued.

4. **Implement well-designed and well-funded financing mechanisms for energy efficiency and low-carbon heat.** Particularly in the context of limited household capital, it is important to offer financial support enabling the investment and compliance with regulation phasing out carbon-intensive heating systems. Member States should scale up existing financing mechanisms and implement new ones.
5. **Ensure fair distribution of costs among different fuels.** Currently most of the costs of the energy transition are allocated to electricity, resulting in misleading incentives especially as the power system gets cleaner. The upcoming review of the energy taxation legislation in Europe offers an opportunity to ensure a fairer distribution of costs among the different fuels.
6. **Encourage the flexible use of heat through the introduction of time-varying prices.** Consumers operating their heating system flexibility should be rewarded for the benefits they provide to the power system and in avoided carbon emissions. This can be achieved through the introduction of time-varying prices.

None of these recommendations on its own can deliver accelerated heat decarbonisation at the scale needed to meet the climate targets. Only when combined will we be able to decarbonise heat and unlock the many benefits that smart heat decarbonisation can bring to the energy system and society as a whole.

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