Benefits of Hybrid Heat Systems in a Low Carbon Energy System

An evidence-based analysis

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[1] On October 11, 2019, Guidehouse LLP completed its previously announced acquisition of Navigant Consulting Inc. In the months ahead, we will be working to integrate the Guidehouse and Navigant businesses. In furtherance of that effort, we recently renamed Navigant Consulting Inc. as Guidehouse Inc.

BENEFITS OF HYBRID HEAT SYSTEMS IN A LOW CARBON ENERGY SYSTEM

Executive summary

Hybrid Heating Systems are a new third vector that offers real-world carbon savings now that are significantly larger than competing technologies.

It has been evidenced that Hybrid Heating Systems can meet the energy demand for all homes irrespective of their energy efficiency rating. Smart control of Hybrid Heating Systems results in up to 80% of a building's heat demand being met by electricity, strongly reducing the amount of gas being required. Hybrid Heating Systems make green gas go further, compounding the benefit of action taken to green the gas grid.

Hybrid Heating Systems thus unlock a robust pathway away from fossil fuels to low carbon heat, since building insulation, installing the heat pump and decarbonising electricity and gas can take place independently.

Hybrid Heating Systems are both an optimal heat transition accelerator and an enduring sustainable destination technology. They provide the sweet spot for when it comes to the 3Cs of the energy trilemma, Cost, Comfort and Carbon, as is summarised below.

Costs	• Upfront investment costs of Hybrid Heating Systems are at least 25% lower than all-electric heat pump only systems • Households can generate up to £150/year in energy system value once market frameworks have evolved
Comfort	• Hybrid Heating Systems can maintain comfort levels in all buildings, regardless of energy efficiency rating • Hybrid Heating Systems can provide the increasingly desirable option to cool buildings • Hybrid Heating Systems maximise customer choice at minimal disruption
Carbon	• Hybrid Heating Systems can save more carbon today than alternative solutions • Accumulated savings for the UK to 2050 can be as much as 106 $MtCO_2$ • Hybrid Heating Systems continue to be a carbon-free option to 2050 and beyond by using green electricity when available, and green gas when it isn't

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Benefits of Hybrid Heating Systems extend to the three Rs, Resilience, Reinforcement and Renewables, representing the energy system side equivalent of the energy trilemma.

Resilience	• The fuel switching ability of Hybrid Heating Systems prevents excessive electricity demand in cold winter spells and when sufficient green electricity isn't available • A 75% deployment of Hybrid Heating Systems could reduce peak electricity demand from the building sector by as much as a factor of 7
Reinforcement	• Cumulative reinforcement cost savings for South Wales are estimated to be £1,500 million for smart hybrids compared to all-electric heat pumps • Annual infrastructure costs for the UK are estimated to be £8 billion less in a Balanced Scenario using Hybrid Heating Systems compared to an Electrified Scenario using air source heat pumps
Renewables	• Hybrid Heating Systems maximise the integration of intermittent renewable electricity as over-production resulting from variable weather conditions can be managed by switching from green gas to green electricity, or vice versa, thus minimising the need for curtailment and avoiding over-investment in low-carbon generation capacity

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Introduction

Hybrid Heating Systems are low-carbon heating systems that combine two sources of energy for space heating and hot water in residential and commercial buildings. Hybrid Heating Systems are an essential technology for the UK to meet its 2050 decarbonisation goals. In this paper, Guidehouse focuses on the benefits of a specific type of Hybrid Heating System, namely the combination of a gas-fired boiler augmented with an air-source electric heat pump.

In these systems, the electric heat pump generally provides base load heat while the boiler contributes to meet peak heat demand. As both electricity and gas go green, they provide a third vector for decarbonised heating, in addition to all-electric and gas-only options.

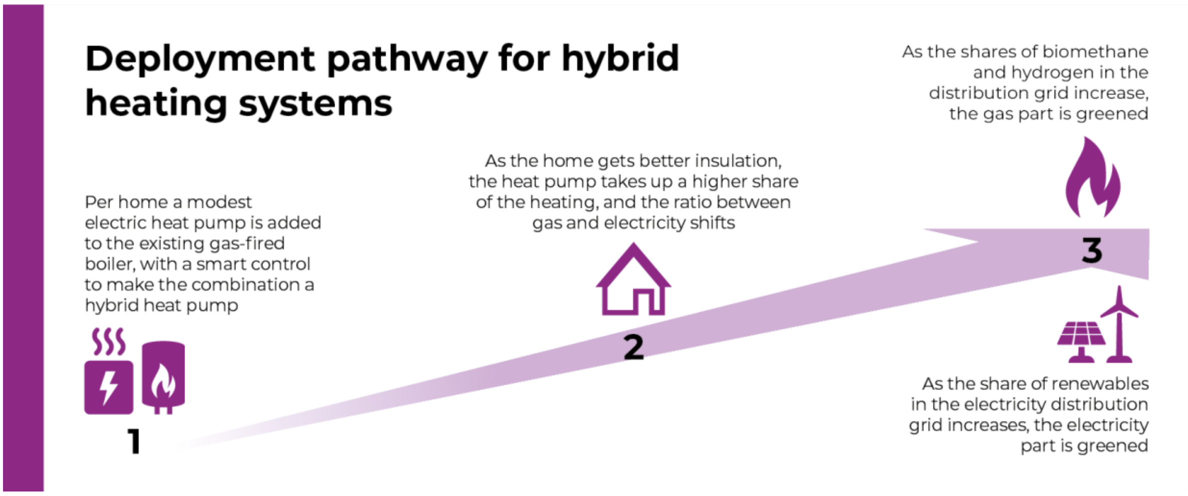

Figure 1 – Deployment pathway for Hybrid Heating Systems, adapted from [1].

Hybrid systems provide distinct advantages not shared with all-electric and gas-only options that include:

- Increased consumer choice with respect to initial equipment purchase and energy vector usage;
- Lower consumer disruption and capital investment costs for buildings;
- Lower network reinforcement costs and peak demand generation capacity;
- Increased energy system resilience by providing fuel switching flexibility;
- Faster decarbonisation through decreased gas consumption that starts *today*.

In the following sections, we will explore each of these aspects in more detail to demonstrate the attractiveness of Hybrid Heating Systems as an enduring destination technology in a fully decarbonised energy system.

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Decarbonising the UK building stock

Decarbonising residential heat in the UK is largely about decarbonising the existing building stock as approximately 75% of the expected building stock in 2050 already exists today (see Appendix A1.1). Natural gas fired boilers are now the dominant heating technology for UK homes: 85% of homes are connected to the gas grid and use a boiler and wet-based central heating system. The remaining 15% use predominantly oil or liquid petroleum gas (LPG) as their main heating fuel or electric heating. Decarbonising residential heat thus largely means replacing natural gas with decarbonised gas (either hydrogen or biomethane) and green electricity, or, in selected cases, district heating with a reliable, long-term waste heat source.

In its 2020 Gas Decarbonisation Pathways study [1], Guidehouse finds that buildings require an 'A' rating to ensure comfort levels can be maintained with an all-electric heat pump during extreme cold weather spells. The latest data on housing energy performance in England shows that less than 1% of current properties have an 'A' energy label (a situation that has only marginally improved for new dwellings). A massive increase in average insulation levels and thereby energy performance would be needed for all-electric heat pumps to become a widely applicable solution. The associated costs, required workforce and customer disruption make this a slow adoption pathway at best.

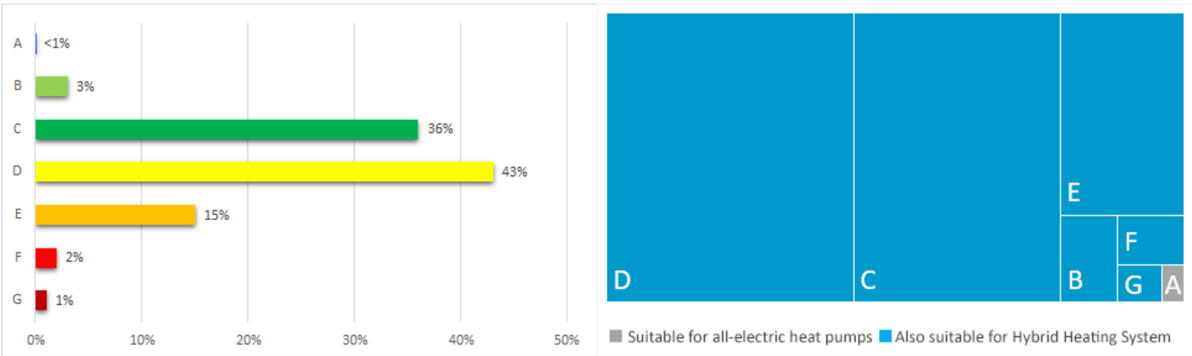

Figure 2 – Energy efficiency ratings for existing and new domestic properties [2]. The tree map in the right panel shows that only a tiny fraction of the current English dwellings is suitable for an all-electric heat pump.

Hybrid Heating Systems, on the other hand, can meet the energy demand for all dwellings irrespective of the energy performance of a building, as was demonstrated in the Freedom Project [3] and are therefore a more relevant decarbonisation option than full electrification of heat.

Decarbonised gas and green electricity are both not expected to be in abundant supply in the near-term future, and uncertainties related to decarbonisation pathways in industry and transport can influence the availability of clean energy for residential heat in the near term. Reducing energy demand from buildings is therefore a key success factor in decarbonising heat.

Large-scale retrofitting of the building stock with economic energy efficiency measures and efficient heating systems enables green energy to go further. The requirements, associated costs, consumer impact and carbon savings differ significantly between low-carbon options as we will illustrate in the next sections.

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A minimally disruptive mature technology…

Hybrid Heating Systems can be fitted with less extensive insulation than all-electric heat pumps as the integrated gas heating provides peak heating demand. In its *Gas for Climate - The optimal role for gas in a net-zero emissions energy system* [4] report from March 2019, Guidehouse analyses Hybrid Heating Systems as benefitting from only moderate insulation efforts like high-performance glazing and loft insulation whereas all-electric heat pumps require deep insulation that additionally includes solid and/or cavity wall insulation and floor insulation. This difference in optimal insulation levels generates a significant cost advantage for Hybrid Heating Systems. For a typical UK dwelling, the costs of deep insulation are >85% higher than the costs for moderate insulation [5].

Also, to heat homes with Hybrid Heating Systems the existing radiators can be retained, which greatly reduces the cost and disruption of moving to a low-carbon heating system. Hybrid Heating Systems for a typical semi-detached house can be installed in one day, whereas installing an all-electric heat pump plus the required low-temperature underfloor heating system typically take multiple weeks. This makes all-electric systems also more expensive: costs are at least 25% higher than the installation of Hybrid Heating Systems [6], but typically substantially higher as additional insulation is required for the vast majority of buildings to make them suitable for all-electric heating.

Hybrid Heating Systems are a mature sustainable technology that is available *now* and provide energy savings of at least 19%. Carbon savings are 25% for grid connected properties and 60% for off-grid properties today, increasing to accumulated savings to 2050 of 37% and 79%, respectively (see Appendix A.5). This is in sharp contrast to all-electric heat pumps that increase whole-system carbon, as emissions are pushed upstream from the buildings sector to the power sector as a result of the inefficiency of decentralised gas generation that isn't offset by the efficiency of the all-electric heat pump.

Carbon savings with Hybrid Heating Systems increase to 100% as the national electricity mix and gas fully decarbonise towards 2050. The deployment of "Hydrogen Ready" boilers once they are commercially available on the market at scale, assumed to be by 2026 [7], provides a flexible and smooth transition path for Hybrid Heating Systems to switch to hydrogen when it is introduced in the building's area, or can remain in use on part of the gas grid that delivers 100% biomethane.

Not all buildings are suitable for Hybrid Heating Systems. Buildings with limited indoor or outdoor space might still require a boiler-only solution, although recent innovations, such as compact hybrid units that don't require an outdoor component, indicate a large part of the building stock might be able to benefit from the advantages that Hybrid Heating Systems hold over alternative low carbon solutions.

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Figure 3 – The Murelle Revolution 30 Hybrid Heating System combines a 24 kW gas condensing boiler and a 4 kW thermal air/water heat pump in a single product and does not require an outside unit The unit measures only 900 x 600 x 390 mm. Image copyright: Sime [8].

…with unique consumer benefits...

The flexibility provided by having two heat sources enables smart controls to reduce consumers' energy bills by almost 50% [3]. The majority of this reduction is due to lower supply costs, but households can recoup part of their investment in Hybrid Heating Systems by providing monetisable energy system services which include retailer portfolio balancing, transmission grid frequency restoration and congestion management at both the transmission and distribution level. Households can generate up to £150 per year in energy system value once market frameworks have evolved, as was demonstrated in the Freedom Project [3]. Such services can be implemented either through demand response options or via Heat-as-a-Service concepts that maximise consumer convenience.

As a third vector that smartly combines green gas and power, Hybrid Heating Systems provide benefits to consumers not seen in either gas-only or electricity-only heating systems. Selected Hybrid Heating Systems can provide the option to cool dwellings, others could be augmented with additional equipment to do so. This cooling benefit is increasingly desirable as average summer temperatures rise and heat waves become more frequent. In the UK, energy demand for residential space cooling is expected to increase by 70% towards 2050. For the EU, an increase of almost 400% is expected [9].

… and system-wide benefits

In the UK winter months there's effectively no solar energy being generated and during cold winter weather spells there's less renewable energy production from wind too (see Appendices A.4.1 and A.4.1). As temperatures drop, the efficiency of all-electric heat pumps drops too, by as much as 60% for outside temperatures of 0 °C compared to ambient

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temperatures of 15 °C (see Appendix A.4.3). As a result, electricity demand peaks while renewable generation drops. The ability of Hybrid Heating Systems to switch to green gas ensures that comfort levels in the home is maintained and prevents the need to over-build renewable generation capacity and flexible peaking power capacity at great expense that would be required in an all-electric scenario.

It is estimated that converting 50% of buildings to Hybrid Heating Systems as opposed to 50% all-electric heat pumps reduces the peak electricity demand by a factor of two for countries in moderate climate zones. For a conversion rate of 75% this could increase to as much as a factor of 7 (See Appendix A.4.4).

Similarly, unforeseen outages from e.g. storms can be managed more easily when there is the ability to switch between gas and power for heating. Hybrid Heating Systems thus provide a level of resiliency not seen in single-fuel solutions and can be seen as a measure to adapt to climate change as well as a mitigation measure.

The significantly increased peak power demand in an all-electric scenario would also trigger substantial grid reinforcements which, in a Hybrid Heating System scenario, can be largely avoided due to the ability to switch to gas for peak heating. The Freedom Project found that savings to 2050 for the South Wales distribution network alone in a fully optimised hybrid scenario (where the cumulative reinforcement cost is around £200m) are about £1,500m compared with the counterfactual scenario featuring all-electric Heat Pumps only [3].

Guidehouse found that in a Balanced Scenario, in which low carbon and renewable gases are used in a balanced combination with low carbon electricity, overall energy infrastructure costs for the UK would be £8 billion per year lower compared to an Electrified Scenario in which low carbon and renewable gas use is limited to cases where no reasonable alternative energy source exists [7]. In this Balanced Scenario, 75% of the buildings (22 million) are equipped with a Hybrid Heating System as opposed to none in the Electrified Scenario, where buildings are heated exclusively by electricity. Further evidence for significantly lower infrastructure costs when deploying Hybrid Heating Systems at scale is presented in Appendix A.4.5.

Stranded assets are avoided as the gas infrastructure continues to play a pivotal role in the UK's future decarbonised energy system, providing extensive storage and flexibility for the long term, as it does today.

The inherent flexibility provided by the ability to switch fuels also enables the integration of renewables at scale, since over- or underproduction resulting from unexpected weather variations can be managed by switching from gas to green electricity, or vice versa, minimising the need for curtailment.

The value of flexibility for a carbon reduction target of 25g CO_2/kWh could be as much £15.2 billion per year, with the avoidance of investments in low-carbon generation capacity presenting the largest flexibility value stream [3].

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The emissions fallacy

Hybrid Heating Systems do not represent a lock-in to fossil fuels but are in fact the best low-carbon technology that should be fiscally stimulated now. Real-world emission reductions that can be obtained now by Hybrid Heating Systems are significantly larger than that of competing technologies.

- All-electric heat pumps can only be used in a tiny fraction of the current building stock. Large-scale application is therefore currently not possible, but also not desirable: lacking sufficient renewable generation all-electric solutions actually results in a net increase in emissions due to the inefficiency of the decentralised gas generation currently required to meet their peak demand, which isn't overcome by the efficiency of the heat pump.
- Both hydrogen and hydrogen boilers are not expected to be available to the market at scale for at least another five years and consequently won't contribute to emission savings in the near future. As is the case with their gas-only counterparts, the boilers of Hybrid Heating Systems are already capable of operating on biomethane and hydrogen blends or bioLPG. They can change for hydrogen-ready units in advance or to 100% hydrogen units where and when parts of the gas grid convert to hydrogen.
- Hybrid Heating Systems can maintain comfort levels in all dwellings and curb emissions at scale starting today. Smart controls enable efficient use of green gas and renewable electricity. In the ramp-up to a fully decarbonised gas system, Hybrid Heating Systems make green gas go further, compounding the benefit of action taken to green the gas grid.

With limited time and carbon budget left to meet the UK's legally binding target of net zero emissions by 2050 and the Paris Climate Agreement goals, decarbonisation of the building stock needs to start now.

To demonstrate the emission savings that can be achieved by Hybrid Heating Systems, an illustrative case is depicted in Figure 4. The left panel shows the decreasing emission factor of the gas grid as defined in Guidehouse's Balanced Scenario [7]. The right panel shows the resulting emissions of a semi-detached property when run on a grid connected gas-only boiler versus running a Hybrid Heating System.

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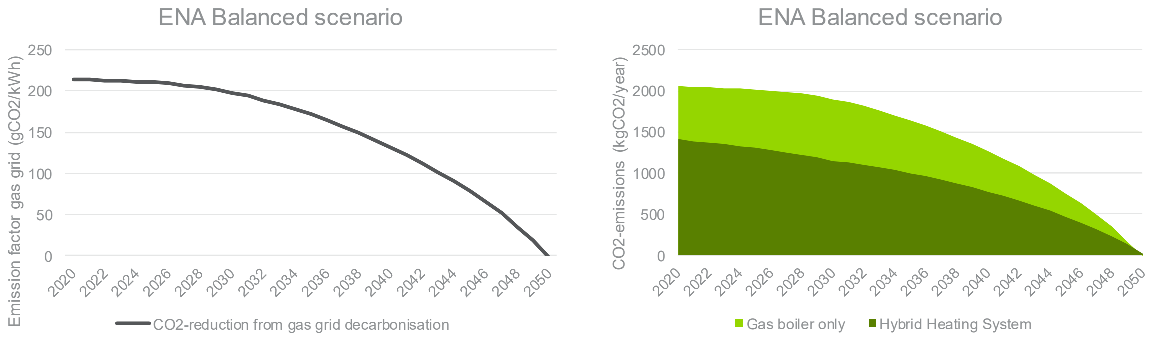

Figure 4 – Emission savings from gas grid decarbonisation (left) and Hybrid Heating Systems in grid-connected configuration (right). Savings calculated for a semi-detached single-family home.

See Appendix A.5 for details and a second scenario based on Wales & West Utilities projected net zero ambition that accelerates gas grid decarbonisation.

The aggregated carbon savings of 37% up to 2050 of hybridising compared to boiler-only systems are substantial. Extrapolating this to the national level, assuming the Guidehouse recommended accelerated building stock renovation rate of 2.5% per year, this would translate into 8.4 $MtCO_2$ savings in year one alone[2], exceeding what can be achieved by converting all 'A' label properties to all-electric heat pumps.

Cumulative savings of Hybrid Heating Systems across the UK until 2050 in this scenario are 106 $MtCO_2$., which is 3 times more than all of London's annual emissions [10].

Hybrid Heating Systems: from transition and green recovery enabler to enduring destination technology

Hybrid Heating Systems are a smart choice now and key technology for an affordable, reliable decarbonised energy system in 2050:

- Hybrid Heating Systems can be used to provide comfort and carbon savings for all dwelling types and energy efficiency. The lower optimal insulation levels generate a significant cost advantage for Hybrid Heating Systems.
- The wide applicability, clear benefits for consumers, the energy system as a whole and our climate makes Hybrid Heating Systems an ideal candidate for a green recovery program.
- Ease of installation and minimal customer disruption enable quick retraining of post-COVID19 job seekers and contribute to high adoption rates.
- Quickly building out a sizeable installed base this way contributes to meeting the UK's emission targets and provides UK householders with an affordable, low-carbon

[2] Note that CO_2-emissions savings for off-grid properties can be as over twice this. High LPG and oil costs result in a far larger share of electricity when smart controls optimize for cost.

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future-proof heating solution that contributes to a resilient, fit for purpose clean energy system.

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APPENDIX A. BACKGROUND DATA AND CALCULATIONS

This appendix contains calculations, references and additional rationale to evidence the statements made in this paper. Appendix sections reflect section titles in the main paper. Data tables, calculations etc. are presented in subsections.

A.1 Decarbonising the UK building stock

A.1.1 Development of the England building stock

The majority of the building stock in the UK is already present today, as can be derived from the calculation provided in Table 1.

Table 1 – Calculating the percentage of the 2050 building stock already in existence today.

Entity	Number
Current number of dwellings [11]:	24.4 million
Annual demolition rate:	0.1%
Estimated new builds per year [12]:	300,000-340,000
Estimated number of dwellings in 2050:	33.3 million
Percentage of the 2050 dwellings already in existence today:	74.8%

As England accounts for the vast majority of the building stock we've used the outcome of this calculation as a proxy for all of the UK.

A.2 A minimally disruptive mature technology…

A.2.1 Upfront costs of Hybrid Heating Systems

Upfront costs of Hybrid Heating Systems are ~25% lower than comparable all-electric heat pumps, see the table below. Data reproduced from [6].

Table 2 – Upfront costs of Hybrid Heating System and standalone air-sourced heat pump for a typical semidetached house

Heating system component	HHS, 5 kW HP (£2016/dwelling)	All-electric (£2016/dwelling)
Boiler	850	0
Heat pump	3,100	4,400
Controller	275	0

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HW cylinder	0	275
Radiator replacement	0	1,800
Installation	2,500	2,500
Total per dwelling	**6,725**	**8,975**

Table 2 shows that upfront costs of Hybrid Heating Systems are 25% lower than those of all-electric heat pumps.

A.3 …with unique consumer benefits...

Hybrid Heat Systems can also be used for space cooling. Residential cooling demand is expected to grow strongly. A recent study for 14 EU Member States projected an increase from 39TWh/year in 2015 to 76TWh/year in 2030 and 190TWh/year in 2050.

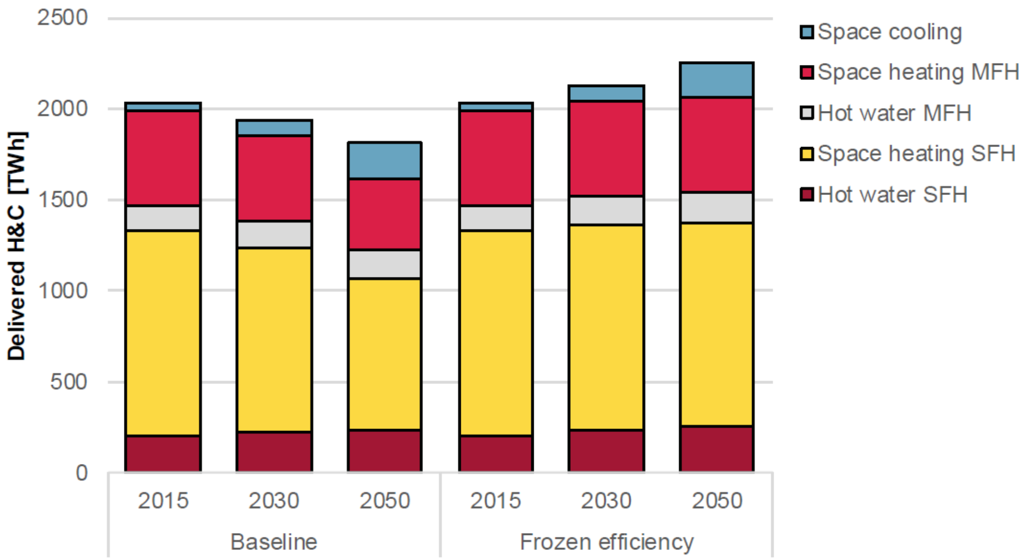

Figure 5 – Energy demand for heating and cooling for 14 EU Member States[3] (including UK) in 2050 [9]. Both scenarios are based on the same living area and the number of buildings, but in the frozen energy scenario no efficiency improvements are included.

For the UK, energy demand for space cooling is 7TWh/year (2015) and is expected to increase with 71% to 12TWh/year in 2050 [9].

[3] AT, BE, CZ, FI, FR, DE, HU, IT, NL, PL, RO, ES, SE and UK (still part of the EU at the time the report was published)

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A.4 … and system-wide benefits

A.4.1 Solar PV generation in winter

The output of solar PV drops dramatically in winter months, as can be seen in Figure 6 below.

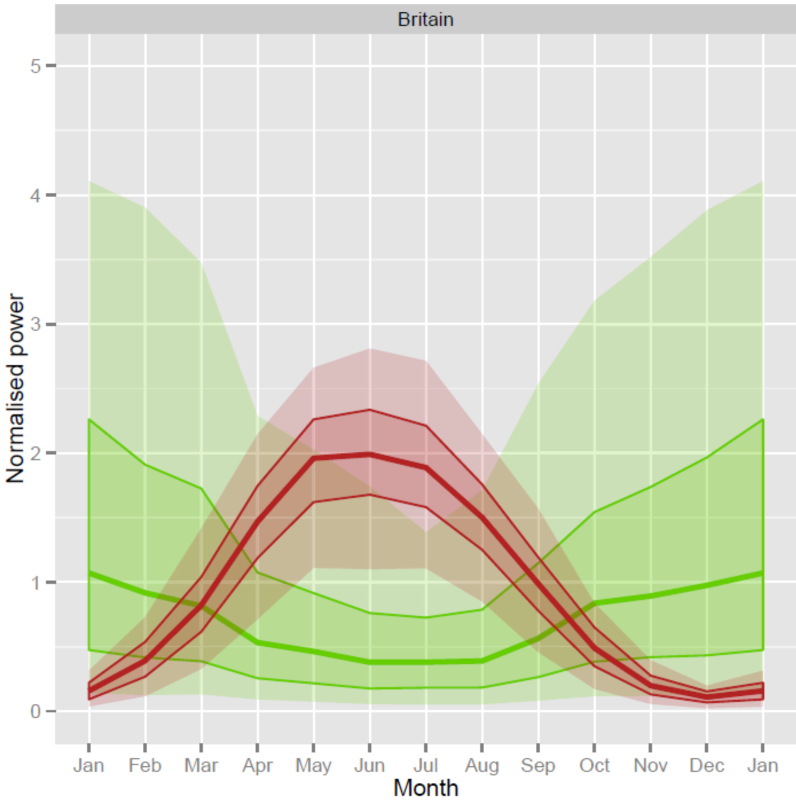

Figure 6 – The distribution of daily-mean wind (green) and solar PV (red) power output each month, both scaled by their long-term all-year average. The lines and shading indicate the medians, 25th & 75th percentiles, and 5th & 95th percentiles of the daily data. Graph reproduced from [13].

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A.4.2 Windless winter weeks

When it's really cold in Europe, there is less wind, as is shown in Figure 7 below.

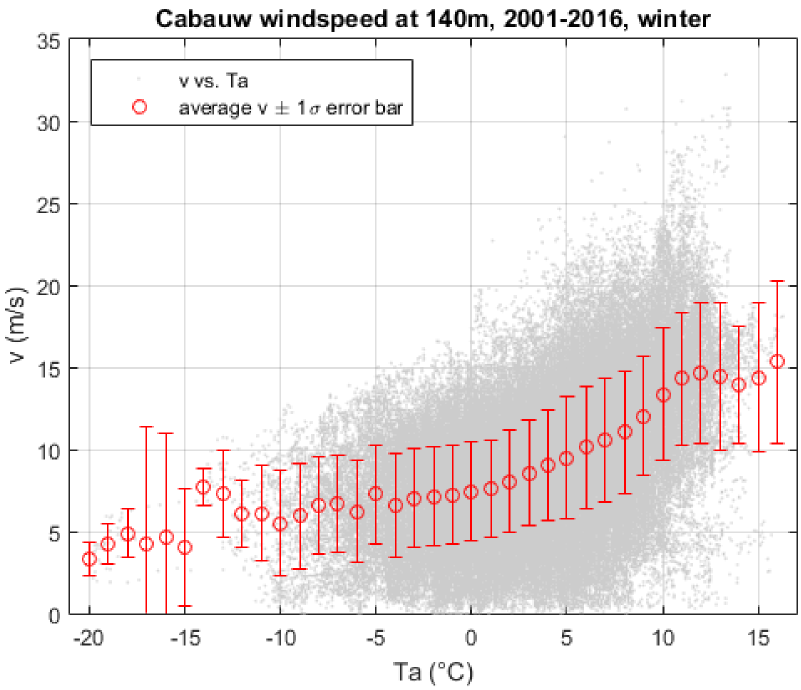

Figure 7 – Data from the Dutch meteorological office KNMI showing average wind speeds v versus average minimum temperature Ta.

A.4.3 Heat Pump efficiencies

Heat pump efficiencies, expressed as a Coefficient of Performance (COP), drop as the difference between the input temperature (the ambient air temperature in the case of Air Source Heat Pumps) and the requested temperature of the heat sink (wet radiator system or underfloor heating) increases. This is graphically depicted in Figure 8.

For an Air Source Heat Pump providing typical wet radiator temperatures of 70 °C, and outside temperature of 0 °C ("Beast from the East" would mean a drop in COP from ~5 at ambient air temperatures of 10 °C to ~2, representing an efficiency drop of 60%.

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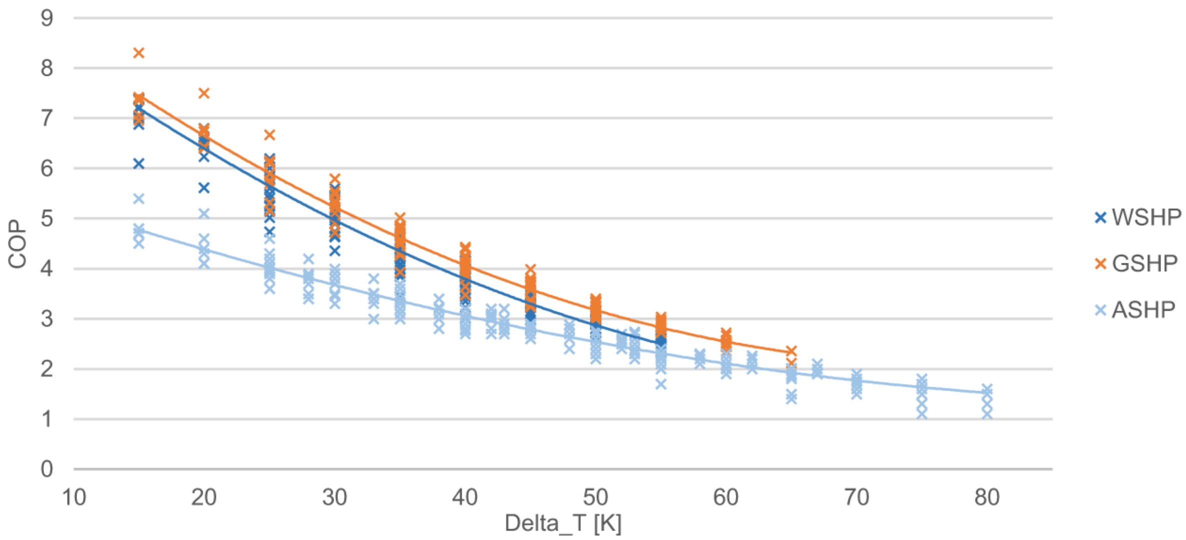

Figure 8 – COP values for water (WSHP), ground (GSHP) and air (ASHP) source heat pumps, based on manufacturer data [14].

A.4.4 Strongly reduced peak electricity demand from the building sector

In its *Routekaart Hybride warmtepomp* [15], Dutch consultancy Beerenschot analyses multiple scenario studies on the impact of heat pumps on electricity peak demand. It calculates that in a scenario where 75% of buildings have heat pumps, peak electricity demand from the built environment increases by 100-350% if all-electric heat pumps are used whereas for Hybrid Heating Systems the increase is maximally 50%.

Since the Netherlands and the UK observe a similar climate, it is reasonable to conclude that opting for all-electric heat pumps can result in up to 7 times higher peak electricity demand from space heating and domestic hot water in the building sector.

A meta-analysis by Beerenschot and DNV GL of various studies showed that the fuel switching capability of Hybrid Heating Systems ensures that the coincident peak demand of dwellings in low-voltage grids does not increase beyond that of a boiler-only scenario whereas for all-electric heat pumps this was found to increase as much as 13-fold [16].

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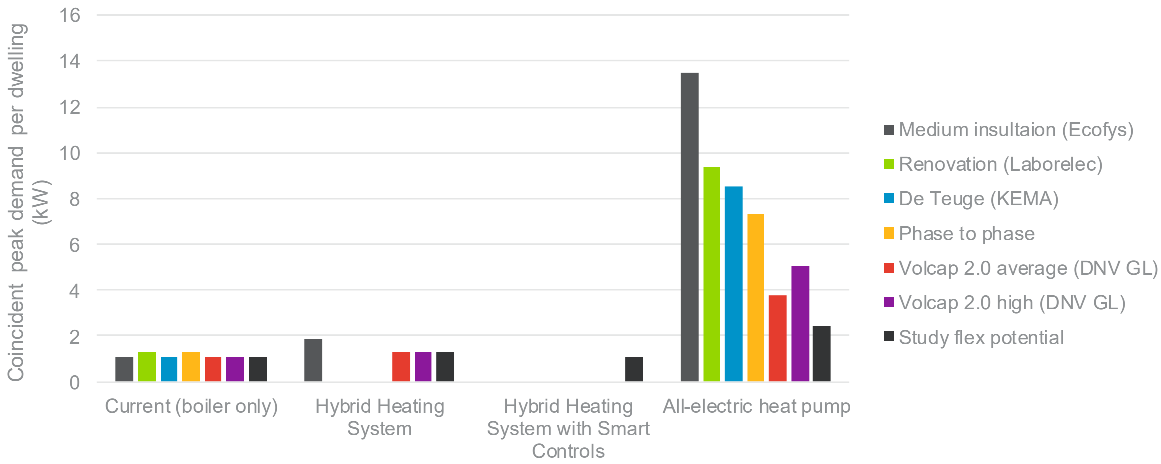

Figure 9 – Coincident peak demand of dwellings for different heating technologies [16].

A.4.5 Case study: transmission and distributions costs in the Netherlands

Ecofys (now part of Guidehouse) found in a large study [17] that the combined annual transmission and distribution costs for gas and electricity for Hybrid Heating Systems are only 16% of what they would be compared to all-electric heat pumps, for a medium building insulation level. In a scenario with high renovation of the building stock to strongly reduce heating demand the difference in costs is estimated to be still almost a factor of 2.

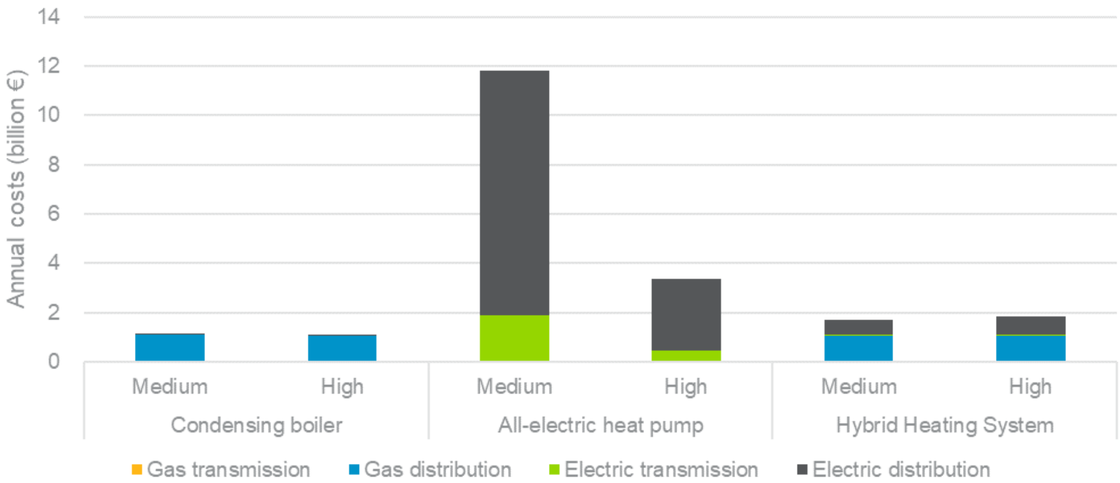

Figure 10 – Comparison of annual transmission and distributions costs for gas and electricity in the Netherlands, for different heating solutions and two levels of building insulation.

A.5 The emissions fallacy

To create insights in the CO_2-emission reduction potential of hybrid heat pumps for a typical single-family semi-detached house, the performance of Hybrid Heating Systems has been compared to a boiler-only case. In total three scenarios were explored: two gas grid-connected cases and one off-grid (LPG) case.

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The following assumptions have been made across the scenarios:

- For each scenario, we assumed a heat demand of 9,600 kWh/year for a semi-detached single-family home. This heat demand arises from applying a 20% energy efficiency gain to Ofgem's TDCV[4] value for this type of property.
- CO_2-emissions from electricity usage are based on National Grids' Two Degrees Future Energy Scenario 2019 [18].

Table 3 provides an overview of the scenario input and output:

Table 3 – Assumptions for emission scenarios Hybrid Heating Systems. Savings calculated for a semi-detached single-family home

Entity	ENA Balanced scenario	WWU scenario	LPG off-grid scenario
Scenario input			
Emission factor development	*Moderate decarbonisation*	*Accelerated decarbonisation*	*No decarbonisation*
2020	198gCO_2/kWh	100gCO_2/kWh	259gCO_2/kWh
2030	132gCO_2/kWh	34gCO_2/kWh	259gCO_2/kWh
2040	-2gCO_2/kWh	6gCO_2/kWh	259gCO_2/kWh
Scenario output			
Efficiency gain from Heat Heating System	19%	19%	25%
COP Heat pump	1.8	1.8	1.4
Heat pump share	29%	29%	83%
Energy demand	Gas: 5500 kWh Electricity: 2280 kWh	Gas: 5500 kWh Electricity: 2280 kWh	Gas: 1200 kWh Electricity: 6000 kWh
CO_2-emissions savings up to 2050 compared to base case	16 tCO_2	8 tCO_2	61 tCO_2

In all scenarios, the use of Hybrid Heating Systems results in both energy and CO_2-emission reduction. In the two grid-connected scenarios (ENA Balanced and WWU) CO_2-emission are further reduced by decarbonisation of the gas grid (Figure 11). In WWU's net zero ambition scenario the CO_2-emission is projected to reduce faster, meaning that the additional CO_2 emissions savings of a Hybrid Heating System are slightly lower (32%) than in the ENA Balanced scenario (37%).

[4] Typical Domestic Consumption Values

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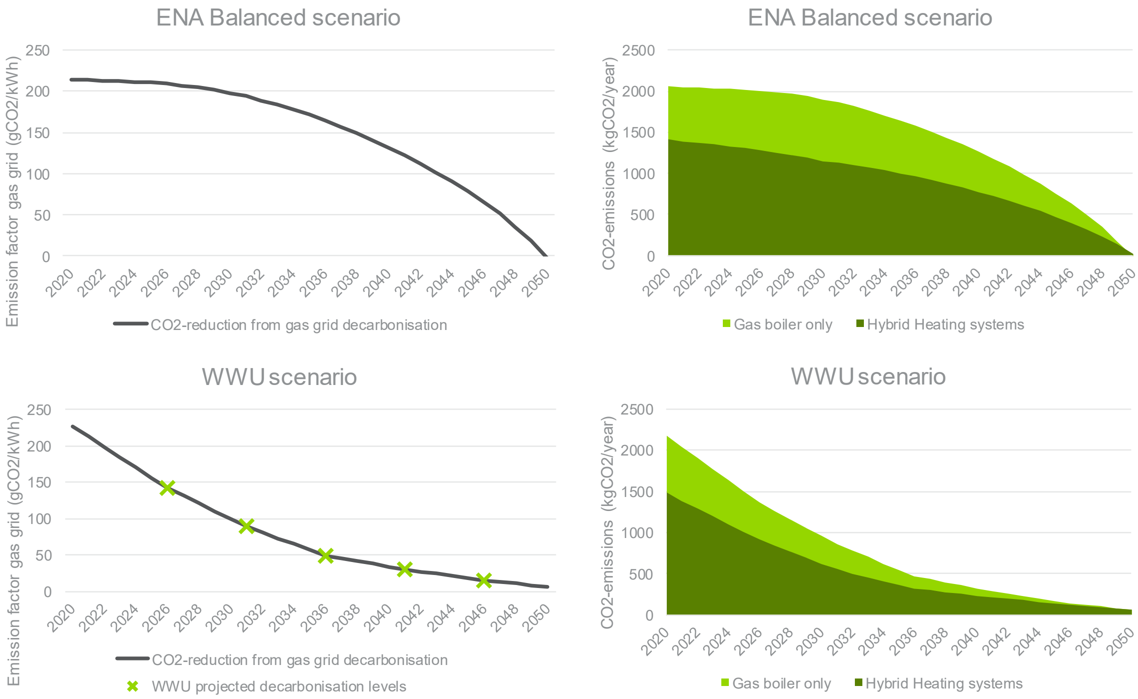

Figure 11 – CO_2-reduction potential of gas grid decarbonisation (left) and hybrid heat system compared to a gas grid boiler (right). The graphs at the top show the results for the ENA Balanced scenario, results for the WWU scenario are shown at the bottom. Savings are calculated for a semi-detached single-family home

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APPENDIX B. BIBLIOGRAPHY

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